POWER TRANSFORMER LIFE MANAGEMENT

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Utility asset management and network reliability have, over recent times, become well researched topics. Electrical utilities, across the globe, recognize the fact that major power system equipment is reaching the end stage of its expected life. The age profiles of this equipment are very similar. Recent power failure events have highlighted how vulnerable electrical distribution networks really are. Events on the east coast of North America and Europe have emphasised the real value of electricity at much higher levels than its selling price.

The ability to extend life expectancies by effective asset management can have a major impact on capital investment planning programs. Power transformers represent the bulk of the asset value for distribution and transmission utilities. Traditional asset management strategies for transformers revolves greatly on time based maintenance methodologies and transformer oil monitoring. With increased demands for electricity power transformers are operated at or beyond its nameplate value. The strategic nature of power transformers makes it highly critical items on the distribution network. It is therefore imperative to manage power transformers to attain optimum utilization and thereby maximising the return on investment without lowering their production and availability levels.

The proposed paper will detail the life assessment process of power transformers and include criteria for subsequent recommended remedial action.

INTRODUCTION

This paper describes the Power Transformer Life Management program currently utilized by Eskom Distribution Western Region.

Eskom Distribution Western Region’s distribution transformer bases consist of approximately 350 units with capacity ranging between 1MVA and 160 MVA and primary voltage between 33kV to 132kV. These units are all of the free breathing type. The total installed capacity is just below 7,500 MVA with about 67% of the total installed capacity being non-firm. These non-firm units are almost always located at non critical loads.

The relatively large geographical area in which the utility distributes is characterized by intense diverse atmospheric conditions (humidity, temperature) and customer profiles, exposing the fleet to a broad spectrum of failure-drivers and risks.

The age distribution of the mentioned fleet is reflective of power system equipment around the globe, with a high percentage of transformers older than 20 years, as indicated in figure 1. Apart from this, older transformers also occupy strategic nodes on the network.

Effective asset management are thus crucial in minimising risks to the distribution network.

![Power transformer age distribution](image)

Figure 1 Power transformer age distribution

Power transformer failure phenomenon

Basic power transformer failure models focus on the paper insulation failures and where the withstand strength of the paper will decrease due to heat, moisture and oxidation. Depending on the application, transformer design, operational conditions one or combinations of the above aging drivers will dominate leading to the failure of insulation and hence the failure of the transformer. The repair costs of these types of failure are usually high with long repair times. Currently transformer failures involving solid insulation breakdown account for approximately 30% of total failures since 1998. Transformer failures due to solid insulation breakdown are increasing. Various aging models are proposed in [1] and [2].

These models do not take into consideration failures on On-load tap-changers (OLTC), bushings, build-in CT’s etc. Repair cost due to these types of failures is relatively low with manageable repair times.

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1 At an n times transformer substation, the load is considered firm if (n-1) times transformer are able to handle the load.
Traditional maintenance strategies are geared to ensure functional reliability of OLTC’s, bushings, breathers etc., with oil sampling the only activity used to establish the condition of the transformer insulation system.

Evaluating the condition of the power transformer insulation system using an oil sampling programme is therefore essential as it forms the core of the Life assessment process.

**Power transformer aging phenomenon**

Aging models described by Sumeneder, Muhr, and Körber [1] and Guuinic [2] correlate well with furan results collected from the above mentioned transformer fleet illustrating the different aging profiles for transformers in different applications and unique sets of operating conditions.

![Age Profiles](image)

**Figure 2 Age Profiles of two actual transformers**

In figure 2 Transformer A is typical of transformers that are exposed to high operating temperatures and normally feeds critical loads. This specific transformer is a 20 MVA 132/22kV transformer feeding a single customer in an environment with a relative high ambient temperature and loading factor throughout the year. Currently this transformer is 15 years old. The transformer has relatively low moisture per dry-weight values and high oil dielectric strength values. These types of transformers are very susceptible to through-faults. The dotted line represents the expected life of the unit. The age profile approximates an exponential decay, \( f(x) = C e^{-kt} \), with the DP probably saturating at 200 as the transformer feed into a cable network with a low probability of through-faults.

Transformer B is typical of transformers that are exposed to more moist conditions with relatively low operating temperatures as well as low loading conditions. These transformers normally feed seasonal less-critical loads. This specific transformer is a 4MVA 66/11kV transformer feeding a coastal residential load. Currently this transformer is over 40 years old. This type of transformers is more exposed to moisture related failures where flashovers could occur due to low a dielectric strength.

Water migration out of the paper into the oil, due to a sudden sustain load increase, could cause the formation of a thin film of water on the outer edge of the paper because of a slow moisture absorption rate into the oil. This turn could cause tracking and insulation breakdown. As indicate in figure 2 it is suggested that this type of failure mode/insulation breakdown occurs over a shorter period.

Depending thus on the combination of the three aging drivers, the expected aging profiles could be plotted as illustrated in figure 2.

Understanding the nature of transformer aging enables the application of an optimum life extension technique and thus effective transformer life management.

**MAINTENANCE STRATEGY**

Traditional preventative transformer maintenance plans revolves on:

- a) Time based OLTC overhaul
- b) Time based transformer inspections
- c) Time based transformer and OLTC sampling
- d) Condition monitoring gas-analysers.
  (Depending on the criticality and strategic importance of unit)

Rarely are maintenance activities directed at the solid cellulose insulation of the transformer to ensure adequate levels of reliability and operability other than oil sampling and online gas detector units. Oil analysis is pivotal in the maintenance strategy of transformers. Over the life cycle of the unit less than 30 % of the total maintenance cost is spend on monitoring the condition of the cellulose.

<table>
<thead>
<tr>
<th>AGING DRIVER</th>
<th>LIFE EXTENSION ACTIVITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat</td>
<td>Investigate heat generation</td>
</tr>
<tr>
<td></td>
<td>Additional Cooling</td>
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<tr>
<td></td>
<td>Check cooling fin valves</td>
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<tr>
<td></td>
<td>Upgrade substation</td>
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<tr>
<td></td>
<td>Limit/eliminate downstream faults</td>
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<td></td>
<td>Contingency plans</td>
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<tr>
<td></td>
<td>Rewinding the core</td>
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<tr>
<td>Moisture</td>
<td>Investigate the source of the moisture</td>
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<tr>
<td></td>
<td>Check breather</td>
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<tr>
<td></td>
<td>Transformer de-hydration/ moisture removal</td>
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<tr>
<td>Oxidation</td>
<td>Investigate excessive oil oxidation</td>
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<tr>
<td></td>
<td>Oil regeneration</td>
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<tr>
<td></td>
<td>Removing sludge from the cellulose</td>
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</tbody>
</table>

Condition monitoring activities do not re-instate the loss of life. It assists the user in understanding the aging process and to detect possible failures in advance. It prompts the
user to apply life extension activities, to reduce the aging rate of the units, or design contingencies to eliminate or minimize the expected risks. Life extension activities depend on the type of aging driver. Examples are listed in table 1.

Transformer oil sampling, as a condition monitoring technique should be complemented with other diagnostic tools, for example, Frequency Response Analysis and Acoustic Response Analysis, to enhance the ability to establish transformer aging profiles.

The maintenance strategy should also involve in giving feedback to transformer designers in order to design out critical failure modes, for example, OLTC failures, bushings etc.

LIFE MANAGEMENT

The Transformer Life Management process, adopted by Eskom Distribution Western Region, is supported by an effective and on-going life assessment process. Critical risks are identified and reviewed, maintenance strategies adopted and input given to capital investment committees as far as network integrity is concerned.

In the life assessment process condition monitoring data is interpreted and diagnosed to define the probability of failure or network risks. Units are firstly evaluated using a general assessment. Depending on the identified risk a more focused assessment is applied. The following paragraphs describe the different stages in the life assessment process.

Initial stage

In the initial stage, units are assessed in terms of the general conditions as to set references for the particular unit. In order to set up aging profiles it is critical to know what the starting point is. This reference should be well defined and in line with the condition monitoring techniques that will be applied during the life cycle of the transformer.

Typical condition monitoring techniques are listed below.

- Frequency Response Analysis
- Acoustic Response Analysis
- Dissolved Gas Analysis
- Moisture assessment of solid insulation
- Moisture assessment of liquid insulation
- Degree of Polymerization
- Oxidation levels
- Dielectric strength of oil
- Tan Delta assessment of bushings

Further to this transformers are ranked according to a set criterion defining its network criticality, customer profiles, equipment failure history and network redundancy.

This stage is crucial in performing trending analysis, constructing aging profiles and identifying network criticality of transformers.

Routine condition assessment stage

This stage comprises of a general assessment component and a more focused condition assessment component.

The general assessment is applied to the entire transformer base on a routine interval. In this mode further consideration is only given to units exceeding pre-define benchmarks. Depending on the margin by which a certain benchmark is exceeded and taking cognisance of the prevailing operating conditions and predefined network criticality, the transformer status is escalated to a certain risk level. Once the transformer has exceeded one or more of the benchmarks impact of the probable failure and focused condition monitoring schemas are identified and applied.

This stage is so designed that each condition monitoring criteria has its own escalation process taking the results of other techniques and operation factors in to consideration.

The criteria used in the general assessment include the following:

- Degree of polymerization (using furans)
- Dissolved Gas analysis
- Dielectric strength
- Moisture content
- Acidity

In this paper the Degree of Polymerization escalation and the Moisture Management escalation process’s are discussion.

Figure 3 shows the required sampling rate for units located in the respective zones. Transformer A would therefore be sampled on a biennially frequency until it moves into the next zone while Transformer B would be sample on a five yearly basis.
yearly frequency. Different life extension activities as well as risk management decisions are linked to each of the four zones in order to assess the network risk at the given stage in the life of the transformer.

Diagram 1 Simple moisture management flow chart

In the above diagram a very high level moisture management flow chart illustrates the moisture escalation process. The general assessment is based on the “Karl Fisher test” (ASTM D1533) plotted on a “Piper Chart” to indicate the percentage moisture in the paper. These charts proved to be highly accurate when sampled at operating temperatures in excess of 40°C. Depending then on the transformer network criticality, capacity, results confidence level, remaining life left of the transformer, substation fault level and through-fault probability, an associated action plan is implemented.

On-line transformer dehydration on larger transformers is considered costly and therefore on-line moisture assessments are performed to confirm excessive moisture in the solid insulation. Similar escalation processes are designed for the other assessment methods which can lead either to further and more in depth condition monitoring or direct network risk mitigation.

CONCLUSION

Power transformer life management is an ongoing process that needs continuous reviewing. In understanding the individual aging profile and reacting to the dominant failure modes the life of the transformer can be extend. Different condition monitoring techniques exist to enhance life assessments. It is in the application of the methods and results that will enable the user to act proactively to ensure optimum utilization.

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LITERATURE


