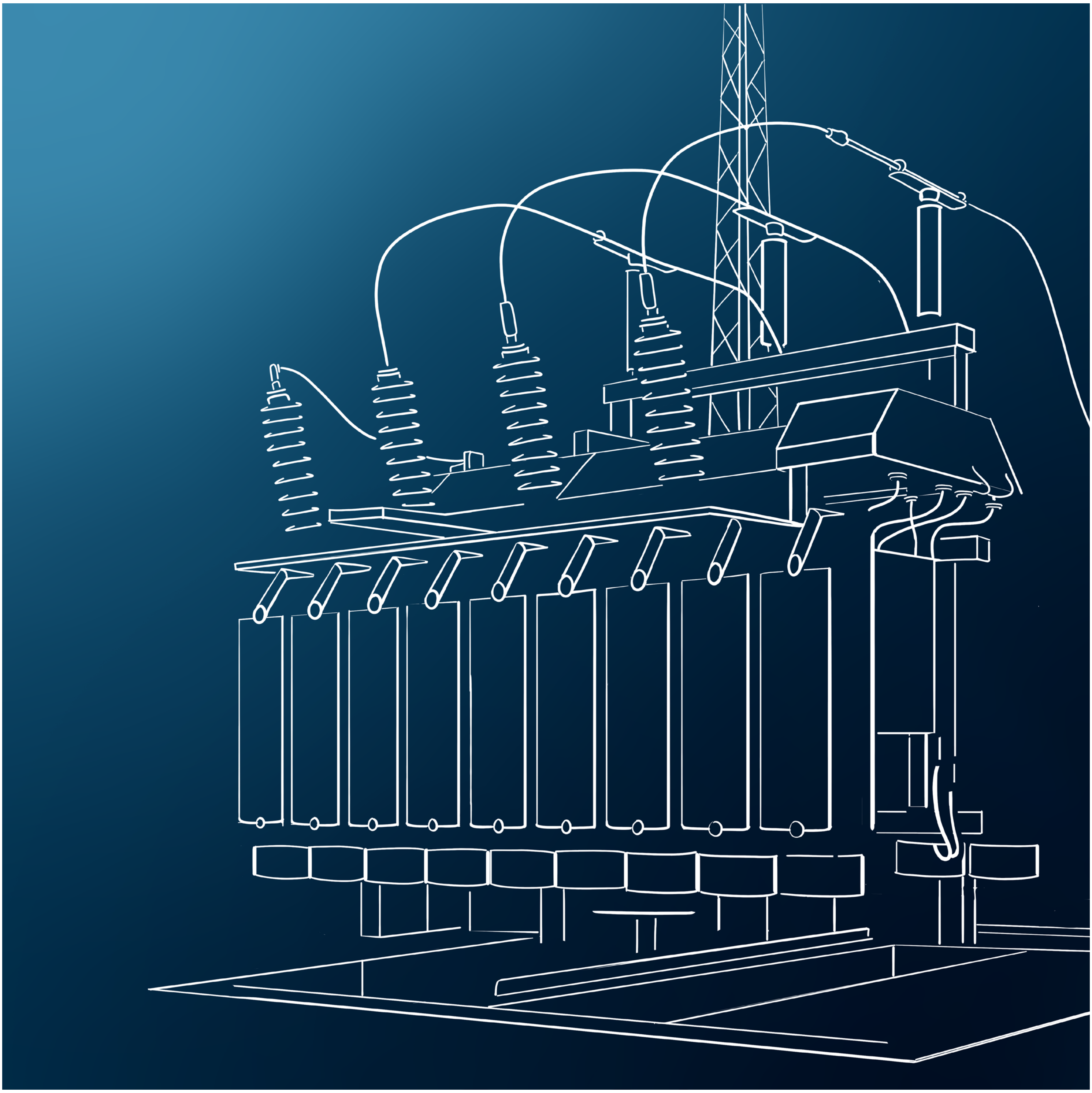
Guide

Condition Assessment of Power Transformers – How To?



Introduction

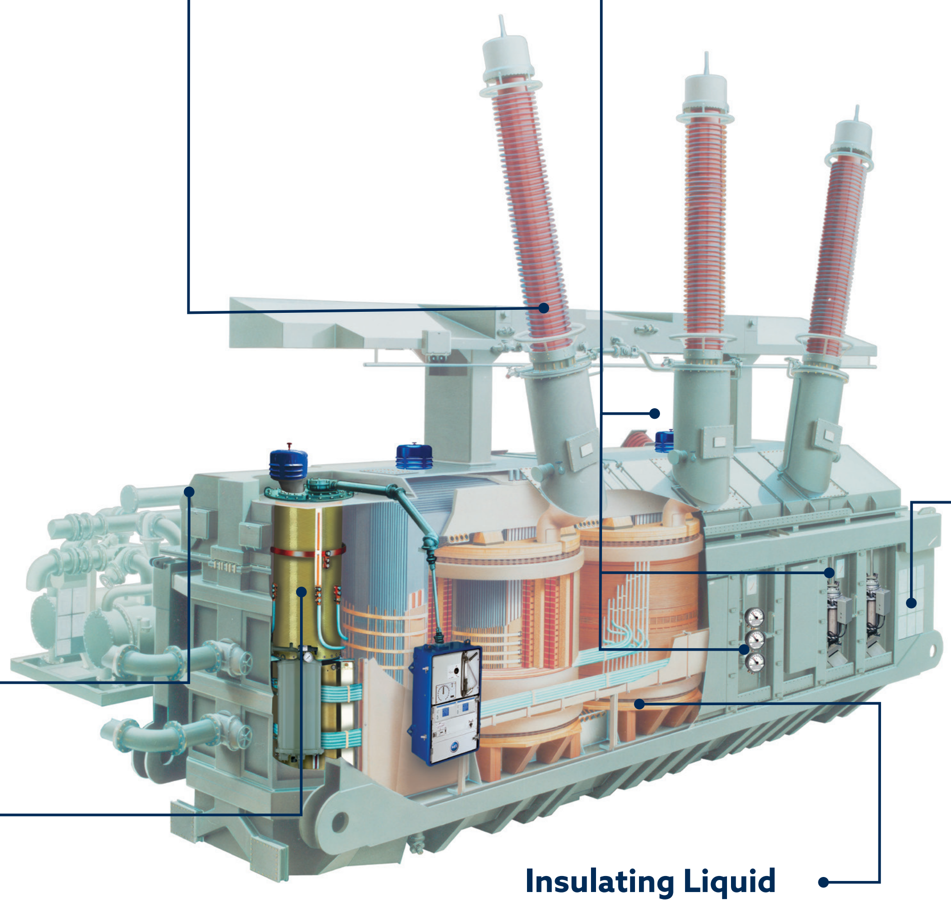
Power transformers are the most expensive and perhaps the most critical and strategic assets in power systems. Accordingly, asset managers both in utilities and in the industry are drawn to optimize their overall financial performance by maintaining a high reliability and extending lifetime at minimal costs.

Having comprehensive knowledge of your transformers' condition is therefore an important step for the implementation of good asset management. But not only the transformers' condition needs to be assessed. In order to have an economic approach, one needs to have in mind the relative costs of failure, modernization and replacement. Looking at the consequences of the issues just mentioned, which can be of a financial, legal, and reputational nature, a systematic approach to condition assessment seems worth striving for.

In this Guide, we show how to find an economically viable condition assessment approach that combines the data of all components, including their failure modes, as well as the associated diagnostic elements. For this purpose, we will show you how to build Transformer Assessment Indices (TAI), which you can use to increase the safety, reliability, and sustainability of your transformer fleet. As an asset manager, you will be able to derive short and long-term asset management strategies that will not only increase the efficient use of your resources, but also the overall success of your company.

1 Available Data

As mentioned in the abstract, a transformer is an asset that consists of many components and subcomponents. Each component has an essential meaning for the functionality of the transformer, which means that a failure of this component can also lead to a failure of the transformer. In the following, significance, failure modes, as well as suitable diagnostical instruments for individual components will be highlighted.



Bushings

Significance
As a connector between the power system or substation and the transformer winding, bushings form an important component of the transformer. But Bushings are subject to electrical, thermal, and mechanical stress and are therefore a leading cause of transformer failure [1].

Possible failures
There may be problems due to moisture, aging, contact problems and high impedance faults between layers, shorted grading layers, leakages, and partial discharges [2].

Possible diagnostical instruments
You can use visual inspections and thermography, as well as some electrical tests (partial discharge, capacitance, dielectric response with FDS/PDC and DF/PF) and oil analysis (DGA, moisture and color) [2].

Cooling System

Significance
The cooling system has a significant influence on the functionality of a transformer. It is extremely important that the energy from losses within the transformer is efficiently transferred to the environment [2].

Possible failures
There may be a fan failure, a pump failure, a control circuit failure, blocked ducts/pipes, closed radiators and fins, leaks, or a high oil viscosity [2].

Possible diagnostical instruments
You can use visual inspections, infrared scanning, temperature monitoring and oil flow monitoring [3].

OLTC

Significance
OLTCs are used to transfer electrical power from one tap winding to the adjacent tap winding. Studies have shown that OLTCs can account for 10% and up to 50% of all transformer failures [4] [5] [6].

Possible failures
There may be (1) contact burning, leading to contact failure, (2) loss of control, leading to drive shaft failure and control circuit failure, (3) oil containment failure, leading to an isolation board failure and (4) a loss of oil containment, leading to gasket failure [7].

Possible diagnostical instruments
You can use Vibro-acoustic measurements, motor torque, DGAs, IR-thermography and dynamic resistance measurements [2].

Ancillary equipment

Significance
A variety of important ancillary equipment is attached to a power transformer, the failure of which also affects the performance of the transformer. In this example, you can see the breather system. Other components include the Buchholz relay, the preservation system, and lightning arresters [2].

Possible failures
The above-mentioned ancillary equipment might be subject to moisture, dirt, corrosion, leakages, aging or misapplication

Possible diagnostical instruments
You can use visual inspections, infrared scanning, insulation resistance testing and power factor testing [2].

Insulating Liquid

Significance
The dielectric liquid has various functions in a power transformer: (1) Heat transfer by circulation, (2) insulation medium between the live parts and the live parts to ground, (3) impregnation of paper-based, solid insulation and (4) diagnostical purposes [2]. If the dielectric fluid is contaminated, this may cause the power transformer to fail.

Possible failures
There may be (1) physical contamination in form of water, particles, or fibres, (2) chemical contamination, as well as (3) degradation in form of oxidation of the dielectric liquid [2].

Possible diagnostical instruments
You can use dielectric tests like tests for acidity, color, water content, breakdown voltage, the dissipation factor, the DC resistivity as well as an DGA analysis [2].

Transformer tank

Significance
Oil, which is the main means of cooling and insulation, is located in the transformer tank. Accordingly, the tank must withstand the high pressure of the oil as well as vacuum pressure. Obviously, damage to the transformer tank can lead to the inability to function [2].

Possible failures
There may be issues due to climatic conditions leading to corrosion. Furthermore, there may be oil leakages from the main tank gasket joint and/or other welding joints, as well as other damages resulting during the transport, installation, and commissioning of the transformer.

Possible diagnostical instruments
You can use visual inspections as well as measurements for the paint's thickness [2].

2 Handling data uncertainty

Since data varies greatly in terms of quality and age, uncertainty arises. Uncertainty can arise from available data, but also from the non-existence of data [2]. When implementing an evaluation matrix, this uncertainty should be considered.

Sources of Uncertainty [2]:

- Data available but aged – Over time, test results become less likely to represent the current condition
- Data available, but incorrect data entry - Due to the manual data input, it is possible that there are typing or spelling errors
- Data available, but uncertainty in the condition assessment - There are differences in the accuracy of different assessment methods
- Data unavailable – The required information to generate an evaluation matrix is not readily available

Possible Solutions [2]:

- Usage of the relative age of data (age compared to average degradation speed) or statistical techniques (attributes are interpreted as distributions)
- Usage of data validation (can be a simple check of digits or data type but also a setting of limits and ranges)
- Usage of a minimum, maximum and average value of uncertain parameter (e.g., boxplot) or statistical techniques (attributes are interpreted as distributions)
- Usage of a default value (most-likely value, worst-case approach, or best-case default), a default value with range (minimum, maximum and average), a statistical inference (mathematical algorithm or Monte Carlo simulation), an imputation technique (imputation of external and local circumstances) or machine learning (e.g., neural networks)

3 Development of an evaluation matrix (Transformer Assessment Index)

Both asset managers and transformer operators often have responsibility over a large number of transformers. As explained earlier, there is a large amount of data collection points and failure modes, as well as data uncertainty, making the identification of critical transformers in a fleet highly complex. For this reason, evaluation models are often used, assigning some value to each transformer based on the available information.

These evaluation models, which are also called Transformer Assessment Indices (TAI), make it possible for the asset manager to identify transformers that would benefit from action or intervention. In general, a TAI can have the following purposes [2]:

- A TAI can focus on the **short-term** perspective and be designed to identify those transformers that need the asset manager's attention or immediate intervention. An example of such a TAI is the Reliability-Index.
- A TAI can focus on the **long-term** perspective and be designed to identify those transformers that benefit most from repair, refurbishment, or replacement. An example of such a TAI is the Remaining-Lifetime-Index.

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Matrix that considers both perspectives

Ideally, the evaluation of the condition assessment takes place in a matrix that considers both perspectives – the (short-term) reliability and the (long-term) sustainability. There are different stakeholder views among transformer operators. They must make both short-term decisions (concerning the OPEX budget) and long-term decisions (concerning the CAPEX budget) based on the condition knowledge.

4 Recommendation for the development of a TAI – The 5 steps

For the development of a TAI, CIGREs working group A2.49 [2] recommends 5 steps which are explained below, including the main takeaways.

1 Determine the purpose of the Transformer Assessment Score and Index

- The users and asset managers should discuss the purpose of the TAI carefully and agree on it
- This purpose should be closely aligned with the decision to be made by the asset managers
- It should be decided whether the TAI is to be used for a whole fleet or a detailed assessment

2 Identify the failure modes to be included in the TAI

- The failure modes to be included should be aligned to the relevant business drivers
- In general, the users are advised to develop (1) either a very complex TAI, which is composed of many TAIs and therefore contains many failure modes, or (2) to develop only one or a few very simple TAIs, which provide a preliminary result on which further analysis can be based on

3 Determine how each failure mode will be assessed

- It is not always necessary to have measurements of high accuracy (sometimes qualitative information might be sufficient)
- When there are multiple indicators for a single failure mode, the more accurate should be used (double counting should be prevented)
- When there are multiple indicators with similar accuracy for a single failure mode, one should use an average system or a worst-case approach
- It should be determined how to proceed in situations where different indicators of a failure mode come up with different assessments
- If more accurate information is not available, design information, family history, loading information and data from site inspections should be considered

4 Design a calibrated system for categorizing failure modes (scoring matrix)

- A scoring matrix should be designed prior to allocating scores
- All failure modes that have a similar effect on the transformer should have a similar score
- Since the assessment of most failure modes show a lack of precision, there shouldn't be more than five levels
- The time scales used in the matrix should be carefully considered and defined
- For the constant application, each level should be clearly defined

5 Calculate a TAI Score for each Transformer

- As there are multiple ways to generate an overall score, the user should choose the method that most suits his individual needs and the purpose of the TAI
- All transformers of a fleet should be ranked within the scoring system so that prioritization is possible
- Transformers with a failure mode that requires urgent attention should be easily identified within the scoring system
- Any user should be able to interpret the results of the scoring systems
- The scoring system should be transparent, as well as reproducible

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The task of asset managers

The task of asset managers is to ensure the safety, reliability, and sustainability of the transformer fleet at the lowest possible cost. This requires a comprehensive knowledge of each transformer within the fleet. Based on this, a prioritization for critical transformers can be made. Without such knowledge, only simple activities, such as time-based maintenance or repairs in case of damage, can be performed.

References

[1] W. Bartley, "Analysis of Transformer Failures," in 79th International Conference of Doble Clients, Boston, MA, 2012.
[2] CIGRE, "Technical Brochure 761 - Condition Assessment of Power Transformers," 2019.
[3] CIGRE, "Technical Brochure 227 - Life Management Techniques for Power Transformers," 2003.
[4] CIGRE, "Technical Brochure 642 - Transformer Reliability Survey," 2015.
[5] L. Allard, M. Foata and e. al, "Paper A2-202 - Vibro-Acoustic diagnostic contributing to an optimized maintenance strategy," , paper A2-202.," in CIGRÉ 2010 Session.
[6] CIGRE, "Electra Reliability Survey," 1988.
[7] IEEE Std, "C57.140 - Guide for Evaluation and reconditioning of Liquid Immersed Power Transformers," 2017.

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