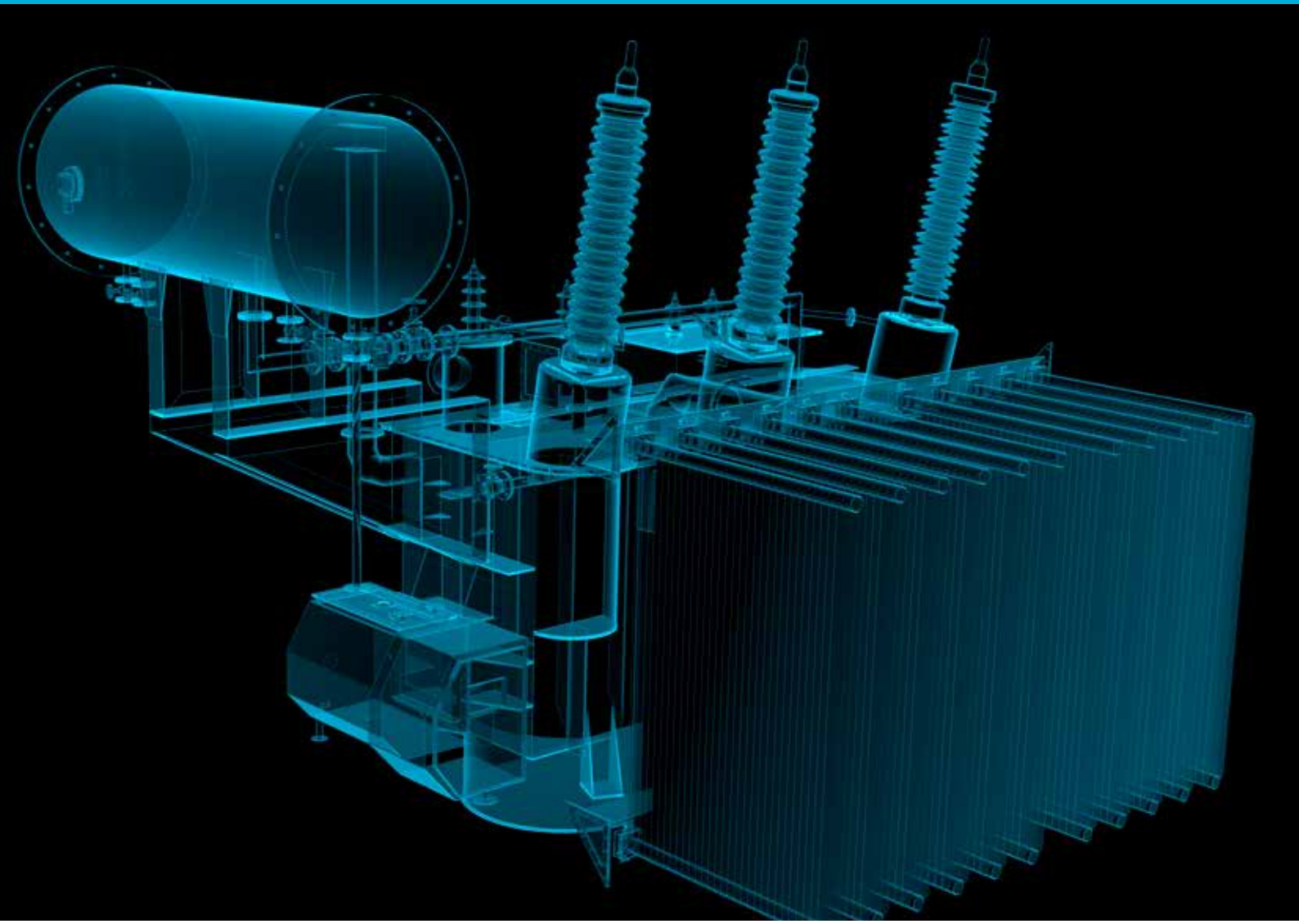

ABSTRACT

Basically, the life expectancy of a power transformer is quite long, known to be around forty years of service before it needs replacing. Nevertheless, during service life of a power transformer, it is necessary to constantly maintain it, mainly in order to make the transformer operate safely as long as possible.

This paper will discuss the main diagnostic methods that could be performed during service life of a transformer. It will also attempt to provide the purposes of the main diagnostic methods carried out by different power transformer stakeholders.

Keywords:

Power Transformers, Diagnosis, Failures, Maintenance

A General Overview of Power Transformer Diagnosis

When diagnosis is used and where to find raw data? Considering 'open databases'.

Introduction

Presuming they operate normally, average life expectancy of power transformers is around forty years. The manufacturer's transformer warranty is valid for one to a few years according the initial contract.

After commissioning and expiration of the initial warranty, the transformer asset is under the full responsibility of its owner.

To make transformers operate safely for as long as possible, it is sometimes necessary to assess its condition in order to prevent a major failure or any significant fault. Also, from the construction of a transformer, or a fleet of transformers, up to the end of its service life, many diagnoses may be performed and analysed.

The last worldwide study on transformer failures was conducted in 1983 by CIGRE Working Group [1] and it produced results based on a precise population of transformers over period of ten years. The average failure rate was around 2 %. Some main points in the report indicated that On Load Tap Changers (OLTC) seemed to increase the risk of transformer failures and that more transformer failure data had to be gathered worldwide and assessed. A significant amount of transformer failure data analysis would statistically lead to more precise studies and appropriate recommendations about transformer failure prevention, maintenance and diagnosis to improve their service life expectancy.

The worst kind of damage that could happen to a transformer is an explosion so we will discuss different ways of preventing such a disastrous event and other possible hazards.

Classic tests and information used for power transformer diagnosis

Failure and condition diagnosis of power transformers can be regarded as a way of testing an ability to withstand voltage and current over time by assessing all possible parts and components related to it.

Two main test types are carried out on power transformers - the factory tests and the field tests. There are two types of factory tests: Quality Assurance (QA) Tests for the manufacturer use during the construction process, and the Factory Acceptance Tests (FAT) which are contractual between the manufacturer and the client.

Power transformers last for decades. Worldwide analysis of major failures could help towards enabling such long service life but it has hardly been updated in the last 30 years.

Those tests are often carried out according to the IEC standard 60076 [2] and are conducted in the client's presence.

Healthy substation three phase power transformer

Afterwards, most of the tests can be carried out onsite [3] but hardly any standard provides precise criteria for the result assessment. At best, they provide trends or slight indications, apart from the oil analysis that has been extensively studied. Finally, field test expertise is required in majority of cases in order to understand and diagnose potential or effective problems, especially if the previous test results indicated an incipient fault, a failure or any out of the ordinary condition of the transformer.

Electrical tests

Electrical tests are divided in two groups: Low Voltage (LV) and High Voltage (HV) tests where the limit is set at 1 kV. Most HV tests, such as induced voltage tests, partial discharge (PD) test or lightning impulse test, require the usage of heavy or highly specialised test devices and the appropriate expertise to interpret the results. Those tests are mostly carried out in the factory and rarely onsite. On the other hand, LV tests, like winding resistance, insulation resistance, tangent delta and voltage ratio, are relatively easy to perform in the factory as well as onsite.

Some recent tests with fingerprints over a frequency band (range) are becoming frequently used as they are easy to carry out, although the results are still not so easy to interpret. These types of tests are

Operational information, electrical tests (LV and HV) and chemical analysis are the basic data used for any power transformer diagnosis.

the Frequency Response Analysis (FRA), from a few Hz to several MHz, mostly used for identification of winding mechanical deformation caused by transportation shock or short circuits, or dielectric spectroscopy, which is a tangent delta test from low (around 100 Hz) to very low (a few MHz) frequency, used to assess the moisture enclosed in the solid insulation of the transformer.

Chemical tests

Two types of most frequently carried out chemical tests are: insulating oil tests and

Substation power transformer on fire

solid insulation tests when paper is accessible (very seldom except at the end of a transformer service life). Solid insulation tests estimate the "remaining life" by measuring the insulation Degree of Polymerisation (DP). There are many tests based on insulating oil (especially mineral oil) studies but the best-known one is the Dissolved Gas Analysis (DGA). It is quite cheap compared to the transformer cost and has been proven to lead to a reliable diagnosis of the transformer's active part. The well-accepted standard for interpretation of the DGA is IEC 60599 [4], including the Duval triangle although further studies have shown some limitations.

Transformer diagnosis is practiced from the design stage to the end of service. Most of it is focused on how to manage the transformer service life safely for as long as possible.

Operational information

An often forgotten but very useful source of information for any diagnosis is all the operational information such as: recent voltage levels, load history, overvoltages, short circuits, temperatures, protection activations if any, etc.

Different stages of power transformer service life and its diagnosis requirements

The life of a transformer could be roughly divided into three main parts that would have different diagnostic requirements: the design up to the manufacturing stage, the onsite commissioning, and finally the service life up to the removal from service due to a devastating failure or failure prevention. Basically, the insurance companies have a choice to take action or offer advice during the service life stages although the insurance companies are mainly concerned with transformer transportation or reduction of service life risks.

From customer requirement to the Final Acceptance Test

When a transformer customer specification has been submitted to a manufacturer, a design will be adopted. It may be of interest to the client to have design reviews with the manufacturer to check if all fixed parameters for the final product fit its operational needs. Then, the workshop performs some internal QA tests during the manufacturing to be sure the transformer assembly is going well, and diagnoses and resolves any existing problem. Finally, the FAT test gives an opportunity to detect any major or minor defects of the transformer under high constraints (i.e. voltages, temperature rises) at the transformer's final construction stage; for example, problems in insulation, design, welding or bolting could appear and be fixed at the last stage.

From factory to commissioning

A critical stage for transformer is the transportation to the site after the FAT

tests and its commissioning. A form of monitoring can be arranged during the transportation in order to detect shocks. Some LV and chemical tests are carried out again for commissioning purpose prior to the first onsite energisation. These tests check if the transportation and the commissioning processes have caused any potential hazard following the FAT tests at the factory. Up to this point, all the diagnostic tests would have been carried out in order to find and fix any faults during the early stage of the transformer service life.

From site to the end of service

Basically, the transformer service life should be quite long, measured in decades, before removal from the service due to a failure or preventive action. Typically, the failure rate of power transformers follows a "bath curve" [5], as in French Transmission System Operator grid fleet.

At this point, two main kinds of diagnostic tests can be carried out over time: condition diagnosis (off-line and/or on-line based) and failure diagnosis. The condition diagnosis is carried out periodically and preventively, and assesses the trend of different parameters (like oil analysis) to test a "steady" condition of the transformer. This kind of diagnosis leads to relatively minor and precise actions to prevent degradation and major failure from happening. On the other hand, some transformer owners carry out transformer diagnostic tests only when a failure has already developed to the stage impossible to ignore. This type of failure diagnosis is a "one shot" diagnosis carried out to locate the precise failure and suggest different ways of fixing it. This kind of maintenance and diagnosis policy can be a problem because the interventions to fix faults are usually quite expensive and some repair work, such as untanking or rewinding, can be very time consuming as most active parts cannot be fixed without untanking or opening the tank.

Transformer diagnosis periodicity is linked to its maintenance policy. All this combined could give more or less options to manage the asset easily over time.

Every power transformer owner has a choice to follow the manufacturer maintenance recommendations or to set their own power transformer maintenance policy, like the main French electric utilities, which maintain large transformers fleets. For example, any transformer owner who wishes to set their own transformer maintenance policy could find many points to adapt in the Cigre Technical Brochure [6] guidelines. Almost every maintenance policy includes some tests (chemical oil analysis, sometimes electrical (LV), and visual inspections) but often disregards the operation parameter history that could potentially help to resolve many problems. LV tests detect major electrical variations that should not normally happen during a transformer service life unless a major internal failure happens within the active part. Comprehensive oil analysis gives a large amount of useful information about the condition and age of the transformer through liquid insulation diagnosis and solid insulation by deduction. The formation and progress of slow occurring internal incipient faults like hot spots or paper degradation (compared to fast transients phenomenon) could be detected by DGA [7] and tracked over time. The quality of the mineral insulating oil, such as acidity or water content, can also be assessed [8] to diagnose complete condition of the transformer.

Condition diagnostic test mainly serves the purpose of preventive and periodic maintenance. It analyses trends (i.e. monitors devices) and diagnoses various progressive faults of the transformers.

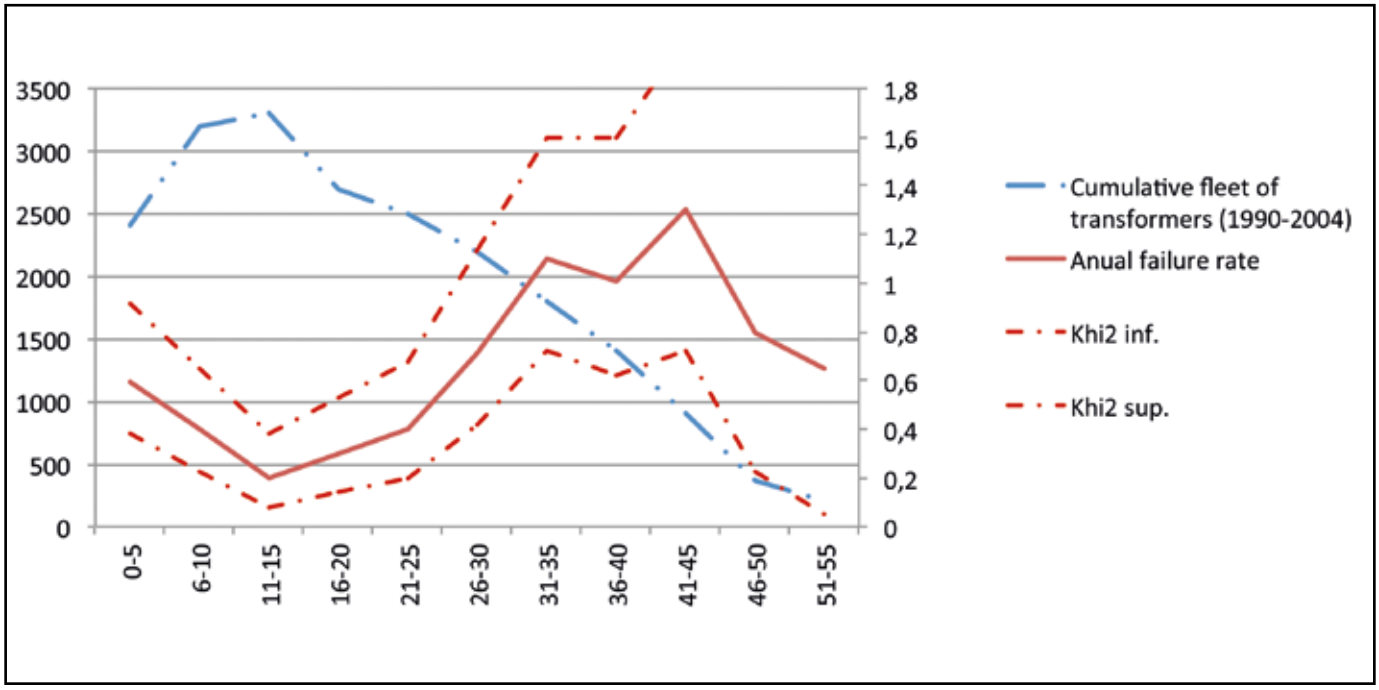

Figure 3.

On the other hand, a failure diagnosis is used to detect and locate a major problem such as a problem caused by the lack of maintenance. In most cases, it implies significant actions to fix internal problems that could have been prevented or minimised through periodic analysis.

In the future some kind of technical transformer open database would allow any party to conduct focused studies on transformers life management and perhaps, steer this field in new directions.

From one transformer to a large number of transformers, a fleet management

Most power transformer owner companies have a whole fleet of transformers. In order to apply or adapt maintenance policies to the whole fleet, two main points must be considered: transformer condition and failure analysis of the existing fleet throughout its service life [9], and Health Index that compares all the transformers through the analysis of many tests and information which result in a unique score by apparatus [10]. Both methods enable the owner company to prioritise actions needed for the specific transformers in the fleet.

Free power transformer data

Many methods of power transformer diagnosis are studied worldwide but the feedback on failure data is extremely difficult to gather and study. The last known large study was conducted 30 years ago [1], and new attempts to update it were abandoned due to lack of data provided by the utilities and transformer users worldwide. Any detailed information, even anonymous, regarding failure and operation of transformers can be firstly organised internally and then submitted externally to any groups (e.g. CIGRE) working on transformer failures and reliability. There will always be room for more precise studies in this field and perhaps in the future, some kind of technical transformer open database would allow any interested party to conduct those kinds of studies, or steer the transformer life management field into new directions.

Conclusion

Power transformer diagnosis is the combination and interpretation of many different kinds of data (electrical, chemical, operational, and offline information) from every stage of the transformer's life. From its correct assembly, to its service condition diagnosis and prevention maintenance to make it operate for as long as possible. At the final stage, the purpose of failure diagnosis is to locate a fault, mostly within the active part of a transformer, and provide often expensive options to repair it or the advice about safe usage up to the end of its service life. Just as the world electrical consumption is still increasing, so does the mostly aging transformer fleet. All this will allow the transformer diagnosis to be a promising and useful field in the years coming! Sharing and improving open knowledge about transformers globally and across many industries has become possible in the last few years with the professional open forum on the Internet [11].

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