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Condition monitoring and diagnostics of power transformers

Surveillance et diagnostic de l'état des transformateurs de puissance

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 108, *Mechanical vibration shock and condition monitoring*, Subcommittee SC 5, *Condition monitoring and diagnostics of machine systems*.

Introduction

This document provides guidance for condition monitoring and diagnostics of power transformers using parameters (such as oil condition, oil contamination, dielectric condition, temperature, power, voltage and current) typically associated with performance, condition and quality criteria. The evaluation of the power transformer function and condition may be based on performance, condition or output quality.

This document is aimed at asset managers, equipment specifiers, owners, operators and reliability and maintenance engineers. It provides a selection process "road map". The parameters and techniques are directed towards best-practice condition-based maintenance, detecting fault conditions, directing maintenance decisions and estimating asset health.

It is principally aimed at people who are not transformer experts, but who have a small number of transformers; for example, supplying power into a manufacturing site where many other items of equipment depend on the power continuing to be supplied by the transformers. The upper limit for the size of such transformers is probably around 50 MVA. While the same principles will also apply to owners and operators of large numbers of transformers such as utilities, which can exceed 50 MVA, it is expected that they will already have their own internal company guidelines and procedures for monitoring their transformers and so are not the primary target of this document.

This document follows on from ISO 17359, which outlines the general process of implementing a condition-based maintenance programme.

Condition monitoring and diagnostics of power transformers

1 Scope

This document gives guidelines for the monitoring techniques to be considered when setting up a condition monitoring programme for power transformers and includes references to associated standards required in this process. It is intended to help in the implementation of a coherent condition monitoring and condition-based maintenance programme, such as described following ISO 17359.

This document is applicable to single-phase alternating current power transformers of ≥ 1 kVA and three phase alternating current power transformers of ≥ 5 kVA.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 13372, *Condition monitoring and diagnostics of machines — Vocabulary*

IEC 60050, *International Electrotechnical Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13372, IEC 60050 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
magnetostriction
property of ferromagnetic materials that causes them to change their shape or dimensions during the process of magnetization

4 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply.

C1	main capacitance of transformer bushings, measured from central current carrying conductor to C1 measurement electrode embedded in the bushing
DGA	dissolved gas analysis
DFR	dielectric frequency response
DETC	de-energized tap-changer

FFT	Fast Fourier Transform: analysis that converts a time-domain signal into a frequency spectrum
FRA	frequency response analysis
IEEE	Institute of Electrical and Electronics Engineers
KOH	potassium hydroxide, used in titration technique for assessing acidity of oil
LV	low voltage NOTE In this document, referring to the lower voltage side of the transformer as distinct from the higher voltage side, rather than to any specific voltage level.
OLTC	on-load tap-changer
OIP	oil impregnated paper, a type of construction for bushings (see also RBP, RIP and RIS)
PD	partial discharge
PDC	polarization and de-polarization current
PF	power factor
RBP	resin bonded paper
RIP	resin impregnated paper
RIS	resin impregnated synthetics
RVM	recovery voltage method
tan-delta	tangent dissipation angle

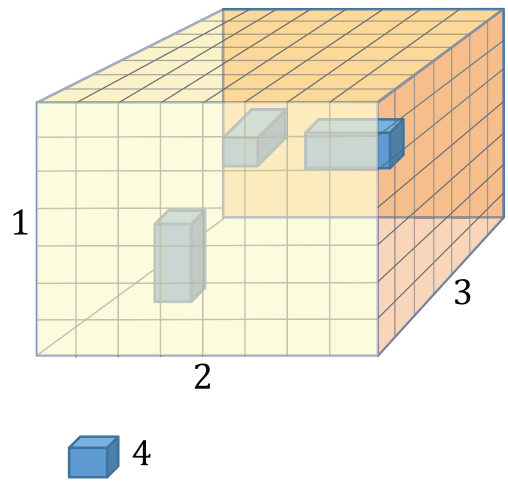
5 Approach to selecting appropriate condition monitoring techniques

5.1 Implementing condition monitoring of transformers

The general process of implementing a condition-based maintenance programme is described in ISO 17359. This document provides more detailed examples and guidance on a range of techniques specifically applicable to the condition monitoring of transformers.

5.2 Components, failure modes and detection techniques

The main objective of condition monitoring is to know about the condition of equipment, to be forewarned of possible failures, and to be able to carry out appropriate maintenance tasks at the appropriate time, i.e. condition-based maintenance. Maintenance tasks are carried out to avoid or rectify failures, so the key to condition-based maintenance is to have an understanding of the failure modes that can affect the equipment, and the techniques that can be used to detect the early stages of those failure modes (potential failure) before functional failure. Specific failure modes affect specific components of the equipment, and certain detection techniques are more applicable to particular failure modes on particular components. Selecting the most appropriate condition monitoring regime therefore involves understanding the most applicable techniques to the particular components and failure modes involved. This can be represented in a three dimensional matrix, as shown in Figure 1 where the blue boxes indicate the area of applicability of particular techniques.



Key

1 failure modes
2 transformer components
3 detection techniques
4 applicable zone

Figure 1 — Matrix of applicable CM techniques vs. components and failure modes

Clauses 6 to 10 explain the different types of transformers in common use, the components involved in those transformers types, the failure modes associated with those components, and the detection techniques for detecting those failure modes.

6 Power transformer types

6.1 Oil-filled transformers

The majority of larger transformers are filled with oil or a similar dielectric fluid for cooling and insulating purposes. These can often be described in a number of ways depending on their size and application. Some typical examples are as follows.

— Main output transformer (MOT) or generator step up transformer (GSU): connects a power generation station to the transmission system, typically in a size range of 100 MVA to 1 000 MVA.

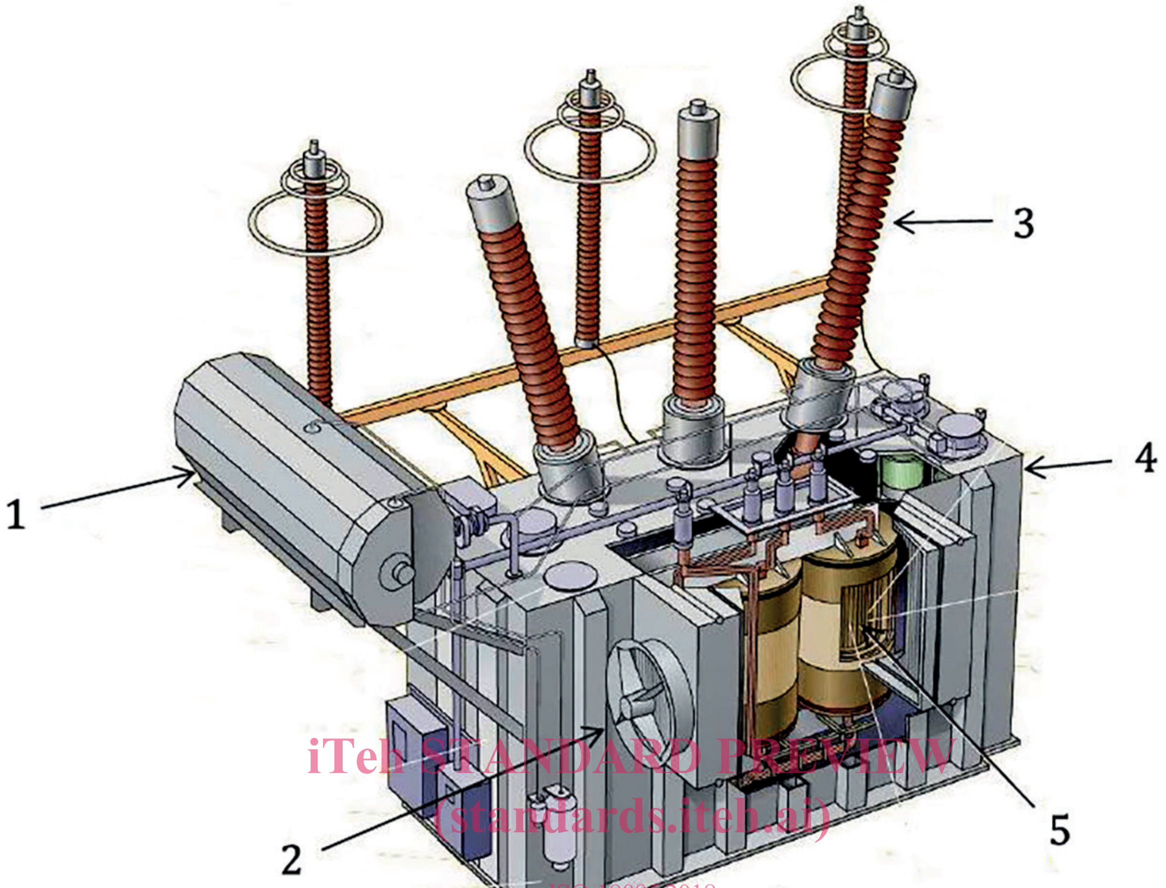
— Transmission transformers: typically 30 MVA to 400 MVA.

— Distribution transformers: typically 2,5 MVA to 70 MVA.

— Pole mounted transformers: typically 10 kVA to 3 MVA.

— Factory or site feed-in transformers: typically 1 MVA to 50 MVA.

A diagram of a typical oil filled transformer is shown in Figure 2, indicating the components involved that are subsequently referred to in 7.1 and Table 2.



Key

1 oil conservator

2 radiator and fan

3 bushings

4 tank

5 windings and core

Figure 2 — Oil filled transformer with key components identified

6.2 Dry-type transformers

Dry-type transformers are used where the avoidance of fire risk and environmental contamination are important. Since they contain no dielectric fluids like oil, their contribution with calorific energy to the source of a fire is very limited. Dry-type transformers are self-extinguishing. They can be used in protected environments where a leakage of oil or other fluids must be avoided.

Typical applications of dry-type transformer are industries (oil and gas, metals and mining, etc.), buildings (hospitals, airports, stadiums, large tower blocks, etc.), on- and off-shore applications (wind turbines, ships, platforms, etc.) and many more.

Currently dry-type transformers are available up to 63 MVA and voltage ratings up to 72,5 kV. They can also be installed with non-liquid insulated on-load tap-changers.

The dielectric insulation is generally provided by a solid insulation or a mixture of a solid insulation and air. The coils are either impregnated with a varnish or resin encapsulated. This sort of construction gives rise to a different set of failure modes compared to oil-filled transformers, since clearly there is no paper insulation or oil to degrade. A typical example is given in Figure 3.

Oil-filled transformers have more components than the dry-type transformer, as is shown in Table 1. This has implications for the failure modes possible and therefore for the maintenance requirements and appropriate condition monitoring techniques.

Dry type transformers can also be equipped with on-load tap changers. Figure 4 shows an example. It is rated at 25 MVA and 69 kV.

NOTE Photo courtesy of ABB Inc.

Figure 3 — Example of dry type transformer

NOTE Photo courtesy of ABB Inc.

Figure 4 — Example of dry-type transformer 69 kV 25 MVA with OLTC device

6.3 Gas-insulated transformers (GITs)

For applications where low flammability is paramount, designs have been developed in which the transformer is insulated and cooled with SF6 gas. This provides an alternative to dry-type construction where it is critical to eliminate the risk of fire and avoid the possible contamination of the environment by oil spillage.

High-voltage SF6 transformers are available at ratings up to 300 MVA at 275 kV and prototype designs have been tested at up to 500 kV. Gas-filled transformers and reactors are more expensive than oil-filled units but the costs may be justified to eliminate a risk of fire, particularly at a site where the cost of land is high and where the overall “footprint” of the unit can be reduced by the elimination of fire-fighting equipment.

7 Power transformer failure mode analysis

7.1 Components

Condition monitoring is directed at detecting incipient failures sufficiently early that appropriate interventions can be made to rectify the problem before complete failure occurs, i.e. to be able to adopt condition-based maintenance. Since failures are associated with particular components within the transformer, the description of the failure modes and detection techniques in this document is structured around the components. The components of different types of transformers are shown in Table 1.

Table 1 — Components of main types of transformer

	Components												
	Wind-ings	Core	Internal connec-tions	Bushings	Insula-tion	Tank/ case	Conserva-tor	Cooling system				Tap-changer	
								Oil	Pump	Radiator	Fans	On-load	De-energized
Oil filled transformers	✓	✓	✓	✓	✓	✓	(✓)	✓	(✓)	(✓)	(✓)	(✓)	(✓)
Dry type transformers	✓	✓	✓	✓	✓	(✓)	–	–	–	(✓)	(✓)	(✓)	(✓)
Gas insulated transformers	✓	✓	✓	✓	✓	✓	(✓)	–	(✓)	(✓)	(✓)	–	(✓)

Key

✓ Always present

(✓) Could be present

– Not normally present

7.2 Categories of failure mode

7.2.1 General

Failure modes in power transformers are typically grouped into the following four categories:

a) dielectric;

b) thermal;

c) mechanical;

d) external.

7.2.2 Dielectric failures

Degradation of insulation between conductors and grounded parts, such as core iron, core frames, and other structural metal parts inside a transformer can lead to increased losses, excessive heating, and for oil-filled transformers, the generation of gases in the oil. As insulation degrades, its ability to withstand voltage stresses decreases, and the transformer's ability to withstand voltage surges can be dramatically reduced. As degradation becomes more severe, the insulation can eventually fail under normal operating conditions, leading to complete catastrophic failure of the transformer.

7.2.3 Thermal

Radiators, coolers, fans, pumps, heat exchangers, oil/water coolers and their associated control equipment all have to be in proper working condition to keep the transformer temperature within acceptable levels. Excessive heating can lead to increased levels of insulation degradation and uneven thermal expansion. High oil temperatures can also create dielectric problems, especially in wet (oil filled) transformers, and can cause oil expansion problems. Many faults (including connection faults, bushing faults, winding faults etc.) can also generate localized heating, leading to problems even when the overall temperature of the transformer is within normal limits.

7.2.4 Mechanical

The primary mechanical concern is the transformer's ability to withstand through-faults, the large currents caused by short circuits external to the transformer. The most common factors affecting the structural integrity of the core/coil assembly are tightness of the core clamping structure and insulation degradation. Loose coils will more likely get damaged by the forces generated by high fault currents. The cellulose that forms the main component of the paper-based insulation in most oil-filled