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Mineral oil-filled electrical equipment in service – Guidance on the interpretation of dissolved and free gases analysis

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CONTENTS

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MINERAL OIL-~~IMPREGNATED~~ FILLED ELECTRICAL EQUIPMENT IN SERVICE – GUIDANCE ON THE INTERPRETATION OF DISSOLVED AND FREE GASES ANALYSIS

FOREWORD

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International Standard IEC 60599 has been prepared by IEC technical committee 10: Fluids for electrotechnical applications.

This third edition cancels and replaces the second edition published in 1999 and Amendment 1:2007. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) revision of 5.5, 6.1, 7, 8, 9, 10, A.2.6, A.3, A.7;

b) addition of new sub-clause 4.3;

c) expansion of the Bibliography;

d) revision of Figure 1;

e) addition of Figure B.4.

The text of this standard is based on the following documents:

FDIS	Report on voting
10/967/FDIS	10/973/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

Dissolved and free gas analysis (DGA) is one of the most widely used diagnostic tools for detecting and evaluating faults in electrical equipment filled with insulating liquid. However, interpretation of DGA results is often complex and should always be done with care, involving experienced insulation maintenance personnel.

This International Standard gives information for facilitating this interpretation. The first edition, published in 1978, has served the industry well, but had its limitations, such as the absence of a diagnosis in some cases, the absence of concentration levels and the fact that it was based mainly on experience gained from power transformers. The second edition attempted to address some of these shortcomings. Interpretation schemes were based on observations made after inspection of a large number of faulty oil-filled equipment in service and concentrations levels deduced from analyses collected worldwide.

MINERAL OIL-~~IMPREGNATED~~ FILLED ELECTRICAL EQUIPMENT IN SERVICE – GUIDANCE ON THE INTERPRETATION OF DISSOLVED AND FREE GASES ANALYSIS

1 Scope

This International Standard describes how the concentrations of dissolved gases or free gases may be interpreted to diagnose the condition of oil-filled electrical equipment in service and suggest future action.

This standard is applicable to electrical equipment filled with mineral insulating oil and insulated with cellulosic paper or pressboard-based solid insulation. Information about specific types of equipment such as transformers (power, instrument, industrial, railways, distribution), reactors, bushings, switchgear and oil-filled cables is given only as an indication in the application notes (see Annex A).

This standard may be applied, but only with caution, to other liquid-solid insulating systems.

In any case, the indications obtained should be viewed only as guidance and any resulting action should be undertaken only with proper engineering judgment.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-191:1990, *International Electrotechnical Vocabulary – Chapter 191: Dependability and quality of service* (available at http://www.electropedia.org)

IEC 60050-192:2015, *International Electrotechnical Vocabulary – Part 192: Dependability* (available at http://www.electropedia.org)

IEC 60050-212:2010, *International Electrotechnical Vocabulary – Part 212: Electrical insulating solids, liquids and gases* (available at http://www.electropedia.org)

IEC 60050-604:1987, *International Electrotechnical Vocabulary – Chapter 604: Generation, transmission and distribution of electricity – Operation* (available at http://www.electropedia.org)

IEC 60475, *Method of sampling insulating liquids*

IEC 60567:~~1992~~ 2011,~~ *Guide for the sampling of gases and of*~~ *Oil-filled electrical equipment* ~~*and for the*~~ *– Sampling of gases and analysis of free and dissolved gases – Guidance*

IEC 61198~~:1993~~, *Mineral insulating oils – Methods for the determination of 2-furfural and related compounds*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions, some of which are based on IEC 60050-191, IEC 60050-192, IEC 60050-212 and IEC 60050-604, apply.

3.1.1
fault
unplanned occurrence or defect in an item which may result in one or more failures of the item itself or of other associated equipment

~~NOTE – In electrical equipment, a fault may or may not result in damage to the insulation and failure of the equipment.~~

[SOURCE: IEC 60050-604:1987, 604-02-01]

3.1.2
non-damage fault
fault which does not involve repair or replacement action at the point of the fault

Note 1 to entry: Typical examples are self-extinguishing arcs in switching equipment or general overheating without paper carbonization or stray gassing of oil.

[SOURCE: IEC 60050-604:1987, 604-02-09]

3.1.3
damage fault
fault that involves repair or replacement action at the point of the fault

[SOURCE: IEC 60050-604:1987, 604-02-08]

3.1.4
incident
~~an event related to an internal fault which temporarily or permanently disturbs the normal operation of an equipment~~
event of external or internal origin, affecting equipment or the supply system and which disturbs its normal operation

Note 1 to entry: For the purposes of the present standard "incidents" are related to internal faults.

Note 2 to entry: For the purposes of the present standard typical examples of "incidents" are gas alarms, equipment tripping or equipment leakage.

[SOURCE: IEC 60050-604:1987, 604-02-03]

3.1.5
failure
~~the termination~~ loss of ability ~~of an item~~ to perform ~~a~~ as required ~~function~~

Note 1 to entry: In electrical equipment, failure will result from a damage fault or incident necessitating outage, repair or replacement of the equipment, such as internal breakdown, rupture of tank, fire or explosion.

[SOURCE: IEC 60050-192:2015, 192-03-01]

3.1.6
electrical fault
partial or disruptive discharge through the insulation

3.1.7
partial discharge
electric discharge that only partially bridges the insulation between conductors. ~~It may occur inside the insulation or adjacent to a conductor~~

Note 1 to entry: A partial discharge may occur inside the insulation or adjacent to a conductor.

~~NOTE 2 – X-wax is a solid material which is formed from mineral insulating oil as a result of electrical discharges and which consists of polymerized fragments of the molecules of the original liquid [IEV 212-07-24, modified]. Comparable products may be formed from other liquids under similar conditions.~~

Note 2 to entry: Scintillations of low energy on the surface of insulating materials are often described as partial discharges but should rather be considered as disruptive discharges of low energy, since they are the result of local dielectric breakdowns of high ionization density, or small arcs, according to the conventions of physics.

~~NOTE 3 – Sparking of low energy, for example because of metals or floating potentials, is sometimes described as partial discharge but should rather be considered as a discharge of low energy.~~

Note 3 to entry: For the purposes of this standard the following consideration may also be added:

– Corona is a form of partial discharge that occurs in gaseous media around conductors that are remote from solid or liquid insulation. This term shall not be used as a general term for all forms of partial discharges

– As a result of corona discharges, X-wax, a solid material consisting of polymerized fragments of the molecules of the original liquid, can be formed.

[SOURCE: IEC 60050-212:2010, 212-11-39]

3.1.8
discharge (disruptive)
passage of an arc following the breakdown ~~of the insulation~~

Note 1 to entry: The term "sparkover" (in French: "amorçage") is used when a disruptive discharge occurs in a gaseous or liquid dielectric.

The term "flashover" (in French: "contournement") is used when a disruptive discharge occurs over the surface of a solid dielectric surrounded by a gaseous or liquid medium.

The term "puncture" (in French: "perforation") is used when a disruptive discharge occurs through a solid dielectric.

Note 2 to entry: Discharges are often described as arcing, breakdown or short circuits. The following other specific terms are also used in some countries:

~~– sparkover (discharge through the oil);~~
~~– puncture (discharge through the solid insulation);~~
~~– flashover (discharge at the surface of the solid insulation);~~
– tracking (the progressive degradation of the surface of solid insulation by local discharges to form conducting or partially conducting paths);
– sparking discharges that, in the conventions of physics, are local dielectric breakdowns of high ionization density or small arcs.

~~NOTE 2 – Depending on the amount of energy contained in the discharge, it will be described as a discharge of low or high energy, based on the extent of damage observed on the equipment (see 5.2).~~

[SOURCE: IEC 60050-604:1987, 604-03-38]

3.1.9
thermal fault
excessive temperature rise in the insulation

Note 1 to entry: Typical causes are

– insufficient cooling;
– excessive currents circulating in adjacent metal parts (as a result of bad contacts, eddy currents, stray losses or leakage flux);
– excessive currents circulating through the insulation (as a result of high dielectric losses), leading to a thermal runaway;
– overheating of internal winding or bushing connection lead;
– overloading.

3.1.10
typical values of gas concentrations
gas concentrations normally found in the equipment in service that have no symptoms of failure, and that are ~~overpassed~~ exceeded by only an arbitrary percentage of higher gas contents (for example 10 % (see 8.2.1))

Note 1 to entry: Typical values will differ in different types of equipment and in different networks, depending on operating practices (load levels, climate, etc.).

Note 2 to entry: Typical values, in many countries and by many users, are quoted as "normal values", but this term has not been used here to avoid possible misinterpretations.

3.2 Abbreviations

3.2.1 Chemical names and ~~symbols~~ formula

Name	~~Symbol~~ Formula
Nitrogen	N_2
Oxygen	O_2
Hydrogen	H_2
Carbon monoxide	CO
Carbon dioxide	CO_2
Methane	CH_4
Ethane	C_2H_6
Ethylene	C_2H_4
Acetylene	C_2H_2

NOTE Acetylene and ethyne are both used for C_2H_2; ethylene and ethene are both used for C_2H_4

3.2.2 General abbreviations

D1	discharges of low energy
D2	discharges of high energy
DGA	dissolved gas analysis
CIGRE	~~Conférence~~ Conseil International des Grands Réseaux Électriques
PD	corona partial discharges
S	analytical detection limit
T1	thermal fault, t <300 °C
T2	thermal fault, 300 °C <t< 700 °C
T3	thermal fault, t >700 °C
T	thermal fault
D	electrical fault
TP	thermal fault in paper
ppm	parts per million by volume of gas in oil, equivalent to µl(of gas)/l(of oil). See IEC 60567:2011, 8.7, note 1.
OLTC	on load tap changer

4 Mechanisms of gas formation

4.1 Decomposition of oil

Mineral insulating oils are made of a blend of different hydrocarbon molecules containing CH_3, CH_2 and CH chemical groups linked together by carbon-carbon molecular bonds. Scission of some of the C-H and C-C bonds may occur as a result of electrical and thermal faults, with the formation of small unstable fragments, in radical or ionic form, such as $H^{\bullet}$, $CH_3^{\bullet}$, $CH_2^{\bullet}$, $CH^{\bullet}$ or $C^{\bullet}$ (among many other more complex forms), which recombine rapidly, through complex reactions, into gas molecules such as hydrogen (H-H), methane (CH_3-H), ethane (CH_3-CH_3), ethylene ($CH_2 = CH_2$) or acetylene ($CH \equiv CH$). C_3 and C_4 hydrocarbon gases, as well as solid particles of carbon and hydrocarbon polymers (X-wax), are other possible recombination products. The gases formed dissolve in oil, or accumulate as free gases if produced rapidly in large quantities, and may be analysed by DGA according to IEC 60567.

Low-energy faults, such as partial discharges of the cold plasma type (corona discharges), favour the scission of the weakest C-H bonds (338 kJ/mol) through ionization reactions and the accumulation of hydrogen as the main recombination gas. More and more energy and/or higher temperatures are needed for the scission of the C-C bonds and their recombination into gases with a C-C single bond (607 kJ/mol), C=C double bond (720 kJ/mol) or C≡C triple bond (960 kJ/mol), following processes bearing some similarities with those observed in the petroleum oil-cracking industry.

Ethylene is thus favoured over ethane and methane above temperatures of approximately 500 °C (although still present in lower quantities below). Acetylene requires temperatures of at least 800 °C to 1 200 °C, and a rapid quenching to lower temperatures, in order to accumulate as a stable recombination product. Acetylene is thus formed in significant quantities mainly in arcs, where the conductive ionized channel is at several thousands of degrees Celsius, and the interface with the surrounding liquid oil necessarily below 400 °C (above which oil vaporizes completely), with a layer of oil vapour/decomposition gases in between. Acetylene may still be formed at lower temperatures (<800 °C), but in very minor quantities. Carbon particles form at 500 °C to 800 °C and are indeed observed after arcing in oil or around very hot spots.

Oil may oxidize with the formation of small quantities of CO and CO_2, which can accumulate over long periods of time into more substantial amounts.

4.2 Decomposition of cellulosic insulation

The polymeric chains of solid cellulosic insulation (paper, pressboard, wood blocks) contain a large number of anhydroglucose rings, and weak C-O molecular bonds and glycosidic bonds which are thermally less stable than the hydrocarbon bonds in oil, and which decompose at lower temperatures. Significant rates of polymer chain scission occur at temperatures higher than 105 °C, with complete decomposition and carbonization above 300 °C (damage fault). ~~Mostly~~ Carbon monoxide and dioxide, as well as water, is formed~~, in much larger quantities than by oxidation of oil at the same temperature,~~ together with minor amounts of hydrocarbon gases, furanic and other compounds. ~~The latter~~ Furanic compounds ~~can be~~ are analysed according to IEC 61198, and used to complement DGA interpretation and confirm whether or not cellulosic insulation is involved in a fault. CO and CO_2 formation increases not only with temperature but also with the oxygen content of oil and the moisture content of paper.

4.3 Stray gassing of oil

Stray gassing of oil has been defined by CIGRE [6][1] as the formation of gases in oil heated to moderate temperatures (<200 °C). H_2, CH_4 and C_2H_6 may be formed in all equipment at such

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[1] Numbers in square brackets refer to the Bibliography.