

Mineral oil-impregnated electrical equipment in service — Guide to the interpretation of dissolved and free gases analysis

The European Standard EN 60599:1999, incorporating amendment A1:2007, has the status of a British Standard

ICS 17.220.99; 29.040.10; 29.180

National foreword

This British Standard is the UK implementation of EN 60599:1999, incorporating amendment A1:2007. It is identical with IEC 60599:1999, incorporating amendment 1:2007. It supersedes BS 5800:1979 which is withdrawn.

The start and finish of text introduced or altered by amendment is indicated in the text by tags **A1** **A1**. Tags indicating changes to IEC text carry the number of the IEC amendment. For example, text altered by IEC amendment 1 is indicated by **A1** **A1**.

The UK participation in its preparation was entrusted to Technical Committee GEL/10, Fluids for electrotechnical applications.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Committee and comes into effect on 15 June 1999

© BSI 2007

ISBN 978 0 580 59335 2

Amendments issued since publication

Amd. No.	Date	Comments
17195	31 July 2007	See national foreword
17332 Corrigendum No. 1	31 July 2007	Amends errors with symbols in Table 3.2.1

English version

Mineral oil-impregnated electrical equipment in service Guide to the interpretation of dissolved and free gases analysis

(IEC 60599:1999)

Matériels électriques imprégnés d'huile
minérale en service — Guide pour
l'interprétation de l'analyse des gaz
dissous et des gaz libres
(CEI 60599:1999)

Im Betrieb befindliche, mit Mineralöl
imprägnierte elektrische Geräte
Leitfaden zur Interpretation der
Analyse gelöster und freier Gase
(IEC 60599:1999)

This European Standard was approved by CENELEC on 1999-01-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B-1050 Brussels

Foreword

The text of document 10/450/FDIS, future edition 2 of IEC 60599, prepared by IEC TC 10, Fluids for electrotechnical applications, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60599 on 1999-01-01.

This European Standard supersedes HD 397 S1:1979.

The following dates were fixed:

- latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 2000-01-01
- latest date by which the national standards conflicting with the EN have to be withdrawn (dow) 2002-01-01

Annexes designated “normative” are part of the body of the standard. Annexes designated “informative” are given for information only. In this standard, Annex ZA is normative and Annex A, Annex B and Annex C are informative. Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 60599:1999 was approved by CENELEC as a European Standard without any modification.

Foreword to amendment A1

The text of document 10/685/FDIS, future amendment 1 to IEC 60599:1999, prepared by IEC TC 10, Fluids for electrotechnical applications, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as amendment A1 to EN 60599:1999 on 2007-05-01.

The following dates were fixed:

- latest date by which the amendment has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 2008-02-01
- latest date by which the national standards conflicting with the amendment have to be withdrawn (dow) 2010-05-01

Endorsement notice

The text of amendment 1:2007 to the International Standard IEC 60599:1999 was approved by CENELEC as an amendment to the European Standard without any modification.

Contents

	Page	Page	
Foreword	2	Table A.5 — Typical faults in instrument transformers	19
Introduction	4	Table A.6 — Ranges of 90 % typical concentration values observed in instrument transformers	19
1 Scope	4	Table A.7 — Typical faults in bushings	20
2 Normative references	4	Table A.8 — Simplified interpretation scheme for bushings	20
3 Definitions and abbreviations	4	Table A.9 — 95 % typical concentration values in bushings	21
4 Mechanisms of gas formation	6	Table A.10 — Ranges of 95 % typical concentration values observed on cables	21
5 Identification of faults	7	Table A.11 — Typical faults in switching equipment	21
6 Conditions for calculating ratios	9		
7 Application to free gases in gas relays	10		
8 Gas concentration levels in service	11		
9 Recommended method of DGA interpretation (Figure 1)	13		
10 Report of results	13		
Annex A (informative) Equipment application notes	15		
Annex B (informative) Graphical representation of gas ratios	22		
Annex C (informative) Bibliography	25		
Annex ZA (normative) Normative references to international publications with their corresponding European publications	26		
Figure 1 — Flow chart	14		
Figure B.1 — Graphical representation 1 of gas ratios	22		
Figure B.2 — Graphical representation 2 of gas ratios	23		
Figure B.3 — Graphical representation 3 of gas ratios — Duval's triangle	24		
Table 1 — Abbreviations	7		
Table 2 — DGA interpretation table	8		
Table 3 — Simplified scheme of interpretation	8		
Table 4 — Ostwald coefficients for various gases in mineral insulating oils	11		
Table A.1 — Typical faults in power transformers	15		
Table A.2 — Ranges of 90 % typical gas concentration values observed in power transformers, in $\mu\text{l/l}$	16		
Table A.3 — Ranges of 90 % typical rates of gas increase observed in power transformers (all types), in $\mu\text{l/l/year}$	17		
Table A.4 — Examples of 90 % typical concentration values observed on a typical network (all types of transformers)	18		

Introduction

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

This guide 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. This second edition attempts to address some of these shortcomings. Interpretation schemes are 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.

1 Scope

This International Standard is a guide describing 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 guide 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).

The Guide may be applied 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 normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60050(191):1990, *International Electrotechnical Vocabulary (IEV) — Chapter 191: Dependability and quality of service.*

IEC 60050(212):1990, *International Electrotechnical Vocabulary (IEV) — Chapter 212: Insulating solids, liquids and gases.*

IEC 60050(604):1987, *International Electrotechnical Vocabulary (IEV) — Chapter 604: Generation, transmission and distribution of electricity — Operation.*

IEC 60567:1992, *Guide for the sampling of gases and of oil from oil-filled electrical equipment and for the analysis of free and dissolved gases.*

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

3 Definitions and abbreviations

3.1 Definitions

For the purpose of this International Standard, the following definitions, some of them based on IEC 60050(191), IEC 60050(212) and IEC 60050(604) apply:

3.1.1

fault

an unplanned occurrence or defect in an item which may result in one or more failures of the item itself or of other associated equipment [IEV 604-02-01]

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

3.1.2

non-damage fault

a fault which does not involve repair or replacement action at the point of the fault [IEV 604-02-09]

NOTE Typical examples are self-extinguishing arcs in switching equipment or general overheating without paper carbonization.

3.1.3

damage fault

a fault which involves repair or replacement action at the point of the fault [IEV 604-02-08, modified]

3.1.4

incident

an event related to an internal fault which temporarily or permanently disturbs the normal operation of an equipment [IEV 604-02-03, modified]

NOTE Typical examples are gas alarms, equipment tripping or equipment leakage.

3.1.5

failure

the termination of the ability of an item to perform a required function [IEV 191-04-01]

NOTE In the 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.

3.1.6 electrical fault

a partial or disruptive discharge through the insulation

3.1.7 partial discharge

a discharge which only partially bridges the insulation between conductors. It may occur inside the insulation or adjacent to a conductor [IEV 212-01-34, modified]

NOTE 1 Corona is a form of partial discharge that occurs in gaseous media around conductors which are remote from solid or liquid insulation. This term is not to be used as a general term for all forms of partial discharges.

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 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.

3.1.8 discharge (disruptive)

the passage of an arc following the breakdown of the insulation [IEV 604-03-38, modified]

NOTE 1 Discharges are often described as arcing, breakdown or short circuits. The more specific following terms are also used:

- 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 which, 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).

3.1.9 thermal fault

excessive temperature rise in the insulation

NOTE 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.

3.1.10 typical values of gas concentrations

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

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

NOTE 2 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

Name	Symbol
Nitrogen	N ₂
Oxygen	O ₂
Hydrogen	H ₂
Carbon monoxide	CO
Carbon dioxide	CO ₂
Methane	CH ₄
Ethane	C ₂ H ₆
Ethylene	C ₂ H ₄
Acetylene	C ₂ H ₂

3.2.2 General abbreviations

- DGA: Dissolved gas analysis
- CIGRE: Conférence Internationale des Grands Réseaux Électriques
- S: Analytical detection limit

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^* , CH_3^* , CH_2^* , CH^* or C^* (among many other more complex forms), which recombine rapidly, through complex reactions, into gas molecules such as hydrogen (H-H), methane ($\text{CH}_3\text{-H}$), ethane ($\text{CH}_3\text{-CH}_3$), ethylene ($\text{CH}_2 = \text{CH}_2$) or acetylene ($\text{CH} \equiv \text{CH}$). O_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 analyzed 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/mole) 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/mole), C=C double bond (720 kJ/mole) or $\text{C} \equiv \text{C}$ triple bond (960 kJ/mole), 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. Mostly carbon monoxide and dioxide, as well as water, are formed, in much larger quantities than by oxidation of oil at the same temperature, together with minor amounts of hydrocarbon gases and furanic compounds. The latter can be analyzed 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 Other sources of gas

Gases may be generated in some cases not as a result of faults in the equipment but through rusting or other chemical reactions involving steel, uncoated surfaces or protective paints.

Hydrogen may be produced by reaction of steel with water, as long as oxygen is available from the oil nearby. Large quantities of hydrogen have thus been reported in some transformers that had never been energized. Hydrogen may also be formed by reaction of free water with special coatings on metal surfaces, or by catalytic reaction of some types of stainless steel with oil, in particular oil containing dissolved oxygen at elevated temperatures. Hydrogen may also be formed in new stainless steel, absorbed during its manufacturing process, or produced by welding, and released slowly into the oil.

Hydrogen may also be formed by the decomposition of the thin oil film between overheated core laminates at temperatures of 140 °C and above (see [1]¹⁾ of Annex C).

Gases may also be produced by exposure of oil to sunlight or may be formed during repair of the equipment.

Internal transformer paints, such as alkyd resins and modified polyurethanes containing fatty acids in their formulation, may also form gases.

¹⁾ Figures in square brackets refer to the bibliography in Annex C.

These occurrences, however, are very unusual, and can be detected by performing DGA analyses on new equipment which has never been energized, and by material compatibility tests. The presence of hydrogen with the total absence of other hydrocarbon gases, for example, may be an indication of such a problem.

NOTE The case of gases formed at a previous fault and remnant in the transformer is dealt with in 5.3.

5 Identification of faults

Any gas formation in service, be it minimal, results from a stress of some kind, even if it is a very mild one, like normal temperature ageing. However, as long as gas formation is below typical values, it should not be considered as an indication of a “fault”, but rather as “typical gas formation” (see Figure 1).

5.1 Dissolved gas compositions

Although the formation of some gases is favoured, depending on the temperature reached or the energy contained in a fault (see 4.1), in practice mixtures of gases are almost always obtained. One reason is thermodynamic: although not favoured, secondary gases are still formed, albeit in minor quantities. Existing thermodynamic models derived from the petroleum industry, however, cannot predict accurately the gas compositions formed, because they correspond to ideal gas/temperature equilibria which do not exist in actual faults. Large temperature gradients also occur in practice, for instance as a result of oil flow or vaporization along a hot surface. This is particularly true in the case of arcs with power follow-through, which transfer a lot of heat to the oil vapour/decomposition gas layer between the arc and the oil, probably explaining the increasing formation of ethylene observed in addition to acetylene. In addition, existing thermodynamic models do not apply to paper, which turns irreversibly to carbon above 300 °C.

5.2 Types of faults

Internal inspection of hundreds of faulty equipment has led to the following broad classes of visually detectable faults:

- partial discharges (PD) of the cold plasma (corona) type, resulting in possible X-wax deposition on paper insulation, or of the sparking type, inducing pinhole, carbonized perforations (punctures) in paper, which, however, may not be easy to find;

- discharges of low energy (D1), in oil or/and paper, evidenced by larger carbonized perforations through paper (punctures), carbonization of the paper surface (tracking) or carbon particles in oil (as in tap changer diverter operation);

- discharges of high energy (D2), in oil or/and paper, with power follow-through, evidenced by extensive destruction and carbonization of paper, metal fusion at the discharge extremities, extensive carbonization in oil and, in some cases, tripping of the equipment, confirming the large current follow-through;

- thermal faults, in oil or/and paper, below 300 °C if the paper has turned brownish (T1), and above 300 °C if it has carbonized (T2);

- thermal faults of temperatures above 700 °C (T3) if there is strong evidence of carbonization of the oil, metal coloration (800 °C) or metal fusion (> 1 000 °C).

Table 1 — Abbreviations

PD	Partial discharges
D1	Discharges of low energy
D2	Discharges of high energy
T1	Thermal fault, $t < 300\text{ °C}$
T2	Thermal fault, $300\text{ °C} < t < 700\text{ °C}$
T3	Thermal fault, $t > 700\text{ °C}$

5.3 Basic gas ratios

Each of the six broad classes of faults leads to a characteristic pattern of hydrocarbon gas composition, which can be translated into a DGA interpretation table, such as the one recommended in Table 2 and based on the use of three basic gas ratios:

$$\frac{\text{C}_2\text{H}_2}{\text{C}_2\text{H}_4} \quad \frac{\text{CH}_4}{\text{H}_2} \quad \frac{\text{C}_2\text{H}_4}{\text{C}_2\text{H}_6}$$

Table 2 applies to all types of equipment, with a few differences in gas ratio limits depending on the specific type of equipment.