



IEEE Guide for the Interpretation of Gases Generated in Mineral Oil-Immersed Transformers

STANDARDS

IEEE Power and Energy Society

Developed by the
Transformers Committee

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(Revision of IEEE Std C57.104-2008)



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of the
IEEE Power and Energy Society

Approved 13 June 2019

IEEE SA Standards Board

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Abstract: Detailed procedures for interpreting Dissolved Gas Analysis results are described in this guide. The document details: 1) Overview of gas generation in transformer and DGA process; 2) The purpose and application of DGA; 3) DGA quality verification and DGA limitations; 4) DGA interpretation and norms; 5) Fault type definitions and identification; 6) Case studies and interpretation example. The intent is to provide the operator with useful information concerning the serviceability of the equipment. An extensive bibliography on gas evolution, detection, and interpretation is included.

Keywords: DGA, gas analysis, IEEE C57.104™, mineral oil, mineral oil-immersed transformers, transformers

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Introduction

This introduction is not part of IEEE Std C57.104-2019, IEEE Guide for the Interpretation of Gases Generated in Mineral Oil-Immersed Transformers.

IEEE Std C57.104™-1991 was officially withdrawn by IEEE based on recommendation by the Transformers Committee of the IEEE Power and Energy Society at the end of 2005. IEEE Std C57.104-2008 was issued with minor changes to address some of the most pressing issues identified from the 1991 version (such as correcting typos, factual errors, and the values listed in Table 1 of the 1991 version of the guide) for use by the industry.

Upon publication of the 2008 document, the working group immediately began the process of further revision to the guide to reflect additional advances in current knowledge and trends, and to incorporate relevant and new material presented during several meetings of both the IEEE Std C57.104 Working Group Task Force (WG TF) leaders and general IEEE Transformer Committee meetings. In addition, results from the analysis of more than a million pieces of laboratory DGA data has resulted in revision of several tables in this guide.

Changes in this revised guide are as follows:

- All clauses reviewed and updated.
- Reduction of Table 1 from four conditions to three DGA status based on 90th and 95th percentile values.
- Modification of Table 1 to include several subcategories and split between Table 1 (90th percentile) and Table 2 (95th percentile) based on results of a large statistical study (Annex A).
- Removal of TCG and TDCG interpretation and associated Table 2 and Table 3.
- Introduction of delta and rate tables: Table 3 and Table 4.
- New interpretation flowchart and methodology with illustrative examples (Annex B).
- Updated fault definitions in Annex C.
- Introduction of the Duval Triangle and pentagon interpretations methods in 6.2 and in Annex D and removal of the Doernenberg and key gas methodology from main text.
- Addition of case studies in Annex E.
- Addition of Normalized Energy Intensity (NEI) methodology in Annex F.
- Preservation of deleted material with historical values in Annex G.
- An updated bibliography in Annex H.

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1. Overview

Over the years, since transformer dissolved-gas analysis (DGA) was first used in the 1960s, accumulated experience and new technology have led to significant improvements. Gas formation processes and severity assessment are now better understood. Chart-based methods and slide rules have been replaced by modern computer-based technologies that bring improved communications, data management, graphical and computational aids, analysis, and electronic reports. Instrument technology has advanced greatly, providing better laboratory instruments, as well as field-portable gas analyzers and on-line gas monitors.

The fundamental purpose of DGA is to discriminate between normal and abnormal conditions. More specifically, DGA aims to provide a reliable and economical method of detecting faults, which may present unacceptable possibility of damage or near-term failure. In transformers, a fault is revealed by the production of new gases. In many cases, active faults generate gases at such a high rate that detection and assessment do not require finesse. On the other hand, the gases generated by a subtle, incipient, or intermittent fault can sometimes be difficult to distinguish from the background of residual gases already present in the transformer during “normal” operation. This situation can arise because of normal variations in gas concentrations due to load and environmental conditions; unavoidable random “noise” from measurement uncertainty (method repeatability and reproducibility), as well as data quality issues arising from poor sampling technique, exposure of samples to air, or mislabeling of samples. As with any decision process based on data subject to “random” interference, a method must be developed to minimize the number of false positives while also minimizing the number of false negatives, i.e., failures to detect real abnormalities.

DGA is one of the most widely used diagnostic tools for transformer condition assessment because experience has proven it to be an effective tool.

Even so, DGA has limitations that warrant some precautions in interpretation, such as:

- Samples can be incorrectly collected, identified, or processed. The veracity of dissolved gas data should be checked before remedial or emergency action is undertaken (i.e., a confirmation sample).
- Unusual causes of gas formation can misdirect DGA diagnosis. For example, when a pattern consistent with “stray gassing” is observed, the possibility of that explanation should be carefully considered before further action is taken.
- Gas concentrations alone are not a sufficient indicator of transformer condition. An understanding of how the gases were produced, and at what rates, is usually needed for judging the significance of the gases found in a sample.

- Multiple phenomena occurring simultaneously, or at different times, can confuse analysis. Examination of changes in gas concentrations helps to reveal the active processes.
- Rates and accelerations of gas formation provide the best basis for evaluating process development, but proper determination of gas formation rates and accelerations requires several measurements over time.
- Characterizing the rate and pattern of gas formation is not always sufficient to identify the origin of gas generation. Comparison with historical information, industry trends, and documented case histories can be helpful. Additional diagnostic tools, such as on-line and off-line electrical, mechanical or acoustic testing, internal inspection and other insulating liquid testing, may be needed.

This guide is based on the collective experience of the industry in using the strengths of DGA and managing its limitations to detect abnormal gas formation, identify its most probable causes, and follow its development to assess the severity of a developing abnormality.

~~The detection of certain gases generated in an oil-filled transformer in service is frequently the first available indication of a malfunction that may eventually lead to failure if not corrected. Arcing, partial discharge, low energy sparking, severe overloading, pump motor failure, and overheating in the insulation system are some of the possible mechanisms. These conditions occurring singly, or as several simultaneous events, can result in decomposition of the insulating materials and the formation of various combustible and noncombustible gases. Normal operation will also result in the formation of some gases. In fact, it is possible for some transformers to operate throughout their useful life with substantial quantities of combustible gases present. Operating a transformer with large quantities of combustible gas present is not a normal occurrence but it does happen, usually after some degree of investigation and an evaluation of the possible risk.~~

~~In a transformer, generated gases can be found dissolved in the insulating oil, in the gas blanket above the oil, or in gas collecting devices. The detection of an abnormal condition requires an evaluation of the amount of generated gas present and the continuing rate of generation. Some indication of the source of the gases and the kind of insulation involved may be gained by determining the composition of the generated gases.~~

1.1 Scope

This guide applies to mineral oil-immersed transformers and addresses:

- a) The theory of combustible gas generation in a transformer
- b) The interpretation of gas analysis
- c) Suggested operating procedures
- d) Various diagnostic techniques, such as key gases, ~~Dornenberg ratios, and~~ Rogers Ratios, [Duval Triangle, and other methods](#)
- e) [Case studies and examples](#)
- f) [Evaluation criteria and guidelines](#)
- ~~e) Instruments for detecting and determining the amount of combustible gases present~~
- g) A bibliography of related literature

1.2 Purpose

[The purpose of this document is to provide a guide for evaluating dissolved gases analysis results from mineral oil-immersed transformers using statistical based analytical tools and fault interpretation methods.](#)

1.3 Limitations to use of this document

[This guide is applicable to mineral oil-immersed transformers and reactors of all types, sizes, voltage classes, construction, and usages, except those excluded in 1.3.](#)

[This guide is not applicable to DGA samples taken during factory testing. For DGA samples taken during factory temperature rise tests, refer to IEEE Std C57.130™ \[B105\].¹](#)

¹ [The numbers in brackets correspond to those of the bibliography in Annex H.](#)

This guide is not applicable to load tap changers (LTC) and to transformers with main tank insulating liquid in contact with LTC insulating liquid, for example, a common expansion tank (refers mostly to in-tank type LTCs) or common air space inside the expansion tank. Load Tap Changer DGA, is covered by IEEE Std C57.139™ [B106].

This guide is not applicable to transformers using any insulating liquid other than mineral oil. Transformers using an ester-based liquid, are covered by IEEE Std C57.155™ [B109]. Transformers using silicone liquid, are covered by IEEE Std C57.146™ [B107].

The user of this guide must consider the internal components of the transformer when choosing to apply the guide to specific transformer types such as wind turbine transformers or network transformers. Such transformers may have auxiliary components such as load break switches (as an example) immersed in the same oil as the transformer itself. As such a component produces an electrical arc and combustible gases as a normal part of its operation, the user of this guide must consider the possibilities that:

- The transformer oil DGA results may be almost entirely a result of switch operation, and not an accurate reflection of the health of the transformer itself.
- The gases produced by the switch operation may be much greater than the gases produced by the transformer itself, and therefore may mask any problems associated with the transformer that might otherwise be detectable via DGA interpretation.

Note that the initial analysis of the data received in preparation of this guide clearly indicated that DGA results from transformers identified as wind turbine or network transformers often had excessively elevated typical values, in some case two orders of magnitude higher than the rest of the DGA database. There was no information to indicate if the transformers were healthy or under extreme distress. Therefore, the DGA data subset from wind turbine and network transformers was not included in the study to obtain the norms used in this guide. Consequently, if the user of this guide applies the norms presented herein to such transformer types, the result may often be high DGA status levels.

In the case of wind turbine transformers in particular, they have special operating conditions in that they are closely connected to power electronics and have frequently and widely fluctuating loads. Some of the earlier generation designs of these transformers were not adequately robust for such operating conditions, and hence the often elevated gas values are seen. For further insight into wind turbine transformer design and their particular DGA issues, refer to “Wind Power Transformer Design” [B102] and “Unusual DGA results in wind turbine transformers” [B129].

Sampling of transformer insulating liquid for DGA should be done by suitably trained personnel following standard procedures such as ASTM D923.² The measurement of gas concentrations should be performed by an analytical laboratory according to the methods defined in ASTM D3612, or by suitably trained personnel using a portable instrument, or by a suitably connected on-line monitoring device.

The interpretation of DGA data should be performed by a suitably trained and experienced person. Computer analysis of the DGA results with tools such as spreadsheets, databases, analytical software, or maintenance management systems, can be used when evaluating the health and condition of a transformer. Any other relevant information, such as transformer nameplate, factory test reports, operational and maintenance records, in service test results and environmental conditions, should also be considered in such evaluation. An aggregate of all available information is generally considered the optimal approach when a detailed interpretation is required. The nature of the interpretation also depends upon the context or application of the DGA.

For various reasons, some of which are explained in this guide, DGA results can sometimes be indeterminate or misleading, and sometimes DGA can fail to detect or identify a fault that may be present.

Drastic or costly measures should not be taken based on DGA results alone, particularly not on an individual, isolated DGA sample, without confirmation by additional DGA results and/or other tests such as electrical performance tests, expert consultation, and due regard to local operating conditions, requirements, and safety issues. It should also be noted that DGA is a detection and diagnostic tool, not a predictive technique. It can only detect an existing or past condition and has no capability to “predict” any future condition. However, when a condition exists, DGA can be used to track and evaluate its evolution over time.

1.4 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (shall equals is required to).^{3,4}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (should equals is recommended that).

The word *may* is used to indicate a course of action permissible within the limits of the standard (may equals is permitted to).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (can equals is able to).

1.2 Limitations

~~Many techniques for the detection and the measurement of gases have been established. However, it must be recognized that analysis of these gases and interpretation of their significance is, at this time, not a science but an art subject to variability. Their presence and quantity are dependent on equipment variables such as type, location, and temperature of the fault; solubility and degree of saturation of various gases in oil; the type of oil preservation system; the type and rate of oil circulation; the kinds of material in contact with the fault; and finally, variables associated with the sampling and measuring procedures themselves. Because of the variability of acceptable gas limits and the significance of various gases and generation rates, a consensus is difficult to obtain. The principal obstacle in the development of fault interpretation as an exact science is the lack of positive correlation of the fault-identifying gases with faults found in actual transformers.~~

³ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

⁴ The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

~~The result of various ASTM testing round robins indicates that the analytical procedures for gas analysis are difficult, have poor precision, and can be wildly inaccurate, especially between laboratories. A replicate analysis confirming a diagnosis should be made before taking any major action.~~

~~This guide is intended to provide guidance on specific methods and procedures that may assist the transformer operator in deciding on the status and continued operation of a transformer that exhibits combustible gas formation. However, operators must be cautioned that, although the physical reasons for gas formation have a firm technical basis, interpretation of that data in terms of the specific cause or causes is not an exact science, but it is the result of empirical evidence from which rules for interpretation have been derived. Hence, exact causes or conditions within transformers may not be inferred from the various procedures. The continued application of the rules and limits in this guide, accompanied by actual confirmation of the causes of gas formation, will result in continued refinement and improvement in the correlation of the rules and limits for interpretation.~~

~~Individual experience with this guide will assist the operators in determining the best procedure, or combination of procedures, for each specific case. Some of the factors involved in the decision of the operator are: the type of oil preservation system, the type and frequency of the sampling program, and the analytical facilities available. However, whether used separately or as complements to one another, the procedures disclosed in this guide all provide the operator with useful information concerning the serviceability of the equipment.~~

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ASTM D923, Standard Practices for Sampling Electrical Insulating Liquids.^{5 4}

~~ASTM D 2945, Standard Test Method for Gas Content of Insulating Oils.~~

~~ASTM D 3305, Standard Practice for Sampling Small Gas Volume in a Transformer.~~

ASTM D3612, Standard Test Method for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography.

[IEC 60567, Oil-filled electrical equipment—Sampling of gases and of oil for analysis of free and dissolved gases—Guidance.](#)⁶

[IEEE Std C57.93™, IEEE Guide for Installation and Maintenance of Liquid-Immersed Power Transformers.](#)^{7,8}

[IEEE Std C57.143™, IEEE Guide for Application for Monitoring Equipment to Liquid-Immersed Transformers and Components.](#)

[IEEE Std C57.152™, IEEE Guide for Diagnostic Field Testing of Fluid-Filled Power Transformers, Regulators, and Reactors.](#)

3. Definitions, acronyms, and abbreviations

~~For the purposes of this guide, the following terms and definitions apply. The Authoritative Dictionary of IEEE Standards Terms should be referenced for terms not defined in this clause.~~

^{5 4} ASTM publications are available from the American Society for Testing and Materials, ~~100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA~~ (<http://www.astm.org/>).

⁶ IEC publications are available from the International Electrotechnical Commission (<http://www.iec.ch>) and the American National Standards Institute (<http://www.ansi.org/>).

⁷ IEEE publications are available from The Institute of Electrical and Electronics Engineers at <http://standards.ieee.org/>.

⁸ The IEEE standards or products referred to in this clause are trademarks of The Institute of Electrical and Electronics Engineers, Inc.

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁹

continuous monitoring: A test protocol in which a transformer is tested at very short time intervals (e.g., daily or several times per day) for characterization of abnormal gas formation, and very early warning of severely abnormal gas formation. This protocol could utilize suitably connected on-line monitoring devices.

DGA status: Classification of DGA results based on statistical norms.

DGA test protocols: A program of DGA applied to a transformer or to a transformer population.

dissolved-gas analysis (DGA): The identification, measurement, and interpretation of gases dissolved in the insulating liquid of electrical equipment.

dissolved-gas analysis norms: Reference values for gas concentrations, rates of change, and ratios that are used to define various degrees of abnormality or unacceptability.

electrical discharge fault: Arcing or sparking between conductive components at different potential.

NOTE—See Annex C.1.

failure: A transformer is considered to have failed when, due to defect, damage, or deterioration, it becomes incapable of remaining in its intended service and either ceases to function (for example by catastrophic failure) or has to be taken out of service for repair or replacement.

fault: A fault is an unplanned occurrence or defect in a transformer that allows an abnormal internal diversion of energy, which could cause damage and lead to failure or increased risk of failure.

⁹IEEE Standards Dictionary Online is available at: <http://dictionary.ieee.org>.

gas concentrations: The concentration of a gas dissolved in insulating liquid is expressed in microliters per liter ($\mu\text{L/L}$), also referred to as parts per million by volume (ppm v/v), both expressed at standard temperature and pressure (STP) conditions (0 °C and 101.325 kPa).

initial verification: A set of DGA performed when a new or repaired transformer is entered into service, or when a DGA screening test protocol is resumed for a transformer after several years without sampling (e.g., after a storage period).

~~3.1 key gases:~~ ~~Gases generated in oil-filled transformers that can be used for qualitative determination of fault types, based on which gases are typical or predominant at various temperatures.~~

partial discharge fault: An electric discharge that only partially bridges the insulation between conductors, and that could ~~may or may not~~ occur adjacent to a conductor.

NOTE—See Annex C.1.

rate: Constant gas generation over a certain period, expressed in $\mu\text{L/L/year}$. In the context of this guide, rate is computed by linear best fit from 3 to 6 consecutive DGA covering a period of at least 4 months to a maximum of 24 months.

screening: A test protocol in which all transformers in a population are tested at regular time intervals (e.g., every year) to identify units which may require additional attention or remedial action. This protocol is used to identify transformers with potential fault activity.

surveillance: A test protocol in which a transformer is tested at relatively short time intervals (e.g., months, weeks, or days) for the purpose of detecting and characterizing any gas formation that may occur and provide early warning of a rapidly worsening condition. This protocol is used to confirm fault activity and determine fault severity. It could also be used when unit condition changes, such as after a relocation of the unit or a loading increase.

thermal fault: An excessive temperature rise, in the insulation or any internal component.

NOTE—See Annex C.1.

3.2 Acronyms and abbreviations

C possible carbonization of paper

D1 discharges of low energy

D2 discharges of high energy

DGA dissolved gas analysis

GIOS gas in oil standard

GSU generator step-up transformer

LTC load tap change (previously designed OLTC)

μL/L microliter per liter; equivalent to ppm v/v (parts per million, volume/volume)

ND not determined or not detected

NEI normalized energy intensity

O overheating of paper or mineral oil

OLTC on load tap changer (deprecated, replaced by LTC)

PD partial discharges

QA quality assurance program

R catalytic reactions

S stray gassing

STP standard temperature and pressure (0 °C and 1 atm)

T1, T2, T3 thermal faults

TCG ~~total combustible gas~~

TDCC ~~total dissolved combustible gas~~

4. The nature, purpose, and application of dissolved-gas analysis

Transformer mineral oils are mixtures of many different hydrocarbon molecules, and the decomposition processes for these hydrocarbons in thermal or electrical faults are complex. The fundamental steps of gas generation are the breaking of carbon-hydrogen and carbon-carbon bonds. Active hydrogen atoms and hydrocarbon fragments are formed. These free radicals can combine with each other to form gases, molecular hydrogen, methane, ethane, etc., or can recombine to form new, condensable molecules. Further decomposition and rearrangement processes lead to the formation of products such as ethylene and acetylene and, in the extreme, to modestly hydrogenated carbon in particulate form. These processes are dependent on the presence of individual hydrocarbons, on the distribution of energy and temperature in the neighborhood of the fault, and on the time during which the mineral oil is thermally or electrically stressed.

The quantity of hydrogen formed can be relatively high and can be insensitive to temperature for some fault types, such as some stray gassing, partial discharges (PD) and catalytic faults. Formation of acetylene becomes appreciable only at temperatures nearing 1000 °C. Formations of methane, ethane, and ethylene also each have unique dependences on temperature. See Figure 1.

The thermal decomposition of mineral oil-impregnated cellulose insulation produces carbon oxides and some hydrogen or methane from the mineral oil. The rate at which they are produced depends exponentially on the temperature and directly on the volume of material at that temperature.

4.1 The nature of dissolved-gas analysis

Dissolved gas analysis (DGA) is the identification, measurement, and interpretation of the gases dissolved in the insulating liquid. The principal gases used in identification of faults (so-called “fault gases”) are hydrogen (H₂); methane (CH₄); ethane (C₂H₆); ethylene (C₂H₄); acetylene (C₂H₂); carbon monoxide (CO); and carbon dioxide (CO₂). Oxygen (O₂) and nitrogen (N₂) are also measured and used in the interpretation, although they are not fault by-products.

The gases containing both of the elements carbon (C) and hydrogen (H₂) are called hydrocarbons, and the gases CO and CO₂ are called carbon oxides. Hydrogen, the hydrocarbon gases, and carbon monoxide are combustible gases, while oxygen, nitrogen, and carbon dioxide are non-combustible gases. Other gases that may be dissolved in the insulating liquid, such as argon (Ar) and higher molecular weight hydrocarbon gases, are ordinarily ignored for transformer DGA. Other light gases, such as propane and propylene, are also generated, but are not used in this guide.

The concentration of a gas dissolved in insulating liquid is expressed in microliters per liter (μL/L), also referred to as parts per million by volume (ppm v/v). The concentration of a gas in the gas mixture collected from a gas space is often expressed as percent by volume. All these quantities are corrected to standard temperature and pressure (0 °C and 101.325 kPa) for reporting in accordance with ASTM D3612. Rates of gas generation are commonly expressed in microliters per liter per day (μL/L/d), ppm per day (ppm/d), microliters per liter per year (μL/L/y), or ppm per year (ppm/y).

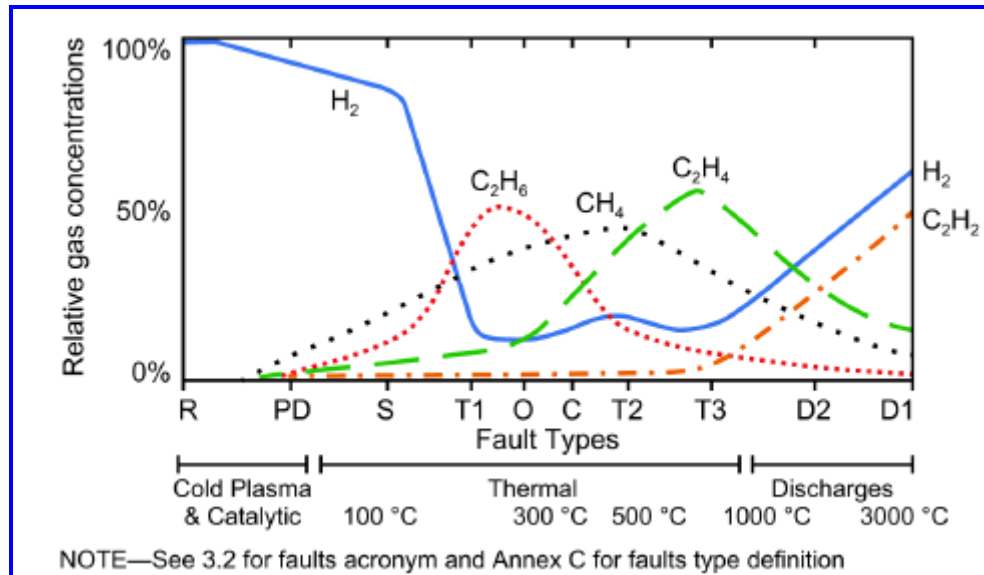
An appropriate sampling procedure, such as ASTM D923, should be followed to obtain a representative insulating liquid sample. To minimize gas loss and air contamination, a gas-tight glass syringe is the preferred sampling vessel. The sample is usually sent to an analytical laboratory, where a standard procedure, such as ASTM D3612, is followed for separating dissolved gas from the insulating liquid and using a gas chromatograph to measure the concentrations of individual dissolved gases. A field-portable gas analyzer, which may or may not be a chromatograph, may be used for a quick determination of gas concentrations from a syringe sample. The use of gas monitors, connected directly to the transformer and automatically collecting and analyzing several samples per day, is increasingly common.

The result of a laboratory analysis is an electronic or paper report identifying the transformer, specifying the sample date, other sampling and processing information, and the concentrations of the gases listed above. Laboratory DGA reports often include interpretive or diagnostic remarks, as well as the data. Many laboratories also provide the analysis results in a data file upon request. Portable gas analyzers and gas monitors typically provide results in the form of an electronic report or a data file. Some portable gas analyzers omit one or more of the atmospheric gases (oxygen, nitrogen, carbon dioxide) from the analysis, and likewise some gas monitors measure only hydrogen or a few of the principal DGA gases.

It is necessary to subject DGA data to a quality check before interpretation. When results are accepted, their interpretation should take into account any earlier DGA results that may be available. The interpretation of transformer DGA results is the main subject of this guide.

The interpretation of gases dissolved in insulating liquid is based on the premise that a liquid immersed transformer in sound condition generates little or no fault gas under normal operating conditions. In preparation for service, the transformer is filled with unused mineral oil, which typically has also been vacuum processed during filling, so that it normally starts out with no dissolved combustible gas, a very small concentration of carbon dioxide, and low concentrations of dissolved oxygen and nitrogen. The transformer insulating liquid preservation system protects it from exposure to air (for a sealed transformer) and from moisture ingress. Under normal operation, the heat generated in the windings and core is absorbed by the insulating liquid and transported to the tank walls and cooling system, keeping the internal temperatures of the transformer within a range where thermal aging of the insulation system is acceptable (for a more information on thermal aging of insulation, see IEEE Std C57.91™ [B104]). Under normal circumstances, some gases, mainly carbon dioxide, carbon monoxide, and hydrogen, are generated very slowly by the aging of the cellulosic insulation and the insulating liquid. Significant concentrations of hydrogen and hydrocarbon gases can be generated within the mineral oil at normal service temperatures, rated loading or from material interaction (such as some metal passivators), even if no fault is present. This phenomenon is known as “stray gassing” (see C.2).

An internal defect, an abnormal system event or anomaly, or operation in environmental conditions outside the designed ranges can result in excessive energy dissipation in the transformer insulation system and may also cause harmful mechanical stress on windings and other internal structures. Some of the diverted energy acts on the insulating liquid or cellulose insulating material resulting in the generation of gases that dissolve in the insulating liquid and are also distributed to all available gas spaces in the transformer. The particular combination of gases that is generated in mineral oil depends on the nature of the fault process and is related to the energy level and temperature at the fault location, as schematically illustrated in Figure 1 (see “Ongoing activities at IEEE, IEC and CIGRE on DGA” [B87]).



(New)

Figure 1—Relative percentage of dissolved gas concentrations in mineral oil as a function of temperature and fault type

4.2 The purpose of DGA

The underlying purpose of DGA, in addition to the more obvious purpose of attempting to detect and identify a possible fault, is to improve safety and equipment reliability while reducing cost. Safety and reliability are improved through awareness of transformer condition, early detection of faults, and monitoring of suspect transformers. Cost reduction is achieved by avoidance or mitigation of transformer damage and failures, and also by optimization of operation and maintenance.

4.3 The application of DGA

It is helpful to distinguish ways in which DGA is used:

— Basic risk management

- [Detection and monitoring of abnormalities](#)
- [Quality assurance metric](#)
- [Fault type identification](#)
- [In-service tripping investigation](#)

[Methods of fault type identification are described in 6.2 and Annex D. Case studies of DGA application are presented in Annex E.](#)

[4.3.1 Basic risk management](#)

[DGA before placing a transformer into service provides an initial baseline, and periodic DGA screening throughout a transformer's lifetime is performed to evaluate its operating condition and to prioritize attention to any transformer that may be generating combustible gases. The frequency of routine DGA screening may be based on considerations such as the economic cost of a forced outage, service criticality, contractual requirements \(e.g., an insurance policy\), and safety.](#)

[Other considerations are the warranty status, replacement cost, and relative importance of the transformer. Annual DGA screening is common.](#)

[If the expected economic cost of forced outage or of replacement is very high, online monitoring or frequent \(monthly or quarterly\) periodic DGA may be justified. IEEE Std C57.143 contains useful guidance regarding the use of gas monitors in transformer asset management.](#)

[Abnormal DGA results can provide early warning of a developing problem, can identify the nature of the process that is generating the fault gases, and \(via rates of change or increment magnitudes\) can indicate how energetic the process is. Experience has shown that not all abnormal gassing events are necessarily related to transformer deterioration or permanent damage. A complete transformer condition assessment should also include other considerations as much as possible, such as electrical test results, recent or historical systems events, and physical inspection. As explained in 1.3 and 6.1, high gas levels do not necessarily predict a future failure.](#)

Users should have in place a transformer DGA protocol or program taking into consideration the DGA status as described in 5.3. This protocol could vary due to several parameters such as transformer type, size, age, criticality, personnel availability, maintenance practice, and other economic considerations.

The general practice, when there is no indication of an abnormality in the operation of the transformer, is to sample the transformer insulating liquid for DGA on a time basis, with the period between samples typically ranging from a few months (for the larger or most critical units), to 1 or 2 years. In some cases, the use of an on-line gas monitor could be part of this protocol.

It should be noted that longer periods between DGA samples can increase the possibility of a fault going unobserved while the transformer deterioration progresses toward failure.

4.3.2 Detection and monitoring of abnormalities

If DGA samples are taken and the results are studied with sufficient frequency, then some major faults are easy to detect because of significant production of fault gas. It is possible, although challenging, to distinguish the lesser gas production of incipient or intermittent faults from the normal temperature-driven variation of residual gas, especially under the influence of measurement uncertainty, occasional sampling problems, or gas loss. However, some ancillary device problems, mechanical, or externally caused failures are not preceded by any DGA forewarning.

When abnormal gas generation is confirmed, the DGA results could be used to identify the apparent fault type (see 6.2 and Annex D). Beyond fault identification, gas increments or rates of gas formation indicate the relative severity of the fault. Changes in increments, rates, or evolution of the fault type (e.g., from a lower energy fault type to a higher energy fault type) may indicate worsening or moderation of the fault process. Unless the gassing behavior is so extreme as to motivate immediate shutdown, it may be prudent to take DGA samples more frequently and monitor long enough to determine the gas formation rates, to investigate whether the abnormality is transient, intermittent, or on-going, and to determine whether the fault type and severity seems to be evolving. If, for operational reasons, it is necessary to continue operating a gassing transformer, more frequent DGA surveillance may provide early warning of increased gas generation, which may indicate that the transformer's condition is worsening.

4.3.3 Quality assurance metric

Another application of DGA is verification of previous DGA measurements and measurement quality assurance. DGA is sometimes performed to provide confirmation of earlier DGA results or gas monitor readings.

Duplicate samples can be used to check laboratory consistency, while gas-in-oil standard solutions (gas-in-oil samples of known, precise gas quantities usually purchased from a certified gas sample supplier) can be used to check both consistency and accuracy. Specific guidelines are provided in 5.1 and 5.2.

4.3.4 DGA samples following a transformer trip

Laboratory DGA samples can be taken as an initial response to a transformer relay alarm or trip (see IEEE Std C57.152-2013, Table 1 [B108]). Relay trips may result in no external indications of transformer damage, therefore, electrical testing and DGA is used to evaluate the condition for continued operation (see “Guide for Transformer Fire Safety Practices” [B73] and “Transformer reliability survey” [B74]). The amount of time after a transformer trip should be noted when obtaining a DGA sample. The location of a fault inside of the transformer and the insulating liquid flow rate have a direct relation to the amount of time for the combustible gases to be distributed throughout the transformer insulating liquid and reach the sampling port of the transformer tank. As examples, a forced flow cooling system may have a short gas transport time if the circulating pumps remain in operation following the trip, while natural convection flow on a very cold day or with a low load prior to the trip can take more than 24 h to completely distribute dissolved gases. Therefore, additional DGA samples may need to be scheduled to monitor for a stable dissolved gas-in-oil condition.

The device or relay that alarmed or caused the transformer to trip will likely suggest the additional testing protocols to be followed. For example, protocol for the trip of a distant breaker may include taking a DGA sample from the downstream transformer even though the breaker is immediately reclosed, and the transformer was brought back into service. But protocol for a differential current trip, normally associated with an internal transformer fault, may suggest that electrical testing of the transformer is required as a condition for continued service, in addition to DGA testing.

The decision to return a transformer to service will depend on the electrical test results, physical inspection results, and is influenced by system needs. Post-trip DGA results should be compared to the previous transformer DGA history and reviewed for changes in the types of gases reported and their concentrations, which may indicate a change in the equipment condition. Suspected changes to the equipment condition should be verified with a confirmation DGA sample. This is also crucial as a baseline for comparing future DGA results.

4.4 DGA sampling context

The interpretation of DGA data should be performed with due regard to the purpose of the sampling. The following basic sampling contexts are the most common ones encountered:

- a) **Initial sample**—An initial DGA sample is one that is interpreted without regard to previous samples. For example, a sample taken before or shortly after energizing a new transformer as part of initial test protocol (see 5.3.1), after major repairs or modifications, or on a transformer that has no previous DGA data associated with it would be considered an initial sample. The gas concentrations and other measurement data associated with an initial sample can be used as baseline values for comparison with later data.
- b) **Periodic screening sample**—A periodic screening sample is one of a series collected at regular time intervals (for example, six months or one year) for verifying that a transformer is operating normally. See 5.3.2.
- c) **Surveillance sample**—A surveillance sample is one of a series collected at shorter intervals (compared to periodic screening intervals) for characterizing a suspected fault or keeping close watch on a transformer's condition during start-up, testing, high stress circumstances, or other exceptional operating conditions. See 5.3.3.

- d) **Continuous monitoring sample**—A continuous monitoring sample is one of a series of samples collected at a high rate (typically from more than one per day to one every few days) for maintaining a close watch on a transformer's condition (see 5.3.4). An on-line dissolved gas monitor could also be used for that purpose. Continuous monitoring is typically applied in cases of higher economic risk; for example, protection of extremely critical or expensive transformers, continuous condition assessment to help extend the service life of older transformers, or investigation and operational safety when a transformer is being operated with a fault or under extreme stress. The use of an on-line dissolved gas monitor with remote data collection capability is a safer alternative than manually extracting an on-site sample from a transformer that is severely gassing and may fail catastrophically without warning.
- e) **Incident investigation sample**—An incident investigation sample is a sample taken after an incident (e.g., gas relay tripping, close-in fault, etc.) to investigate whether the transformer has been damaged.
- f) **Quality assurance sample**—A quality assurance (QA) sample is one processed for the purpose of evaluating measurement accuracy, repeatability, or reproducibility. QA samples are not for transformer condition analysis. QA samples may be purchased or may be prepared as a gas-in-oil standard (see ASTM D3612). Where accuracy is not being evaluated and greater variation is tolerable, QA checking may be done using consecutive or split transformer samples.
- g) **Verification sample**—A verification or “check” sample is one that is drawn from a transformer and submitted for analysis and comparison with anomalous DGA results from a recent sample from the same transformer or recent gas monitor readings. See 5.2.

4.5 Procedures for obtaining samples ~~of gas and oil~~ from the transformer for laboratory analysis

~~8.1 Gas samples for laboratory analysis~~

~~8.2 Gas dissolved in oil~~

All samples of insulating liquid taken ~~oil~~ from electrical apparatus ~~for being taken for the purpose of~~ dissolved gas-in-oil analysis should be taken in accordance with ASTM D923. A gas-tight, glass syringe is the preferred container for DGA sample. The sampling procedure should always ensure that the samples are taken safely, without compromising the transformer insulating liquid level, without contaminating the sample with air, and without allowing air to enter the transformer during the sampling process.

Under certain fault conditions, some portions ~~stratification~~ of ~~dissolved gases in~~ the insulating liquid ~~oil~~ may have higher dissolved gas concentrations for several hours before occur, and complete mixing with the bulk of the insulating liquid has occurred ~~could require many hours~~. In these cases, where possible, ~~oil~~ samples should be obtained from more than one location on the transformer and a confirmation sample should be taken the following day.

Particular care should be taken that good sampling procedures are in place and are followed at all times. Proper personnel training for DGA sampling should be an integral part of the DGA policy. Particular attention should also be given on properly filling out the form accompanying samples, especially since DGA is applied to a large range of apparatus (main tank, bushings, cable, LTC, etc.) with different DGA interpretation methods (e.g., different types of insulating liquid).

All due safety precautions should be taken when sampling is performed. Particular attention in this respect should be given to avoid possible ingress of air into the transformer.

CAUTION

Sampling from a transformer tank when negative pressure is known or suspected should never be done, as it will result in air ingress and possible immediate or future catastrophic failure of the transformer.

Purging the sampling valve should be performed each time to avoid air ingress and to help guarantee a representative sample. To properly purge, the sampling system should be open to atmosphere when the transformer valve is initially opened to allow any trapped air to escape. The sample should be taken only when the valve has been purged of all trapped air and of stagnant insulating liquid. See “Where Does the Air Go? (Second Edition)” [B121].

Correct information about transformers, especially serial number and location, sampling compartment and location, reason for sampling, kV and MVA ratings, preservation type, type of insulating liquid, transformer manufacturer and manufacturing year, cooling type, and nature of service (GSU, transmission, etc.) is helpful for DGA database management and proper interpretation of DGA data. Accurate identification and other relevant transformer information should also be supplied to the analytical laboratory.

5. DGA data interpretation

The interpretation of DGA data begins with the detection of an abnormal condition. When found, it should be followed by severity assessment and fault identification. The fault detection and severity assessment part of DGA consists of comparing the gas levels and rates of change, to their respective norms and assigning a status condition according to which norms (if any) were exceeded. When there is an indication of a problem, a fault identification or diagnosis should be obtained by a reliable technique, such as the Duval Triangle method. See 6.2 and Annex D. Graphical visualizations of the data in various ways as discussed in Annex E and Annex D often provides insights into fault identification, evolution, and severity. Other relevant information, such as maintenance activity records, electrical diagnostic test results, lightning strike occurrences, load history, etc., should be consulted to seek a better understanding of what may be causing the gassing activity, and to confirm or modify the DGA condition assessment. See Annex E for case studies of DGA interpretation.

The interpretation of DGA results can begin only after a data quality review to identify and correct data quality problems has been performed. It is important to understand that a review of data cannot identify all possible data quality problems. Therefore, when unexpected or alarming results are obtained, it is highly advisable to collect and process another sample to confirm results.

5.1 Data quality review

This subclause contains the recommended practices to be followed to ensure the quality of the DGA results data. The working group realizes that a data review at the level of detail provided in 5.1.1 to 5.1.8 is not practical for many users. Therefore, any data points that seem to be unusual, compared to the history of the prior samples, should be investigated.

A data quality review is necessary to identify signs of data corruption, which could confuse or mislead the interpretation of the data. Data corruption can occur throughout data management, work management, sampling, analysis, and reporting phases of producing DGA data. Each phase has its characteristic data issues.

Data management and work management systems sometimes contain and propagate incomplete and inaccurate equipment identification and information. Long after corrections are made, forms generated with incorrect information can be copied and used, sometimes for years. This type of error could also cause duplication of equipment in database or result in incorrect DGA interpretation (e.g., DGA from an LTC identified as from the main tank).

Sampling provides several opportunities for data corruption. For example, the sampler, using a blank field data form, can incorrectly transcribe nameplate information; using a preprinted field data form can reduce errors identifying the equipment. The sampler can introduce errors by waiting to label the samples after they have all been collected. The sampler can provide information on the field data form that is different from the information on the sample container, can collect the sample from the wrong sampling point, can use contaminated tubing and fittings, or can contaminate the sample with air. Laboratory testing also provides several opportunities for data corruption. Transcription errors, swapped samples, carryover contamination, air contamination, calibration errors, gas identification, and quantization errors are the most likely types.

Data quality review most often amounts to comparing current test information to prior test information. In the case of an initial sample, the reviewer is limited to reality checks. Confirming an error and identifying its source may require access to the sample records. In some cases, problems can be resolved by asking the laboratory to check their records. When data quality problems cannot be corrected, it is recommended to resample the equipment.

5.1.1 Transcription and typographical errors

Transcription and typing errors show up in characteristic ways. A sequence of values that are all shifted by one position, a skipped or missed value in a sequence of values, two values that are swapped, digits that are added or lost in a value and swapped digits in a value usually appear as abrupt changes in individual values or as strange individual values. For example, oxygen concentration shown as 508 when its previous values had been around four or five thousand; a digit was omitted. Another example: ethylene reported as 87 following several samples around 8, with no evidence of any other combustible gas change; this type of error could be caused by a dropped decimal point. Transcription or typing errors in an equipment identifier result in a misidentified unit.

5.1.2 Missing or duplicated data

Occasionally some values may be accidentally omitted or deleted from the data. Sometimes the data for an earlier sample may be reported again instead of the latest data. This is particularly likely when all gas concentrations, $\mu\text{L/L}$, are the same as the previous sample (normally some variation is to be expected, especially for the high values, such as CO_2 , N_2 and O_2).

5.1.3 Misidentified or swapped sample

An incorrect or incomplete serial number or other equipment identifier may associate a sample with equipment that it did not come from, or with equipment that simply does not exist. There can also be problems with identification of the sampling point (e.g., main tank instead of LTC) or incorrect notation of the sample date. A swap of samples causes the same misidentification.

5.1.4 Sample mishandling

5.1.4.1 Air exposure

A leaky syringe, poor sampling technique, or mishandling of the sample can expose the sample to air, resulting in loss of much of the hydrogen, often accompanied by an increase of oxygen and nitrogen. A very low hydrogen concentration (especially if hydrogen was higher in earlier samples), with an O₂/N₂ ratio above 0.2 (for sealed transformer), or O₂ and N₂ reported levels above saturation values, may indicate that the sample was exposed to air. Air exposure of a sample from a breather type transformer, where the insulating liquid is normally saturated with air, could be more difficult to detect.

5.1.4.2 Air contamination

Entrainment of air during sampling, handling or processing results in oxygen, nitrogen, oxygen/nitrogen ratio and total gas concentration changes. The amount of change ranges from barely perceptible to extreme. Without knowledge of the adulterating process, rates and changes of fault gases calculated from these should be considered suspect.

5.1.5 Cross contamination

The results of carryover contamination during sampling (e.g., reusing sampling tubes) or processing (e.g., storage in contaminated tank) can vary widely. Appearance of a trace gas or gases, appearance of a fault and change of fault identification are all characteristic of this problem. As with any question of quality, a significant change of condition should prompt confirmation with a follow-up test.

5.1.6 Inconsistent values

A single sample, which is drastically different from earlier samples from the same equipment, may belong to a different piece of equipment (e.g., from the LTC compartment instead of main tank), or it may indicate a fault. Confirmation by resampling may be necessary. If there are large inconsistencies in several successive samples, there could be a sampling or measurement problem.

5.1.7 Chronically absent or low hydrogen

If the hydrogen concentration is always extremely low, even when other combustible gases are not, and especially when hydrogen is also chronically low in other transformers, there may be a problem with sampling technique, leaky syringes, or measurement. It may be necessary to submit a quality control standard (with known gas concentrations) to confirm that the laboratory or portable gas analyzer is measuring hydrogen correctly.

5.1.8 Inconsistent O₂/N₂ ratio

Isolated large increases in the O₂/N₂ ratio, especially when correlated with decreases in hydrogen, may indicate an air exposure problem. Mistyped values for oxygen or nitrogen can cause the O₂/N₂ ratio to assume unusual or impossible values. The saturation value for air dissolved in mineral oil normally gives an O₂/N₂ ratio between 0.4 and 0.5. If the ratio begins to approach that value for sealed transformers, it would be prudent to look for air leaks. For transformers with a bladder equipped conservator, rapidly increasing concentrations of oxygen can indicate a leaky or ruptured bladder. For a transformer with an open breather, the O₂/N₂ ratio will change little (near 0.4 to 0.5), but the total reported amount of O₂ and N₂ levels could increase above saturation values in case of air ingress into the sample.

5.2 Reliability of DGA results

5.2.1 Accuracy

Highly inaccurate gas concentration measurements can lead to incorrect assessment of fault severity or misidentification of the fault type. In extreme cases, errors can lead to inappropriate and costly mitigative action such as premature removal from service. Failure to notice severe conditions when they do occur can result in unnecessary outages, damage, or failures.

Recommendations to have accuracies better than ±15% on DGA results to avoid misidentification of faults can be found in IEC 60567 and in “Report on Gas Monitors for Oil-Filled Electrical Equipment” [B71]. Several laboratories meet this requirement, but several others do not (with measurement errors as high as ±60% or more for some gases).

It should be noted however that, at the time of the preparation of this guide, no reproducibility or repeatability values are presently available in ASTM D3612 for method C (head space) to help DGA users verify whether the DGA results they receive from their laboratories and on-line monitors are accurate enough or not. Such guidelines are presently available only from IEC and CIGRE. Laboratory quality control is a key aspect of choosing a laboratory but can be a very time-consuming activity. One example of quality check for laboratories is the ASTM Committee D27 Proficiency Testing Program.

The practical recommendation to DGA users in case of critical transformers with abnormally high gas levels or with high gassing rates, where DGA results provided by different laboratories and on-line monitors are widely different (especially if they indicate drastically different actions to be taken on the transformer), is to verify the general accuracy of the DGA results from a given source using gas-in-oil standards (GIOS) and following IEC 60567 and “Report on Gas Monitors for Oil-Filled Electrical Equipment [B71].

GIOS can be prepared by DGA laboratories, following Annex A1 of ASTM D3612 or section 6.3 of IEC 60567. They can also be purchased commercially. An example where the reproducibility of several DGA laboratories was evaluated with GIOS is given in Table 1 of ASTM D3612 for method A. The procedure for evaluating the accuracy of on-line monitors is indicated in Appendix B of “Report on Gas Monitors for Oil-Filled Electrical Equipment” [B71], which also uses GIOS.

At gas concentrations below about five times the DGA method detection limit (a few $\mu\text{L/L}$, depending on the method and the gas), relative measurement uncertainty can be large. It is not recommended to base fault type identification or practical decisions on such low values without some confirmation of their accuracy. It is not recommended to attempt fault identification using the methods described in 6.2 and Annex D if all of the gas levels are below the Table 1 values.

Particular caution in interpretation should be used when acetylene is the only gas above the Table 1 [1 to 2 $\mu\text{L/L}$ (ppm)] values but is still below five times the detection limits. Fault identification in such a case may be unreliable.

A DGA expert, a person with experience in both transformer operation and DGA results interpretation, might attempt fault identification, after applying additional rules, when all gases are below the Table 1 values, but are above five times the detection limits and the laboratory processes are proven to meet accuracy requirements. This could provide advance information on incipient faults. However, as noted above, the results may be highly unreliable due to the low levels of gases present and should be used with caution.

5.2.2 Consistency

When DGA results consistently fluctuate widely (30% or two to three times the values in Table 3) from one sample to the next, it usually indicates sampling or analytical errors. Therefore, the results should not be used for fault identification or severity assessment, unless the reasons for these fluctuations have been established. If the most recent sample is very different from previous samples, engineering judgement may be required, and resampling is recommended.

Operations that can affect gas concentration should be identified. For example, venting of sealed main tanks [e.g., 4, pressure relief operation during thermal transits and leaks (sometimes resulting in pressure gauge reading zero)] can lower combustible gas and increase atmospheric gas concentrations. Changes in system parameters could cause variations in reported gas concentrations, for example, load changes. It is often difficult to quantify the effects of these factors compared to the gross changes in reported gas concentrations. Transformer monitoring of gases, moisture, temperatures, load, fans and other parameters can be useful in correlating changes and understanding what may have caused them.

5.3 Context of DGA data interpretation

From an operational point of view, it is important to establish the following priorities:

- a) **Detection:** Detect the generation of any gases that exceed “normal” quantities and utilize appropriate guidelines, so the possible abnormality may be recognized at the earliest possible time to minimize damage or avoid a failure. If this analysis concludes that a fault exists, then proceed with evaluation.

b) **Evaluation:** Evaluate the impact of an abnormality on the serviceability of the transformer, using a set of guidelines or recommendations. Expert opinion, operator experience, and unit specific conditions should be part of the evaluation.

c) **Action:** Take the recommended action, beginning with increased surveillance and confirming or supplementary analysis. For example, if a thermal fault is suspected, which may be load sensitive, load reduction (if possible) may help with the diagnosis. If it is not possible, then alternatives, as drastic as removal of the unit from service, may need to be considered. This guide does not cover the procedure required to determine what remedial or operating action may be necessary. This is ultimately the sole responsibility of the transformer owner.

It is useful to look at graphs of gas levels over time (see Annex D) for quick visual detection of suspicious changes, parallel long-term upward rates, or inconsistencies. Whenever a fault is suspected, past and present data should be analyzed and plotted, using one of the methods, such as the Duval Triangles, found in 6.2.3 and Annex D, to see whether there is a consistent pattern or evidence of orderly fault evolution.

The recommended action and resampling interval can be based on the fault diagnosis and the verified DGA status, plus the use of expert judgment. Because of the potentially serious consequences and high cost of misinterpreting transformer test data, an inflexible interpretation, based on an exclusively mechanical scoring approach, without the application of expert judgment, is highly inadvisable.

It is helpful to define DGA status levels to establish sampling intervals and maintenance activities on operational transformers. See 6.1.2 for more information.

— **DGA Status 1:** Screening DGA results are acceptable. Continue routine operation.

— **DGA Status 2:** Incipient or modest recent gas production or moderately elevated gas level. Resample for confirmation and monitor possible gas evolution.

- **DGA Status 3:** High gas levels or continuing significant gas production. Mitigative actions or other responses should be considered (i.e., continuous monitoring).

5.3.1 Initial verification test protocol

When a new transformer is added to a DGA program, or when DGA sampling is resumed for a transformer after several years without sampling, an initial verification is recommended. This is also applicable when there is no prior DGA history for the transformer, or when insulating liquid processing, repairs, or other factors “reset” the transformer’s DGA history. In such cases, there may not be any prior DGA data providing a basis for calculating combustible gas increments or rates of change.

It is suggested to take a sample before and during commissioning procedures and several more samples over a short period of time (a few weeks to a few months) following energization to establish a DGA baseline and ensure that no abnormal gassing is taking place.

For new and repaired transformers, if any of the combustible gas concentrations are above their respective detection limits without a reasonable explanation (such as residual gas from an earlier fault diffusing into the insulating liquid from the paper insulation in a repaired transformer), it may be prudent to schedule another sample to be taken immediately to check for active gas production. A diagnostic method may be applied to see what the initial sample’s pattern of gas concentrations matches, but the diagnosis cannot be considered unless a second sample confirms active fault gas production in a pattern that confirms the diagnosis.

The usual outcome of an initial verification test program would be either the assignment of DGA Status 1 with a recommendation to carry on with DGA periodic screening test protocol per company DGA policy, or the assignment of DGA Status 2 with a recommendation to sample more frequently to check for evidence of change and to discuss the test results with the manufacturer. If a resample confirms an elevated level of gases, contact the manufacturer to review the situation and evaluate the follow-up action.

It is to be noted that typically in an initial verification context, gas level norms lower than Table 1 are used. Often, for new transformers under warranty, the manufacturer will supply its own norms.

See 5.13 of IEEE Std C57.93-2007 for an example of installation sample protocol.

5.3.2 Periodic screening test protocol

Most DGA results fall into this category.

The method of interpreting screening DGA data is explained in 6.1 and in the Figure 2 flowchart. If, the DGA status is 1, and there are no apparent reasons for concern, no fault interpretation is necessary, and no special action is needed. The interpretation of the DGA data is complete and the next sample should be taken according to the DGA screening test protocol.

If analysis of a test result produces a DGA status of 2, or if any unusual shift in gas pattern suggests an anomaly, a fault diagnosis should be obtained using a reliable method (see 6.2 and Annex D).

If the fault diagnosis reveals an issue of a low temperature fault (T1), or stray gassing (S), this would be treated as a less urgent issue, however a low temperature fault (T1) may affect the future life of the insulation system.

If there is an indication of high-energy arcing (D2) or a high-temperature thermal fault (T3), or if paper insulation appears to be involved in the fault, another analysis step may be prudent. Some users will consider extra steps with increased surveillance, as recommended for a unit with a DGA status of 3.

If a DGA status of 3 is obtained, then a fault diagnostic and a DGA surveillance test protocol are warranted. See 5.3.3.

5.3.3 Surveillance test protocol

The purpose of the DGA surveillance test protocol is usually either:

- To confirm the absence of suspicious gas activity

- To characterize and diagnose suspicious gas formation
- To provide early warning of dangerous changes or a fault reaching the pre-failure runaway stage

Gas history charts, a stacked chart showing all individual combustible gases, and the Duval Triangles with multiple samples are the most useful graphical tools for surveillance and monitoring.

A short-term rate of increase should be compared with their respective norms to obtain an updated status code. This may be increased if there is evidence of accelerating combustible gas formation. If there is evidence of a fault, a Duval Triangle or pentagon (see 6.2 and Annex D), with all surveillance data plotted on it, can be used to diagnose the fault and to watch for consistency or evolution of the fault type. For example, it could help to see if a thermal fault evolves toward a higher temperature fault.

If the results of a surveillance test indicate a serious or deteriorating situation, it will lead to a Status 3 evaluation. That should lead to consideration of starting a continuous monitoring test protocol, as suggested in 5.3.4.

It may be prudent at this point, that the user consult experts and the transformer manufacturer, as no two transformers are the same. What could be perfectly normal for a given transformer, could be a sign of a dangerous condition in another transformer. In such context, experience from experts is an invaluable tool. See Annex E for additional information.

5.3.4 Continuous monitoring test protocol

The continuous monitoring test protocol should be used when there is a clear indication that the transformer is not operating normally and is generating gas in a significant manner. This protocol should be considered for units with a DGA Status 3, although this should not be automatic. It should be implemented only after a complete review of the DGA results, together with all other available information. Monitoring may be started temporarily until further investigation is completed; or permanently, if the situation is deemed sufficiently serious to warrant it.

In continuous monitoring, the transformer is subjected to frequent sampling and tested at very short, time intervals (e.g., daily or several times per day) for accurate characterization of normal or abnormal gas formation, and very early warning of severely abnormal gas formation. This protocol may lead to the temporary or permanent installation of a suitable on-line monitoring device on the transformer.

The high sampling rate of on-line monitors permits early detection of abnormalities and accurate characterization of rates. Multiple readings may be combined using statistical methods to arrive at improved estimates of the dissolved gas concentrations, and to average over short-term cyclic gassing behavior. Because of the high volume of data generated by on-line monitoring, graphical visualization is essential. Time series graphs with rate values are useful in detection of the onset of increased gassing activity. The technique of plotting DGA results on a Duval Triangle or pentagon is useful in detecting changes in the nature of the fault (see 6.2.3 and Annex D). Also, since rates are obtained in real time over a short period, care should be taken to account for the intrinsic fluctuations of the DGA levels generated by the monitoring process. Gassing rates should be calculated using statistical methods and using trailing data spanning over a long enough time duration to control the likelihood of nuisance gas rate alarms.

In a continuous monitoring test protocol, the various norms used in screening DGA interpretations no longer apply, especially in regard to rates of gas generation. For on-line monitoring, it is not uncommon to use higher rate values than the ones used for laboratory DGA. Each situation is unique.

5.4 Selecting norms values

It is important to understand some of the impacts and limitations of selecting a set of DGA norms for identifying suspicious behavior in a transformer. The choice of 90th and 95th percentiles for norms in this guide is conventional. For some transformer populations other criteria could be chosen based on engineering judgment and local operating and maintenance requirements. The norms shown in Table 1, Table 2, Table 3, and Table 4 were obtained by statistical analysis of a large database of laboratory DGA results. The agglomerated data used to obtain these norms came from several sources in North America, which had notable percentile value differences between themselves. They might not be representative of what could be obtained with a different data set from different sources or countries. See 6.1.2.5 and Figure A.8 for an example of variability between sources.

It should also be understood that while high-fault gas levels in a transformer suggest an eventful past, gas levels, whether high or not, in themselves are not necessarily a direct assessment of the condition of the transformer, if they are stable. A transformer with twice the gas level of another transformer, is not necessarily twice as likely to fail. On the other hand, active fault gas formation, even with low gas levels, indicates that something might be wrong and may necessitate an investigation or other follow-up activities.

The methodology used in this guide will generate a certain amount of “false positive” cases where extra investigation will simply confirm that there is nothing of concern in the transformer condition. A norm chosen at the 90th percentile (Table 1) will select 10% of all the DGA results for review. Table 3 (95th percentile of Delta) will add about 5% of the DGA results to this. If Table 1 and Table 3 contain values for more than one gas, and that any one gas above a norm is enough to flag the DGA results, it is reasonable to expect that about 40% of all DGA results will need further review. This could be a large number for a major DGA program and should be considered in the implementation of the program. See NOTE 1 below.

In a similar manner, Table 2 uses the 95th percentile as the norm, so it should be expected that 5% of results will exceed these values. If those with an elevated rate of rise are added (Table 4), it is expected that about 20% of the DGA results will be evaluated as Status 3. See NOTE 1 below.

NOTE 1—It should be noted that these values will be true for a large set of DGA results having the same general characteristics as the set used to obtain the norms used in this guide. For smaller sets (for example from a single station), or for notably different DGA populations, a different proportion of selected DGA could be obtained. See Figure A.8 for an example of variations between populations.

This might represent a large investment in time and resources that should be considered by the transformer owner. There is always some trade-off between having too many transformers in normal conditions flagged as “investigate” against the possibility of not detecting a potentially catastrophic condition. If the norms are set too low, excessive investigation will result and faith in the program could be affected. If the norms are set too high, there is an increased possibility of missing a faulty transformer.

Part of the planning and set-up of any DGA program should include deciding what norms to use and which procedure to follow when those norms are exceeded. It is also critical to ensure that sufficient resources are available to handle the level of investigation generated. Transformer owners and operators are strongly encouraged to perform their own study based on their own data, if available, to confirm that the selected norms are adequate for their transformer fleet.

One finding from the analysis of the DGA results (approximately 1.5 million samples) is that certain parameters, most notably the ratio of O₂/N₂ and the transformer age, have a large influence on the typical levels of gases. Other subsets of the data, such as insulating liquid volume, rating, and voltage class, did not produce significant differences, so they were not included.