IEEE

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

C57.104™

IEEE Power & Energy Society

Sponsored by the
Transformers Committee

IEEE
3 Park Avenue
New York, NY 10016-5997, USA

2 February 2009

IEEE Std C57.104™-2008
(Revision of
IEEE Std C57.104-1991)

IEEE Std C57.104™-2008
(Revision of
IEEE Std C57.104-1991)

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

Sponsor

Transformers Committee
of the
IEEE Power & Energy Society

Approved 26 September 2008

IEEE-SA Standards Board

Abstract: Detailed procedures for analyzing gas from gas spaces or gas-collecting devices as well as gas dissolved in oil are described. The procedures cover: 1) the calibration and use of field instruments for detecting and estimating the amount of combustible gases present in gas blankets above oil, or in gas detector relays; 2) the use of fixed instruments for detecting and determining the quantity of combustible gases present in gas-blanketed equipment; 3) obtaining samples of gas and oil from the transformer for laboratory analysis; 4) laboratory methods for analyzing the gas blanket and the gases extracted from the oil; and 5) interpreting the results in terms of transformer serviceability. 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: gas analysis, oil, oil-filled transformers, transformers

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Second printing: 9 March 2009: A correction to Figure 3 is included in this printing.

PDF: ISBN 978-0-7381-5834-1 STD95846
Print: ISBN 978-0-7381-5835-8 STDPD95846

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board. The IEEE develops its standards through a consensus development process, approved by the American National Standards Institute, which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and serve without compensation. While the IEEE administers the process and establishes rules to promote fairness in the consensus development process, the IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

Use of an IEEE Standard is wholly voluntary. The IEEE disclaims liability for any personal injury, property or other damage, of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance upon this, or any other IEEE Standard document.

The IEEE does not warrant or represent the accuracy or content of the material contained herein, and expressly disclaims any express or implied warranty, including any implied warranty of merchantability or fitness for a specific purpose, or that the use of the material contained herein is free from patent infringement. IEEE Standards documents are supplied "**AS IS**."

The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

In publishing and making this document available, the IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity. Nor is the IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing this, and any other IEEE Standards document, should rely upon his or her independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration. A statement, written or oral, that is not processed in accordance with the IEEE-SA Standards Board Operations Manual shall not be considered the official position of IEEE or any of its committees and shall not be considered to be, nor be relied upon as, a formal interpretation of the IEEE. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position, explanation, or interpretation of the IEEE.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Comments on standards and requests for interpretations should be submitted to the following address:

Secretary, IEEE-SA Standards Board
445 Hoes Lane
Piscataway, NJ 08854
USA

Introduction

This introduction is not part of IEEE Std C57.104-2008, IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers.

IEEE Std C57.104-1991 was officially withdrawn by IEEE based on recommendation by the Transformers Committee of the IEEE Power & Energy Society at the end of 2005. The intent of this document has been focused on making minor changes to address some of the most pressing issues (such as correcting typos, factual errors, and the values listed in Table 1 of the 1991 version of the guide), and to publish this guide for use by the industry.

Upon publication of this document, the working group plans to immediately begin the process of further revision to the guide to reflect additional advances in current knowledge and trends, and to incorporate relevant material presented during a previous unsuccessful attempt to revise the guide.

Notice to users

Laws and regulations

Users of these documents should consult all applicable laws and regulations. Compliance with the provisions of this standard does not imply compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Copyrights

This document is copyrighted by the IEEE. It is made available for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making this document available for use and adoption by public authorities and private users, the IEEE does not waive any rights in copyright to this document.

Updating of IEEE documents

Users of IEEE standards should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect. In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit the IEEE Standards Association Web site at http://ieeexplore.ieee.org/xpl/standards.jsp, or contact the IEEE at the address listed previously.

For more information about the IEEE Standards Association or the IEEE standards development process, visit the IEEE-SA Web site at http://standards.ieee.org.

Errata

Errata, if any, for this and all other standards can be accessed at the following URL: http://standards.ieee.org/reading/ieee/updates/errata/index.html. Users are encouraged to check this URL for errata periodically.

Interpretations

Current interpretations can be accessed at the following URL: http://standards.ieee.org/reading/ieee/interp/index.html.

Patents

Attention is called to the possibility that implementation of this guide may require use of subject matter covered by patent rights. By publication of this guide, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this guide are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

Participants

At the time this guide was submitted to the IEEE-SA Standards Board for approval, the DGA Guide Working Group had the following membership:

Richard Ladroga, *Chair*
Susan McNelly, *Secretary*

Claude Beauchemin
Oscar Bello
Paul Boman
Bill Chiu
C. Clair Claiborne
Jerry Corkran
John Crouse
William Darovny
Jim Dukarm
James Gardner
James Graham
Bill Griesacker
Joseph Kelly
Stan Lindgren
James McIver
Kent Miller
Dan Perco
Donald Platts
Thomas Prevost
Timothy Raymond
Hyeong Sim
Brian Sparling
David Wallach
Barry Ward
Jim Zhang

The following members of the individual balloting committee voted on this guide. Balloters may have voted for approval, disapproval, or abstention.

William J. Ackerman
Steven Alexanderson
I. Antweiler
Stan Arnot
Carlo Arpino
Ali Al Awazi
Barry Beaster
Stephen Beattie
Robert Beavers
W. J. (Bill) Bergman
Wallace Binder
Thomas Bishop
Thomas Blackburn
Thomas Blair
Steven Brockschink
Chris Brooks
Kent Brown
Carl Bush
James Case
Donald Cash
Juan Castellanos
Bill Chiu
C. Clair Claiborne
Stephen Conrad
Tommy Cooper
Jerry Corkran
Stephen Dare
Willaim Darovny
Alan Darwin
John Densley
Dieter Dohnal
Donald Dunn
Fred Elliott
Gary Engmann
Donald Fallon
Gene Del Fiacco
Joseph Foldi
Bruce Forsyth
Marcel Fortin
James Gardner
Saurabh Ghosh
James Graham
Randall Groves
Kenneth Hanus
Robert Hartgrove
Gary Heuston
Scott Hietpas
David Horvath
James Huddleston
Francis Huguet
R. Jackson
James Jones
Lars Juhlin
Robert Keefe
Joseph Kelly
Gael Kennedy
Joseph L. Koepfinger
Neil Kranich
David W. Krause
Jim Kulchisky
Saumen Kundu
John Lackey
Richard Ladroga
Chung-Yiu Lam
Stephen Lambert
Debra Longtin
William Lowe
Thomas Lundquist
G. Luri
Keith N. Malmedal
J. Dennis Marlow
John W. Matthews
William McDermid
Susan McNelly
Joseph Melanson
Gary Michel
Daniel Mulkey
Jerry Murphy
R. Musil
Michael S. Newman
Raymond Nicholas
Joe Nims
Robert Olen
J. Patton
Christopher Petrola
Donald Platts
Alvaro Portillo
Bertrand Poulin
Gustav Preininger
Thomas Prevost
Iulian Profir
Jeffrey Ray
Johannes Rickmann
Michael Roberts
Charles Rogers
John Rossetti
Thomas Rozek
Dinesh Pranathy Sankarakurup
Daniel Sauer
Bartien Sayogo
Devki Sharma
Hyeong Sim
James E. Smith
Steve Snyder
John Spare
Brian Sparling
S. Thamilarasan
James Thompson
T. Traub
John Vergis
David Wallach
Barry Ward
William Wessman
Kenneth White
William Wimmer
Roland Youngberg
Kipp Yule
Theodore Zeiss
Waldemar Ziomek
Ahmed Zobaa

When the IEEE-SA Standards Board approved this guide on 26 September 2008, it had the following membership:

Robert M. Grow, *Chair*
Thomas Prevost, *Vice Chair*
Steve M. Mills, *Past Chair*
Judith Gorman, *Secretary*

Victor Berman
Richard DeBlasio
Andy Drozd
Mark Epstein
Alexander Gelman
William Goldbach
Arnie Greenspan
Ken Hanus
Jim Hughes
Richard Hulett
Young Kyun Kim
Joseph L. Koepfinger*
John Kulick
David J. Law
Glenn Parsons
Ron Petersen
Chuck Powers
Narayanan Ramachandran
Jon Walter Rosdahl
Anne-Marie Sahazizian
Malcolm Thaden
Howard Wolfman
Don Wright

*Member Emeritus

Also included are the following nonvoting IEEE-SA Standards Board liaisons:

Satish K. Aggarwal, *NRC Representative*
Michael Janezic, *NIST Representative*

Lisa Perry
IEEE Standards Project Editor

Matthew J. Ceglia
IEEE Standards Program Manager, Technical Program Development

Contents

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

IMPORTANT NOTICE: This standard is not intended to assure safety, security, health, or environmental protection in all circumstances. Implementers of the standard are responsible for determining appropriate safety, security, environmental, and health practices or regulatory requirements.

This IEEE document is made available for use subject to important notices and legal disclaimers. These notices and disclaimers appear in all publications containing this document and may be found under the heading "Important Notice" or "Important Notices and Disclaimers Concerning IEEE Documents." They can also be obtained on request from IEEE or viewed at http://standards.ieee.org/IPR/disclaimers.html.

1. Overview

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

e) Instruments for detecting and determining the amount of combustible gases present

f) A bibliography of related literature

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.

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 D 923, Standard Practices for Sampling Electrical Insulating Liquids.[1]

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

[1] 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/).

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

ASTM D 3612, Standard Test Method for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography.

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.

3.1 Definitions

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.

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

3.2 Acronyms and abbreviations

TCG	total combustible gas
TDCG	total dissolved combustible gas

4. General theory

The two principal causes of gas formation within an operating transformer are thermal and electrical disturbances. Conductor losses due to loading produce gases from thermal decomposition of the associated oil and solid insulation. Gases are also produced from the decomposition of oil and insulation exposed to arc temperatures. Generally, where decomposition gases are formed principally by ionic bombardment, there is little or no heat associated with low-energy discharges and partial discharge.

4.1 Cellulosic decomposition

The thermal decomposition of oil-impregnated cellulose insulation produces carbon oxides (CO, CO_2) and some hydrogen or methane (H_2, CH_4) due to the oil (CO_2 is not a combustible gas). The rate at which they are produced depends exponentially on the temperature and directly on the volume of material at that temperature. Because of the volume effect, a large, heated volume of insulation at moderate temperature will produce the same quantity of gas as a smaller volume at a higher temperature.

4.2 Oil decomposition

Mineral transformer 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 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 they 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.