White Paper

Dissolved Gas Analysis

Retain for future use.

Abstract

Oil-filled transformers are a major component in medium voltage distribution. Due to their critical contribution, it is important to monitor the transformers over their period of operation, typically comprising of twenty years or more. Dissolved Gas Analysis (DGA) is a diagnostic method used to ascertain normal operating conditions of oil-filled transformers. This paper will cover the process of dissolved gas analysis, different gases produced during cellulose and mineral oil degradation, gases generated under fault conditions, and testing procedures. The paper highlights the issue of faulty diagnosis caused by dissolved gases during normal operating conditions and the effect of transformer size on dissolved gas threshold. Methods to avoid faulty diagnosis and improving the testing procedure are discussed.

Introduction

During a fault, oil-filled transformers generate gases which help in identifying abnormal working conditions. The generated gases can be found dissolved in the insulating oil or in the space above the oil. The analysis of the type of dissolved gases generated based on the insulating medium helps in determining the fault conditions comprising of one or more thermal and electrical faults. However, it should be noted that the process of diagnosis of dissolved gases and the interpretation of its results is more of an art than exact science. The variables in the detection process comprise of the following:

1. Fault type, its temperature and location;
2. Type of oil preservation system;
3. Solubility and degree of saturation of different gases in oil;
4. Rate and type of oil circulation;
5. Type of material in contact with the fault; and
6. Differences in sampling and measurement procedures.

Additionally, gases are produced within the transformer during the manufacturing and assembling process. Some of the typical gases present under normal operating conditions will be discussed in later sections of this paper.

There are some industry standards guides for DGA, consisting of IEEE Standard C57.104-2008 "Guide To the Interpretation of Gases in Oil Immersed Transformers" and IEC 60599 "Mineral Oil-Impregnated Electrical Equipment in Service - Guide to the Interpretation of Dissolved and Free Gases Analysis". The scope of the IEEE guide comprises of:

1. Detection of dissolved combustible gases;
2. Operating condition guidelines;
3. Interpretation of results based on Total Dissolved Combustible Gas (TDCG) parameters provided in the guide; and
4. Providing diagnostic techniques and instruments for detecting dissolved combustible gas.

Mineral transformer oil is made up of hydrocarbons and its decomposition results in creation of combustible gases: hydrogen (H_2), methane (CH_4), and ethane (C_2H_6). Further decomposition of mineral transformer oil results in generation of ethylene (C_2H_4) and acetylene (C_2H_2). For example, presence of acetylene gas suggests possibility of high temperature arcing fault, while the presence of methane suggests low energy electrical or thermal fault. The IEEE TDCG threshold guidelines are used to determine occurrence and type of faults in mineral oil-filled transformers. The thermal decomposition of oil-impregnated cellulose insulation produces carbon monoxide (CO) and carbon dioxide (CO_2) due to the cellulose, with trace amounts of hydrogen and methane due to the oil. Carbon dioxide gas is non-combustible; hence, the CO_2/CO ratio is used to determine cellulose insulation degradation. For normal operation this ratio should be in the range of three to ten. The amount of gas produced in cellulose decomposition is directly proportional to the volume of insulating material; hence, the transformer size is significant in determining fault conditions.

Types of Faults

Common faults in the transformers are arcing, overheating, overloading, partial discharge, and low-energy sparking. These can be broadly categorized into either thermal or electrical faults.

Thermal Faults

Depending on the temperature a mix of hydrocarbons are produced during mineral oil decomposition. During the temperature range of 150 to 500°C (302 to 932°F) large quantities of lower molecular weight gases like hydrogen and methane are produced with trace amounts of higher molecular weight gases like ethylene and ethane. At slightly higher fault temperatures the amount of hydrogen gas production exceeds that of methane, accompanied with significant quantities of ethane and ethylene. Finally at very high temperatures of up to 700°C (1292°F), increasing amounts of hydrogen and ethylene gases are produced with trace amounts of acetylene.

In case of cellulose, thermal decomposition produces carbon oxides (CO, CO_2) and water vapor along with trace amounts of combustible gases, hydrogen and methane. Since cellulose decomposes at temperatures lower than oil, trace amounts of CO and CO_2 are present during normal operating conditions.

Electrical Faults—Low Intensity Discharges and High Intensity Arcing

Low intensity discharges consist of partial discharges and low intermittent arcing. They result in the production of mainly hydrogen, some amount of methane and trace amounts of acetylene. As the intensity of the discharge increases to an arc or continuous discharge proportions, the percentage of acetylene and ethylene increases in the dissolved gas.

Operating and Testing Procedure

Detection, Evaluation and Action are three main steps to follow from an operational point of view. To identify the presence of any gases which exceed normal operational levels and to ensure that it is detected in earliest possible time to minimize damage, is termed as Detection. Note that it can be difficult to determine normal operating gas levels of a unit if its DGA history is not available. This could lead to faulty diagnosis and additional tests to determine the cause of abnormality. IEEE Std. C57.104-2008 states that in the absence of transformer DGA history a four-level criterion for fault diagnosis as shown in Table 1, can be referred to as a starting point of analysis. The table was developed based on data collected from several large power transformers. In the four-level criterion Condition 1 indicates satisfactory transformer operation, Conditions 2–4 indicate abnormal transformer operating conditions where 2 being least severe and 4 being most severe.

Table 1: Dissolved Gas Concentrations

Status	Dissolved Key Gas Concentration Limits [µL/L (ppm)a]							
	Hydrogen (H_2)	Methane (CH_4)	Acetylene (C_2H_2)	Ethylene (C_2H_4)	Ethane (C_2H_6)	Carbon Monoxide (CO)	Carbon Dioxide (CO_2)	TDCG[b]
Condition 1	100	120	1	50	65	350	2500	720
Condition 2	101–700	121–400	2–9	51–100	66–100	351–570	2501–4000	721–1920
Condition 3	701–1800	401–1000	10–35	101–200	101–150	571–1400	4001–10000	1921–4630
Condition 4	>1800	>1000	>35	>200	>150	>1400	>10000	>4630

NOTE 1: Table 1 assumes that no previous tests on the transformer for dissolved gas analysis have been made or that no recent history exists. If a previous analysis exists, it should be reviewed to determine if the situation is stable or unstable. Refer to 6.5.2 for appropriate action(s) to be taken.

NOTE 2: An ASTM round-robin indicated variability in gas analysis between labs. This should be considered when having gas analysis made by different labs.

[a] The numbers shown in Table 1 are in parts of gas per million parts of oil [µL/L (ppm)] volumetrically and are based on a large power transformer with several thousand gallons of oil. With a smaller oil volume, the same volume of gas will have a higher gas concentration. Small distribution transformers and voltage regulators may contain combustible gases because of internal expulsion fuses or load break switches. The status codes in Table 1 are also not applicable to other apparatus in which load break switches operate under oil.

[b] The TDCG value does not include CO_2 which is not a combustible gas.

After determining the abnormality, its impact on the operation of the transformer is evaluated based on a set of guidelines and recommendations. This process is termed as Evaluation. Finally, appropriate action is taken to remedy the fault condition, which could vary from reducing the load on the transformer to removing the transformer from service in extreme cases. For further description on the operating and testing procedure for TDGA refer to IEEE Standard C57.104-2008 [1].

Effect of Transformer Size on TDCG Threshold

“Note a” in Table 1: Dissolved Gas Concentrations in IEEE C57.104-2008 mentions that the values representing possible fault conditions are based on large power transformer data and the same criterion cannot be applied directly to small transformers. Small distribution transformers may contain some combustible gases due to internal expulsion fuses and load break switches. Apart from the "Note a", which forewarns against directly applying the table for transformer DGA irrespective of size, there is another criteria which needs attention while doing DGA. Carbon monoxide and carbon dioxide gases are produced during cellulose degradation and as transformer size increases the ratio of oil to cellulose insulation increases. The oil to paper ratio impacts the generation of carbon oxides, hence, CO and CO_2 gases generated are higher for smaller transformers and could flag fault conditions. An independent study done by Weidmann Diagnostics [2] states that based on the conservative IEEE C57.104-2008 carbon oxide levels the 90th percentile level for CO and CO_2 gases though abnormal for all three size ranges, is worse for small transformers as shown in Table 2. Note that the normal range for CO_2/CO ratio is three to ten.

Table 2: Percentiles for CO_2/CO Ratio

Size Range	90th Percentile	10th Percentile
30–2500 kVA	17	3.7
2500–10000 kVA	17	3.2
>10000 kVA	13	3.0

Gases Present under Normal Operating Condition

Based on the analysis of several new transformer samples, it has been noted that dissolved gases are present in the insulating oil or in the gas blanket just after transformer installation. Gases trapped in winding during processing and testing come out when the oil is getting filled. Additional presence of moisture should be checked as the transformers are supposed to reach the site dry, and then are filled up. It should be noted that only very large transformers are shipped without oil. Some of the possible dissolved gases based on tests are as follows:

Carbon Oxides–Carbon oxides are produced during thermal decomposition of cellulose and the CO_2/CO ratio of less than three and greater than ten indicates abnormality. However, the transformer manufacturing process of removing moisture by subjecting the units to 100°C (212°F) creates carbon oxides in the paper insulation. Once oil filled, these gases will dissolve into the oil insulation for a period of time until equilibrium is attained between the gas in the paper and oil causing Condition 2-4 threshold levels. Test samples taken from these transformers will show abnormality, hence, in order to determine whether cellulose degradation has actually taken place we have to perform the Furan Test. This is a non-evasive test used to determine the remaining life of the transformer insulation.

Carbon Oxides are also produced during the process of cover welding in transformers. The test conducted by Westinghouse Electric Corporation on four three-phase distribution transformers before and after cover welding showed increased amount of carbon oxides along with trace amount of hydrocarbons like acetylene and ethylene [3].

Acetylene–The transformers are manufactured in such a manner that cover welding is completed post oil filling and testing. It is common for oil to reach the upper lip while being transferred from the testing station to the cover welding station. Once arriving at the cover welding station, the cover is placed on the top lip and welded into place. The temperature of the residual oil on the upper lip can exceed 700°C (1292°F) during welding of the cover, at which point gases, including acetylene, will be produced. The manufacturing facilities use a gas purging system inside the head space of the transformer to assist the removal of acetylene and other gases; however there are cases when all of the gases, including acetylene, will not be removed. The acetylene level could be as high as 3 parts per million which is equivalent to Condition 2 level defined by IEEE [1]. This could cause faulty diagnosis of possible arcing in the transformer. However, in case of high energy arcing, other hydrocarbons like hydrogen, methane, and ethylene are also produced and in the absence of these hydrocarbons it is safe to conclude that acetylene is introduced by process of cover welding.

Moisture–Moisture may condense on any surface cooler than the surrounding air. When a transformer is installed at a location warmer than itself, proper care should be taken to determine that all external condensation has disappeared. Additionally transformers should not be opened on a day with humidity above 70%, without precautions to prevent entrance of moisture. The manufacturing process causes trapped moisture in the transformer winding. If insulating oil is filled without drying the transformer thoroughly then this trapped moisture along with presence of carbon oxides produced in welding will mimic the thermal decomposition of cellulose.

Conclusion

The dissolved gas analysis process is based on several variants, hence it is considered more of an art than science. However, by improving the sample taking process, analysis and prior knowledge of possible gases present during normal operating conditions, faulty diagnoses can be minimized. Multiple samples–instead of one–should be collected over a period of time in order to determine the trend of the dissolved gases in transformers. DGA and moisture content testing should be done after the first day of installation in order to identify presence of gases introduced by the manufacturing and installation process. This data will help determine the normal operating conditions for the transformer and future test results can be analyzed based on these threshold values. A follow up DGA test should be conducted at three months, then at six months, and finally based on what the sample looks like, it could be done on one- or three-year intervals.

Transformer manufacturers and laboratories should analyze the first gas sample after transformer installation. The laboratories follow IEEE threshold values, whereas the transformer manufacturers have prior knowledge of possible gases generated during the manufacturing process and over the normal operating lifetime of the transformers. Together they can come up with a more realistic DGA. The transformer size should be considered during sample analysis as smaller transformers could have a higher CO_2/CO ratio without occurrence of a fault. IEEE is looking at 44,000 transformer data samples for differences between small versus large transformers, however due to dependence on several variants, it will be some time before we see any conclusion.

References:

[1] IEEE Standard C57.104-2008, "Guide for the interpretation of Gases in Oil Immersed Transformers".

[2] "Dissolved Gas Threshold Levels Based on Transformer Size", Thomas A. Prevost, Weidmann Diagnostic Solutions Inc.

[3] "Generation of Combustible Gas During the Cover Welding of Distribution Transformers", D.J. Struemph, Westinghouse Electric Corporation, Distribution Transformer Division.

Schneider Electric USA, Inc.
800 Federal Street
Andover, MA 01810 USA
888-778-2733
www.schneider-electric.us