High Voltage Service

Turning DGA Test Results into Required Actions

You Can Stop Failure with the Proper Interpretation of your Dissolved Gas

One of the current methods used to determine and predict failure of oil-filled electrical equipment is Dissolved Gas Analysis (DGA). DGA is a non-invasive method by which a sample of the dielectric mineral oil is drawn in a glassy syringe and analyzed for combustible gases and water content. The American Standards Group (ASTM) and the International Standards Group (IEC) have for many years recognized DGA as a viable and accurate method of determining incipient failures based on which gases are produced, in what quantities, and the rate at which these gases are produced.

All energized electrical equipment containing mineral oil produces some gas. Most are considered low order gases, such as propane and butane. These gases are produced due to the natural degradation of mineral oil, a hydrocarbon produced in nature just like any other product derived from crude oil. When this oil is subjected to higher than normal temperatures, different gases are produced. These gases can be broken down into three categories:

1. Partial Discharge Gases

(HYDROGEN / CARBON DIOXIDE / CARBON MONOXIDE)

In simpler terms, high voltage similar to static is leaking through the oil to a potential difference or a ground source. This can be a ground shield or a conductor that is too close. Typically this discharge has very little current. Left unchecked, this discharge will eventually destroy the paper insulation of the equipment and a failure will occur. The water content of the oil affects the amount of Hydrogen produced due to the water being a conductor within the oil. The higher the water content, the more Hydrogen produced. When Hydrogen is detected, the equipment should be monitored very closely. The rate of rise and overall quantity will determine the course of action. If the level is high and the rate of rise is fast, the unit should be taken out of service immediately. This decision should be based on need for the equipment in service and level of severity. The resolution of most hydrogen problems can be delayed for short periods of time to get through a system emergency. In many cases, if the water content of the suspect unit is high (see chart on page 4) and the unit is overloaded, Hydrogen will be produced naturally.

This gas tendency will reverse itself if the load is reduced or the water content of the oil is decreased. Because Hydrogen is lighter than air, it will evolve to the head space in a nitrogen-blanketed unit and dissipate. In a sealed system the Hydrogen will still find a method of escaping, but at a much slower rate.

2. Gases Produced Due to a Power Arc

(ACETYLENE)

This gas is produced when both voltage and current are present and are passing either from phase to phase, phase to ground or within a phase such as a broken conductor or no load tap connection.

This is the most catastrophic gas to be produced. Typically when Acetylene is produced in a non-load breaking compartment over a few parts (see chart on page 4), the piece of equipment is very close to failure and should be taken out of service immediately. Depending on the quantity, and most certainly on the rate of rise, little discussion should take place other than to determine how fast the unit can be removed from service and de-energized. Large quantities of Acetylene can, and do, lead to explosions due to the combination of the power arc generating the gas and a source of ignition.

Larger quantities of Acetylene are seen as a precursor to problems in load tap changing equipment or circuit breakers. Other gases are used to determine overall health of the equipment in those cases.

3. Gases Produced Due to Overheating and Extreme Overheating of Mineral Oil

(HOT METAL GASES: METHANE / ETHANE / ETHYLENE CARBON DIOXIDE / CARBON MONOXIDE)

When hydrocarbon mineral oil is heated in the range of 200^{o}C (392^{o}F,) **Methane** gas is produced. Overloading of equipment produces methane. The gas is evidence of winding heat which, over a period of time, damages the insulation by drying out the natural moisture contained in the cell structure of the paper and the paper to disintegrate. This moisture will show up as an increase in the water content of the oil and will be detected by the Water in Oil test called the Karl Fisher Test. This test is done concurrently with DGA. Additionally, the ratio of the CO to CO2 will be abnormally low. Normal levels should be around 10:1. Any ratio less than 3:1 should be considered reason for intense investigation of paper quality and life expectancy.

Small levels of Methane can be tolerated, but large quantities are cause for investigation as to loading and other operational conditions. Typically, the production of Methane for short periods of time can be overlooked because of the nature in which it is produced. As long as the overloading is relatively short in duration, the Methane produced is tolerable. As in all overloading conditions, eventual failure will occur due to paper insulation failure. **Note**: High levels of Methane on a bank put in service for the first time or returning from rewind may be caused by residuals from the Methane fired dry-out ovens used in the remanufacturing process. This gas should not be ignored, but monitored for rate of rise. Any large change should be treated as a problem.

Ethane is produced when a point source of heat raises the oil at the source to 400^{o}C or 750^{o}F. This level of heat begins to damage the paper very quickly. Over a period of time, the insulation level of a piece of equipment will degrade to a point where the insulation becomes very brittle and, if subjected to strong forces that tend to move the windings such as a close in fault, will short circuit the windings and cause catastrophic failure. High levels of Ethane, coupled with rate of rise, should be predominant factors in determining when a unit will be pulled from service and electrical tests performed on the insulation strength and dielectric ability.

Ethylene is produced when a point source of heat reaches 600^{o}C or 1080^{o}F. This temperature is hot enough to melt copper. Problems like no load tap changers and winding strand-to-strand failure produce Ethylene. At this point there is a serious problem in the unit. Any substantial rate of rise should be an alarm condition and immediate plans should be made to remove the unit from service. Ethylene formed in a load tap changing compartment such as an LTC presents another problem. An LTC compartment should be at ambient temperature most of the time. Any heat sources high enough to generate Ethylene will also melt the contacts and form coke, a form of carbon and a by-product of the oil, on the contacts. This coke adds to the problem and soon causes blinking or no light calls. The coke acts as an insulator and, in electrical terms, acts the same as a carbon film resistor. The coke limits the amount of arcing that will take place in a tap changer or breaker, but at the same time will absorb the energy released by the arc and convert it to heat. The accumulation of coke retains the heat, ultimately destroying the contacts and possible the unit.

DGA provides for early diagnosis of gassing conditions and when interpreted correctly can be used to accurately determine when to remove the unit for service and/or repairs. The use of DGA is accepted worldwide and has proven to save millions of dollars in equipment and revenues annually.

APPLICATION TO EQUIPMENT

DGA can be applied to the main tank of transformers or regulators where the tap changing under load takes place.

In the main tanks of transformers and regulators, small quantities of low order hot metal gases are common. As the load increases, the winding temperature raises to a point at which gases such as **Butane** and **Propane** are generated. These gases are not tracked. As the heating continues to above 100^{o}C, **Methane** begins to be cracked off the molecular chain and deposited in the oil as a gas. Higher temperatures generate **Ethane** and **Ethylene,** as described earlier. When large amounts of these gases are generated or the rate of rise is high, an investigation should be conducted to find the cause. **Hydrogen** can be produced in two unique circumstances. The first is because of **Partial Discharge** taking place in the main tank. This low energy discharge from metal to metal or oil to metal causes **Hydrogen** to be released from the oil and redeposited as a gas. The second reason is high moisture in the oil. The moisture decreases the dielectric of the oil to a point where current leakage through the oil again causes **Hydrogen** to be released. Additionally, the water breaks down into its basic components of **Hydrogen** and **Oxygen,** therefore increasing the **Oxygen** in the unit as well as adding to the **Hydrogen**. Any time **Hydrogen** is being produced, a check for **CO2** and **CO** should be made to check on insulation damage. This is not an absolute check for insulation damage, but merely one type of indicator.

Once the heating or discharge damages enough insulation, an arc begins. This arc not only carries voltage, but can support current as well. **<u>This is the final phase of failure.</u>** It is the combination of voltage and current that generates **Acetylene** and very quickly destroys the equipment. It is very obvious that any accumulation of **Acetylene** is reason to immediately remove a unit from service regardless of rate of rise.

DGA can be applied to load breaking (LB) or tap changing equipment (LTC)

When applied to LBs or LTCs, DGA has been proven to be a very useful tool in determining when an LTC needs service. Under normal conditions a healthy LTC generates very few gases, including **Acetylene**! Most people are under the misunderstanding that all LTCs generate large quantities of **Acetylene** and it cannot be used to indicate trouble within the unit. As a contact gas, its natural process of becoming thinner increases contact mating resistance due to lessened spring pressures. The increased resistance produces heat. The heat accelerates the annealing or softening of the spring material, making the electrical contact point even less effective. This deformation of the springs causes two distinct problems. The first is contact placement. The contact is no longer held in alignment causing bending or breaking of the mounts. The resulting condition leads to an increase in arcing and the high rise in **Acetylene.**

The second problem is poor contact makeup. This can be from weak springs or poor alignment and causes a decrease in the surface tension and surface area. Both cause an increase in resistance and heat. The heat forms coke, a carbon-like deposit, on the hot surface of the contact. This carbon in turn decreases the arcing due to its inherent carbon film resistance. The result is more heat, furthering the damage to the contacts. Eventually the LTC fails due to the loss of contacts.

<u>NOTE:</u> The chart on the following page is intended to help determine when to remove equipment for servicing based on past DGA results and outcomes. Final determination depends on gas rate of rise above previous base line and previous equipment histories.

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LTC/REG TYPE	Free Breather	Desiccant Breather	Sealed	Vacuum Sealed	Vacuum Free/Des	Main Tank
Hydrogen	750	900	4,500	40	25	200
Methane	1,200	1,500	8,500	30	15	80
Ethane	1,200	1,500	8,500	30	15	35
Ethylene	1,000	1,200	10,000	20	10	100
Acetylene	1,500	2,000	12,000	4	2	3
Carbon Monoxide	N/A	N/A	N/A	N/A	N/A	1,000*
Carbon Dioxide	N/A	N/A	N/A	N/A	N/A	10,000
Oxygen	15,000	15,000	15,000	15,000	15,000	15,000
Water in ppm	75	55	55	55	75	35/30/25#

*Upper levels should still be below the given values. Levels greater than shown indicate the transformer is heating above normal design limits. The ratio of CO and CO2 needs to be 10 or greater. Any ratio less than 10 indicates paper damage in a main tank.
Water levels in the main tank are dependent on the voltage class: 35ppm for 69KV and below, 25ppm for 345KV and above. Tap changer water levels are typically higher due to thermal cycling, but should be below the given values to maintain dielectric integrity.

The High Voltage Service Transformer Service team has the expertise necessary to perform and accurately interpret your DGA, ensuring proper maintenance and reliable performance of your transformers.

Experienced Technicians—The extensive experience and versatility of our NETA-certified field technicians assures they are able to provide planned services and that they will be able to handle any additional issues found on site with the same level of quality—something you should expect from a superior Transformer Service Company.

Equipment Capabilities—Our advanced oil processing, electrical testing and LTC service equipment, as well as our full line of mechanical services, provide the necessary tools for our technicians to resolve any problems you have.

Responsiveness— Whether scheduled service or emergency response, you can rely on our team to deliver the service you need, when you need it.

High Voltage Service
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