Dissolved Gas Analysis (DGA) of mineral oil used in transformers

Er. Lee Wai Meng discusses a procedure for monitoring the functioning of this important category of power supply equipment.

Introduction

Mineral oil performs two important functions in transformers. It cools the transformer and provides electrical insulation, as well. Therefore any deterioration in the oil can lead to premature failure of the equipment.

When the mineral oil is subjected to high thermal and electrical stresses, it decomposes and, as a result, gases are generated.

Different types of faults will generate different gases, and the chemical analysis of these gases, performed through a procedure called DGA (Dissolved Gas Analysis), will provide useful information about the condition of the oil, and help to identify the type of fault in the transformer.

DGA requires the removal of an oil sample from the transformer, and this can be done without de-energising it. The oil sample is analysed in the laboratory using gas chromatography.

Mechanism of gas generation

The cause of gas generation is the breaking of the chemical bonds between the atoms that make up the hydrocarbon molecules of the mineral oil. The faults in the transformer produce the energy that is needed for breaking the chemical bonds. The gases generated include hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), carbon dioxide (CO_2) and carbon monoxide (CO). The chemical structure of these gases is shown in Figure 1.

These gases, when generated, will initially dissolve in the oil. As more gases are generated, more will dissolve in the oil. However, there will come a point when the oil will be totally saturated with dissolved gas, and further generation of gases will result in their being released as they can no longer be dissolved by the oil.

Lower amounts of energy or lower temperatures are required to create or break the C-H molecular bonds. Higher amounts of energy or higher temperatures are needed, to create, or break, in ascending order, C-C single bonds, C=C double bonds, and C≡C triple bonds.

Methane and ethane will form at lower temperatures because of the single bond (C-H and C-C). Ethylene gas will form at higher temperatures of more than 500 ° C because of the double bond (C=C). Even higher temperatures, of at least 800 ° C to 1200 ° C, are required for the formation of acetylene gas because it has a triple bond (C≡C).

Types of faults

IEC-599 is the guide to the interpretation of the DGA results for mineral oil. The faults are broadly divided into thermal and electrical types. Figure 2 describes the types of thermal and electrical faults.

For thermal fault T1, occurring at a temperature of less than 300 ° C, the paper insulation of the transformer will turn brownish. For thermal fault T2, occurring at temperatures between 300 °C and 700 ° C, the paper insulation will carbonise. For thermal fault T3, occurring at a temperature of more than 700 ° C, the oil will carbonise and metal will become coloured or will fuse.

Electrical faults include partial

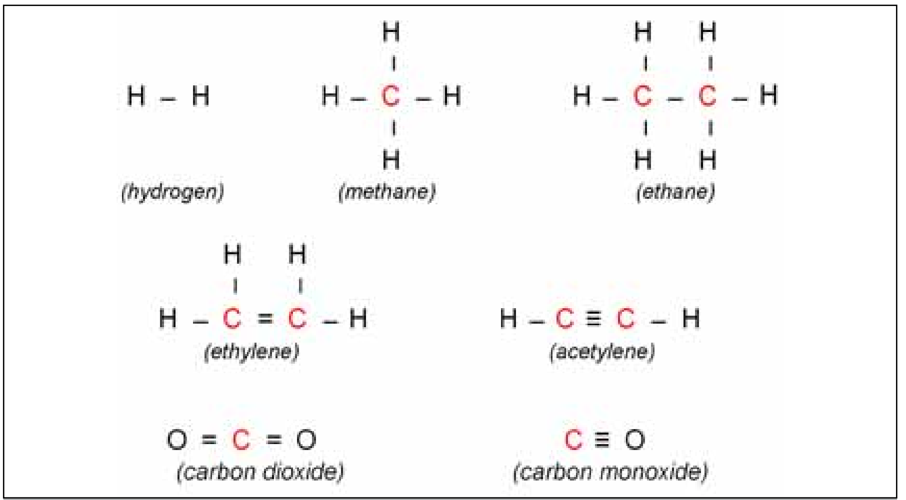

Figure 1.

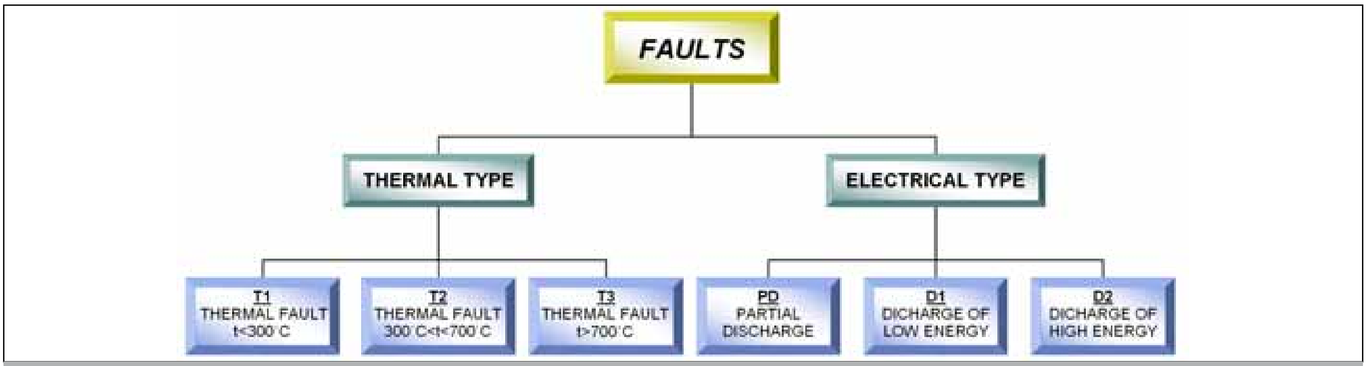

Figure 2.

discharge, low energy discharge, and high energy discharge. Partial discharge may cause wax to form in the oil. Low energy discharge and high energy discharge can be due to electrical discharge through the oil, through the paper insulation, or at the surface of the paper insulation, or due to degradation of the surface of the paper insulation resulting in the formation of conducting paths or small arcs.

Normal values of dissolved gas

When mineral oil contains normal values of dissolved gas, it indicates no incipient fault in the transformer. Figure 3 shows the normal values of dissolved gases in the oil. When the DGA results for all the seven key gases, are less than the values in Figure 3, it can be concluded there are no incipient faults in the transformer. Should the DGA results for any one of the gases, exceed the values in Figure 3, then IEC-599 recommends the use of gas ratio analysis.

IEC gas ratio analysis

Three gas ratios are used in DGA - methane/hydrogen, acetylene/ethylene, and ethylene/ethane. Figure 4 shows the relationship between the fault type and the gas ratio. Faults often start as incipient, low energy faults which may develop into more serious higher energy or higher temperature faults. When a fault is detected, it is important to determine the trend in the rate of increase of the gas. An increase in gas values of more than 10% per month above the normal values, will indicate that the fault is active. It is also important to determine the trend in the occurrence of different types of faults, and to detect early, any deterioration towards a more serious fault, such as, for example, the evolution of an existing T2 thermal fault into the more serious T3 thermal fault. Determining the trend in both the rate of increase of the individual gases, and the occurrence of different types of faults, will provide information on the health of the transformer. Figure 5 gives the flow chart for the entire process, which will help in the interpretation of the DGA results for mineral oil.

CO_2 / CO gas ratio

When a transformer is overloaded, the paper insulation will be subjected to high temperature. Both carbon dioxide and carbon monoxide will be generated. When the normal values for both gases, as shown in Figure 3, are exceeded, the next step is to calculate the CO_2/CO ratio. A ratio outside the 3 to 11 range, will indicate a fault involving the paper insulation.

Gas	Hydrogen (H_2)	Methane (CH_4)	Ethylene (C_2H_4)	Acetylene (C_2H_2)	Carbon dioxide (CO_2)	Carbon monoxide (CO)
ppm	100	50	50	5	5000	200

Figure 3: normal values of dissolved gas in oil.

Case	Characteristic fault	Acetylene / Ethylene	Methane / Hydrogen	Ethylene / Ethane
PD	Partial discharges	NS[1]	<0.1	<0.2
D1	Discharges of low energy	>1	0.1-0.5	>1
D2	Discharges of high energy	0.6-2.5	0.1-1	>2
T1	Thermal fault t < 300°C	NS[1]	>1	<1
T2	Thermal fault 300°C< t <700°C	<0.1	>1	1 - 4
T3	Thermal fault t > 700°C	<0.2[2]	>1	>4

1) NS = Non-significant whatever the value.
2) An increasing value of the amount of C_2H_2 may indicate that the hot spot temperature is higher than 1000° C.

Figure 4: IEC gas ratio.

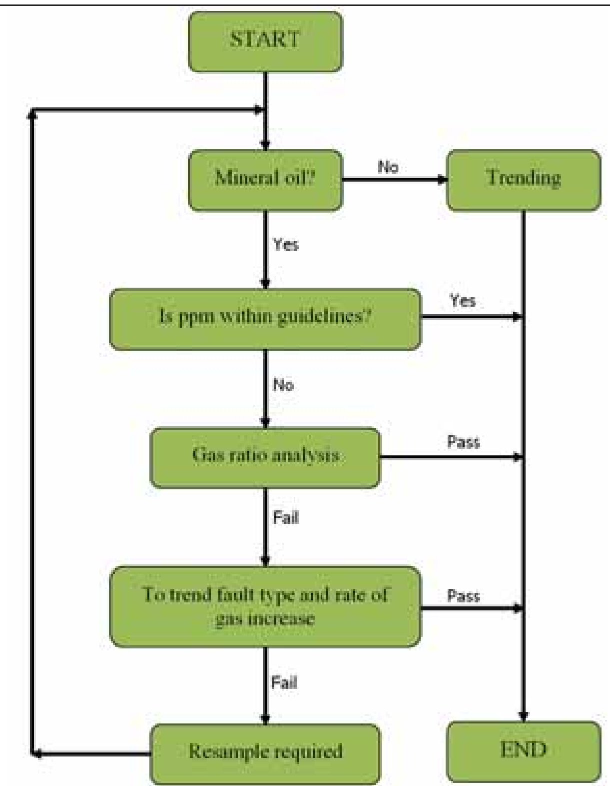

Figure 5: DGA interpretation flow chart.

Conclusion

DGA is a chemical rather than an electrical method. It does not suffer from electrical interference and can be done without de-energisation of the transformer. The cost of each DGA is relatively inexpensive. All these factors make DGA a powerful tool in the preventive maintenance of transformers.

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