IEEE DISSOLVED GAS ANALYSIS GUIDELINES

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The Key Gas Method of interpreting DGA is set forth in IEEE [11]. Key gases formed by degradation of oil and paper insulation are hydrogen (H_2), methane (CH_4), ethane ($C_2 H_6$), ethylene ($C_2 H_4$), acetylene ($C_2 H_2$), carbon monoxide (CO), and oxygen (O_2). Except for carbon monoxide and oxygen, all these gases are formed from the degradation of the oil itself. Carbon monoxide, carbon dioxide (CO_2), and oxygen are formed from degradation of cellulose (paper) insulation. Carbon dioxide, oxygen, nitrogen (N_2), and moisture can also be absorbed from the air if there is an oil/air interface, or if there is a leak in the tank. Some transformers have a pressurized nitrogen blanket above the oil, and in these cases, nitrogen may be near saturation (See table 4). Gas type and amounts are determined by where the fault occurs in the transformer and the severity and energy of the event. Events range from low energy events such as partial discharge, which produces hydrogen and trace amounts of methane and ethane, to very high energy sustained arcing, capable of generating all the gases including acetylene, which requires the most energy.

Transformer Diagnosis Using Individual and Total Dissolved Key Gas Concentrations. A one to four condition DGA guide is used to classify risks to transformers with no previous problems has been developed by the IEEE [11]. The guide uses combinations of individual gases and total combustible gas concentration. This guide is not universally accepted and is one of the many tools used to evaluate transformer condition. The four conditions are defined below:

Table 4. --Dissolved Key Gas Concentration Limits in Parts Per Million (ppm)

Status	H_2	CH_4	$C_2 H_2$	C_2H_4	C_2H_6	CO	CO_2[1]	TDCG
Condition 1	100	120	35	50	65	350	2,500	720
Condition 2	101-700	121-400	36-50	51-100	66-100	351-570	2,500-4,000	721-1,920
Condition 3	701-1,800	401-1,000	51-80	101-200	101-150	571-1,400	4,001-10,000	1,921-4,630
Condition 4	>1,800	>1,000	>80	>200	>150	>1,400	>10,000	>4,630

[1] CO_2 is not included in adding the numbers for TDCG because it is not a combustible gas.

Condition 1: Total dissolved combustible gas (TDCG) below this level indicates the transformer is operating satisfactorily. Any individual combustible gas exceeding specified levels in table 4 should have additional investigation.

Condition 2: TDCG within this range indicates greater than normal combustible gas level. Any individual combustible gas exceeding specified levels in table 4 should have additional investigation. A fault may be present. Take DGA samples at least often enough to calculate the amount of gas generation per day for each gas. (See table 5 for recommended sampling frequency and actions.)

Condition 3: TDCG within this range indicates a high level of decomposition of cellulose insulation and/or oil. Any individual combustible gas exceeding specified levels in table 4 should have additional investigation. A fault or faults are probably present. Take DGA samples at least often enough to calculate the amount of gas generation per day for each gas. (See table 5.)

Condition 4: TDCG within this range indicates excessive decomposition of cellulose insulation and/or oil. Continued operation could result in failure of the transformer (table 5).

Condition numbers for dissolved gases given in IEEE C-57-104-1991 (table 4) are extremely conservative. Some transformers have operated safely with individual gases in Condition 4 with no problems; however, they are stable and gases are not increasing, or are increasing very slowly. If TDCG and individual gases are increasing significantly (more than 30 ppm/day), the fault is active and the transformer should be removed from service for additional testing, investigation and analysis when Condition 4 levels are reached.

A sudden increase in key gases and the rate of gas production is more important in evaluating a transformer than the amount of gas. One exception is acetylene (C_2H_2). The generation of any amount of this gas above a few ppms indicates high energy arcing. Trace amounts (a few ppm) can be generated by a very hot thermal fault (500 °C). A one-time arc caused by a nearby lightning strike or a high-voltage surge can generate acetylene. If C_2H_2 is found in the DGA, oil samples should be taken weekly to determine if additional acetylene is being generated. If no additional acetylene is found and the level is below the IEEE Condition 4, the transformer may continue normal in service operation. However, if acetylene continues to increase, the transformer has an active high-energy internal arc and should be taken out of service. Further operation puts the transformer at risk and may result in failure. Operating a transformer with an active high-energy arc is extremely hazardous.

Table 4 assumes that no previous DGA tests have been made on the transformer or that no **recent** history exists. If a previous DGA exists, it should be reviewed to determine if the situation is stable (gases are not increasing significantly) or unstable (gases are increasing significantly). **Deciding whether gases are increasing *significantly* depends on a particular transformer, family/design, and/or local operational conditions.**

Compare the current DGA to older DGA test history. If the production rate (ppm/day) of any one of the key gases and/or TDCG (ppm) has suddenly gone up, gases are probably increasing significantly. Refer to table 5, which gives suggested actions based on total amount of gas in ppm and rate of gas production in ppm/day.

Before going to table 5, determine transformer status from table 4; that is, look at the DGA and see if the transformer is in Condition 1, 2, 3, or 4. The condition for a particular transformer is determined by finding the highest level for any **individual gas** or by using the **TDCG [11]. Either** the individual gas or the TDCG can give the transformer a higher Condition number, which means it, is at greater risk. If the TDCG number shows the transformer in Condition 3 and an individual gas shows the transformer in Condition 4, the transformer is in Condition 4. Always be conservative and assume the worst until proven otherwise.

NOTES: 1. Either the **Highest Condition Based on Individual Gas** or **Total Dissolved Combustible Gas** can determine the condition (1,2,3,or 4) of the transformer [11]. For example, if the TDCG is between 1,941 ppm and 2,630 ppm, this indicates Condition 3. However, if hydrogen is greater than 1,800 ppm, the transformer is in Condition 4, as shown in table 4.
2. When the table says, "determine load dependence," this means, if possible, find out if the gas generation rate in ppm/day goes up and down with load. Perhaps the transformer is overloaded. Take oil samples every time the load changes; if load changes are too frequent, this may not be possible.

3. To get TDCG generation rate, divide the change in TDCG by the number of days between samples that the transformer has been loaded. Down-days should not be included. The individual gas generation rate ppm/day is determined by the same method.

Sampling intervals and recommended actions. When sudden increases occur in dissolved gases, the procedures recommended in table 5 should be followed. Table 5 is **paraphrased** from table 3 in IEEE C57.104-1991. To make it easier to read, the order has been reversed with Condition 1 (lowest risk transformer) at the top and Condition 4 (highest risk) at the bottom. The table indicates the recommended sampling intervals and actions for various levels of TDCG in ppm. **An increasing gas generation rate indicates a problem of *increasing severity*;** therefore, as the generation rate (ppm/day) increases, a shorter sampling interval is recommended. (See table 5.)

Table 5. --Actions Based on Dissolved Combustible Gas

Conditions	TDCG Level or Highest Individual Gas (See Table 4)	TDCG Generation Rates (PPM/Day)	Sampling Intervals and Operating Actions for Gas Generation Rates	
			Sampling Interval	Operating Procedures
Condition 1	720 ppm of TDCG or highest condition based on individual gas from table 4	<10	Annually: 6mo for EHV trans	Continue normal operation.
		10-30	Quarterly	
		>30	Monthly	Exercise caution. Analyze individual gases to find cause. Determine load dependence.
Condition 2	721-1,920 ppm of TDCG or highest condition based on individual gas from table 4	<10	Quarterly	Exercise caution. Analyze individual gases to find cause. Determine load dependence.
		10-30	Monthly	
		>30	Monthly	
Condition 3	1,941-2,630 ppm of TDCG or highest condition based on individual gas from table 4	<10	Monthly	Exercise extreme caution. Analyze individual gases to find cause. Plan outage. Call manufacturer and other consultants for advice.
		10-30	Weekly	
		>30	Weekly	
Condition 4	>4,630 ppm of TDCG or highest condition based on individual gas from table 4	<10	Weekly	Exercise extreme caution. Analyze individual gases to find cause. Plan outage. Call manufacturer and other consultants for advice.
		10-30	Daily	
		>30	Daily	Consider removal from service. Call manufacturer and other consultants for advice.