NOMOGRAM
FOR INTERPRETATION OF LTC DGA DATA

I. INTRODUCTION

Very significant progress has been made since our previous publication on the interpretation of dissolved gas analysis (DGA) data for on-line load tap changers (LTCs). Since then an IEEE working group has made advances in its development of a simple statistical DGA method for detecting abnormal LTC conditions. The LTC DGA nomogram published earlier has now been redesigned for the use of both gas concentration and gas ratio limits.

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II. DETECTION OF PROBLEM LTCS

IEEE Transformers Committee working group C57.139 has developed a guide for the interpretation of LTC DGA data. Key concepts expressed in the guide are:

- Many LTC abnormalities can be detected by means of statistically derived limits for combustible gas concentrations and combustible gas concentration ratios.
- Derivation of generic fault detection limits for all LTCs is not possible because of the wide variation in LTC design, breathing configuration, and operating conditions. Limits must be derived for specific models of LTCs.

Documentation for the IEEE C57.139 working group's statistical method for derivation of caution and warning limits can be obtained by contacting the authors.

The origin of the gases found in LTCs has been discussed in our previous publication, which provides a good understanding of the gas production process.

Gas concentration ratios that have proven useful for LTC condition diagnostics are listed in Table 1. Note that ratios that include hydrogen as an arcing gas are no longer recommended. This is because hydrogen's ability to diffuse rapidly out of the oil and escape through the LTC breather into the atmosphere tends to make the hydrogen concentration and the ratios using hydrogen unreliable.

Ratio	Formula	Comment
$\frac{ethylene}{acetylene}$	$\frac{C_2H_4}{C_2H_2}$	$\frac{\text{Major Heating Gas}}{\text{Arcing Gas}}$
$\frac{methane + ethane + ethylene}{acetylene}$	$\frac{CH_4 + C_2H_6 + C_2H_4}{C_2H_2}$	$\frac{\text{Heating Gases}}{\text{Arcing Gas}}$
$\frac{ethane}{methane}$	$\frac{C_2H_6}{CH_4}$	Ratio Increases with Increasing Temperatures
$\frac{ethylene}{ethane}$	$\frac{C_2H_4}{C_2H_6}$	Ratio Increases with Increasing Temperatures
$\frac{nitrogen}{oxygen}$	$\frac{N_2}{O_2}$	Ratio increases when oil oxidizes rapidly

Table 1: *Diagnostic gas concentration ratios*

Nitrogen and oxygen are not fault gases, but their concentrations in oil are shown in DGA reports. The ratio of nitrogen to oxygen in the atmosphere is 3.76, but in air-saturated oil the ratio is about 2 due to the different solubilities of these gases in oil. In a free-breathing LTC, dissolved oxygen is replaced as fast as it is consumed, so the N_2/O_2 ratio value typically remains near 3. If an LTC breathes through a desiccator and the desiccator is blocked, the ratio increases as oxygen is consumed without replacement. Consumption of oxygen by the oil results in the production of compounds that coat LTC contacts and lead to the formation of coke.

III. GRAPHICAL DATA INTERPRETATION METHODS

Several graphical methods have been published for interpretation of DGA results for power transformers. These methods are well documented and widely used. One of these methods, the Duval Triangle, has been modified for LTC-DGA data. We have previously published a nomogram for power transformers and a separate nomogram for LTCs. An improved nomogram has now been developed for LTCs.

IV. NOMOGRAM DESIGN

The original gas ratio nomogram for LTCs employs two vertical logarithmic scales, one for each fault gas involved in the ratio. A line is drawn connecting the two gas concentrations as reported for an oil sample. The slope of this line represents the ratio of the two gas concentrations, which is correlated with fault type and severity.

The improved nomogram, shown in Figures 1 and 2, has three vertical logarithmic scales. The two leftmost scales represent the numerator and denominator gas concentrations, and the rightmost scale represents the numeric value of the ratio. Note that for geometrical reasons the ratio value scale is inverted, with the largest values at the bottom.

This arrangement permits the subdivision of the scales into Normal, Caution, and Warning zones according to the limits provided for the gas concentrations and the gas ratio. When a line is plotted on the nomogram representing a specific case, it is immediately apparent whether any limits have been exceeded.

V. APPLICATION EXAMPLE

A case study illustrates the design and application of the nomogram. For this example, nomograms are shown for ethylene/acetylene and nitrogen/oxygen. Similar gas ratio nomograms can be plotted, as required, for the other diagnostically useful gas ratios mentioned in Table 1. The example LTC has a single compartment with oil-immersed arcing contacts. Table 2 lists the DGA history of this unit. The applicable fault detection limits for this population of LTCs are as shown in Table 3.

Date	Hydrogen	Methane	Ethane	Ethylene	Acetylene	C_2H_4/C_2H_2	Oxygen	Nitrogen	N_2/O_2
24 Dec 2003	251	99	46	518	2700	0.19	40039	124481	3.11
18 Feb 2004	203	114	39	491	2803	0.18	44744	99797	2.23
07 Apr 2004	79	55	20	292	1587	0.18	31387	55329	1.76
27 Aug 2004	370	89	27	318	1914	0.17	30786	76591	2.49
08 Nov 2004	225	74	27	388	1784	0.22	29192	66597	2.28
21 Jan 2005	33	88	29	439	1858	0.24	29483	86993	2.95
20 Jun 2005	197	94	29	523	1251	**0.42**	14846	62041	4.18
24 Oct 2005	202	52	20	325	860	**0.38**	12325	56479	4.58
08 Feb 2006	558	1994	660	4537	778	**5.83**			

Table 2: *DGA history for LTC case history*

	Caution	Warning
Ethylene	1157	2020
Ethylene/Acetylene ratio	0.3	0.4
Oxygen/Nitrogen ratio	7	---

Table 3: *Applicable fault detection limits for the example*

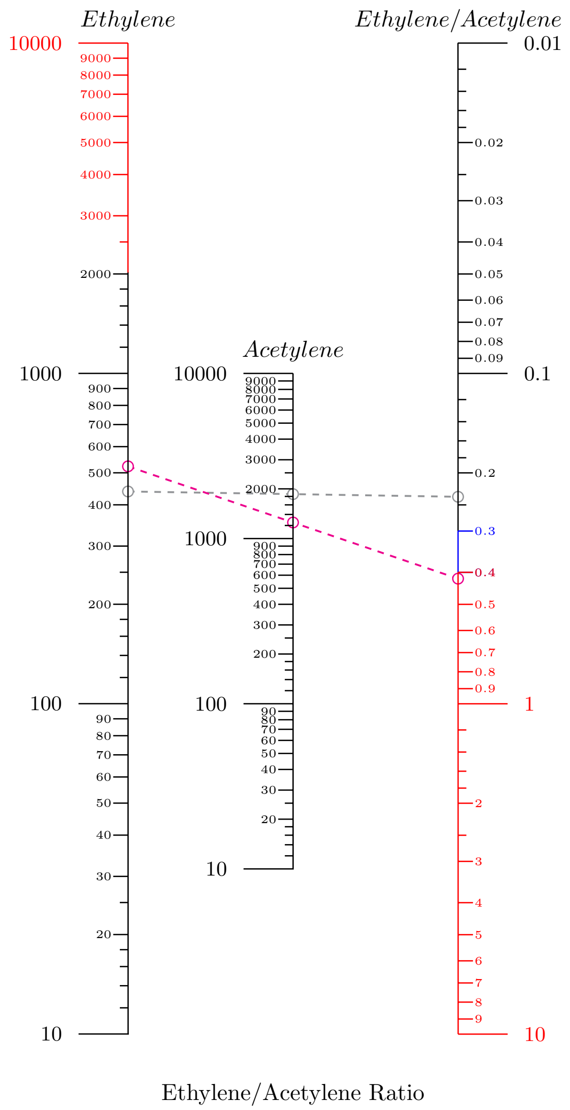


Figure 1: *Gas ratio nomogram for Ethylene/Acetylene ratio*

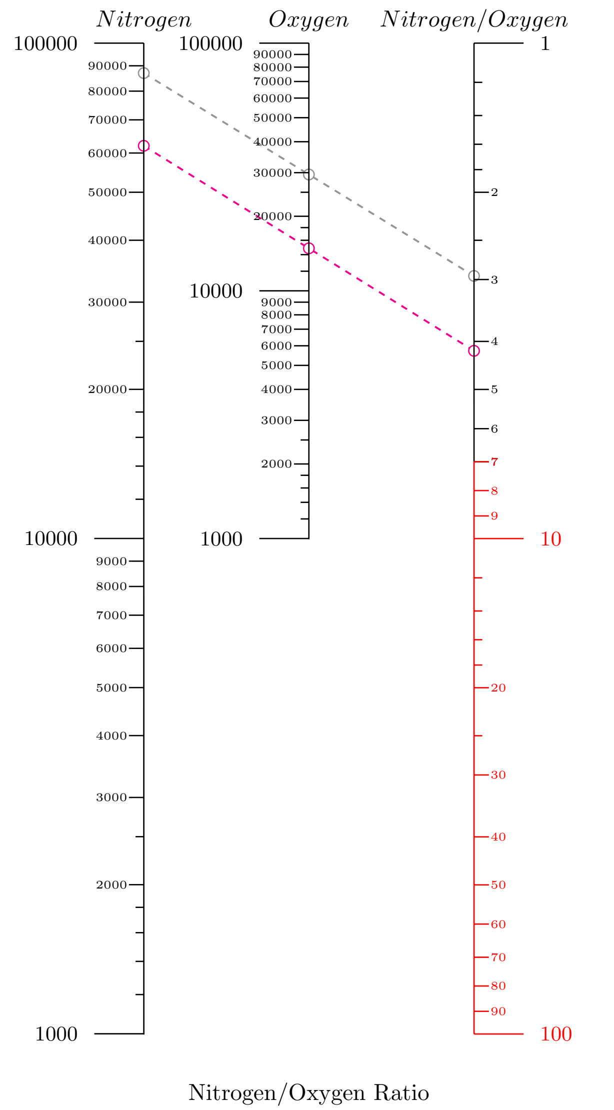


Figure 2: *Gas ratio nomogram for Nitrogen/Oxygen ratio*

Figure 1 is a nomogram for the ethylene/acetylene ratio. The gray dashed line joining all three scales represents the January 21, 2005, oil sample which, with 1858 ppm of acetylene and 439 ppm of ethylene, is similar to the previous samples. From the nomogram, it is evident that the gas concentrations and the ratio value for that sample are within their normal ranges.

The colored, dashed line represents the June 20, 2005, sample, with 1251 ppm of acetylene and 523 ppm of ethylene. In this case, the ethylene/acetylene ratio value falls inside the Warning range on the ratio value scale. An excessively high value of that ratio in LTCs of this type is usually a sign of an arcing contact problem, such as coking,

Illustration 1: *Burned reversing switch contacts*

which greatly increases the amount of heat produced per operation. This LTC was kept in service until much worse DGA results were obtained in February 2006. Internal inspection revealed severe coking of the reversing switch contacts, as shown in Illustration 1.

Figure 2 is a nomogram for the nitrogen/oxygen ratio. The gray, dashed line represents the January 21, 2005, oil sample, with 86993 ppm of nitrogen and 29483 ppm of oxygen and a nitrogen/oxygen ratio of 2.95. The colored, dashed line represents the June 20, 2005, sample, with 62041 ppm of nitrogen and 14846 ppm of oxygen and a ratio value of 4.18, which does not exceed the limit of 7 but in connection with the ethylene/acetylene result could raise the question of whether the oil condition is deteriorating.

REFERENCES

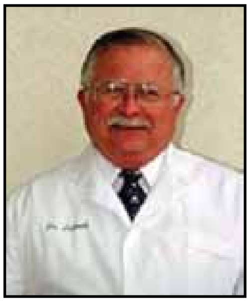
Jakob, F., Jakob, K., Jones, S. And Youngblood, R. "A Nomograph for Interpretation of LTC-DGA Data", NETA Conference, San Antonio, Texas, March 15, 2004.

Duval, Michel, "A Review of Faults Detectable by Gas-in-Oil Analysis in Transformers", IEEE Electrical Insulation Magazine May/June 2002, Vol. 18 No. 3, pp. 8-17

Duval, Michel, "The Duval Triangle for Load Tap Changers, Non-Mineral Oils , and Low Temperature Faults in Transformers", IEEE Electrical Insulation Magazine, Vol. 24, No. 6, Nov-Dec 2008

Church, J.O., Haupert, T.J. and Jakob, F., Electrical World, Vol. 201, No. 10, October 1987, pp. 40-44

Pruente, John, Personal Communication



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