A statistical approach for the calculation of DGA limits may seem simple, however, it is not straightforward and easy to calculate a 90 % statistical limit, for example

ABSTRACT

DGA plays a vital role in the diagnostics and maintenance of the transformers. It is a multidisciplinary and complex field that is not easy to master. That is the reason why this article is oriented to explaining the learning and understanding the process associated with DGA.

KEYWORDS

basics, DGA, diagnostics, gasses, oil, principles

Basic principles of DGA - Part II

Learning, using, and creating your own view on DGA

Limits values for DGA tests and results

The exact specification for DGA is something that all transformer users, managers, specific DGA software manufactures, online devices producers, and all the industry are looking for. For other oil test types, it is a usual behaviour to refer the measured value to the relevant limit from the corresponding guide or standard. Having limits like for dissipation factor or oil acidity does not work for DGA. It is probably the key obstacle for DGA manual or software-based diagnosis. The hard challenge here becomes selecting values that represent the specific equipment in the light of new developments and knowledge, and also considering the maintenance policy of the transformer owner. Adopting the published and already processed value is an excellent stage for the initial learning process for DGA interpretation. Using such general limits or normal or cut-off values may lead to substantial pricey consequences.

In this essential aspect, a new version of IEEE C57.107 [9] published the 90 % approach of limits value, shown in Table 1.

This approach was previously presented in CIGRÉ WG on DGA [11] and is a significant step forward to improve the uniqueness of the DGA limits values.

The readers will be able to understand and exercise this statistical approach for DGA limits. Even if it may seem simple to calculate a 90 % statistical limit, it is not a straightforward statistical calculation. The ones who need to compute are demanded to select different options from the primary and extensive database to the specific 90 % limits. Of course, the challenge is inversely proportional to the size of the database. The constrains of data securities imply minimum size databases, and therefore more extensive efforts to develop such kind of limits.

The countenance of these difficulties also comes into view from the new CIGRÉ WG approach, as shown in Table 2. The selected values for two options of database size emphasise the importance of these selections and the meaning of the relation between the database size and the 90 % computed value.

An additional important factor that CIGRÉ BT 771 introduces and the emphases is the fault severity and gas apparition. Here again, the unimportance of hydrogen is notable from Table 3. This gas appears in a minority of cases, and even then, it indicates non-severe faults.

Table 1. Dissolved gas concentrations [9]

Status	Table 1- Dissolved gas concentration limits [μL / L (ppm)]							
	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*
Condition 1	100	120	1	50	65	350	2500	720
Condition 2	101-700	121-400	2-9	51-100	66-100	351-570	2500-4000	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.
• TDCG – total dissolved combustion gas

Table 2. Typical values of gas concentrations in the database of the WG and IEC 60599 [12]

Database of WG47 Typical values in ppm	Number of DGA results	H_2	CH_4	C_2H_2	C_2H_4	C_2H_6	CO	CO_2
All results	337,805	118	85	111	56	5	700	6300
Only last results	85,059	21	55	54	48	2	730	6660
IEC 60599 (No OLTC)	N/A	50-150	30-130	60-280	20-90	2-20	400-600	3800-14,000

The laboratory DGA tests are usually the preferred choice compared to an online DGA device since its efficiency and capabilities, in most cases, are superior to the best available DGA online monitor

From this, Table 3 shows it is evident that the same gas may be sourced from different insulating materials, liquid (oil) and cellulose, and may indicate various phenomena with totally different severity. In addition to the different materials, the location of gas sources inside the transformer may also have a significant impact on the accurate diagnosis.

The readers will be able to realise and discern among those options.

CIGRÉ Technical Brochure 783 describes the effectiveness of the number of gases for the online detector device related to fault capability detection. Table 4 shows the relevant table from this brochure.

Evidently, the costs of the online monitors highly depend on the number of the gases detected, and therefore to the capability to detect the transformer internal faults. The efficiency and capabilities for offline DGA in a specialised laboratory are, in most cases, superior to the best available DGA online monitor. In many circumstances, the laboratory DGA tests are the preferred choice, not just because of their substantial low cost compared to an online DGA device. Some users unjustifiably abandon all offline DGA performed in a monitored lab after installing an online DGA device.

The comparison of performance DGA in laboratories versus online DGA is also elaborated in the last CIGRÉ brochure. Table 5 presents the developments in DGA analytical performances by those two options in the previous 20 years.

In the last two decades, most of the laboratories have switched to a much hastier DGA method, but with lower accuracy, repeatability, and dependability on much more factors. The influence of switching

Table 3. Fault severity by CIGRÉ 771 [12]

Fault :	**In paper**		**In oil**	
Type:	Main products formed	Severity	Main products formed	Severity
D2	C, C_2H_2	Very High	C_2H_2, C	Very High
D2				Moderate
T3	C, C_2H_4,		C_2H_4, C	
T2	C, CH_4	High	CH_4	Low
T1, O	C_2H_6 , CO	Moderate	C_2H_6	Very low
Corona PD	H_2	Low	H_2	
S, T<200°C Aging	CO_2, Furans, alcohols, Low DP's of paper	Very low		

Table 4. Effectiveness of measured gas in oils correlated to fault detection capability [13]

Application	Type of monitor	Gases Measured	Faults Possible to identify	Faults not Possible to identify
Fault Diagnostic	M8 (M9)	H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, CO, CO_2, O_2, (N_2)	-all 10 faults in Table 2.2 at an early stage	- none
	M6 , M(7)	H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, CO, (CO_2)		-Faults in the paper very often are not detected correctly with CO only with M6, M5 and M2
	M5	H_2, CH_4, C_2H_4, C_2H_2, CO	-the 6 basic faults only	-the 5 sub-types of faults
	M3	CH_4, C_2H_4, C_2H_2		
Fault Detection	M2	H_2, CO	-none of the 10 faults can be identified	-may not detect faults D1, D2 in their early stages, only in their late, sometimes catastrophic stages.
	M1	H_2		
	M1*	Composite reading of H_2 and others gases		

Table 5a. The accuracies of DGA methods through the methods and ages [13]

	Average accuracy of labs in % at:		**Number of inaccurate labs in % at:**	
Method	> 100 ppm	< 8 ppm	> 100 ppm	< 8 ppm
A – Partial degassing	12	18	17	0
B – Stripping	19	65	60	63
C – Headspace	28	51	75	42
IEC Spec	15	30	CH4	Low

Accuracy of laboratories using gas extractions methods: A - Partial degassing, B - Stripping, C- Headspace

Table 5b. The accuracies of DGA online monitors through the ages [13]

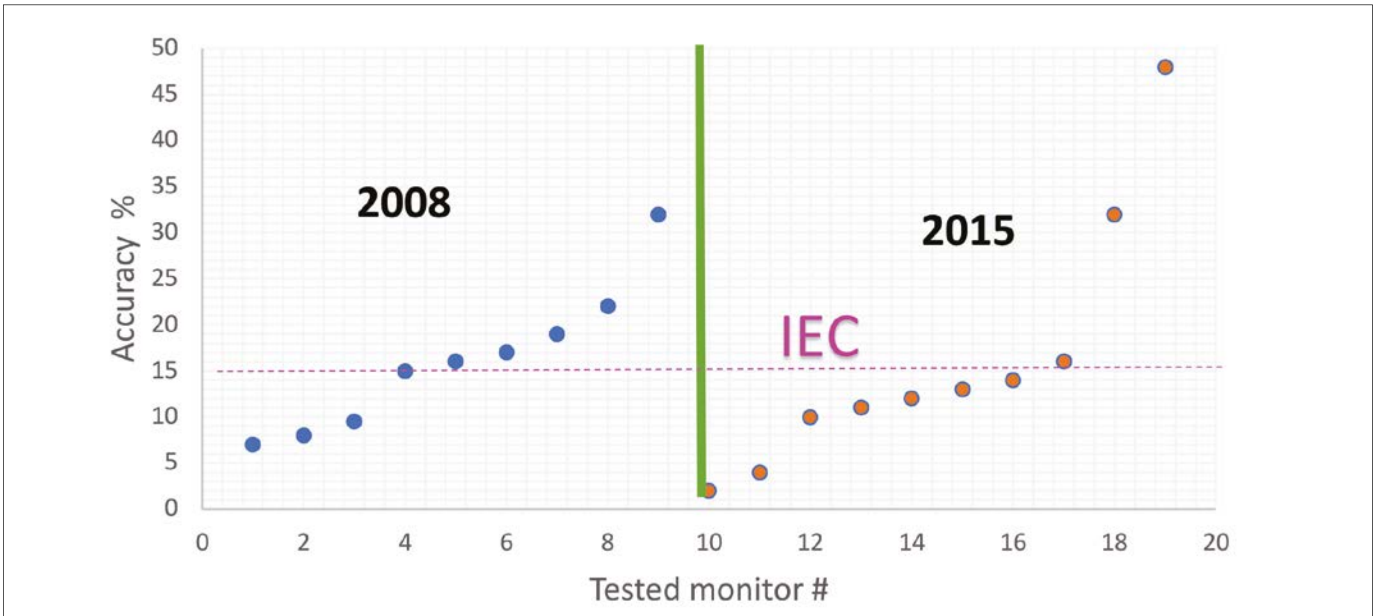

Table 6. Early DGA diagnosis method based on the gas ratio [14]

DGA diagnosis by Mueller, Schliesing, Soldner (MSS)					
Ratio range	C_2H_4/C_2H_2	H_2/CH_4	C_2H_4/C_2H_6	C_2H4/C_3H_6	CO_2/CO
< 0.3	0	0	0	0	1
0.3 to < 1.0	1	0	0	1	1
1.0 to < 3.0	1	1	1	2	1
3.0 to < 10.0	2	2	1	3	0
10 ≥	2	3	1	3	2
Diagnosis	**Number of sequences**				
Normal ageing of insulant	0	0	0	0	0
Discharge of high energy	2	1	1	2/3	1
Discharge of low energy	2	2	1	2/3	1
Partial discharge with high energy	1	3	0	n.i	0
Partial discharge with low energy	0	3	0	n.i	0
Local overheating up to 300 °C	0	0	0	1	2
Local overheating from 300 °C to 1000 °C	0	0	1	2	2
Local overheating and discharge	1	0	1	2/3	2
Local overheating and discharge partial	1	1	1	2	2
Local overheating up to 300 °C	0	3	1	2	2

There may be inconsistencies of various DGA interpretation and diagnosis methods, which is the reason why the same diagnosis methods are ranked differently by different experts in terms of success

from a vacuum-based approach to the famous headspace is shown in Table 5a by taking into consideration that method A was the popular method 20 years ago and is almost absent in 2020. If one is interested in increasing the DGA performance and reliability, one should use a more sensible and accurate way. Assuredly, the readers will understand better and be able to select the best option, concerning the budget and expected performances.

As displayed in Table 5b, the analytical performances of online devices were considerably improved due to massive investments in this market niche. The demands of such devices express the importance of power transformer continuous operation along with intense activities for critical market research done by CIGRÉ DGA Working Groups in the last decades.

Offline DGA performed in specialised laboratories remains a valuable tool in the transformer maintenance portfolio. The analytical performance and reliability of a DGA test in a lab remain superior versus most of the online devices.

The following paragraphs will focus on overall description of DGA.

The DGA begins from the test priorities and sets the test intervals for each transformer through the bidding process or selecting the proper locations for the tests. It is finalised by correct diagnosis and internal inspection if needed. All those stages will be elaborated through the DGA articles.

Table 7. A comparison of two studies of DGA diagnoses accuracies [19, 20]

Diagnose method	Rogers	Key gas	Duval	IEC
Successful prediction in % by Ref 19 *	23-50	45-100	50-100	23-82
Successful prediction in % by Ref 20	76.24	85.15	91.09	69.31

*Different faults possess different successful prediction values

DGA is a multidisciplinary field and to become an expert on DGA, it is required to dig deep and study all available DGA related materials, literature, and other sources of information

A variety of many diagnosis schemes is presented briefly. Table 6 shows one of the early gas ratio approaches. The pros and cons for the diagnosis techniques will be described in the following articles as well.

The consistencies of DGA also do not diagnose a consensus. Different experts or software are not evaluating equally the DGA diagnosis outputs. This means that the same diagnosis methods are ranked differently by different experts in terms of success, correctly revealing the incipient failure. Table 7 shows a comparison of two studies of DGA diagnosis accuracies. The following articles will explain the reasons for those discrepancies along with more studies of this subject. The readers will understand the basics of those differences and the adequate modality to select the proper diagnosis and even to develop their own.

How to become a DGA expert?

Probably the main reason for the discrepancy of the importance of DGA for all transformer operations and the contemporary level of uncertainty level of the DGA methodology, emerge from the knowledge divergence between oil chemists and power transformer electrical engineers.

Every reader of these materials possesses unique and valuable information on DGA and / or related aspects. Active reading will permit sharing the information, merging knowledge, and resolving the uncertainty from many different points of views. These articles will emphasise the chemical for a better balance of the light and explain it better to non-chemist readers. There is a general awareness that in 2020 the virtual media is already saturated with webinars and literature on this subject and the potential readers and attendees have to select very carefully the ones they should invest their time and expenses. This article offers some necessary information that may be a proper basis for reading further similar articles, or attending classes on this topic, and of course, getting a better understanding of any commercials offers.

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