
## ABSTRACT

The literature and most of the offline and online seminars on DGA deeply and extensively elaborate on the DGA diagnosis and some DGA separation and measurements novelties. Sampling aspects can mainly be found on short videos on YouTube, released by major companies. This trend is probably responsible for attributing an image of low-tech and low importance to sampling procedures in comparison with the sophisticated and high-tech stage of diagnosis. On the contrary, the sampling phase combined with vessel selection and packaging for transport is the most deciding step for an accurate and valuable transformer diagnosis by DGA. This column is inspired by three sessions presented at Transformers Academy, dealing with DGA sampling: when to sample, how to sample, which vessels to use for DGA sampling and some suggestions for an economical and precise sampling procedure.



## KEYWORDS:

DGA, sampling, recommendations, diagnostics

**There is an abundance of new diagnostic methods based on the DGA, but much more significant and clear advancement may be achieved by paying more attention to the sampling stage**

# Timing and modality to obtain representative and beneficial DGA sample for liquid-filled device

## 1. Introduction

For Transformers Magazine readers, the importance of DGA to transformer health and transformer owner's reputation does not have to be described or promoted. But most of the readers are attracted by new algorithms, software and methods for improving the reliability of the DGA diagnosis. There is an abundance of diagnostic methods within new and well-established companies that intend to gain more credibility for the DGA methodology by new investments and offering sophisticated diagnostics. Much more significant and clear advancement of DGA may be achieved by paying more attention to the sampling stage. This can be attained with the right decision on when to sample, from which valve and by whom. A transformer maintenance engineer needs to hire and employ only competent, experienced and well-trained staff. The same criteria as for a DGA diagnosis expert needs to be observed when hiring the sampling personnel. The DGA value is the same as the sampling quality. Thus, no sophisticated measurements or diagnosis may overcome a poor sampling procedure.

Firstly, it is necessary to stabilize the DGA sampling timing and frequency. For some transformer types, it is important to establish a maximum of 5 years between two samplings, and for others, a frequency for a routine DGA of three months will be the maximum frequency. The frequency test is also relevant for an online device with

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the real implication on a diagnostic assessment.

Is the trend magnitude obtained by an online and offline DGA device comparable? The quick answer is yes, but the correct one is, of course, no, and the reasons for this will be described below.

After deciding on the best time for sampling as a compromise between the transformer loading regime, transformer owners, sampling team availability, and external parameters such as weather, holidays, budget etc., are needed to determine the laboratory identity. The laboratory must be selected according to its capabilities, performance, methods and standards, and above all, the prices. It is a well-known fact that in our epoch, the final decision is made by finance departments. Here, the discussion is focused on is it better to be faithful to our previous testing lab or is it possible to switch to a suitable one and / or the one with the best capabilities. The transformer owner must make sure to take into consideration all the factors, such as distance, service provider's experience, vessel transportation and a couple of others.

The next stage will be the sampling itself, and here it is necessary to have the most skilled and experienced team for the specific transformer type and the specific sampling vessel.

The last important phase of sampling is proper oil filling and proper packaging, adequate to the size of the vessel, materials, and the modes of transport.

## 2. Routine DGA test frequencies for specific transformers

Power transformers should be tested according to their importance on the grid and maintenance policy of the operators or shareholders. On the one hand, it is always recommended to perform as many tests as affordable, but on the other hand, too many tests may prove non-beneficial, confusing, and sometimes even harmful for the transformer or entire organization, even if your organization may afford to multiply the number of oil and DGA tests, it is always better to consider if there is a real benefit from the increase offline tests frequency.

Consider NOT to perform regular periodical oil tests for a small oil-filled transformer and other electrical equipment filled with any oil type. The first test within the warranty period is generally enough, and after that, it needs to be performed only in special cases or once in 5 to 10 years.

If there is a need for a test, the manufacturer's recommendation should be first taken into consideration.

Having a multi-gas online device theoretically allows for doubling the DGA test frequency or increasing the time interval between offline tests, but it does not eliminate the necessity of performing an offline DGA test. It is now a well established practical practice that the online device substantially increases the frequency of offline tests, which is clearly contradictory to the transformer owner's expectation. This occurs equally with cheap and expensive online monitors, mainly because the user needs to confirm much smaller notices or even warnings. It is a well-

Table 1. DGA test frequencies for specific transformers - after considering the manufacturer's recommendations

| Class | Description | Years |
|---|---|---|
| A | Power transformer connected to > 180 kV, or > 250 MVA furnace transformers<br>Nuclear power station<br>Very important and critical assets for the owner | 1/4–1/2 |
| B | Step-up and autotransformers<br>Industrially important power transformers<br>All transformers filled with non-mineral oils (with a conservator) | 1 |
| C | All other power transformers 10 – 250 MVA | 1-2 |
| D | Power transformers with a conservator and less than 10 MVA | 5 |
| E | Instrument transformers and oil-filled equipment without a conservator for oil expansion (provided oil may be refilled after sampling) | First year and then 8-15 |
| F | Tap-changer tanks for all voltages | 6 |

Figure 1. Sun or cosmic radiation may induce a high amount of gases in static oils

known fact that after spending time and budget on those devices, it is impossible to ignore their alarms.

Contrary to online DGA devices, portable devices may decrease the dependence on DGA laboratory tests. In some cases, they may even eliminate them from routine tests. Reasons and conditions for these will be discussed in further columns.

Table 1 describes a recommended routine sampling interval for similar transformer groups as described by IEC60422. Also, for this table and generally, it is important to emphasize that the transformer manufacturer's recommendation always has priority over other sampling recommendations. Most transformer manufacturers do not provide such recommendations separately from published guides and standards. The main reason for this is that transformer owners set the sampling interval mainly by the transformer's importance in the fleet, and this cannot be predicted by the transformer manufacturer.

Besides the routine tests in most fleets and transformers, approximately one-third of the sampling and tests are non-routine samplings for DGA. In transformers that are highly monitored and indispensable for the grid or industry, the non-routine test may comprise even 50 % of the DGA tests. As stated before, experience has shown that online monitored units usually have an increased frequency of the DGA tests. If it is purely an issue of technical, psychological or typical industrial behaviour, it is for the reader to decide.

**You may be surprised by the presence of gases in a freshly degassed oil, but this may happen due to improper oil treatment or compatibility issues, improper oil or storage**

## 2.1 Sampling DGA for special circumstances

Special circumstances may be one of the following cases:

### A new transformer

- after filling, before energizing
- 24 hours after energizing
- half a month after energizing
- one month before warranty expiration

Immediately (24-48 hours) after the final oil filling, it is recommended to test the oil included DGA for obtaining a baseline. You may be surprised by the presence of gases in a freshly degassed oil, but this may happen due to improper oil treatment or compatibility issues, improper oil or storage.

DGA tests after one and after three months are important, too, because the fault probability of a newly made transformer is potentially high. Here, a DGA test may reveal some unpleasant situations. This is a much more important test for a transformer that was not tested at the factory with a heat run test, including DGA.

Half-year tests became important in our days mainly because of the stray gas phenomena. In addition to the new diagnos-

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tic methods for stray gas, such as Pentagon 2 by Dr Duval, sample timing may assist in distinguishing between a real fault and stray gas. Gases produced by this phenomenon will not appear significantly in the first month from energizing and certainly will not start increasing one year after energizing. These time-related phenomena will be further discussed in the next columns.

Testing before the warranty expiration allows the transformer owner to observe any abnormal incident. This timing may be one of the most beneficial ones in an unpleasant case of any abnormal gas appearing. The users may then ask the transformer manufacturer for an explanation and, in case of a malfunction, to open and repair it.

For all those tests in the early stage of a transformer's life, it is crucial to perform sampling and testing by a proven, sensitively calibrated DGA system. The best quality oil sample is important, usually by syringes meticulously sampled. Free bubbles samples here is a must.

**Power stations transformers (applicable for all transformers)**

- One month before scheduled periodical maintenance time.
- One month after the power transformers were energized again, valid for all transformer categories.

In the normal operation of a power transformer, it is recommended to sample the oil, especially for DGA, one month before a long term de-energizing. This may allow for the detection of any abnormal phenomena within a convenient period for opening the transformer without overly affecting the energy supplied or received.

One month after re-energizing, it is also recommended to test DGA and other oil tests as well. A new equilibrium of gases, water, and all other oil properties is obtained at these stages, mainly with the oil absorbed in the solid insulation. Immediately after energizing, the DGA may reflect the quality of oil treatment, especially if any topping-up was needed. DGA and other oil tests may reveal mixture issues.

### 2.2 Abnormal DGA results - repeat the test

When a test exceeds typical values compared to the previous test values, it is very important to perform further tests, preferably by more experienced sampling technicians, and possibly to send samples to another laboratory or use another measurement device. Sample two sets of vessels at the same time and send one to the current provider and the second one to another test provider. Measurement uncertainties should be lower than the changes in the test values. It is also recommended to obtain a valuable oil sample from two valves on the main oil tank. By this procedure, an internal failure condition may be revealed along with the approximate location inside the transformer.

Online devices are also susceptible to uncertainties due to sampling procedure, and in some cases, their errors may be even higher than for offline DGA. In case of abnormal DGA measurements, it is important to take at least two DGA samples: one from the online device sampling valve and the second from the nearest main tank valves. Those two DGA samples may reveal in these cases any online DGA inaccuracy in addition to a probability of the transformer failure.

Because most of the online DGA devices have a predefined value for gas alarms, which have been defined as default by the device manufacturer or transformer manufacturer, in most cases, these set values are incorrect but oblige the transformer's owner to verify the correctness of the values. Unfortunately, this situation must be considered even when important gases such as acetylene display a significant increase. The reasons and causes will be explained in future sessions and columns.

### 2.3 Sampling DGA as a consequence of abnormal external events

Grid, transmission, and step-up transformers are sensitive to external meteorological seismic and cosmic disturbances. Those are the common external events that necessitate additional DGA sampling:

- After intense loading peak periods: short terms of very high loading, or medium loading during prolonged periods. For a region with summer electricity peaks, it is usual to have additional tests after the summer ending and winter peak regions accordingly. It recommended to sample the oil close to the excessive loading time.
- External events such as thunderbolts storms or extra-terrestrial geomagnetic storms: thunderbolts have a specific gas characteristic that can be easily recognized and related to these phenomena that have become quite common in our days due to global warming. Also, geomagnetic disturbance from extra-terrestrial geomagnetic storms may have a huge impact on the transformer operation, and first, they may produce a huge gas amount. The appearance of such phenomena is usually announced by space agencies such as NASA, as may be seen in (R. Jerry and G. Gope, 2018).
- Failures of interconnected electrical components of the grid, especially another transformer.
- Adjacent electrical grid malfunction or failure or short circuit may impose a necessity of performing a DGA in order to test for any unpleasant impact or even a gas increase inside the transformer.

**When a test exceeds typical values compared to the previous test values, it is very important to perform further tests, preferably by more experienced sampling technicians, analyzed in another laboratory with different equipment**

- Besides those cases, the transformer owner may consider any additional event as a good opportunity to perform additional tests.
- If those gases are related to the external event, they may detect dangerous phenomena inside the transformer and also prevent further alarms if the origin of the gases is unknown.

**The cost of inadequate diagnosis may be orders of magnitude higher than unnecessary sampling, and it is justified to conduct a new sampling if a DGA expert consider that a gas concentration exceeds a predefined limit**

Figure 2. Special external events that may influence DGA of transformers: (a) lighting, (b) geomagnetic storms

**It should be noted that the DGA is a statistical method, so a 100 % success rate in failure prediction cannot be achieved all the time**

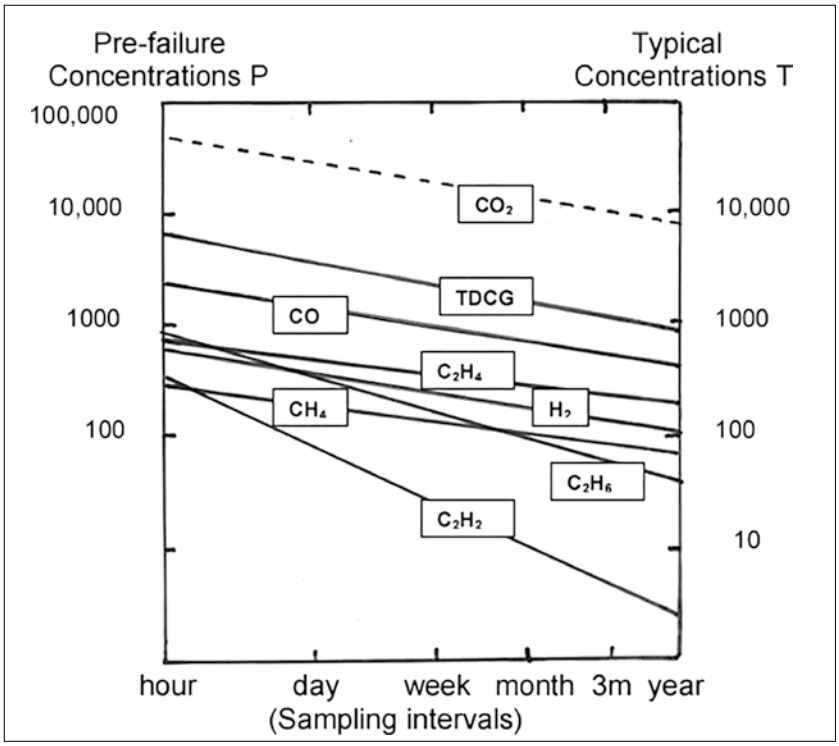


Figure 3. Determination of sampling intervals as a function of gas concentration in service for an average US power transformer (Duval 2008)

### 2.4 Testing intervals for certified abnormal transformer state

This is the most common reason for having a DGA before the next scheduled time. The rationale for it is increased and abnormal gas values and trend.

If a DGA expert, human or dedicated software consider that a gas concentration exceeds a predefined limit, they or it may request a new sampling. The cost of inadequate diagnosis is justified by unnecessary sampling. This is, of course, more convenient than an unnecessary inspection or oil treatment.

Dr Michel Duval has presented (Duval, 2008) this simple graph in Fig. 3 in a very simple and informative way, with most of the gases measured by a typical DGA test procedure. The X-axis is on the logarithm scale and represents the way one finds the right sampling interval according to the fault severity translated, in this case, into gas concentration magnitudes.

In later studies, also done by Dr Duval for CIGRE Brochure 771, based on huge DGA database results, and in collaboration with many worldwide experts, other parameters were elaborated. The first and probably most crucial for a transformer

**Table G.2—Actions based on TCG and TCG rate**

| | TCG levels (%) | TCG rate (%/day) | Sampling intervals and operating procedures for gas generation rates | |
|---|---|---|---|---|
| | | | Sampling interval | Operating procedures |
| Condition 4 | ≥5 | >.03 | Daily | Consider removal from service. |
| | | .01-.03 | Daily | Advise manufacturer |
| | | <.01 | Weekly | Exercise extreme caution.<br>Analyze for individual gases.<br>Plan outage.<br>Advise Manufacturer |
| Condition 3 | <5 to ≥2 | >.03 | Weekly | Exercise extreme caution. |
| | >-2 to <5 | .01–.03 | Weekly | Analyze for individual gases. |
| | | <.01 | Monthly | Plan outage.<br>Advise manufacturer. |
| Condition 2 | <2 to ≥.5 | >.03 | Monthly | Exercise caution. |
| | >-0.5 to <2 | .03–.01 | Monthly | Analyze for individual gases. |
| | | <.01 | Quarterly | Determine load dependence. |
| Condition 1 | <0.5 | >.03 | Monthly | Exercise caution.<br>Analyze for individual gases.<br>Determine load dependence. |
| | | .01–.03 | Quarterly | Continue normal operation. |
| | | <.01 | Annual | |

Figure 4. Sampling intervals and operating procedures TDCG for gas generation rates are NOT to be used (IEEE Std C57.104-2008)

operation is a slope value of the trend for a specific gas. Not all gases display the same fault severity, so the trend, the gas name and absolute concentration should be taken into consideration in the differential method.

The previous version of the IEEE standard describes that the testing frequency depends on two factors, the absolute value of total combustion gases and the rate of increase. The rate is the function of both elements. This approach takes into consideration only the total combustion gases, the arithmetic sum of some combustion gases.

It is important here to understand that the total combustion gas according to this standard is not a value currently calculated by all software. In the historical view, the TCG represents ALL the combustion gases present in a specific oil. This value is more related to the flashpoint value than to the arithmetic values of some gases measured by DGA. And of course, the chemical energy stored in their molecules and combustion potential of all those gases is very different and therefore their impact on the transformer conditions.

This table is not applicable anymore, and TCG should not be used for any purpose, especially not for establishing sampling frequencies. More on important, differences between the two standards, IEEE Std C57.104, version 2008 and 2019, will be discussed in future sessions and columns.

Instead of the cancelled table from IEEE Std C57.104-2008, I have used for many years a similar approach based on a singular gas, its absolute value, comparing it with adapted reference values for a specific transformer, fleet, and with its severity interpretation. Table 2 shows such consideration for acetylene. For example, if the acetylene appears for the first time or continuously increases by 20 % PPM per month, and its concentration is 5 PPM, the next sampling is recommended within the next four months, and if the value is stable within the next eight months. The logic is that once it appears and is correct measured, the only importance is that it does not increase from the previous sampling until the next one because some special condition for a gas generation has not been met. It does not mean at all that the failure condition would repair itself without any intervention. It is probable that in the very near future the state of the transformer will be aggravated very suddenly. Of course, for an active failure condition, the probability of worsening is even higher. DGA is only a statistical method, so please do not expect at any time to achieve 100 % success in failure prediction.

Fig. 5 presents a case of successful intensive DGA monitoring in the first year of operation. Sensitive DGA sampling and measurements permit distinct a low gas concentration unacceptable for the specific transformer at this specific life period. The transformer owner saves a high budget for future repairing and even failure.

It is very important to test any new transformer at least three times within the warranty period. The first test should be performed manually in a sensitive and specialized DGA offline laboratory with a similar methodology to those implied by DGA after heat run tests. As the absolute concentration increases and the value of the trend increases, the sampling frequency should be at least increasing. Other measuring modalities will be described

Table 2. Proposed sampling interval based on concentration and trend for acetylene. The considerable rate is 20 % PPM per month or greater. The frequency is the maximum frequency recommendation.

| Acetylene absolute value in PPM | TEST frequency [month] First appearance or continuously increase (> 20 % PPM / month) | Test frequency [month] at a stable increase rate (< 20 % PPM / month) |
|---|---|---|
| 1 | 1 | 6 |
| 5 | 8 | 4 |
| 10 | 6 | 3 |
| 15 | 4 | 2 |
| 20 | 2 | 1 |
| 30 | Weekly | Daily |
| 50 | Daily to weekly | Hourly or out of service for the second increase |

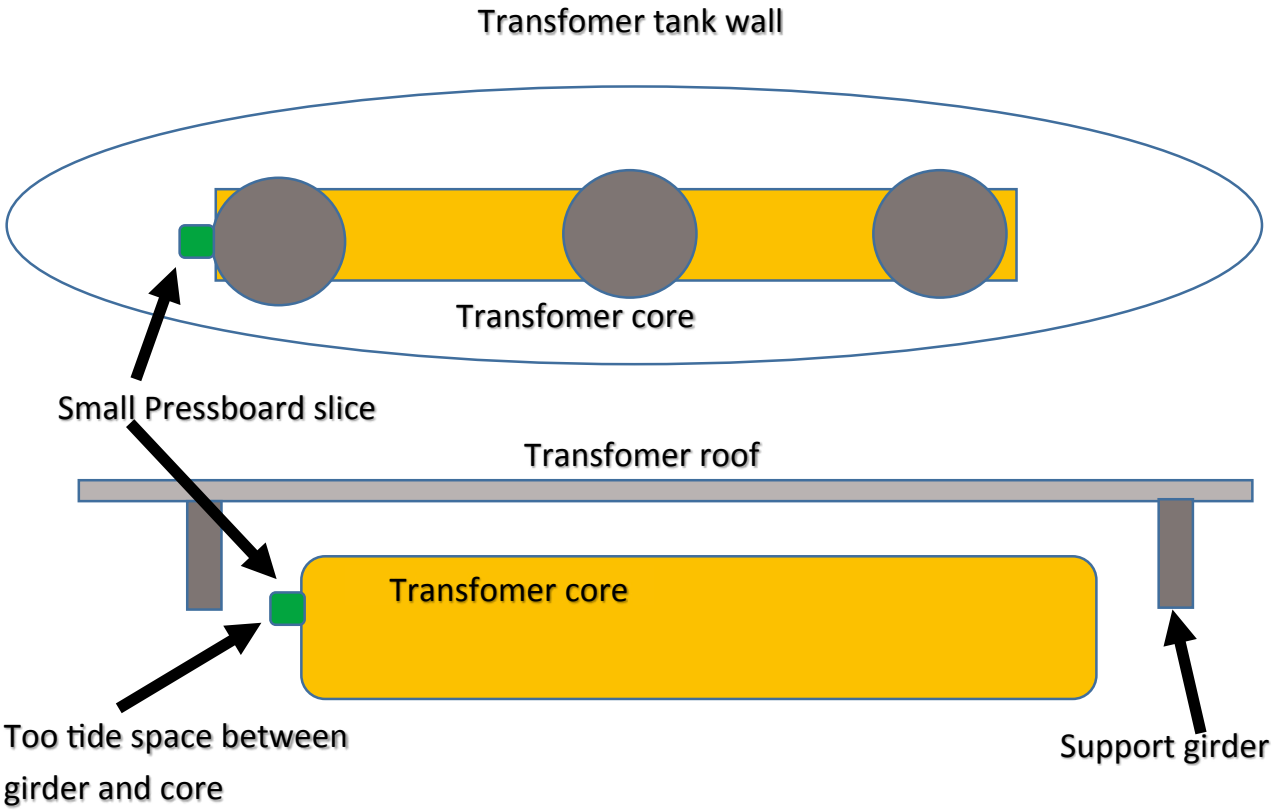


Figure 5(a)

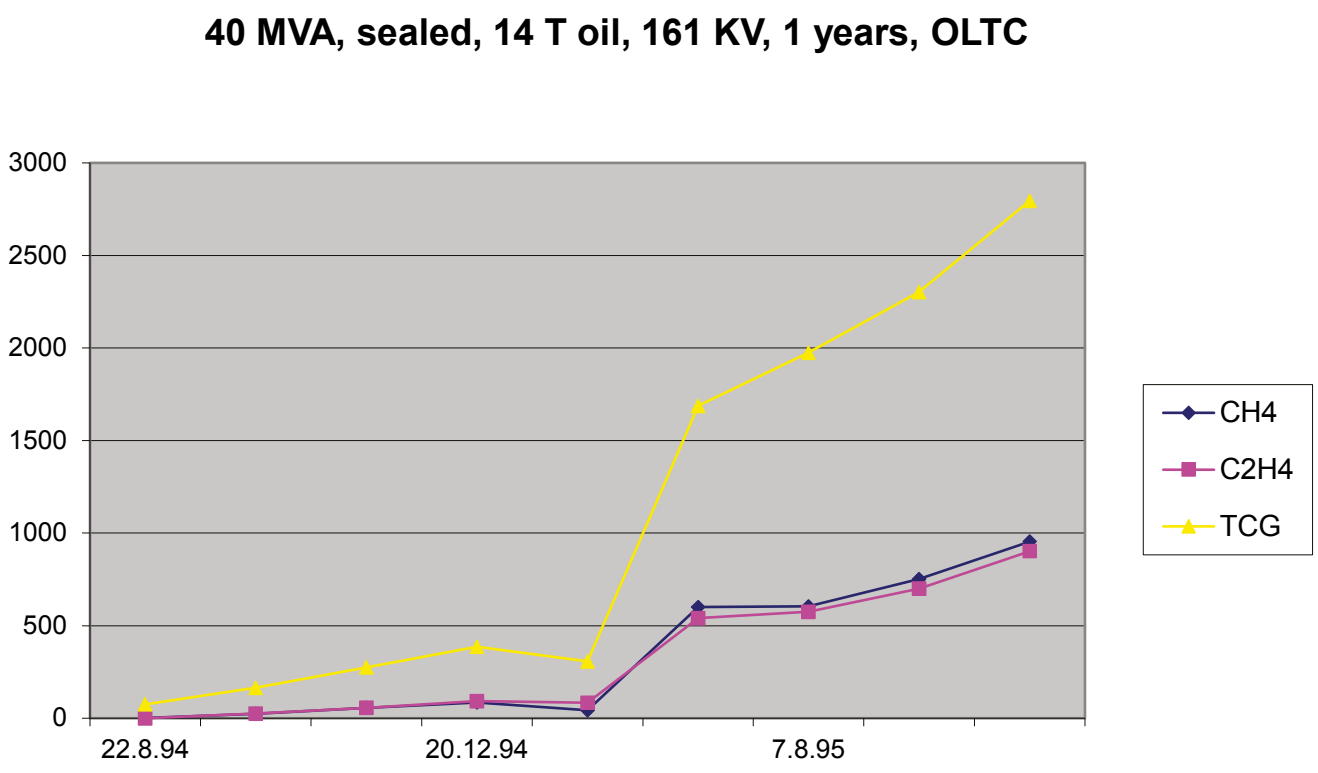


Figure 5(b)

Figure 5. Transformer design problem detected in the first year of operation within the warranty period: (a) the finding after inspections, (b) DGA values and trends graph.

in the next sessions. In other words, the value of the first derivation of the PPM curve versus time directly correlates with the sampling frequency. The steep magnitude of the trend slope graph is directly proportional to the probability of failure, and therefore it is recommended to increase the DGA frequency. This approach is similar to that in the previous versions of IEEE C57.104.

In the next column, the following subjects will elaborate on issues related to sampling:

- Sampling vessels, syringes versus all others.
- Sampling valves: where to open, how to open and close them, how much oil to take.
- Synchronizing a sample vessel with the transformer, laboratories and sample team specifications and capabilities.
- Important safety issues relating to the sampling procedure. The personnel and transformer safety.
- Selecting the best test supplier for DGA tests, loyalty versus profitability.
- Advanced methodologies for reliable and economic sampling.
- Online DGA sampling issues and optimization.
- Special sampling topics, such as sampling from the Buchholz relay.

Of course, all those subjects and much more are already available within the Transformers Academy DGA course. To register please sign up via this link: https://transformers-magazine.com/course/dga-course/.

**It is very important to test any new transformer at least three times within the warranty period, and the first test should be performed manually in a sensitive and specialized DGA offline laboratory**

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[3] *Advances in DGA interpretation*, CIGRÉ Technical Brochure 771, JWG D1/A2.47, 2019

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## Author


**Marius Grisaru** has an MSc in Electro-Analytical Chemistry from the Israel Institute of Technology. He has almost 30 years of intense experience in almost all transformer oil test chains, from planning, sampling and diagnosis to recommendations and treatments, mainly in Israel but also in other parts of the world. He is responsible for establishing test strategies and procedures and creating acceptance criteria for insulating liquids and materials based on current standardization and field experience. In addition, he trains and educates electrical staff on insulating matrix issues from a chemical point of view. He is an active member of relevant Working Groups of IEC, CIGRE, and a former member of ASTM. He is also the author and co-author of many papers, CIGRE brochures, and presentations at prestigious international conferences on insulation oil tests, focusing on DGA, analytical chemistry of insulating oil, and advantageous maintenance policy for oil and new transformers.


### Correction to "Basic principles of DGA - Part II" by Marius Grisaru

The article published in the Transformers Magazine, Issue 8-1, January 2021, contains an error in Table 2, where columns $C_2H_6$ and $C_2H_2$ were switched. The table should read:

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 | $H_2$ | $CH_4$ | $C_2H_6$ | $C_2H_4$ | $C_2H_2$ | 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 |