IMPROVEMENT OF DGA INTERPRETATION METHOD FOR POWER TRANSFORMERS IN LATVIA

GHA DATU INTERPRETĀCIJAS METODES PILNVEIDOŠANA LIELJAUDAS TRANSFORMATORIEM LATVIJĀ

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Introduction

Detection of the faults in their early stage provides high coefficient of readiness of electrical equipment, including power transformers, as it makes possible to perform necessary precautionary measures in time. Variety of different diagnostic methods and assessment criteria can be applied in practice, however dissolved in oil key gas (hydrogen H_2, methane CH_4, ethane C_2H_6, ethylene C_2H_4, acetylene C_2H_2, carbon monoxide CO, carbon dioxide CO_2) analysis (DGA) is rated as the most important and the most informative method for transformer's technical condition assessment [1, 2, 3]. DGA gives large and reliable information on unit's technical condition, on type of possible defect and it's progressing rapidity, furthermore it is provided and suitable for technical condition assessment of loaded transformer. DGA method's accuracy is high; it is possible to ensure reiterative measurements, unsophisticated data processing and summarizing in databases makes DGA method appropriate for the use in expert systems.

Since not sufficiently performed interpretation of the DGA results can lead to unit's failure and significant economical losses, the analysis and interpretation of the DGA results should be performed accurately and precisely. DGA data interpretation methods can be divided into 3 groups:

- Methods based on key gas concentration limits, that mainly prescribe comparison of current DGA data sample with definite gas concentration limits, thus gaining initial unit's technical condition assessment, mostly the information about the existence of the defect;
- Key gas ratio methods, that prescribe analysis of various key gas ratios (such as CH_4/H_2, C_2H_2/C_2H_4, CO_2/CO, C_2H_2/H_2 etc.) to determine the type and progressing rapidity of the possible defect in power transformer;
- Artificial intelligence methods (expert systems, fuzzy logic, artificial neural networks), that prescribes automatic DGA data processing, consideration of unit's specific features, maintenance history, working conditions and other information, thus increasing accuracy of unit's technical condition assessment.

Influence of transformer's maintenance and other factors on the interpretation of DGA results

There are numerous different DGA interpretation methods. Dornenburg interpretation method, Rogers Ratio method, Duval Triangle method, key gas ratio method in the standard IEC 60599, Total dissolved combustible gas TDCG method (standard IEEE C57-104), and logarithmic nomograph method is rated as most commonly used. Unfortunately not a single one-interpretation

method can be used for all-purpose application [4]. Expected lifetime and possible defects of power transformers varies widely depending on the manufacturer's design, quality of assembly, materials used, operating history, current operating conditions and current unit's age, maintenance history, and other factors. Thus the interpretation of the DGA results is complex and complicated operation, and still information about amounts of key gasses dissolved in oil can't come up with full account on transformer' technical condition.
There are 4 basic variations of DGA data interpretation, as shown in Table 1.

Table 1.

Basic condition of DGA data interpretation

Condition	Key gas concentration limits exceeded	Presence of defect in unit
S_1	No	No
S_2	Yes	No
S_3	No	Yes
S_4	Yes	Yes

All these conditions can be observed in practice, though condition S_3, when key gas concentration limits based on standards or other diagnostic methods are not exceeded but at the same time there is a defect in the unit, is the most undesirable condition. Primary cause of the condition S_3 is long-drawn, low compared to rated, load of a particular power transformer [5].
Relatively low loading is one of the main specific features of power transformer's maintenance in Latvia since in the time period from 1991 to 1993 there were rapid decrease of electrical energy consumption, and today at an average the loading of transmission network and substations reach 60 %. In accordance with above mentioned higher possibility of defect in a unit even if key gas concentration values don't exceed definite levels, additional caution should be applied at interpretation process of DGA data from power transformers whose loading are low [6].
As very important aspect that can influence the results of DGA data interpretation is the fact that approximately one third of power transformers in Latvia have operated above their rated working life. As one of the possible versions how to consider current age of power transformers during interpretation of the DGA results is to estimate and to apply coefficients for separate groups of power transformers with varied age, as, for example, less than 25 years, 25-30 years, 30-45 years, and more than 45 years. Thus dissimilar technical condition assessments and different types of possible defects can be determined for power transformers with identical DGA data sample but with different current age.
Commonly for the interpretation of DGA results various measures can be used such as:

- Key gas concentration limits prescribed in standards like IEC 60599 and IEEE C57-104;
- Interpretation methodologies worked out by concerns;
- DGA data from factory tests for new equipment;
- Acceptable key gas amplitudes from previous measuring for particular operating unit;
- Typical gas concentration limits etc. [3].

Condition numbers for dissolved gases given in international standards are tentative and relatively conservative. There are numerous researches such as [7, 8, 9] that show necessity of modifying and differentiate gas concentration levels. Mostly it is recommended to increase these limits, since liberalization of energy market and elevated competitive conditions require a conversion from previously scheduled repair system to a more operative repair system based on units' technical condition prognosticating also unit's work with acceptable risk level. The necessity of limits differentiation in accordance with transformer's construction is based on the aspect that specific

features of particular unit such as age, working conditions in power system, loading etc. haven't been considered in the international standards.
Since the year 1999 specialists from joint stock Company "Augstsprieguma tīkls" perform dissolved gas analysis of oil samples with periodicity twice a year. Thereby DGA sampling database unfortunately isn't large. DGA data interpretation methods worked out by different enterprises generally are based on particular transformers' testing and maintenance history of several decades, therefore some difficulties can occur identically adapting these methods in our power system. Another important aspect is that there is a lack of factory DGA testing data for unit's installed before 1999, which successfully is used as initial point of reference. Thereby the improved DGA interpretation method which analyses the average key gas (H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, CO, CO_2) concentration limits of similar units (with the same design, construction, installed capacity, age, operating in similar environment) and take into consideration above mentioned main specific features of power transformer's maintenance could be perspective in use in Latvia.

Calculation method of average key gas limits

The probability of having a defect in power transformer is related to gas concentration levels. Below certain concentration levels, the probability of having a failure is lower, thus significant primary assessment information can be obtained by calculating individual key gas concentration limits as diagnostic criterion. The probability of having a failure may increase at values much above these limits, and for even though it may never occur; the risk of having one is high. Accordingly for the purpose of monitoring transformer technical condition preferable to mark out units with probable defects, that requires more often DGA sampling. The less are these gas concentration limits the larger amount of power transformers will be marked out for intensified control, and vice versa.
The probability of the appearance frequency of all seven key (H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, CO, CO_2) gases has to be calculated. If the selection size $n \leq 100$, the size of interval c can be determined by formula (1)

$$c = \frac{A_{i\max} - A_{i\min}}{1 + 3{,}32 \cdot \lg n}, \quad (1)$$

where A_{imax} – maximum value of a particular key gas;
A_{imin} – minimum value of a particular key gas.
But if n>100, then size of interval c can be found by formula (2)

$$c = \frac{A_{i\max} - A_{i\min}}{5 \cdot \lg n}. \quad (2)$$

The probability P_n, which characterizes the appearance frequency of particular gas concentration, can be found by formula (3)

$$P_{ni} = \frac{p_i}{T}, \quad (3)$$

T – total amount of transformers;
$p_i = {n_i}/{n}$, n_i – appearance frequency of particular gas concentration;
n – selection size.
Individual key gas concentration limits are calculated as integral function (4).

$$F_{ni} = \sum_{i=1}^{k} P_{ni}, \quad (4)$$

where k ≤ n.

Case study

To increase the accuracy of diagnostic criterion based on dissolved in transformer's oil key gas average limits units are divided into several groups in accordance with:

- Transformer's age since isolation parameters changes in the course of time and thus indications of the DGA measurements may differ;
- Transformer's construction (similar rated voltage, capacity, working conditions including the loading);

For the purpose of this research 230 110 kV power transformers in Latvian transmission network were subdivided into following 5 age groups:

- 1st group – units whose working life is 0-9 years;
- 2nd group – units whose working life is 10-19 years;
- 3rd group – units whose working life is 20-25 years;
- 4th group – units whose working life is 26-30 years;
- 5th group – units whose working life is over 30 years.

Such classification was chosen since it gives possibility to analyze the DGA data separately for new transformers (1st and 2nd group), for units' whose rated working life draws to an end that in accordance with [10] is 25 years (3rd group), for unit's that slightly exceed rated working life (4th group), and finally for unit's that exceed rated working life for more than 5 years (5th group).
Table 2 shows calculated the most probable average key gas concentration limits for 110 kV power transformers in transmission network in Latvia

Table 2.

The most probable average key gas concentration limits

Key gas	***Average key gas concentration limits, ppm***				
	0 – 9 years	**10 – 19 years**	**20 – 25 years**	**26 – 30 years**	**> 30 years**
Hydrogen (H_2)	14	5	8	13	28
Methane (CH_4)	5	2	5	7	7
Ethane (C_2H_6)	2	1	4	4	5
Ethylene (C_2H_4)	15	6	36	56	56
Acetylene (C_2H_2)	9	4	14	32	9
Carbon monoxide (CO)	350	136	220	373	398
Carbon dioxide (CO_2)	2476	942	1473	1851	2476
	99 data samples	*184 data samples*	*541 data samples*	*618 data samples*	*886 data samples*

Conclusions

1. Study of scientific research papers shows that variety and dissimilarity of different DGA data interpretation methods can be applied in practice, unfortunately not a single one-interpretation method can be used for all-purpose application.

2. There is higher probability of having the most undesirable condition, when key gas concentration limits based on standards or other diagnostic methods are not exceeded but at the same time there is a defect in the unit.
3. The improved DGA interpretation method which analyses the average key gas concentration limits of similar units and take into consideration unit's age and above-mentioned main specific features of power transformer's maintenance could be perspective in use in Latvia.
4. Calculated the most probable concentration limits are useful diagnostic criterion since for the purpose of monitoring transformer technical condition it is preferable to mark out units with probable defects. If the measuring results show significant, rapid and steady (observed in several measurements) increase of key gases in comparison with determined values additional supervision would be desirable.

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Vītoliņa S., Dirba J. GHA datu interpretācijas metodes pilnveidošana lieljaudas transformatoriem Latvijā.
Rakstā analizēta eļļā izšķīdušo defektu gāzu hromatogrāfijas (GHA) piemērotība slogotu lieljaudas transformatoru tehniskā stāvokļa kontrolei, ņemot vērā agregāta ekspluatācijas īpatnības. Analizēta Latvijas transformatoru ekspluatācijas apstākļu un īpatnību, no kurām svarīgākais ir liels novecojušu agregātu īpatsvars, relatīvi zemā pārvades elektrotīkla noslodze, kā arī vēsturisko GHA datu iztrūkums, ietekme uz GHA rezultātu interpretēšanu.
Balstoties uz šo ekspluatācijas īpatnību analīzi, rakstā secināts, ka perspektīvā Latvijā varētu tikt izmantota uz līdzīgu agregātu (vienādas konstrukcijas, jaudas, vecuma agregātu, kuri darbojas aptuveni tādos pašos ekspluatācijas apstākļos) galveno defektu gāzu (H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, CO, CO_2) koncentrāciju vidējo vērtību analīzi balstīta GHA rezultātu interpretācijas metodika.
Rakstā dots aprēķinu piemērs – galveno defektu gāzu koncentrāciju vidējo vērtību aprēķins Latvijas pārvades sistēmas 110 kV lieljaudas transformatoriem.

Vitolina S., Dirba J., Improvement of DGA interpretation method for power transformers in Latvia.
The authors consider the adequacy of dissolved-in-oil gas analysis (DGA) as a diagnostic criterion for technical condition estimation of loaded power transformers. The consideration also concerns such peculiarities of the maintenance of power transformers in Latvia as the great number of outdated units with the expired term of service life, relatively low loading of transformers (which makes it difficult to estimate their technical condition), and the lack of historical DGA data. These peculiarities are given particular attention.
The improved DGA interpretation method is based on the estimation of the mean concentration values for the main defective gases (H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, CO, CO_2) at similar plants (of the same design, installed capacity, age, and ambient). The authors show that the proposed method can successfully be used in Latvia. In the paper, an example is given for calculation of the mean concentration values of the main defective gases for the 110kV power transformers.

Витолиня С., Дирба С., Усовершенствование методики интерпретации данных ХАРГ для силовых трансформаторов в Латвии.
В данной статье проанализирована пригодность хроматографического анализа растворенных в масле газов (ХАРГ) для технического контроля состояния нагруженных силовых трансформаторов с учетом особенностей эксплуатации. В статье анализированы такие основные особенности эксплуатации мощных силовых трансформаторов в Латвии, как большое число устаревших агрегатов с просроченным нормативным сроком службы, относительно небольшая загрузка трансформаторов, которая усложняет оценку его состояния и отсутствия исторических данных ХАРГ. Этим особенностям должно быть уделено особое внимание интерпретируя результаты ХАРГ.

На основании исследования эксплуатационных особенностей силовых трансформаторов, в статье сделано заключение, что в Латвии может быть использована методика интерпретации результатов ХАРГ основанная на анализе средних значений концентрации главных дефектных газов (H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, CO, CO_2) схожих агрегатов (одинаковых конструкций, мощности, возраста, работающих в подобной окружающей среде).
В статье дан пример расчета средних значений концентрации главных дефектных газов для силовых трансформаторов в сети 110 кВ Латвии.