Development of DGA indicator for estimating risk level of power transformers

Gints Poiss
Riga Technical University
Department of Electrical Machines and Devices
Riga, Latvia
gints.poiss@rtu.lv

***Abstract*—Regular evaluation and risk assessment of the technical condition of power transformers is very important. It is known that good condition state guarantee system's reliability. Various parameters of power transformer can be evaluated, and decision can be made manually or with help of mathematical model. With dissolved gas analysis (DGA) method it is possible to detect faults by using dissolved gases in transformer oil. By using DGA as one of the indicators, a new mathematical risk-assessment model for power transformers is being developed for power system in Latvia, and the new model will be based on specific features. Development of DGA indicator is presented in this paper and as a case study results of DGA of different transformers are analyzed and discussed.**

Keywords—power transformers, dissolved gas analysis, risk analysis

I. INTRODUCTION

A power transformer is an essential element in the power system of each country. Power transformer failures may lead to outage of the power system and inability to deliver electricity may cause extensive financial loses. Besides, power cuts may affect work of factories and other important customers.

Globally, every individual power system chooses their own way to reduce the risk of power transformer failure and to increase its power system reliability [1], [2], [3]. Many solutions are expensive, however, technical guides and approved standards point out the basic way for evaluating power system elements and keeping them in a good technical condition, especially power transformers.

In Latvia, the technical condition of power transformers is evaluated by experienced engineers. In the most cases the assessment of technical condition is based on evaluating individual measurements of every control parameter separately, which may result in misleading conclusions. In order to obtain general overview of the technical condition of a transformer, the full spectrum of results should be evaluated, and specific features of the particular power system should be considered.

In the early stage of the risk assessment development, an overview of power transformers in the Latvian power system was performed and specific features were found [4]. The analysis provided the following conclusions:

- 21% of power transformers are older than 40 years;
- 1/3 are reserve (backup) transformers;
- from 100 analysed transformers 32% have increased C_2H_2 gas values due to communicating on load tap changer (OLTC);
- load in urban areas – 50 % to 80 % and in rural areas 25% to 40 % of nominal power;
- difference in oil volume, for example, power transformers with similar voltage rate of 25 MVA have oil volume of either 28,300 litres or 14,700 litres.

A common global practice is to develop a risk matrix model in the last stage of transformer evaluation, where the probability of failure and the severity of potential consequences are assessed in order to visually depict the significance of potential fault [5], [6], [7].

Indicators for the risk matrix for power system in Latvia are proposed in [4] (see Table 1). Indicators have been selected based on the available diagnostic tools, and also to cover different important sections of a power transformer.

DGA is considered a reliable and wide spread method for identifying the incipient faults. However, in this paper DGA is used as a part of a risk assessment methodology, which, combined with other indicators specified in Table 1, provides data for the risk matrix.

The objective of the paper is to give insights in the DGA indicator and a method for determining the numerical value.

TABLE I. CONDITION INDICATORS AND PARAMETERS

Operation and maintenance	**Transformer oil**		**Electrical measurements**
	Oil analysis	**DGA**	
Age	Dielectric strength	H_2, CH_4	Insulation resistance
Loading	Moisture content	C_2H_4	Tgδ
Tripping per year	Acidity	C_2H_6	No-load loss
Importance in the system	Dissipation factor	C_2H_2	Winding resistance
Maintenace history	Mechanical particles	CO, CO_2	FRA and Short-circuit impedance
	Flash point		

e-ISBN 978-1-5090-0908-4

II. DEVELOPMENT OF THE DGA INDICATOR

The indicator DGA is a powerful tool that warns about impending problems and allows for an early diagnosis. There are many interpretation techniques and improved method variations based on DGA, for example, IEC Standard Code, Key-Gas method, Rogers ratio, etc. [8], [9].

The traditional IEC standard-based assessment methodology for power transformers, depicted as a flowchart [10] can be described in 5 steps.

Step 1, includes the examination of DGA results and comparison with a previous sample and typical values. Step 2 is to determine if at least one gas is above typical values or all gases are below them. If there are gases below typical values, the equipment has good technical condition; if not, in Step 3 it is necessary to identify the fault. ALERT condition is assigned when gas concentration does not exceed the fault of discharge of high energy (D2). In Step 4, when gas concentration is above alarm values of gas concentration and the rates of gases increase or change to type D2, ALARM condition requires to take an immediate action. In the last, fifth step all processed information is collected and are sent to data storage.

DGA indicator in Fig. 2 has some similarities with the IEC assessment model of typical value comparison, but it also has several specific features, such as communicating OLTC, transformer loading, oil treatment, and the Energy Standard of the Latvian Electrotechnical Commission (LEK 118) gas value upper limits (S1, S2) and condition levels. Indicator K may be in the range between 1 and 5. This value is an important part of the risk evaluation methodology and it can determine or change the position of the power transformer in the risk matrix where the overall technical condition is assessed on the scale from good to poor.

For the description of DGA indicator the flowchart in Fig. 2 also can be divided into separate parts.

The first part differs from the IEC model with seven gasses divided in G5 (H_2, CH_4, C_2H_4, C_2H_6, C_2H_2) and G2 (CO_2 and CO), sample date, transformer loading and information about oil treatment. These variables give the necessary values for input, and separation of gases more accurately determines whether the damage could have been caused by the transformer solid insulation and degradation.

The second part involves gas comparison with gas value upper limits for level S1 and S2, where indicator K=1 and K=2 can be assigned. If gas values reaches 1.25*S2, value K=5 is assigned. Values of gas limits S1 and S2 for transformers manufactured in accordance with the technical standard of IEC and GOST are shown in Table 2. The difference in oil volume is the main reason why typical gas upper limits in LEK 118 differ from values specified in the IEC Standard or IEEE guide.

In the third part, gas value comparison with G5 and G2 >0.75*S2 serves to verify which gases require further analysis. If these are gases G2, CO_2/CO ratio is checked if there is a possibility that solid insulation has begun to deteriorate. As value that indicates possible fault CO2/CO<3 is used for transformers manufactured according to the technical standard of IEC, but those compliant with the technical standard of GOST other ratio values are defined by LEK118. Gas ratios that indicates possible fault are CO_2/CO<5 and CO_2/CO>13, this is due to transformers have been long in operation and are aged.

If it is necessary to perform further analysis of gases G5, at first values of acetylene and communicating OLTC feature are checked. DGA data of one hundred power transformers out of 269 operated by the Latvian Transmission System were analyzed, and 32 transformers had elevated C_2H_2 (Fig.1). In 32 of these transformers no discharge-related faults were detected. C_2H_2 values, when compared to typical values [11] may indicate on a fault. Communicating OLTC feature may prevent misleading results in transformer assessment.

If at least one gas is above 0.75*S2 with or without increased C_2H_2, the transformer loading and oil treatment has to be taken into account. When load reaches 50% of nominal transformer power, ethylene, ethane and methane gases may increase. If load is less than 50 % and gases reach level 0.75*S2, such situations are dangerous and, when left unnoticed, may lead to transformer fault in case of increased load or when switching a transformer on.

If no oil treatment has been performed during the last 2 years and loading is up to 50%, Data Processing is used, where IEC gas ratios in Fig. 2 are arranged to assess the risk level. Therefore, fault types are labeled as R1 – partial discharge (PD), R2 – discharge of low energy (D1) and thermal fault t < 300 °C (T1) and R3 – discharges of high energy (D2) and thermal fault T>300 °C (T2 and T3).

In the last stage of the IEC assessment model data are stored for future use, whereas in the DGA indicator model, the indicator K forms a part of the methodology.

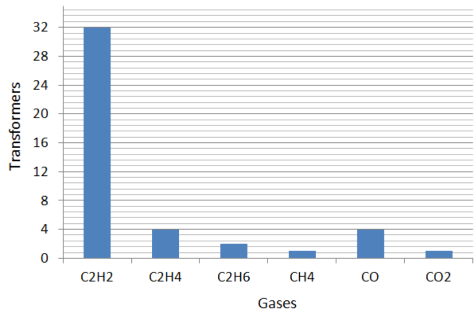

Fig. 1. Power transformers with gas value above 0.75*S2

TABLE II. LEK 118 POWER TRANSFORMER CONCENTRATION LIMITS

Upper limit	H_2, ppm	CH_4, ppm	C_2H_2, ppm	C_2H_4, ppm	C_2H_6, ppm	CO, ppm	CO_2, ppm
Manufactured according to the technical standard of GOST							
S1	60	45	1	15	30	350	1500
S2	100	100	10	100	50	500	8000
Manufactured according to the technical standard of IEC							
S1	60	45	1	15	30	250	1500
S2	100	100	10	70	50	400	3800

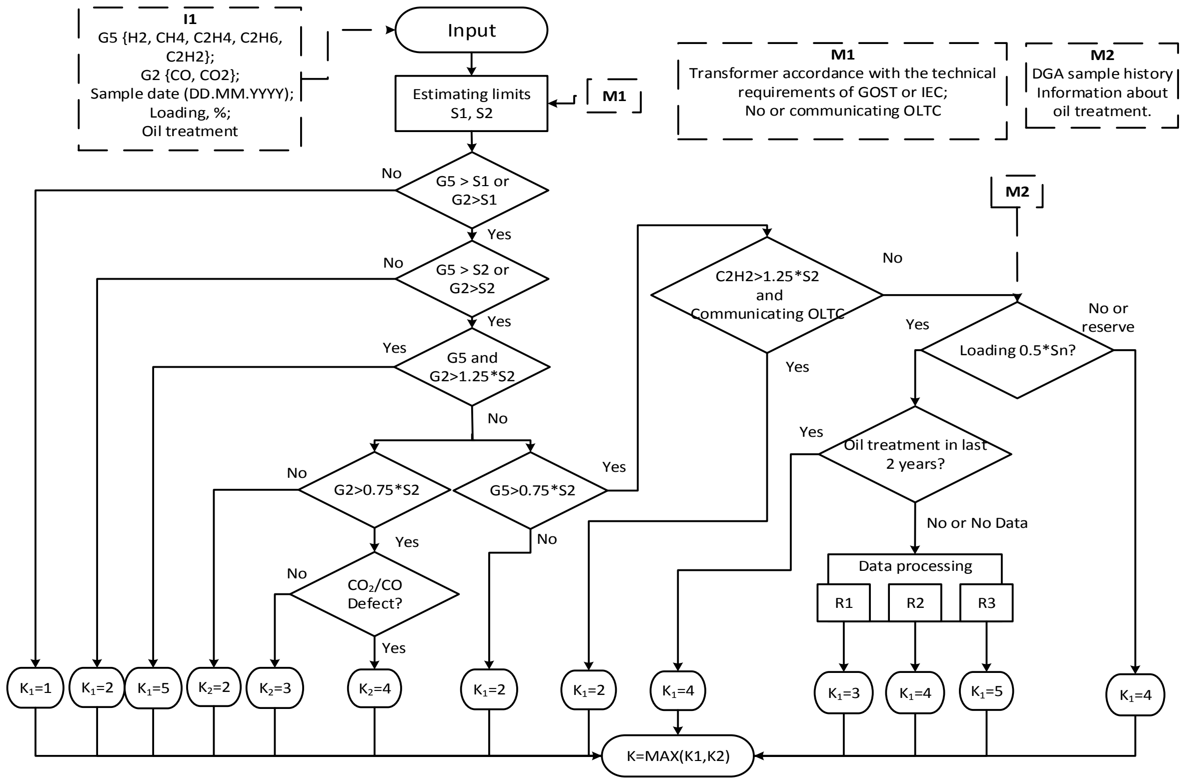

Fig. 2. Flow chart DGA indicator K

III. Results of the Case Study

The latest power transformer DGA data used to test the developed DGA indicator were kindly provided by the Latvian Transmission System Operator.

One hundred power transformers were analyzed, and 7 power transformers were specially selected for the case study. The case study uses the IEC assessment model's typical concentration upper limit values and proposed DGA indicator. In the end, the comparison of these two models are discussed.

TABLE III. Case Study Transformer Description

Case	*Type*	*Voltage / Rated power*	*Manufacture standard*	*Communicating OLTC*
1	TDTN	110 kV / 25 MVA	GOST	YES
2	TDTN	110 kV/ 16MVA	GOST	YES
3	TDTN	110 kV/ 10MVA	GOST	YES
4	ADTCDN	330,110 kV/ 125MVA	GOST	YES
5	TONRL3a	110 kV/ 40MVA	IEC	YES
6	TRP	110 kV/ 32MVA	IEC	YES
7	TDTN	110 kV/ 10 MVA	GOST	YES

Transformers used in the case study, except for cases 6 and 7, have attracted-engineers' attention. Data obtained from the Latvian Transmission System Operator revealed that case 1,TDTN 25000/110 and case 2 TDTN 16000/110 power transformers were removed from operation after a gas analysis and electrical measurements. Case 3 is with increased C_2H_2 gas value, which is normal for communicating OLTC. In Case 4 a degradation of solid insulation degradation was suspected.

Occasionally, factory defects in a new transformer may lead to increased gas values after some time, as in Case 5 – to increased hydrogen level.

In Cases 6 and 7, gas concentration in oil is negligible, and these cases were chosen to verify different assessment - with above mentioned assessment models.

TABLE IV. Case Study Transformer DGA Values

Case	H_2	CH_4	C_2H_4	C_2H_6	C_2H_2	*CO*	CO_2
1	3.5	34.8	219.2	50.6	0.9	38.3	794.4
2	8.6	4.4	206.7	0.1	15.2	290.9	1905.7
3	4.14	4.29	29.6	1.33	59.5	51.8	1473
4	4.5	29.4	6.03	8.83	0.09	593	8673
5	230	14.3	0.11	3.37	0.17	12.9	197
6	1.62	2.64	0.26	0.26	0.06	121	1112
7	3.51	2.46	8.79	1.06	0.07	44.3	1086

Power transformers selected according to IEC typical concentration value upper limit and the flowchart in [10] were assessed, and their condition in each case was classified in such categories as a Healthy Equipment, ALERT or ALARM. Typical concentration values for communicating OLTC were used.

TABLE V. EVALUATION RESULTS

Case	IEC model Result	DGA indicator Indicator K
1	Healthy Equipment	5
2	Healthy Equipment	5
3	Healthy Equipment	2
4	Healthy Equipment	4
5	ALERT	4
6	Healthy Equipmen	1
7	Healthy Equipment	1

The comparison provided in Table 5, in Cases 1 and 2, the IEC typical gas concentration model showed that there is no problem with transformers although transformers were removed from service due to suspected defects. Case 3 where increased C_2H_2 due to communicating OLTC and Case 4 increased CO_2 and CO gases, DGA indicator model assigned K=2 and K=4, but IEC result - healthy equipment. In Case 6 where increased H2 ALERT result for IEC model and K=4 assigned for DGA indicator. Last two cases assigned as healthy equipment and K value 1.

IV. CONCLUSION

All power systems differ from one to another and that is the reason why each power system must build their own assessment methods based on existing features, otherwise using available assessment models without regard to the features of the respective system and transformer features may result in misleading conclusions.

Oil volume, communicating OLTC and parameters as transformer loading and oil treatment can help to determine the level of risk for power transformers and are factors that need to be considered when choosing the appropriate assessment method.

The further development of the methodology continues with power transformer oil analysis.

ACKNOWLEDGMENT

The author thanks to Latvian Transmission System Operator (Augstsprieguma tīkls AS) for providing DGA data for case study.

This paper has been partly supported by the State Research Programme „LATENERGI".

REFERENCES

[1] J.A. Lapworth and A. Wilson, "The Asset Health Review for Managing Reliability Risks Associated with Ongoing Use of Ageing System Power Transformers", 2008 International Conference on Condition Monitoring and Diagnosis, Beijing, China, April 21-24, 2008.

[2] Ninil U.A. Wardani, "A. Pharmatrisanti, Power Transformer Assessment Adjusted to Tropical Environment and Utility Requirement", 2011 International Conference on Electrical Engineering and Informatics, Bandung, Indonesia, 17-19 July 2011.

[3] C.L. Kwong, C.Y. Tim, W.M. Kwong, L.C. Kit, K.Y.Yan, "Remarkable Life Cycle Management by Effective Condition Monitoring and Assessment System of Power Transformer in CLP Power System", 2014 IEEE PES Asia-Pacific , 7-10 Dec. 2014.

[4] G.Poiss, "Development of a risk matrix considering specific features of the power transformer park of Latvia," 12th International Conference of Young Scientists on Energy Issues, CYSENI-2015, Kaunas Lithuania May 2015, pp. 1-6.

[5] W. Hu, H. Yang, J. Yan, X. Zhu, "The Transformer Fault Management Information System Design Based on the Risk Assessment", High Voltage Engineering and Application (ICHVE), 17-20 Sept. 2012, pp.528 – 531.

[6] T. Suwanasri, C. Suwanasri, R. Phadungthin, "Risk Assessment Based on Condition and Importance Criteria for Power Transformer in Thailand Transmission Network", John & Wiley & Sons, Inc., IEEJ Trans. 2015,10 pp. 18-27.

[7] K. Taengko, P. Damrongkulkamjorn, "Risk Assessment for Power Transformers in PEA Substations using Health Index", Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), 2013 10th International Conference on 15-17 May 2013, pp. 1 – 6.

[8] S. Saranya , Uma Mageswari, N. Roy, R. Sudha "Comparative Study Of Various Dissolved Gas Analysis Methods To Diagnose Transformer Faults", International Journal of Engineering Research and Applications, Vol. 3, Issue 3, May-Jun 2013, pp.592-595.

[9] Taha, I.B.M., Ghoneim, S.S.M. Zaini, H.G, "Improvement of Rogers four ratios and IEC code methods for transformer fault diagnosis based on dissolved gas analysis", North American Power Symposium (NAPS), Oct. 2015, pp. 1 – 5.

[10] IEC 60599:1999 Mineral Oil-impregnated electrical equipment in service- Guide to the interpretation of dissolved and free gases analysis.

[11] Latvian Electrotechnical Commission (LEK) Transformer oil testing. Latvian Energy Standard LEK 118, Latvia, 2014, p. 45. (Latvian).