Study Committee D1

Materials and Emerging Test Techniques

Paper D1-PS2-10609

Universal method for assessing oil-filled equipment based on the results of DGA

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Motivation

- There are several time-tested methods for identifying the type of defect in a power transformer based on the results of the DGA, which determine about 6 defects. Identification of defects **in other types of oil-filled equipment is less developed**.
- **The purpose of this study** is to develop a method for identifying the type of defect based on DGA for oil-filled equipment of various types: power transformers (PT), shunt reactors (SR), current transformers (CT), voltage transformers (VT), high-voltage bushings of power transformers (VST) and high-voltage bushings of oil circuit breakers (HMV). The new method should take into account the design features and the intensity of the aging processes of equipment of various types.

Approach

- The authors used real equipment defects identified over 25 years of its operation. For example, 256 CT defects were accumulated. Each defect had the history of damage development, reflected in the results of DGA and other types of measurements, as well as a description of the defect found during the opening of the equipment.
- Third-party experts classified all cases of defects based on the description from the results of opening the equipment.
- For each case, the relative concentrations of gases a^i (formula 1) were calculated for the results of the DGA before the equipment was taken out of operation. The obtained relative concentrations a^i were coded by letters in accordance with some accepted rules.
- By machine learning, letters were identified that are characteristic of gases for each of 8 defects of various types.

Essence of the new method

- In the method developed by us for diagnosing oil-filled equipment, the relative concentrations of gases a^i H_2 (hydrogen), CH_4 (methane), C_2H_6 (ethane), C_2H_4 (ethylene), C_2H_2 (acetylene) are used, calculated by the formula:

$$a^i = A^i_t / A^i_{PV}, \quad (1)$$

where:
A^i_t - the value of the concentration of the *i*-th gas, measured on the date t, ppm;
A^i_{PV} - permissible value of the *i*-th gas concentration, ppm.

- Identification of the type of defect is based on coding the obtained values of the relative concentrations ai into an alphabetic code and the rules for assigning the received code to codes describing 8 types of defects (Table 1).
- The coding of the obtained values of the relative gas concentrations a^i is carried out in accordance with the following rules:

A - is the main gas for this defect, at the maximum relative concentration of a^i_{max} of hydrocarbon gases and H_2 and the condition of $a^i_{max} \geq 1$;

C - gas with a high content, its relative concentration a^i is the second largest among the gases under consideration and $a^i \geq 1$;

D - gas at a relative concentration a^i of the third largest or second largest, but $a^i < 1$;

G - all other gases.

- Using the obtained five-digit code (set of letters), which describes the relative gas concentrations of the analyzed DGA sample, it is possible to determine the type of defect using Table 1.

Table 1 - Determination of the type of defect by the characteristic composition of gases

№	Predicted defect type	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2
1	Thermal fault up to 300 °C	D, G	C	A	G, D	G
2	Thermal fault from 300 to 700 °C	G	A	D	C	G
3	Thermal fault more than 700 °C	G	C	D	A	G
4	PD	A	D	G	G	G
5	Discharges of low energy	A	D	G	G	C
6	Discharges of high energy, arc	C	D	G	G	A
		G	D	G	C	A
7	Composition of electrical and thermal faults with a predominance of electrical defect	G	C	G	D	A
8	Composition of electrical and thermal faults with a predominance of thermal defect	D, G	A	C	G	D, G

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- If the resulting five-digit alphabetic code does not completely coincide with any of those given in Table 1, you should find the most similar of the defect codes.
- To do this, first, defect codes are selected by the coincidence of the gas marked with the letter "A".
- If there are more than one such code, then a code is selected by concurrence of the gas marked with the letter “C" (or “D" in the absence of the letter “C" in the code).
- The ratio of CO_2/CO gas concentrations is used additionally to clarify the localization of defects shown in Table 1. The interpretation of the CO_2/CO ratio is carried out according to IEC 60599.

Accounting for insulation aging rates and design features of oil-filled equipment

- The permissible value of gas concentrations A^i_{PV} should be considered as a threshold above which the increased rate of gas formation makes it possible to detect the development of a defect in the equipment, provided that the influence of operating factors is excluded.
- In order for the Davidenko-Ovchinnikov method to be universal (it could be used for different types of equipment), then when calculating the relative concentrations of gases a^i according to formula 1, one should use its own A^i_{PV} values for each type of equipment.
- A^i_{PV} values were calculated according to the method [1] for each type of oil-filled equipment (for PT, SHR, CT, VT, BPT, BCB), taking into account its design features and service life. The strength of the influence of the design features and the service life of the equipment on the gas concentration was determined using variance analysis.
- The following influencing factors were investigated:
  - ➢ voltage class (for all types of equipment);
  - ➢ method of oil protection (for all types of equipment);
  - ➢ brand of oil (for all types of equipment);
  - ➢ service life (for all types of equipment);
  - ➢ power (for PT);
  - ➢ type of cooling system (for PT);
  - ➢ type of on-load tap-changer (for PT);
  - ➢ type of insulation (for CT, VT).

- Based on the results of the dispersion analysis, taking into account the most significant factors of influence, a decision was made to differentiate the regulated values of gas concentrations.
- A^i_{PV} values were determined by the integral distribution function for different types of equipment at different levels. According to the methodology described in [1], the levels were selected in accordance with the values of failure rate flow for equipment of different types and different service lives.
- Thus, for each type of equipment, its own system of criteria for assessing the ARG was created, which takes into account the design features of equipment of various types, as well as different rates of insulation aging.

Example of applying the method

The example (given in Table 2) shows the identification of the type of defect according to the DGA results for a nonhermetic current transformer of the TFZM 110 kV type with a service life of 18 years, filled with GK oil.

Table 2 - Assessment of the CT technical condition

Gas	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2
Measured gas concentration A^i_t, ppm	1586.6	1724.0	428.0	1.4	0.2
Permissible value of gas concentraton A^i_{PV}, ppm	1700	1100	400	6	1.5
The ratio of gas concentrations to its permissible value a^i	0.93	1.57	1.07	0.23	0.13
Gas presence in the sample	G	A	C	G	G
Type of defect - composition of electrical and thermal faults with a predominance of thermal defect	D, G	A	C	G	D, G
Result description of opening the equipment	The protruding part of the potential equalization conductor from the oil sight glass mounting bolt caused a breakdown of the insulating gap.				

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Testing the method for the accuracy of identifying the type of defects

- The proposed method was tested in PJSC "Rosseti" on cases of defects in oil-filled equipment, with confirmation of the type of defect by the results of an autopsy or other diagnostic method. These are 139 cases of PTs damage, 22 cases of CTs damage, 7 cases of VTs damage, 30 cases of bushings damage.
- Further, 3 most accurate, according to the experience of the authors, methods were selected for comparative analysis: the Duval triangle (IEC 60599), the Davidenko-Ovchinnikov method and the nomogram method [2].
- The sample used to test the accuracy of DGA interpretation methods included 134 PT faults. All cases had reliably known causes of defects and the nature of their manifestations expressed in the description of the result of PT opening. Third-party experts assigned defect type codes to each damage case according to Table 1 based on the studying results the nature of the defect manifestation.
- All of the methods under consideration determine rather well the nature of the defect - thermal or electrical. However, all methods were mistaken in identifying defects at the initial stage of their development: "thermal fault up to 300 ° C" and " PD". The Davidenko-Ovchinnikov method recognizes a "thermal fault up to 300 °C" better than other methods by 20%. Other methods confuse it with intense "thermal fault more than 700 °C" or a mixed defect.
- Note that it is not uncommon for the methods to erroneously determine the serviceable state of the transformer when there is an actual "PD" defect. The methods of Davidenko-Ovchinnikov and nomograms identified correctly "PD" by 33% better than the Duval method.
- The method of nomograms determines the defect "Discharges of low energy, creeping discharges" better. Duval's triangle confuses this defect with "Arc, discharges of high energy ", and the Davidenko-Ovchinnikov method with "PD".
- The defect "Arc, discharges of high energy " is diagnosed by all methods quite well. The Duval's triangle and the nomogram method in half of the cases confuse the "composition of faults with a predominance of electrical defect" with the defect "thermal fault more than 700 °C". The accuracy of the Davidenko-Ovchinnikov method in determining this defect is 25% higher.

Conclusion

- The method developed by Davidenko-Ovchinnikov is easy to use, practically has no cases of unrecognizable defects in the state of transformers.
- The method, developed by Davidenko-Ovchinnikov, takes into account the design features and the intensity of the aging processes of equipment of different types, since it uses the permissible values of gas concentrations A^{i}_{PV}, which, in turn, are calculated for different groups of equipment, taking into account the influence of design features and service life.
- The accuracy of the proposed method in recognizing the fault types such as "PD" and "Low intensity heating" is higher than that of the Duval's triangle and nomograms.
- The method developed by Davidenko-Ovchinnikov includes the identification of two additional defects: a composition of electrical and thermal defects with a predominance of an electrical defect or a predominance of a thermal defect.
- The proposed method is universal, since it can be used for PT, SHR, CT, VT and high-voltage bushings and, at the same time, is tuned to the characteristics of each type of equipment, due to the use of relative gas concentrations.
- The use of A^{i}_{PV} values calculated for your country/region allows you to adjust the Davidenko-Ovchinnikov method to the design features of the equipment fleet of your country/region, and the features of the insulating materials used.

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