Criteria of Fault Type Identification in Bushings Based on DGA

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***Abstract* — The paper considers oil-filled bushings criteria based on the results of oil-dissolved gases analysis. Identification criteria for ten types of faults are presented in the article. The suggested approach of bushings state estimation can be used for early fault identification and bushings ranging according to their technical condition.**

Keywords -- bushings; diagnostics; oil-dissolved gases analysis

I. Introduction

Interpretation of DGA results is widely used for early diagnostics of imperfections progressing in oil-filled equipment. The process of diagnosis setting can be divided into 2 steps:

- establishing of existence of progressing imperfection via exceeding of permissible values and maximum permissible values (PV and MPV) of gas concentrations and velocity of their generation;
- identification of imperfection character.

It is obvious that for bushings different from power transformers in design (different paper/oil volume ratios), exploitation conditions, peculiarities in the causes of imperfection occurrence, the use of diagnostics criteria of their own should be preferred. Experience accumulated during operation, diagnostics, repair and investigations of bushing failures helps to extend and specify criteria for their technical condition estimation. The aim of this research was determination of bushing diagnostics' criteria set both for the diagnostics testing step and imperfection identification step based on the accumulated experience.

Improvement of bushings diagnostics criteria is necessary because accuracy of their technical condition estimation is one of the determining factors of this equipment reliable exploitation.

II. Criterion of Permissible and Maximum Permissible Values of Typical Gas Concentrations

The aim of the first step of diagnostics is to separate bushings based on the DGA results into groups of imperfections free and with progressing imperfection. Criterion calculations of permissible and maximum permissible values (PV and MPV) of gas concentrations and their velocities are based on accumulated DGA bushings data processing via the methods of mathematical statistics according to the procedures worked out by the author [1].

The research has become possible thanks to information accumulated in the database of expert-diagnostic and information system "Albatros" (EDIS "Albatros") during 19 years of its exploitation at power companies of Russia, Moldavia, the Ukraine, and Latvia (more than 123 enterprises, over 210 workplaces) and experience of such research. Calculations were based on the data selected at enterprises with considerable volumes of DGA results accumulated during exploitation, reasonable confidence to this information depending both on the enterprise operation organization quality, measurements' staff qualification, and perfection of the applied methods and instrumentation. To get the PV and MPV criteria of gas concentrations and velocities of their generation in 110-750 kV bushings we considered 5578 bushings, 14897 DGA results.

At the beginning factors effecting the PV and MPV of gas concentrations of bushings were detected by dispersion analysis according to Fisher-Snedecorn criterion, their degree of influence was determined.

The following conclusions were made as a result of the conducted dispersion analysis. Expedient is to differentiate PV and MPV in accordance with:

- the type of oil protection (hermetic and nonhermetic);
- power class (110, 220-330, 500-750 кV);
- period of exploitation (under 9 , 9-22, 22-32, over 32 years);
- oil grades (oil grades were divided into 2 groups depending on the content of aromatic hydrocarbons, so this index is connected to gassing ability and oil oxidation rate**:** with C_A=1,6-3% minimal content and C_A=9-15% average content);
- type of designation (bushings of transformers and circuit breakers).

The factors of influence here were ranged on their decreasing degree effect.

Next the whole data array was selected in accordance with revealed factors of influence. PV and MPV were determined for every selection via integral distribution function of bushings gas concentrations.

At this the PV and MPV were determined on the levels, selected taking into account the damageability flow values, that were detected for various periods of exploitation:

- for PV under 9 years – 97,5%; 9 through 22 years - 96,3%; 22 through 32 years - 96,3%; over 32 years - 95,7%;
- for MPV under 9 years - 99,7%; 9 through 22 years - 99,5%; 22 through 32 years - 99,5%; over 32 years - 99%.

Table 1 contains regulated values of gas concentrations for 220 kV bushings, calculated for exploitation period of 9 through 20 years.

TABLE I. - REGULATED VALUES OF GAS CONCENTRATIONS FOR 220 KV BUSHINGS WITH 9-22 YEARS OF EXPLOITATION

Oil Grade	Value Type	Gas Concentration Values, ppm							No.of Measu-rements
		H_2	***CH_4***	***C_2H_4***	***C_2H_6***	***C_2H_2***	***CO***	***CO_2***	
T-750	PV	***hermetic transformer bushings***							175
		600	320	60	75	2	830	4600	
	MPV	1150	350	90	120	3	1100	6500	
GK	PV	1300	170	80	90	2	900	4000	149
	MPV	2500	250	140	150	5	1000	4700	
T-750	PV	***nonhermetic circuit breaker bushings***							134
		330	50	760	840	6	360	2800	
	MPV	400	100	850	920	10	400	3000	
GK	PV	380	120	70	81	4	220	1800	118
	MPV	450	270	140	150	8	310	2400	

Supplementary usage of PV and MPV criterion of gas concentration growth rate makes it possible to estimate progressing imperfection degree of danger as well as separate cases of exceeded PV and MPV gas concentrations, caused by exploitation and technological factors from the progressing imperfection cases. The array of relative velocities per month for gas concentration changes was calculated based on the DGA data. Later the factors with considerable effect on PV and MPV of gas concentration changes rates were detected with the help of dispersion analysis.

The conducted research has revealed the necessity of PV and MPV separation of bushing gas concentration changing rates based on the following factors:

- hermeticity (for H_2,C_2H_4, CH_4);
- period of exploitation (for all gases);
- oil grade (for H_2, CH_4, CO);
- power class (for H_2, CH_4, C_2H_4, C_2H_6).

Then the array of gas concentration changes rates was divided into data samples based on the revealed factors of influence. Velocity PV and MPV was determined for each data samples via integral distribution function in accordance with appropriate values of damageability flow. Table 2 contains the defined values of 220 kV bushings' relative velocities of gas concentration changes that were calculated for the exploitation period of 9 through 20 years.

If concentration of one or more gases of a bushing being diagnosticated exceeds PV values given in Table 1 one must make sure that this excess is connected with progressing imperfection. For this aim growth of relative velocities of gases concentrations are compared with their PV values, presented in Table 2. Dangerous velocity of gas concentration growth for bushing differs from the one specified for power transformers because of the lesser oil volume and absence of oil circulation [2].

TABLE II. - REGULATED VALUES OF RELATIVE VELOCITIES OF GAS CONCENTRATION CHANGES OF 220 KV BUSHINGS WITH 9 THROUGH 20 YEARS OF OPERATION

Oil Grade	Value Type	Relative Velocity Values, % per month							No, pcs
		H_2	***CH_4***	***C_2H_4***	***C_2H_6***	***C_2H_2***	***CO***	***CO_2***	
T-750	PV	***hermetic***							159
		10	8	5	10	9	10	8	
	MPV	30	20	12	20	12	25	20	
GK	PV	9	9	8	8	9	9	11	145
	MPV	25	25	18	18	12	20	25	
T-750	PV	***nonhermetic***							106
		15	9	5	14	8	9	7	
	MPV	30	20	12	25	14	20	18	
GK	PV	8	7	6	11	8	9	8	109
	MPV	25	22	18	20	14	13	15	

If the object being diagnosticated has fixed indexes higher than those stated in Tables 1 and 2 it is advisable to proceed to the imperfection identification step.

III. BUSHING IMPERFECTIONS IDENTIFICATION BASED ON DGA RESULTS

Gases appearance in bushings' oil may be caused by both

- aging processes: cellulose degradation, oil decomposition products generation (yellow deposits, slime sedimentation, X-wax generation);
- production technological irregularities: rough edges of metallic parts, frame imperfections, insulation heterogeneity, foreign inclusions, circuit generation caused by bushing elements offsetting, assembling leakage, loose contact;
- exploitation factors: wetting caused by breathing imperfection, mechanical dirt presence, oil loss, rubber seals displacement as well as
- the external factors influence: overvoltage, current overcharge.

To obtain identification criteria of bushing imperfections type based on DGA 185 cases of imperfect bushings' unsealing were investigated. Over one half of the considered cases were collected by designers of EDIS "Albatros" at the enterprises where it was applied, while the rest of the cases were given by the manufacturing company.

In all the cases we have got reliable descriptions of unsealing and measurements results, made before unsealing, DGA included.

Based on manifestations of imperfection traces, revealed at unsealing and analysis of their origin causes, 10 types of imperfections have been selected:

- low energy PD;
- high energy PD;
- low energy discharge;
- high energy discharge;
- thermal fault;
- yellow deposit generation;
- X-wax generation;
- creeping discharge;
- thermal breakdown;
- frame wetting.

Table 3 contains correlation between the type of imperfection, causes of its origin and description of its traces revealed at its unsealing.

TABLE III. - TYPES OF BUSHINGS' IMPERFECTIONS AND THEIR IDENTIFICATION CRITERIA

Designation of Imperfection	**Origin causes**	**Desciption of Imperfection Type Based on Unsealing Case**	**Methods of Identifiacation**	
			Characteristic Gases	**Characteristic Ratios**
Imperfection free	Natural aging	Undetected	-	-
Low energy PD	Rough edges of metal units, diffusion from frame technological gases	Undetected	H2*	H2/CH4>5
High energy PD	Oil wetting (frame), presence of mechanical dirt in oil, paper fibres, gases. Jags of metal units.	Point disruptions in some layers of paper insulation. Carbon tracking at edges of foil layers.	H2**, CH4*	H2/CH4<4 CO/CO2≤0.3
Low energy discharges	Units' displacement, their insufficient attaching that bring about circuits generation and intermittent contacts appearance	Carbon particles in intermittant contact spot. Disturbed insulation as a result of electrical effect .	CH4**и/или C2H2**, H2*, C2H6*	H2/CH4≤1 C2H2/C2H4≤1
High energy discharges (arcing)	Capacitive high-voltage tap for measurement break or damage or fault of its ground connection	Temper colors on metal parts, their melting. Carbon particles in oil. Paper distruction through it being on the arc path or at overheating.	C2H2**, C2H4*, H2*, C2H6*	C2H2/C2H4≥1.5 C2H4/C2H6≥3
Thermal fault	Poor contacts in bushing's upper section, worsened cooling, generation of insulation discharge centre	Changed color of paper insulation, metal oxidation.	C2H4**, H2*, C2H6*	C2H4/C2H6≥0.8
Yellow deposit generation	Aging processes in transformer 'warm' bushings with T-750 oil.	Film in a kind of yellow highly dispersed deposit on porcelain covers and frame	H2**, CO2*	H2/CH4>6 CO/CO2<0,3
Creeping discharge	Paper wetting or electric field heterogenity or deposit generation and its wetting.	Carbonized paths and 'trees' both on the frame surface and inside the paper layers	H2**, CH4*, C2H6*	C2H6/CH4>0.3 H2/CH4>6
X-wax generation	Aging processes of 220 kV bushings of circuit breakers and bushing of underloaded transformers with GK oil	X-wax deposits between the insulation layers.	H2**,C2H6**, CH4*, C2H2"	H2/CH4>5 C2H4/C2H6<0,7
Frame wetting	Sealing damage in hermetic bushings, aging and direct penetration of moisture in nonhermetic bushings	Frame heaving	C2H2**, C2H4*, CH4*, H2", C2H6"	C2H2/C2H4≥1 H2/CH4≤3
Thermal breakdown	Wetting and dirtying of paper layers, break of connection conductors of first foil layer	Paper insulation colour changing. Damage of it: burnout of frame insulation layers .	C2H4**и/или H2**, CH4* C2H2", C2H6"	C2H4/C2H6>0,8 C2H2/C2H4>1 CO/CO2>0,2

** - gas with the maximum excess of its permissible value;
* - gas with considerable excess of its permissible value;
" - gas with inconsiderable excess of its permissible value.

To get imperfection identification criteria all the cases of equipment unsealing have been classified by experts to the types of imperfections according to Table 3. Later it was obtained criteria of fault type identification based on DGA with the software support. Software implementing methods of criteria receive both as a kind of characteristic gases set and as and characteristic ratio pairs of gases set (Table 3). The essence of the methods is as follows. Selections for each imperfection from the cases collected are to be formed in several variants: taking into account one type of imperfection progressing into the other and different imperfections combinations. For example, the following chains of progressing imperfections are possible:

- accumulation of yellow deposit as a product of aging – appearance of conditions for the creeping discharge developed along it – bushing breakdown caused by deposit breakdown;
- accumulation of X-wax as a product of aging, accompanied by PD strengthening – thermal breakdown of frame;
- discharges originated through frame insulation wetting (possibly oil wetting to begin with, and later proceeded by frame insulation wetting) – frame breakdown.

For every selection indexes of mathimatic statistics were calculated for the degree of exceeded gas concentrations, their PV and ratios of gas pairs. Dispersion indexes were taken into account for characteristic gases and their ratios detection. As a result two methods of identification of 10 types of imperfections with the help of a set of characteristic gases and ratios of gas pairs were obtained, which are presented in Table 3. Both of the developed methods for DGA interpretation may be used either independently or complementing each other.

Let us consider examples of bushings diagnostics with the suggested criteria.

Diagnosticated object is a 220 kV transformer bushing, hermetic, T-750 oil grade, produced in 1997.

Measured gas concentration values are as follows: H2=604 ppm, CH4=150 ppm, C2H2=386 ppm, CO=467 ppm, C2H4=257 ppm, C2H6=83 ppm, CO2=1073 ppm.

At the first step of diagnostics the measured gases concentrations values of diagnosticated bushing are compared with their permissible values selected from Table 1 in accordance with its design features and age (H2=600 ppm, CH4=320 ppm, C2H2=2 ppm, C2H4=60 ppm, C2H6=75 ppm, CO=830 ppm, CO2=4600 ppm).

Obtained as a result is the gas with the maximum excess of its permissible value - C2H2**, gases with considerable excess of their permissible values were ranged as follows: C2H4*, followed by C2H6*, H2’’.

Having defined ratios of gases’ pairs we get: C2H2/C2H4=1.5; C2H4/C2H6=3.1; H2/CH4=1.8; C2H6/CH4=0.23; CO/CO2=0.18.

Comparing the obtained values of pairs of gases ratios with the characteristic ratio values taken from Table 3, we conclude that there is ‘a high energy discharge’ being developed in the bushing. The same diagnosis is obtained after the comparison of diagnosticated bushing set of gases where PV is exceeded with gases’ sets characteristic of different imperfections (Table 3). At this bushing unsealing “burning-out of soldering place of capacitive high-voltage tap for measurement; carbon black particles suspended in oil” was discovered.

Diagnosticated object is a 220 kV bushing of a circuit breaker, nonhermetic, GK oil grade, produced in 1989.

The measured gases concentrations values are: H2=3648 ppm, CH4= 720 ppm, C2H2=8 ppm, CO=52 ppm, C2H4=40 ppm, C2H6=1360 ppm, CO2=947 ppm.

At the first step of diagnostics the measured gases concentrations’ values of diagnosticated bushing are compared with their permissible values, selected from Table 1 in accordance with its design features and age (H2=380 ppm, CH4=120 ppm, C2H2=4 ppm, C2H4=70 ppm, C2H6=81 ppm, CO=220 ppm, CO2=1800 ppm).

Obtained as a result is the gas with the maximum excess of its permissible value – C2H6**, gases with considerable excess of their permissible values were ranged as follows: H2*, then CH4*, C2H2’’.

Having defined ratios of gases pairs we get: H2/CH4=5.1; C2H4/C2H6=0.03; CO/CO2=0.06; C2H6/CH4=1.9; C2H2/C2H4=0.2 .

Comparing the obtained sets of gases where their PV is exceeded and pairs of gases ratios of diagnosticated bushing with imperfections identification criteria, given in Table 3, we may conclude that there is ‘X-wax generation’ in the bushing. “Considerable X-wax content in insulation thickness, copper pipe burnout” was discovered at unsealing.

As it is obvious in both cases bushing unsealing has proved the defect character being established with the help of the suggested criteria.

IV. Conclusion

DGA of bushings provides opportunities for imperfection identification at the early stage of its development, makes arrangements for its timely control and have the required additional measurements conducted in due time, which in its turn makes provisions for the prevention of serious nonreversible damage of bushing itself and the equipment connected with it. It should be noted that there is no other type of measurements able to provide such a wide palette of imperfections identification as DGA (ref. Table 3). Precise imperfection identification is helpful in the choice of required operational arrangements and their timely performance corresponding to situations. But to take decision on bushing disability guided by its PV and MPV excess values only, in many cases from our point of view, is unreasonable. Such a decision should be taken based on the determined kind of imperfection as per DGA results and confirmed diagnosis made at least by still another type of measurement. Imperfection identification based on several measurements types makes provisions for bushings diagnostics with extended reliability and wider set of recognizable imperfections.

References

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