19th International Symposium on High Voltage Engineering – ISH 2015
Pilsen, Czech Republic, August 23 – 28 2015, ISBN 978-80-261-0477-3, http://www.ish2015.org

ANALYSIS OF TAP CHANGERS DAMAGING AND TECHNICAL CONDITION EVALUATION BY DGA RESULTS

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Abstract:

The article includes the detailed damaging (both defects, which were found by operating staff, and failures) analysis of tap changers and its units: selector switch, diverter switch and drive. There have been investigated the type and location of defects, reasons and initiators of defect appearance, the influence of operation life and tap changers (TC) construction features on the damaging. The efficiency of different measurement types of tap changers defect detection is evaluated on the data in addition to the analysis of TC reliability. Next the article considers the capabilities and improvements of diverter switch condition control by DGA. On the basis of dispersion analysis is shown the influence degree of number TC switchers, transformer load capacity and TC operation life on the maximum permissible value (MPV) of DGA. As the result the authors advise using criterion of exceeding MPV of DGA content for diverter switch accounting these factors. There are given recommendations on defect identification in diverter switch in gas ratios accounting authenticity of gas pair relations. Then we examine the character detection experience of defect developing in TC selector switch by DGA. We should note that MPV DGA for accuracy evaluation of technical condition of in-tank selector switch must be differentiated with respect to the type of oil protection and oil grades, operation life and PT power class. Authors show the own procedure of defect identification by DGA that has two advantages: it does not have unrecognizable conditions; it allows detecting defect combinations of heat and electrical nature with different level of development. The article demonstrates examples showing the proposed procedures of defect identification by DGA results for diverter and selector switch that have the defects as the result of TC unsealing.

1 INTRODUCTION

One of the effective ways for increasing reliable work of power transformers is well-timed defect detection in tap changers (TC) as the TC defect is one of the basis reasons of transformers failures according to statistics. During the analysis of power transformer (PT) damaging and its units there is the problem of collecting data of faults because the failure is rather rare. That is why the collection of sufficient data needed for analysis requires a long time on many energy enterprises. The source for researched sample of TC faults is database of expert-diagnostic and information system (EDIS) of technical condition estimation of electrical equipment "Albatros". EDIS has wide (about 400 working places) and long-term (22 years) implementation. There were examined 364 cases of 35-500 kV PT faults, 107 of which were connected with TC faults. All faults of researched sample have history of evolution confirmed by measurement results which are conducted during the operation of transformers. Authors verified result description of PT unsealing according to measurements before faults in all cases.

2 THE ANALYSIS OF DAMAGING AND TAP CHANGER EFFICIENCY DIAGNOSIS

Tap changer equally with winding is the least reliable unit of transformer (our research unites tap changers on load and no-load tap changers). The share of TC faults is 31% from all PT faults.
Figure 1 shows the TC damage (defects found by operating staff and failure) rate depending on PT operation life.

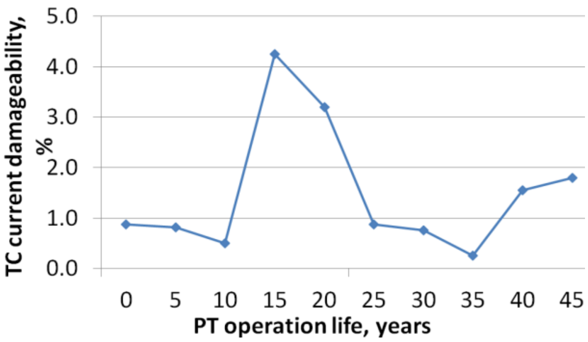


Figure 1: Damage rate of OLTC and NLTC according to operation periods

The figure 1 shows TC running-in period, the period of reliable operation life and periods of higher damaging. The first point of higher damaging is 15-20 years of operation and it may be explained by repairs and partially TC replacement. The second increase of damaging is caused by repairs and following failures of TCs. The next figure presents faults distribution over TC units.

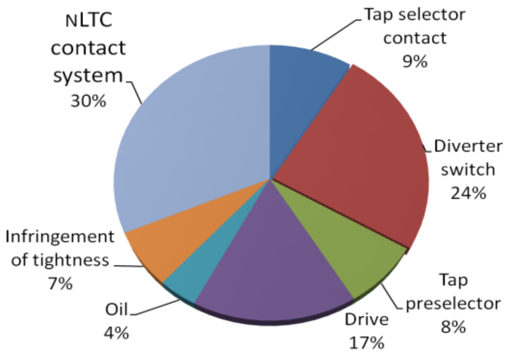


Figure 2: Damaging of TC units.

Both contact of OLTC tap selector and NLTC contact system have the most number of faults (39%). The weakest point of the units is contacts suffering from high load during TC switches. These are influences as mechanical (friction of contact surfaces) as well as thermal and electrical nature (during wrong TC work there can appear sparking and the contact is burnt). The contact faults of OLTC tap selector and NLTC happen in 64% cases and oftener they are electrical than thermal. The reasons of electrical faults are the following: mechanical wear, detail shift, contact breach and consequently its burn and fusion, and break of conductor chain.

The reasons of thermal faults are contact worsening due to oxidation, carbonization or weakening of pressure. These aging processes lead to contact burn.

The faults of preselector are 8% and mainly they are poor contacts.

Approximately 10% of faults are caused by OLTC drive. Mainly the motor drive and the automatic drive control are broken. These faults are specific for OLTC with the lifetime more than 18 years.

OLTC diverter switch and drive are on the second place of faults. For diverter switch faults are specific mechanical contact failures. There are rarely solder failures, details shift, frailness of paper-bakelite tanks, contact spring weakening because of metal features changing during aging.

Besides the analysis of TC reliability the existing data helps to estimate efficiency of different measurement types for TC fault detection.

According to data 73% of TC faults are timely detected by the staff during the plan-prophylactic measurements and it does not impact on the other equipment. 18% of TC faults become clear after activation of different preventive means of PT, and 12% - after PT failure. The first time developing TC faults are shown by the following tests and measurements:

- DGA from the tank of transformers – 83%;
- measurements of winding resistance- 10% (mainly these are the cases when DGA is not conducted);
- measurements of isolation characteristics – 2%;
- both physical and chemical analysis of oil and thermal-imaging control - 1%;
- method of measurement dynamic transitional resistance - 3%.

In each third case the basis for PT out of work is measurement of winding resistances. Each tenth case the output of PT is based on results of DGA and thermal-imaging control. High percentage of TC faults detection by DGA results can be explained by frequent use of DGA and DGA response to contacts heating before the interphase difference of winding resistance exceeds the permissible value (2%).

The fault of diverter switch is detected worse than other units of TC and ill-timed. This fact is confirmed by statistics: 44% faults lead to disabling of other equipment, 39% cases - are detected through activation of different preventive means of PT, 6% cases ends with PT failure. Possibly it happens as DGA for TC diverter switch is not included into the list of needed measurement standard of technical service in Russia [1]. That is why there are no criteria of DGA assessment from diverter switch oil in the Russian standard.

TC manufactures and component suppliers are guilty in 14% of faults. 36% faults are caused by wrong actions (or inaction) of operation and repair staff.

The shown analysis of OLTC and NLTC damageability does not pretend to be absolutely objective because it has been done on the data that was available to authors.

3 DGA OF DIVERTER SWITCH

The next task was to receive impartial criteria of DGA assessment of OLTC diverter switch, installed in separate tank. DGA was conducted on the gas chromatograph «Crystal» with the following gas detection limits: for H_2 - 5 ppm; for CH_4, C_2H_4, C_2H_6 - 1 ppm; for C_2H_2 - 0,5 ppm; for CO, CO_2 - 20 ppm. The objectivity and accuracy criteria were achieved by their differentiation according to factors impacting on the DGA results. The research has taken 946 DGA results from diverter switch tank that were accumulated in DB of system EDIS in enterprises – “Tyumenenergo” and “Lipetskenergo”. According to earlier researches [2] oil type, oil protection, oil grade, voltage class and operation life influence on DGA results of PT and bushings. Oil grades were divided into 3 groups according to content of aromatic hydrocarbon Ca [3] as this measure effects on the nature of aging process and absorption of gases: Ca less than 3%, Ca from 9% to 15% and Ca over 18% [2].

The examined DGA sample included results of equipment with free breathing and the same voltage class (110 kV) and so next the influence of oil grade and operation life of equipment were examined.

The researches confirmed the earlier results [2]:

- higher hydrogen concentration for oil with low Ca at initial period of operation;
- evident tendency to accumulation of carbonic monoxide and acetylene with the increase of operation life.

Next step researched the impact of transformer load and number of OLTC switches on concentration of dissolved gases. Information of load and switches was obtained by dispatch service of enterprises.

Figure 3 shows the most dependence of gases concentration on transformer load.

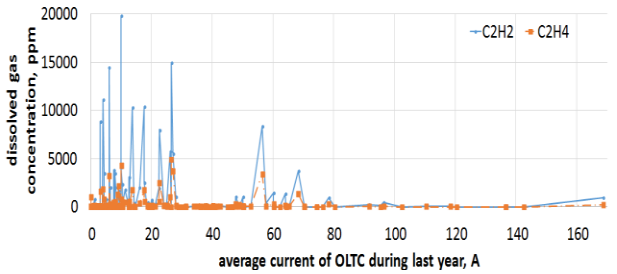


Figure 3: Gas concentration dependence on real PT load

Based on obtained graphs of DGA results, we can say that PT load does not influence on the gases concentrations in OLTC diverter switch.

Next the influence of OLTC switches number on the results of DGA diverter switch was conducted by the dispersion analysis method. The sample included 180 DGA results as the rest of OLTC worked without switches.

The research results have shown the most influence of OLTC switches on the content of hydrogen and acetylene, and the least influence on the content of ethylene and carbonic oxide. These results are shown on the figures 4 and 5. Influence of OLTC switches on the content of methane and ethane is average, figure 4.

It should be noted that variation of hydrocarbon gas content values decreases with the increasing number of switches. Perhaps this is because switch contacts frequently do not have time for oxidation.

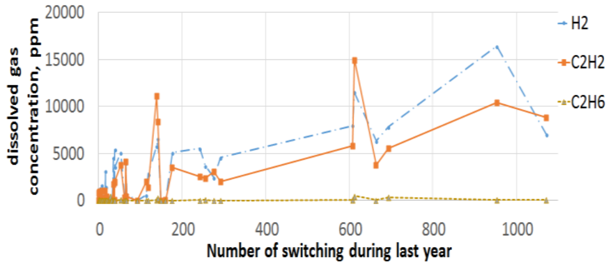
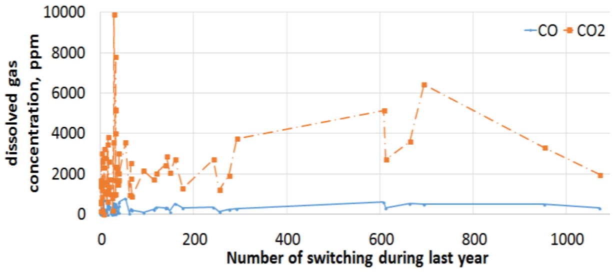
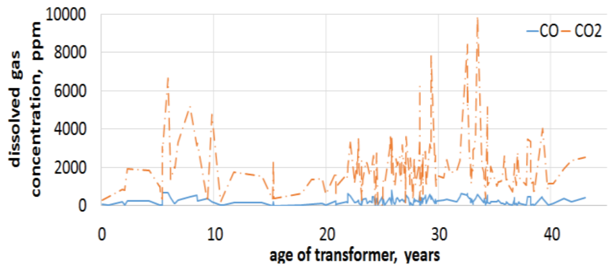


Figure 4: Gas concentration dependence on OLTC switches per year

Figure 5 and 6 show that for OLTC with frequenly switches the influence of lifetime on the carbonic oxides concentration is higher than impact of switches.



Figures 5: Carbon oxides dependence on the number of OLTC switches



Figures 6: Carbon oxides dependence on OLTC lifetime

The figures 4, 5 show the increase of gases with more than 40 OLTC switches per year. On the basis of received results there were proposed the next findings. The assessment of technical condition of OLTC diverter switch with low count of switches (or without it) by DGA results could use the same criteria of maximum permissible values of gas content.

The assessment of technical condition of OLTC diverter switch with more than 40 switches by DGA results for hydrogen and acetylene should use specific trends depending on the number of switches. For other gases should use criteria of MPV differentiated in groups according to the number of switches.

The international technical documentation and articles devoted to interpretation methods of OLTC dissolved gas analysis use the next gas ratios: C_2H_4/C_2H_2, $(CH_4+C_2H_6+C_2H_4)/C_2H_2$, C_2H_4/CH_4, N_2/O_2, C_2H_4/C_2H_6. Based on dispersion analysis of switches influence on gas concentration in OLTC with more than 40 switches we recommend use next gas ratios:

- C_2H_4/C_2H_6 for detection of contact fault caused by overheating;
- C_2H_2/H_2 for detection of contact fault caused by sparking (arc). with less dependence

The first ratio (C_2H_4/C_2H_6) includes gases less dependent on switches and the second one (C_2H_2/H_2) - gases with similar dependence (figure 4).

The last ratio for OLTC with free breathing should be used taking into account low hydrogen solubility and high solubility of acetylene in oil. Next figure 7 shows how C_2H_2/H_2 ratio depends on OLTC switches. The variation of this ratio is not big. The maximum point on the figure (4,26) corresponds to the breach of shunt resistor inside the tank of OLTC diverter switch. The rest of OLTC have no defects.

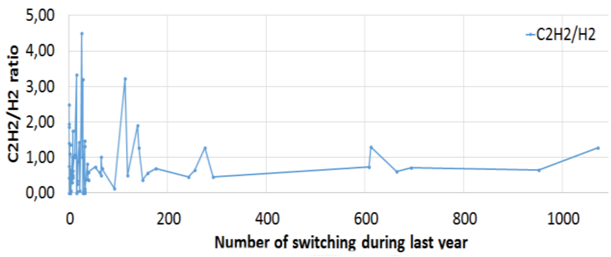


Figure 7: Dependence of C_2H_2/H_2 ratio on OLTC switches number

For now we are not prepared to recommend the values of gases ratio for defect identification in diverter switch because we do not have sufficient representative sample data of diverter switches faults. However, on the basis of conducted research it is supposed that C_2H_2/H_2 ratio can be used for assessment of diverter switch DGA.

4 DGA OF NLTC AND OLTC TAP SELECTOR

According to authors 90% faults of NLTC and OLTC tap selector and preselector (both installed in PT thank) are initially detected with the help of DGA results from PT tank. It is explained by high sensitivity of DGA method and its more frequent usage in comparison with other methods (semiannually).

The estimation of PT technical condition consists of two steps:

1 step: detection of developing defect by exceeding of permissible (PV) and maximum-permissible values (MPV) of controlled parameters and their trends;

2 step: defect type identification.

Consider the improvements of both phases of diagnosis proposed by the authors. These improvements were incorporated into the EDIS knowledge base and passed the long test of practical application in Russian enterprises.

The increase of objectivity and accuracy of detection step of developing defect is achieved by the usage of well differentiated criteria of PT DGA estimation.

The criteria collection is differentiated with:

- oil type protection (film and nitric protection, free breathing);
- voltage class (up to 35, 110-150, 220, 330, 500, 750 kV);
- oil grades (3 groups with different content of aromatic hydrocarbons);
- operation life (3-5 periods);
- severity level – PV and MPV.

The set of given criteria was received by EDIS developers on the methodology described in [2]. Representative DGA array for calculations was accumulated in system DB for a long operation life.

EDIS uses 4 author's methods (1 method is analytical and 3 are graphical ones) for defect type identification. Two graphical methods (assembly of specific gases and chart of gases content) will be described below and third method - Davidenko leaf-chart – is described in [4].

Method of defect type detection on the basis of the gases content chart is the modification of method [4]. The concentration of carbonic oxides is additionally used for making the chart of gases content (on a scale 150:1). This gives information about whether a defect has an impact on the solid insulation. The measured gases concentrations are divided onto maximum concentration in the analysis for making the chart. Then each gas is pointed with the value of received ratios and these points are combined with lines.

Next the resulting chart of gases content of transformer is compared with chart image of typical defects. The defect identification consists of finding image that is more similar to the examined DGA chart.

EDIS knowledge base includes 14 defect images. They were received by comparing the results of DGA transformer having defects and descriptions of the defect type on the basis of the results of PT unsealing.

The received images replicate approximately by 70% the ones of the report [5]. The examples showing the usage of this method are given in column 2 of table 2, where blue chart corresponds to DGA results from PT tank and red one demonstrates the defect image.

The method of defect type identification according to assembly of specific gases is described below. Firstly we find the ratios of measured values of gas concentration to its MPV and represent them as it is shown in the table 2. If the gas concentration exceeds MPV, then the corresponding ratio is shown in red. If the gas content is lower than PV, then the ratio is shown in green, otherwise – yellow. Next it should be marked out according to the table 1:

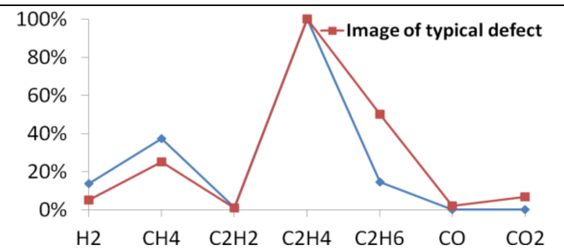
- gas with maximum exceed of MPV;
- estimate the gas group that exceeds MPV and defines electrical type of defect;
- estimate the gas group that exceeds MPV and defines thermal type of defect.

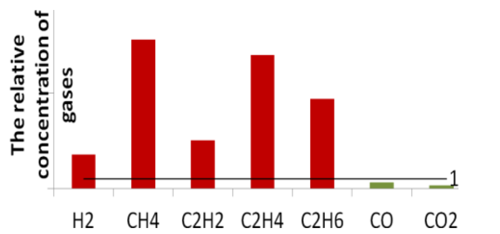
The rules for interpretation are given in the table 1.

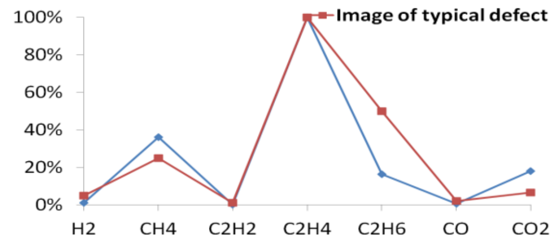
Table 1: Identification of defect type by specific gas assembly

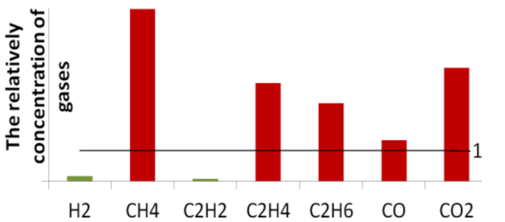
Type of defect groups			
electrical		**Thermal**	
Gas	**Defect type**	**Gas**	**Defect type**
H_2	PD	C_2H_6	low-temperature heating
CH_4	sparking	C_2H_4	average-temperature heating
C_2H_2	arc	C_2H_2	high-temperature heating

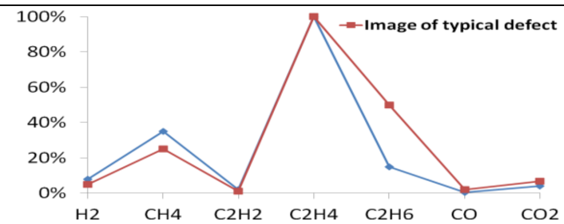
Table 2: Examples of most frequently met TC defects

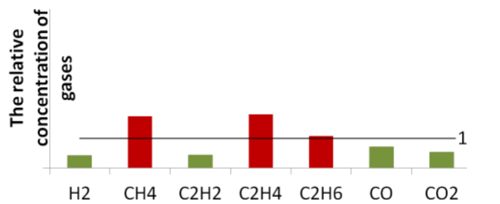
<table>
<tr><th>№</th><th>Defect identification by chart of gases content</th><th>Defect identification by assembly of specific gases</th><th>Result of PT unsealing</th></tr>
<tr><td>1</td><td>

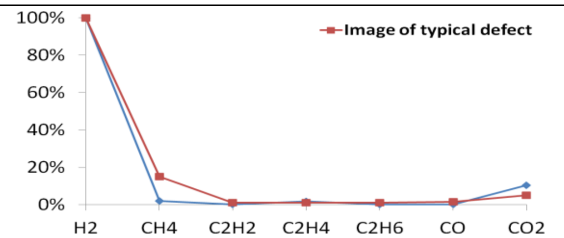
Thermal defect in the range of average temperatures</td><td>

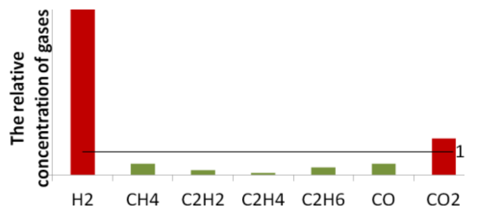
Heavy sparking accompanied with heating of average temperatures</td><td>Burn-out of tap selector contacts. OLTC replacement</td></tr>
<tr><td>2</td><td>

Thermal defect in the range of average temperatures</td><td>

Sparking accompanied with heating, accelerated paper aging</td><td>Burnt of contacts.
OLTC repair</td></tr>
<tr><td>3</td><td>

Thermal defect in the range of average temperatures</td><td>

Heating in the range of average temperatures and sparking</td><td>Carbon build up of contacts OLTC repair</td></tr>
<tr><td>4</td><td>

Low energy PD</td><td>

PD and paper aging</td><td>Oxidation of contacts was removed by multiple OLTC switch</td></tr>
</table>

The proposed methodology of defect identification by DGA results has some advantages:

- It allows identifying fault combinations of thermal and electrical nature with different development levels;
- It has no unrecognizable technical conditions of equipment;
- It is easy in use;
- It is universal because suitable not just for interpretation of PT DGA but for high-voltage bushings and measurement transformers.

The accuracy of methodology depends on objectivity of PV and MPV gases concentrations that should be specific for PT, measurement transformers and bushings, and reflect their construction features and operation life.

We recommend using both methods that are mentioned earlier as the method of specific gases assembly allows making significant additions of defect characteristics to the method of gases content chart.

Table 2 shows the examples of most frequently met TC defects. Examples 1, 2 and 3 represent that we get different gases assemblies exceeding their MPVs with the same charts of gases content.

These assemblies of specific gases clearly show the defect type and its level of development.

Example 1 differs from 2 and 3 by the prevailing gases group of electrical character defect. The defect result in example 1 was burning-out of contacts and necessity of OLTC replacement but in examples 2 and 3 was possible OLTC repair.

Example 4 represents the beginning of defect developing. Both methods identified the same defect but specific gases assembly additionally shows more intensive aging of paper. Measurement of winding resistance in the example 4 revealed interphase disagreement in the third position of OLTC. After multiple OLTC switch it (interphase disagreement) was normalized. Next the content of hydrogen was also normalized.

5 CONCLUSION

Accounting that TC faults happen regularly and 36% of them are caused by ill-timed or poor quality of maintenance operations it can be noted that there is a reserve of increasing PT reliability without additional investments.

It is known that DGA from PT tank allows detection of PT damage at early stages. However, the evaluation of OLTC condition on the basis of DGA from tank is not usual and widely spread in Russia. We consider that DGA usage for technical condition estimation of OLTC diverter switch allows reducing accident rate and increasing the TC diagnosability.

We recommend evaluating the technical condition of OLTC diverter switch, installed in separate tank, by DGA results next ratio of gas pairs:

C_2H_4/C_2H_6 for detection of contacts faults caused by overheating

C_2H_2/H_2 for detection of contacts faults caused by sparking (arc).

These gases ratios are less dependent on OLTC switches number, as the ratio C_2H_4/C_2H_6 includes gases less dependent on switches and the ratio C_2H_2/H_2 - gases with similar dependence.

To improve the accuracy of estimation of TC technical condition by the criterion of PV and MPV of gases concentrations, these values should be differentiated by TC construction features and operation life.

The accuracy increase of defect type detection according to DGA results should be done joint using method of gases content chart and method of specific gases.

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