Development of express method for liquid dielectric quality control as a step to increase the reliability and effectiveness of oil-filled equipment exploitation

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Abstract. Presented the results of researches, aimed to develop methods for express-analysis of transformer oil quality indicator "Acid Value". Developed an algorithm of preparation for and conducting measurement. Proposed implementation of mixed indicator. Outlined the valuation criteria for results of "AV" semiquantitative measurement via express-method.

1 Introduction

The aging equipment park requires medium and capital repairs, which are followed by regenerative work to restore the exploitational and resource characteristics of the liquid dielectric. The physico-chemical analysis of the oil is an extremely reliable tool that allows to influence the efficiency of these works: to control the technological cycle, to determine the point of the procedures completion. At the same time, carrying out control chemical measurements involves the need to transport samples to chemical laboratories with considerable time losses. The search for a minimum set of control parameters and the development of methods for their rapid analysis will improve the quality and efficiency of repair work in oil-filled equipment.

2 Determination of oil quality key parameter that allows to indirectly assess the change in the insulation resource

All the processes taking place in the insulation of oil-filled equipment affect, above all, the impregnating mineral oil and spread to solid cellulose materials (paper, cardboard). At the present time, there have been developed theoretical provisions on the fundamental aging processes of individual insulation components - oil and paper [1].

In [2], there is revealed a considerable influence of the oxidation processes occurring in the transformer oil and the aging products formed in it on the state of solid insulation, affecting, eventually, its electrical insulation characteristics and durability.

Considering the significant contribution of transformer oil in damage to the insulation of oil-filled equipment, the most important exploitational characteristics of a liquid dielectric are their chemical stability, i.e. the ability not to change their properties for a long time in the process of exploitation, as well as their chemical resistance - the ability for a long time not to destroy the solid insulation [3].

During the scientific analysis [2], it was established that these properties are in close connection with the processes of oil aging and the resulting oxidation products. Accordingly, timely and sufficient removal of aging products from the oil with subsequent restoration of its resource allows maintaining stable and reliable characteristics of both power transformers insulation and liquid dielectric.

The carried scientific experiment [2] statistically proved a significant relationship between the oil antioxidant stability (oil resource) and a number of quality indicators which are indicative also for aging products, among which are the indicators "Acid value" (further AV), "Water-soluble acids and alkalis" (further WAA), "Dielectric loss angle tangent" (hereinafter Tangent), "Antioxidant Additive Content" (hereinafter the Additive). In work [2] it is shown:

- The multicollinearity [4] of the indicators of AV and WAA, which means that there is a close relationship between them (high closeness);
- By the methods of correlation-regression analysis, it was revealed a significant direct relationship between AV and antioxidant stability (hereinafter Stability), a moderate direct relationship between Stability and Tangent and a weak inverse relationship between Stability and Additive.
- By the three non-parametric methods (trees of classifications, determinant analysis and logistic regression), the AV was found to be the main grouping factor of transformers in the indicator Stability.

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Thus, AV is a key indicator of quality, allowing with a high degree of reliability to indirectly assess the change/deterioration of the oil resource. The obtained results of the studies [2] indicate that exactly the AV index is a reliable key parameter of the oil quality, which allows to empirically measure the efficiency of oil regeneration (restoration of the oil resource) and determine the work completion point with subsequent controlled regulatory measurements.

Due to the fact that a significant part of the oil regeneration work in the period of overhauls of power transformers is carried out at the place of their installation (at substations), there is an urgent need to develop a rapid method for estimating the AV, which will eventually result in:

- reducing the loss of time for the delivery of intermediate samples to the laboratory, and, accordingly, will affect the reduction in the duration of direct capital repairs;
- reducing the cost of capital repairs: reducing the idle time of crews before obtaining the results of control measurements, increasing the efficiency of regeneration machines by sorbent timely replacement based on the results of control measurements, reducing costs by eliminating the excessive carrying out of expensive laboratory measurements;
- improvement of the quality of directly regenerative work due to the provision of operational control without loss of organizational procedures, and accordingly to increase the period in-between overhauls of transformers, increase the reliability and durability of their isolation.

3 Development of a laboratory experiment on the search for the method of express analysis of transformer oil according to the AV index. Results of trial experiments

One of the recognized modern methods of measuring transformer oil AV is the method [5] providing for volume titration (titrimetric method) using an “Pigment Blue 61” indicator. In this case, unlike the more common method [6] of determination of AV using the indicator of nitrazine yellow, the method [5] does not contain boiling procedures.

Thus, method [5] of the author of this article is taken as a basis for the development of express analysis of the quality index of AV. The developed technique is an empirical (semi-quantitative) method for assessing the compliance of the AV of the analysed mineral transformer oil with a given initial value. To assess the results, a categorical assessment is used: "less than the set value" and / or "more than the set value". In the implementation of the rapid analysis of the AV, preliminary preparation of working solutions in laboratory conditions is provided, followed by carrying out test measurements at the facility (substation).

On the basis of mentioned [5] quantitative method for measuring AV, a list of additional solutions was determined, with the interaction of which with the defined volume of the transformer oil sample, according to the adopted rules, by the colour shifts the range of AV values characteristic for a given liquid dielectric is determined.

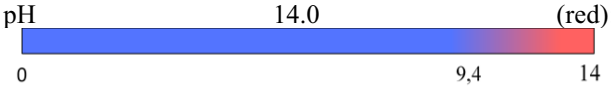
All experimental measurements are carried out on the basis of the chemical laboratory of PJSC "IDGC of the North-West" "Komienergo". During the installation of trial experiments, it was found that for a number of oils there is no more or less bright colour transition, which makes it difficult to determine the end point of titration: the category of evaluation.

4 Mixed indicator

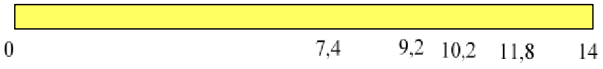
Indicators are chemical compounds capable of changing the colour of a solution depending on environmental conditions without directly affecting the test solution and the direction of the reaction. Dissolved in water chemical compounds dissociate into positively charged ions - cations and negatively charged - anions. If the concentration of hydrogen and hydroxyl ions in the solution is the same, then such solutions are neutral and pH = 7. At a concentration of hydrogen ions corresponding to a pH from 0 to 7, the solution is acidic, if the concentration of hydroxyl ions is greater (pH from 7 to 14) alkaline. Qualitatively, the reaction of the solution can be determined with the help of special indicators (acid-based), changing their colour depending on the concentration of hydrogen ions. The advantage of acid-based indicators is cheapness, speed and demonstrativeness, however, due to subjectivity of colour determination and low accuracy, pH indicators are not always convenient. To improve the accuracy of pH measurement, the use of mixed indicators is recommended. For this purpose, two indicators with close intervals of the pH colour transition are selected, which have additional colours in this interval [7].

So, in order to provide a more noticeable transition of the color of the indicator during titrimetric analysis, a mixed indicator was chosen: “Pigment Blue 61” + curcumin. Justification of the choice of indicators:

1. “Pigment Blue 61” has a pH range of the color transition (in aqueous solutions): from pH 9.4 (blue) to pH 14.0 (red):



2. Curcumin has the first range of the pH colour transition (in aqueous solutions): from pH 7.4 (yellow) to pH 9.2 (brown-red); The second range of the pH colour transition (in aqueous solutions): from pH 10.2 (brown-red) to pH 11.8 (orange-yellow):



When using the above-mentioned pair of indicators at the same time, it is expected that the yellow colour of the curcumin indicator in an acidic region will not affect the

initial colour of the analysed mixture, given the original yellow colour of the oil. At the same time, in combination with the blue colour of the indicator of "Pigment Blue 61" in a mixture with oil, a strengthening of green shades is expected. When approaching the equivalence point, curcumin begins to give the red-brown colour of the mixture before the "Pigment Blue 61", and then strengthen the red colour it.

Thus, the use of an additional indicator made it possible to make the green tint of the colour more pronounced and hence the (more clearly observed) disappearance of the green tint is considered an achievement of the end point of titration.

5 Research results

The key objectives of the study are:

- Development of the methodology for express analysis of transformer oil AV: determination of conditions and algorithm for conducting measurements, a list of necessary reagents, the order of evaluation of measurement results;
- search for the dependence of the change in the colour component composition of the reaction mixture according to the RGB model from the measured value of the AV.

For the analysis of one working sample of transformer oil, a list of necessary solutions, an algorithm for preparing and conducting an express analysis of the AV quality index were developed (see Fig. 1).

Based on the results of the test measurements, it is envisaged to form a conclusion about the compliance of the AV to one of the set values. In the developed method of rapid analysis of the AV, the following interpretation of the results of the test analysis is provided without taking into account the numerical representation / change in the component composition of the colour of the solution during a chemical reaction:

- if the colour of the solution in the test tube with an aliquot of the sample retains the main colour / shade (red with tints) and significantly differs from the colour / shade of the test solution (green with tints), this means that the substances causing the oil AV are not sufficient to neutralize all the amount of KOH contained in Solution 2. Accordingly, it can be concluded that the AV of the oil sample does not exceed the preset AV value in Solution 2;
- if the colour of the solution in the test tube with an aliquot of the sample changed the main colour / shade became green and / or close to the colour / shade of the test tube with the reference solution, this means that the substances causing the oil AV in the mixture are contained in excess, all KOH is neutralized. Accordingly, it can be concluded that the AV of the oil sample exceeds the preset AV value in Solution 2.

The analysis of the colour component constitution of the solution in tubes is carried out according to the RGB model using the «ColorAnalyzer» software: the data is read in three channels - R (red), G (green) and B (blue), followed by its fixation. On the basis of the experimental data obtained, the dependence of the change in the component constitution of the solution colour during chemical reactions on the obtained test value of the AV is sought: the determination of the decision point.

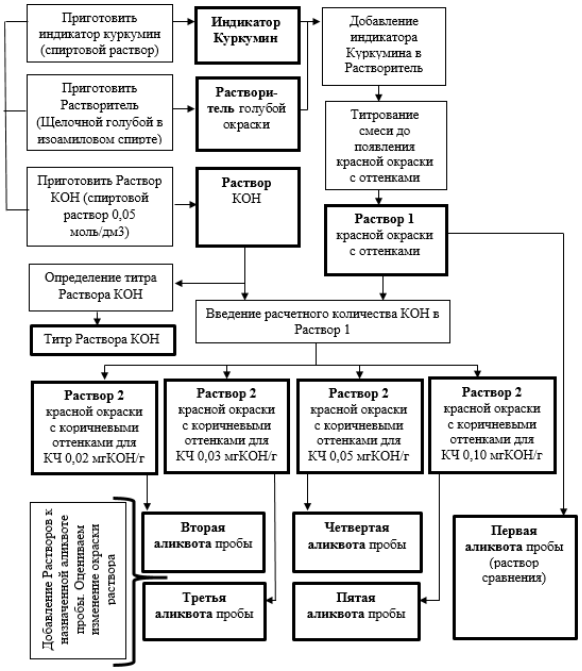


Fig. 1. Algorithm of preparation and conducting AV express-analysis

The evaluation of the reliability of the first developed rapid analysis method for AV is carried out by evaluating the ratio of the results of the analysis, obtained by the newly developed method to the results of the studied oil samples, the measurement of the AV in which was carried out using a control certified method [5].

According to the above algorithm, 40 samples of transformer oil with different values of AV were measured. Based on the results of the studies, it was found that in most of the analyzed samples, an acceptable visualization of the determination of the titration end point is found.

After carrying out in the laboratory conditions procedures of oil regeneration with the subsequent control measurement of the AV by the express-method, it also revealed the dynamics of the color change of analyzed ssolution, depending on AV change (decreasing of it). At the same time, it is continued to search for dependence of the change in the colour component composition of the reaction mixture according to the RGB model on the measured value of the AV.

6 Conclusions

1. The important properties of a liquid dielectric are chemical stability and chemical resistance, the restoration of which is mandatory during capital repairs of power transformers.
2. Substantiated the necessity of the development of express analysis of the AV oil quality parameter as a step

allowing to increase the efficiency of capital repairs of power transformers.

3. The method of AV express analysis is developed, the algorithm of preparation and carrying out of measurements is presented. A mixed indicator is proposed. Developed a list of solutions necessary for preparation in laboratory conditions followed by application in "field" conditions. Proposed the criteria for estimating the results of a semi-quantitative measurement of the AV by the express method.

References

1. G.G. Lysakovskii, *Research of transformer oil aging in paper-oil insulation in close to exploitational circumstances* (*Liquid fuel and oil in energetics*: treatise collection. - M.: «Energoizdat», 1982)

2. S.P.Vysogorets, *Development of the new methods and quality valuation algorithm of 35-110kV power transformer exploitational oil. Dissertation for the degree of Candidate of Engineering Sciences* (SPb., 2012, 260 p).

3. *Enchiridion of repair and maintenance of power transformers*. (M.: IPKgossluzhby, 2008, 852 p).

4. D.E. Hank, *Business-forecasting* (translation from english – 7th edition. – M.: Publishing House «Williams», 2003, 665 p).

5. *MKHA 05-09 Measurement methods Determination of transformer oil acid number by titrimetric method*. - SPb.: Scientific and Production Association «Electrum» (2009 (2014 edition)) – 15 p.

6. *GOST 5985-79 (ST SEV 3963-83) Petroleum products. Method of acidity and acid number determination*. (M.: Izdatelstvo Standartov, 1994, 9 p).

7. *Reagents for technical analysis: B.R.* (M.: Metallugria, 1988, 384 p).