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Regression Model for Determining the Breaking Voltage of Cleaned Transformer Oils

Yusupov Dilmurod Turdaliyevich , Khamrakulova Hilola Abdurashidovna

LLC "Scientific and Technical Center" JSC "Uzbekenergo", Senior Researcher
Fergana Polytechnic Institute, assistant professor

ABSTRACT: The process of carrying out experimental research on the cleaning of spent transformer oils is a labor-intensive work. As a result of research, not all samples of waste transformer oils are cleaned from various impurities. In order to save on the cost of conducting field experiments on the purification of spent transformer oils, mathematical models are given in this paper. The developed regression mathematical models allow to predict values of breakdown voltage of transformer oils to be cleaned without carrying out field experiments.

KEY WORDS: regression model, ceramic membrane filter, silica gel, zeolite, basic parameters of regression, experimental values, estimated values.

I. INTRODUCTION

In the liquid insulation of power transformers with long-term operation, aging processes occur, which significantly reduces its electrical strength, which ultimately can lead to an emergency and economic losses.

Pure transformer oil, free from various impurities, regardless of its chemical composition, has a high breakdown voltage sufficient for practice (more than 60 kV) [1]. If you gradually increase the voltage applied to the dielectric, then when a certain value is reached, the resistance of the dielectric decreases sharply. This critical voltage at which the dielectric becomes a conductor determines the dielectric strength of the oil. The voltage at which oil breakdown occurs in a standard arrester is called the breakdown voltage (kV). A decrease in the breakdown voltage indicates, as a rule, that the oil is contaminated with various impurities [2-5].

In order to increase the breakdown voltage of the used transformer oil, it is purified. Purification of used transformer oil is one of the most effective ways of organizing its reuse.

Experimental studies on the purification of used transformer oils with a volume of 30 liters were carried out on the basis of a developed and manufactured laboratory installation [6-7]. The spent transformer oils were gradually passed through a ceramic membrane filter, an adsorbent — silica gel, and an adsorbent — zeolite [8]. The results of each cleaning stage were checked for breakdown voltage in accordance with the normative document [9]. All refined transformer oil samples met the requirements of regulatory documents [10-11]

The process of conducting experimental studies on the purification of used transformer oils using a ceramic membrane filter and adsorbents is a laborious work and requires the necessary time. As a result of research, not all samples of used transformer oils are cleaned from various impurities.

Therefore, an urgent task is to predict the values of the breakdown voltage to be cleaned of transformer oils without carrying out field experiments, which allows saving costs (for carrying out field experiments). In this regard, the purpose of this scientific work is the development of mathematical models for determining the breakdown voltage of purified transformer oils using a ceramic membrane filter and adsorbents.

II. OBJECTS AND METHODS OF RESEARCH.

The efficiency of the process of cleaning used transformer oils depends mainly on the breakdown voltage of the liquid dielectric. The average values of the obtained experimental data on the breakdown voltage of transformer oil before and after each stage of purification served as the basis for the development of a regression mathematical model [6-8].

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To develop mathematical models for determining the breakdown voltage of purified transformer oils using a ceramic membrane filter and adsorbents, the mathematical apparatus of regression analysis was used.
Regression analysis is a statistical method for investigating the effect of one or more independent variables x_1, x_2, ..,x_p on the dependent variable y.

The regression equation [12], which establishes a linear relationship between the two indicators, is:

$$y_i = a + bx_m \quad (1)$$

Where,

y_i is the effective indicator after cleaning the used transformer oil;

x_m - factor index of used transformer oil;

a is a regression constant that does not depend on the factor x;

b - regression coefficient, which shows the effect on the effective indicator of changes in the magnitude of the factor per unit of its measurement.

To solve the equation, we will use the least squares method, linear regression, which has the form

$$\begin{bmatrix} n & \sum x_i \\ \sum x_i & \sum x_i^2 \end{bmatrix} \begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} \sum y_i \\ \sum x_i y_i \end{bmatrix} \quad (2)$$

Where,

n is the number of the experiment performed;

$\sum x_i$-sum of indicators of used transformer oil;

$\sum y_i$-the sum of effective indicators after cleaning the used transformer oil.

The solution to the system gives unbiased estimates of b and a:

$$b = \frac{n\sum x_i y_i - \sum x_i \sum y_i}{n\sum x_i^2 - (\sum x_i)(\sum x_i)} \quad (3)$$

$$a = y_i - bx \quad (4)$$

III. EXPERIMENTAL DATA AND DISCUSSION OF RESEARCH RESULTS.

The regression model for determining the breakdown voltage of transformer oil purified using a ceramic membrane filter is given by the equation:

$$y_1 = a_1 + b_1 x_1 \quad (5)$$

Where,

y_1 - indicator of the breakdown voltage of the used transformer oil after cleaning with a ceramic membrane filter, kV;

x_1 - indicator of the breakdown voltage of the used transformer oil before cleaning, kV;

a_1 - regression constant;

b_1- is the regression coefficient.

Using formulas (3) and (4), we determine the coefficients of the regression model: $a_1 = 1.012$; $b_1 = 10.73$.

The regression model for determining the breakdown voltage of transformer oil purified using a ceramic membrane filter is as follows:

$$y_1 = 1{,}012 + 10{,}73x_1 \quad (6)$$

According to (6), we determine the calculated values of the breakdown voltage of the used transformer oil after cleaning with a ceramic membrane filter and draw a graph for comparison with the experimental values (Figure 1). Figure 1 shows that the calculated values almost coincide with the experimental values.

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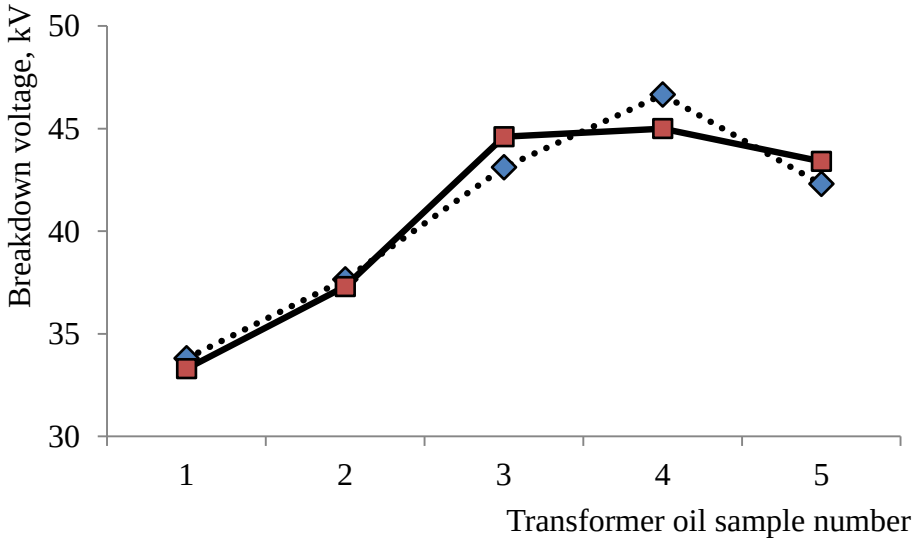

Fig.1. Experimental and calculated values of the breakdown voltage of the used transformer oil after cleaning with a ceramic membrane filter

The regression model for determining the breakdown voltage of transformer oil purified using a ceramic membrane filter and an adsorbent (silica gel) is given by the equation:

$$y_2 = a_2 + b_2 x_1 \quad (7)$$

Where,

u_2 is the breakdown voltage indicator of the spent transformer oil after cleaning with a ceramic membrane filter and an adsorbent (silica gel), kV;

x_1 - indicator of the breakdown voltage of the used transformer oil before cleaning, kV;

a_2 - regression constant;

b_2 is the regression coefficient.

Using formulas (3) and (4), we determine the coefficients of the regression model: $a_2 = 24.75$; $b_2 = 0.747$.

The regression model for determining the breakdown voltage of transformer oil purified using a ceramic membrane filter and an adsorbent (silica gel) is as follows:

$$y_2 = 24{,}75 + 0{,}747 x_1 \quad (8)$$

According to (8), we determine the calculated values of the breakdown voltage of the spent transformer oil after cleaning with a ceramic membrane filter and an adsorbent (silica gel) and build a graph for comparison with experimental values (Figure 2). Figure 2 shows that the calculated values almost coincide with the experimental values.

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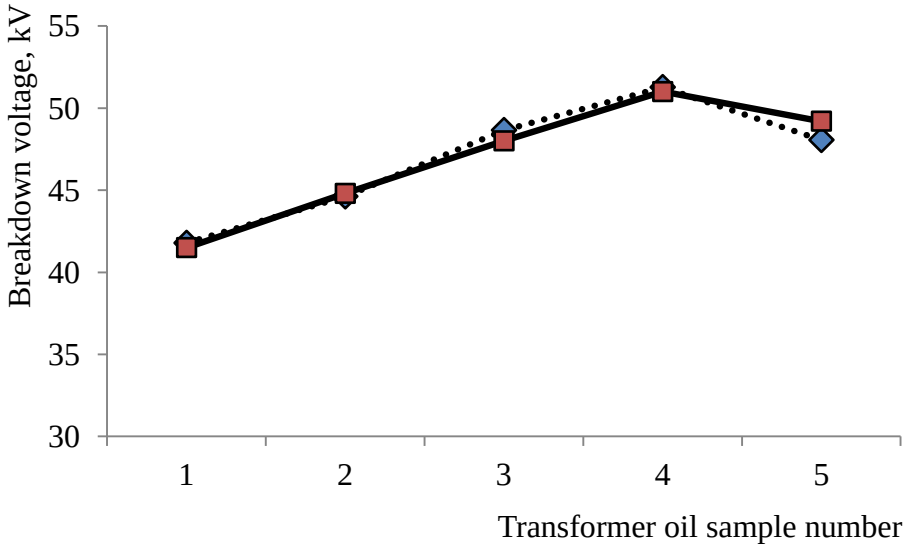

Fig.2. Experimental and calculated values of the breakdown voltage of the used transformer oil after cleaning with a ceramic membrane filter and an adsorbent (silica gel)

The regression model for determining the breakdown voltage of transformer oil purified using a ceramic membrane filter and adsorbents (silica gel and zeolite) is given by the equation:

$$y_3 = a_3 + b_3 x_1 \quad (9)$$

Where,

y_3 - indicator of the breakdown voltage of the spent transformer oil after cleaning with a ceramic membrane filter and adsorbents (silica gel and zeolite), kV;

x_1 - indicator of the breakdown voltage of the used transformer oil before cleaning, kV;

a_3 - regression constant;

b_3- is the regression coefficient.

Using formulas (3) and (4), we determine the coefficients of the regression model: $a_3 = 59.99$; $b_3 = -0.026$.

The regression model for determining the breakdown voltage of transformer oil purified using a ceramic membrane filter and adsorbents (silica gel and zeolite) is as follows:

$$y_3 = 59{,}99 - 0{,}026x_1 \quad (10)$$

According to (10), we determine the calculated values of the breakdown voltage of the spent transformer oil after cleaning with a ceramic membrane filter and an adsorbent (silica gel) and build a graph for comparison with experimental values (Figure 3). Figure 3 shows that the calculated values almost coincide with the experimental values.

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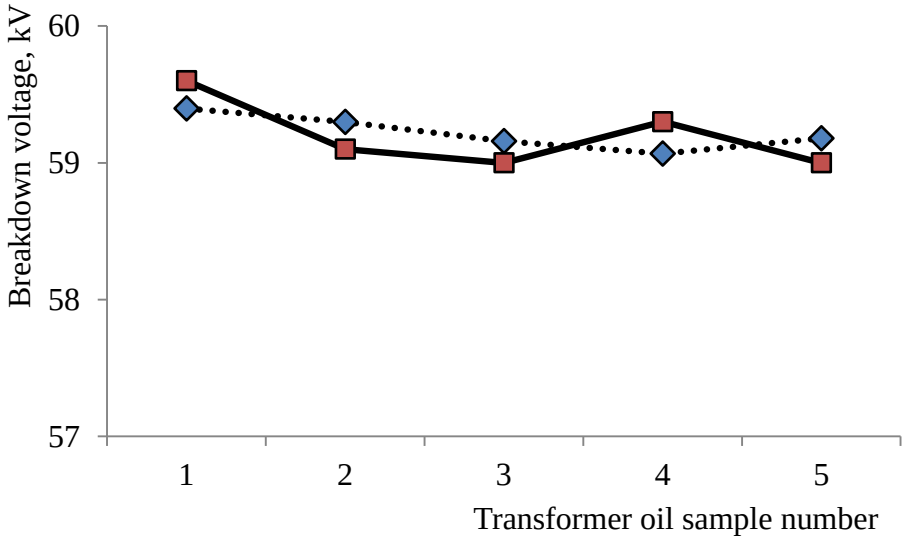

Fig.3. Experimental and calculated values of the breakdown voltage of the used transformer oil after cleaning with a ceramic membrane filter and adsorbents (silica gel and zeolite)

IV. CONCLUSION

1. As a result of the study, mathematical models were developed to determine the breakdown voltage of purified transformer oils using a ceramic membrane filter and adsorbents based on regression analysis.

2. The obtained regression mathematical models make it possible to predict the values of the breakdown voltage of transformer oils to be cleaned without carrying out field experiments.

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