International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

September 2024 Issue 60 Volume 16 Number 3 Pages 127-134

# DETERMINATION OF INSULATION DEGRADATION LEVEL AND LOCATION BETWEEN WINDINGS OF TRANSFORMER

**N.A. Mufidzade G.G. Ismayilova S.A. Khanahmedova**

*Power Faculty, Azerbaijan State Oil and Industry University, Baku, Azerbaijan*
*mufidzada@yahoo.fr, gulgaz77@mail.ru, samira1009@mail.ru*

**Abstract-** The presented article is devoted to the study of the degree of damage to the longitudinal insulation (inter-winding insulation) of the transformer windings and the localization of damage in the winding. The problem under consideration is studied using mathematical modeling. For this purpose, a well-known replacement circuit for an equivalent transformer circuit was used. The article discusses a new method for diagnosing the longitudinal insulation of transformer windings. To determine the location and degree of damage (aging) of the longitudinal insulation of the winding, a simple circuit is used - the winding is connected to a pulse voltage source through a resistor, and the neutral to the second resistor has a resistance equal to the characteristic resistance of the winding. Two issues are considered - determining the degree of destruction of the longitudinal insulation and localization of damage in the circuit. The input and output currents are measured, as well as the frequency of vibrations of the winding when damage of varying severity is detected at different points of the winding. The dependences of the input and output currents, as well as the oscillation period of the winding on the location and degree of insulation damage, are determined. Using the obtained curves of these dependencies, the location and degree of damage to the insulation of the transformer winding are determined. Power transformers are one of the main elements of electrical networks, and their damage often leads to serious breakdowns in electrical systems, which, in turn, lead to large economic losses. To reduce the likelihood of such accidents, the insulation level of the transformer windings is regularly checked using various tests, that is, the insulation level is diagnosed.

**Keywords**: Insulation Diagnostics, Impulse Voltage, Damage Insulation, Insulation Aging.

## 1. INTRODUCTION

As a rule, damage to the insulation of transformer windings is usually caused by the wear of this insulation. Therefore, to determine the degree of wear of the insulation of the windings, a systematic check of their insulation level is carried out, that is, a diagnosis of the insulation condition of the windings is carried out. Thus, in addition to the natural aging of the insulation due to long-term operation, accidental defects in the circuit are also detected. According to the results of diagnostics carried out in transformers, the degree of wear of the insulation of its elements is determined. In important cases, a decision is made to carry out urgent preventive maintenance.

As the insulation of the transformer winding wears out, its electrical parameters and corresponding characteristics change. Changing the circuit parameters changes the specific frequency, shape, and amplitude of voltages and currents in its various parts, as well as the distribution of this voltage across the circuit. Such changes make it possible to determine with sufficient accuracy the degree of insulation wear and accidental defects in any part of the circuit, that is, the condition of the transformer.

For the normal operation of transformers, it is very important to identify problems that arise in them before any serious accident occurs. Currently, the importance of having more sophisticated diagnostic methods that ensure the high reliability of transformer elements and the growing demand for this are quite obvious. Various methods are used to determine the electrical and technical condition of the insulation. Using this set of methods, the general state of isolation is determined [1, 5]. However, the importance of having more advanced diagnostic methods that ensure the highest reliability of transformer elements and the growing demand for them is always very obvious.

All the progress made in the field of insulation diagnostics is being implemented in practice by creating a set of techniques that assess the condition of the transformer, and thus more complex diagnostic methods are being created, and this work is constantly ongoing. In recent years, quite interesting, high-precision, non-destructive methods have been introduced. Of these, the most commonly used methods are Frequency Response Analysis (FRA), Low-Voltage Pulse Method (LVIM), and Scan Frequency Response Analysis (SFRA) [2, 8, 10]. The FRA method is used for electrical and mechanical testing of transformers. This method is used to identify defects that occur in transformers after their transportation and eliminate severe short circuits in the system, seismic events, and severe fires. The LVIM method is used to detect defects in transformer windings.

Registered: 240109 Article Info: 1840 Accepted: 240826
Reserved: 240519 Available: 240930

In some cases, sensitivity is not enough. The SFRA method is also one of the most widely used methods. Using this method, the frequency in the circuit is measured and the insulation quality is evaluated based on the value obtained. The disadvantages of these methods are that many devices are used in their application, some of which are quite expensive devices, experiments are lengthy, and the analysis of the results (curves) takes a long time.

## 2. ISSUE AND PURPOSE

All the progress made in the field of insulation diagnostics is implemented in practice by creating a set of techniques that assess the condition of the transformer. Among these methods, the method of frequency analysis of verification results is considered as a method with high accuracy, economical and non-destructive [1, 3]. The presented article is devoted to the study of the degree of damage to the longitudinal insulation (inter-winding insulation) of the transformer windings and the location of the damage in the winding. The considered problem is studied through mathematical modeling. For this, the well-known equivalent replacement scheme of the transformer circuit was used. In the replacement scheme, it was assumed that the winding of a TD-80000/220 transformer type consists of 13 parts [2, 3].

In order not to complicate the obtained current and voltage curves and not to complicate their analysis, it was considered advisable to use a pulse voltage as the applied voltage. The amplitude of this voltage was taken in a value convenient for the report. In the work under consideration, a pulse voltage with parameters of 1.2/50 μs was used as a pulse voltage, which is used in all electrical testing laboratories. The amplitude of this pulse is 1000 V. The pulse voltage is applied to the input of the transformer winding through a resistor with a resistance of 100 Ohms. The purpose of this is that in various versions of the report, no voltage at the transformer input does not change in magnitude (equal to the voltage of the source), and current can be measured at this point.

Usually, in scientific research, insulation breakdown is modeled as a change in the electrical parameter of the corresponding element of the equivalent replacement circuit at a location taken as the insulation breakdown point. Since the presented work studies the determination of the degree of destruction of the longitudinal insulation, the change in the longitudinal capacitance at the point of damage to the circuit is considered. In the contour, at the point of insulation breakdown, the longitudinal throughput is considered as $C=KC_{ni}$, that is, since the longitudinal throughput of the contour element in the normal case of insulation increases by $K$ times $C_{ni}$. A change in $K$ in the range of $1\div10^3$ was accepted.

In this article, two issues are considered, the determination of the degree of failure of the longitudinal insulation and the location of the failure in the circuit [4, 6, 7]. Determination of the degree of breakdown of insulation in the course is considered for cases when the breakdown occurs at the points 0.1l, 0.25l, 0.4l, 0.5l, 0.75l loop (l is the length of the loop). In each case, the longitudinal throughput varies in the above interval.

Since the task under consideration is to determine the breakdown of the longitudinal insulation of the circuit, the study of the voltage distribution along the circuit is not considered here, since the failure of the longitudinal insulation of one element of the circuit leads to the fact that the circuit is divided not into n parts, but into $n-1$ element, and in both cases, the voltage distribution is not so much different. It is very difficult to detect such small differences. Therefore, in the issue under consideration, the distribution of currents along the circuit should be investigated, since the failure of an element in the circuit changes its resistance, which affects the magnitude of currents [2, 5, 7].

Since two points need to be measured in transformers - the winding input and the neutral point, current curves can only be obtained at these points. One issue that should be clarified here, is the neutral circuit mode. The current wave returning from the neutral changes the current throughout the circuit, including the current at the input of the circuit. On the other hand, since insulation breakdown can occur in any part of the circuit, reverse current waves are generated at this point, and the effect of these waves on the current values in different parts of the circuit is also different. To reduce the impact of return waves, it is more desirable to reduce the number of these waves. Therefore, a resistor must be connected to this neutral, the resistance of which is equal to the wave resistance of the circuit, so that a return wave does not occur in the neutral of the circuit. For this purpose, in the study under consideration, the wave resistance of the transformer circuit was first determined, a resistor corresponding to this resistance was added to the neutral in the reporting circuit, and then current curves were removed for cases of varying degrees of insulation breakdown at different points of the circuit [5, 6].

## 3. MATHEMATICAL MODEL OF THE RESEARCH OBJECT

Given that in real transformers, the windings have only two available points - the input of the winding and its neutral - the current can be measured at these two points. Therefore, in this work, the dependence of the currents at the input and the neutral of the winding and their frequency on the degree of damage to the longitudinal insulation and its location in the winding is investigated. Here, attention should also be paid to the fact that the values of these currents with different degrees of damage to the longitudinal insulation at different points of the winding will be differently affected by the reflected current wave from the neutral winding, which is of great importance (almost equal to the value of the DC wave) in this neutral mode. To obtain more accurate results, it is necessary to minimize the influence of the reflected current wave and, at best, create a neutral mode in which this wave will be absent. To do this, a resistor with a resistance equal to the characteristic resistance of the winding should be connected to the neutral winding of the transformer, after which all necessary calculations should be performed. By this, the design scheme of the winding will have the following form (Figure 1) [6].

The $r_{bx}$ is a resistor connected to the input of the winding, and $r_b$ in is a resistor having a resistance equal to the characteristic resistance of the winding, which is connected to its neutral. The equations describing the electromagnetic process occurring in the transformer winding when exposed to voltage have the following form [7, 9]:

$$u_1 - u_2 = r_1 i_1 + L\frac{di_1}{dt} + \sum_{1,k\neq 2}^{n} M_{1k}\frac{di_k}{dt} \tag{1}$$

$$u_2 - u_3 = r_2 i_2 + L\frac{di_2}{dt} + \sum_{1,k\neq 2}^{n} M_{1k}\frac{di_k}{dt} \tag{2}$$

$$u_{n-1} - u_n = r_n L_1 i_{n-1} + L\frac{di_{n-1}}{dt} + \sum_{1,k\neq n-1}^{n} M_{1k}\frac{di_k}{dt} \tag{3}$$

Currents flowing through branches [3, 8]:

$$i_1 - i_2 = -C_k\frac{du_1}{dt} + \left(2C_k + C\right)\frac{du_2}{dt} - C_k\frac{du_3}{dt} \tag{4}$$

$$i_2 - i_3 = -C_k\frac{du_2}{dt} + \left(2C_k + C\right)\frac{du_3}{dt} - C_k\frac{du_4}{dt} \tag{5}$$

$$i_{n-1} - i_n = -C_k\frac{du_{n-1}}{dt} + \left(2C_k + C\right)\frac{du_n}{dt} - C_k\frac{du_{n+1}}{dt} \tag{6}$$

$$i_n - i_d = -C_k\frac{du_n}{dt} + \left(C_k + C\right)\frac{du_{n+1}}{dt} \tag{7}$$

The solution to these equations determines the voltage and current at any point in the winding. For example, the expression for voltage is [2, 8]:

$$U_{\max}\left(x\right) = U_{inst}\left(x\right) + \sum_{1}^{\infty} U_k\left(x\right)\cos\omega t \tag{8}$$

where, $\sum_{1}^{\infty} U_k\left(x\right)\cos\omega_k t$ is the sum of the amplitudes of all harmonics, which can be determined from this expression at $t$=0:

$$\sum_{1}^{\infty} U_k\left(x\right) = U_{inst}\left(x\right) - u\left(x\right) \tag{9}$$

Then the maximum voltage value at each point of the winding will be determined as,

$$U_{\max}\left(x\right) = U_{inst}\left(x\right) + \sum_{1}^{\infty} U_k\left(x\right) \tag{10}$$

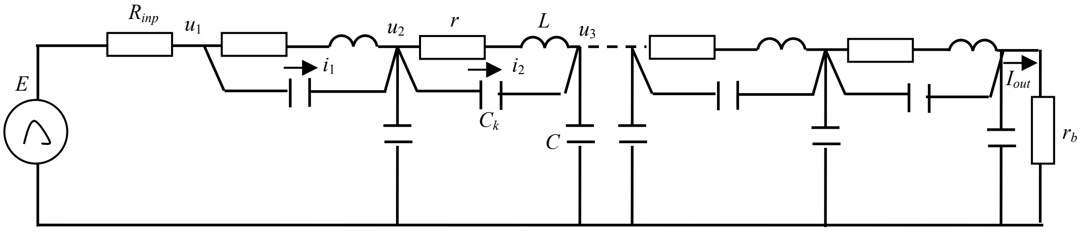


Figure 1. Electrical circuit for diagnostics longitudinal insulation of transformer winding

The current in the winding is determined similarly. If there is damage in the winding, the current in the winding section between the start and the damaged point will increase, and in the section between the damaged point and the neutral will decrease. The deeper the damage and the closer the damage is to the beginning of the winding, the more these currents will change. Therefore, using the current values at the beginning and in the neutral of the transformer winding, it is possible to judge the location and depth of damage in the transformer winding [1, 9, 10].

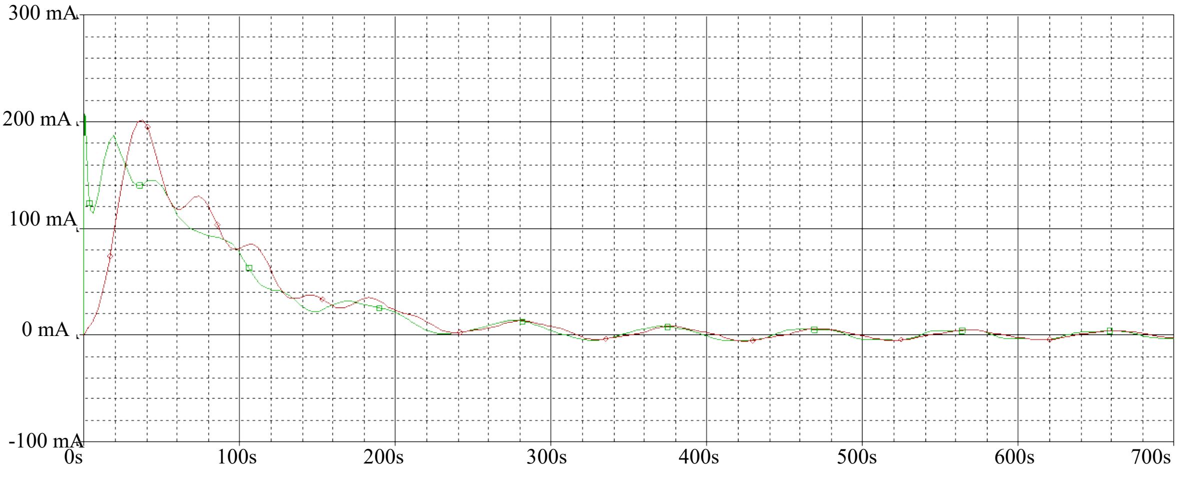
As a rule, in studies, the deterioration of the longitudinal or transverse insulation of the winding is modeled by changing the electrical parameter of the corresponding element of the equivalent circuit (longitudinal or transverse capacitance) located at a point that is taken as the point of damage. Therefore, two tasks are considered in this paper - determining the degree of insulation damage (or the degree of insulation aging) and its place in the transformer winding. Determination of the degree of damage to the longitudinal insulation [7, 9].

## 4. STUDY OF THE REPORT

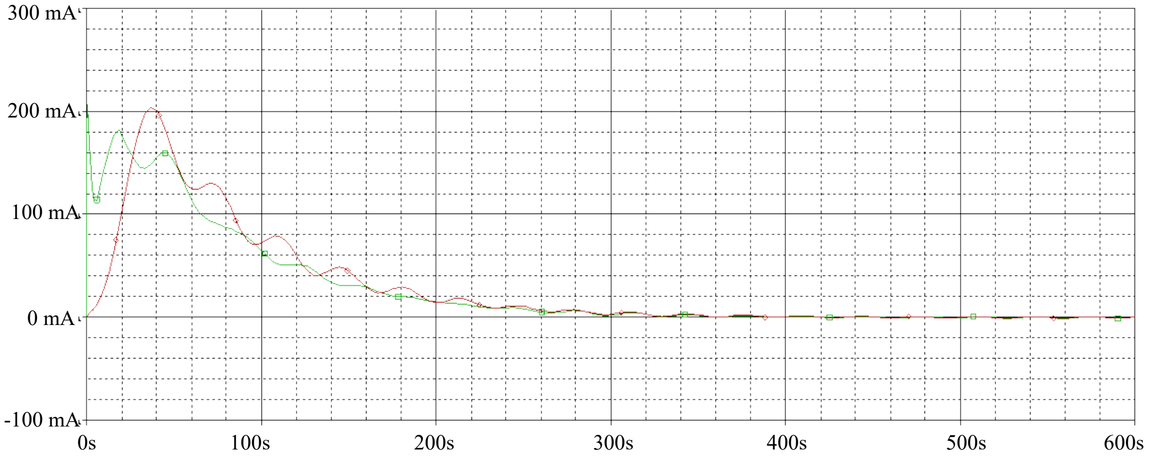
The above calculations were performed using computer technology for cases of normal and damaged insulation to varying degrees in different parts of the transformer winding. As can be seen from Table 1, in all cases under consideration, as the value of the longitudinal capacitance increases at each of the five points (at points 0.11, 0.25l, 0.41, 0.51, 0.751), the input current in the winding increases and as the damaged point moves away from the beginning of the winding, the rate of this increase decreases. Thus, if the winding is damaged at the point of 0.11, an increase in the longitudinal capacitance by 1000 times leads to an increase in the input current of the winding from a value of 206.7 mA to a value of 229.5, and if there is damage at the point of 0.751, this current increases to 208 mA, those. only 2 mA. The minimum input current value of 206.7 mA corresponds to the case of normal winding insulation.

Figure 1 shows the curves of the input and output currents of the winding for normal insulation and in two different degrees (10 and 100 times) of its damage at point 10 of the winding ($x$=0.751) of the transformer. As can be seen from Figure 2, the amplitude and period of input current oscillations increase with increasing capacitance in the damaged section of the winding. A strong increase in the longitudinal capacitance of a part of the winding, as it were, short-circuits this part, i.e. removes this part from the general circuit of the winding and therefore the total longitudinal capacitance of the winding increases, which leads to an increase in its oscillation period.

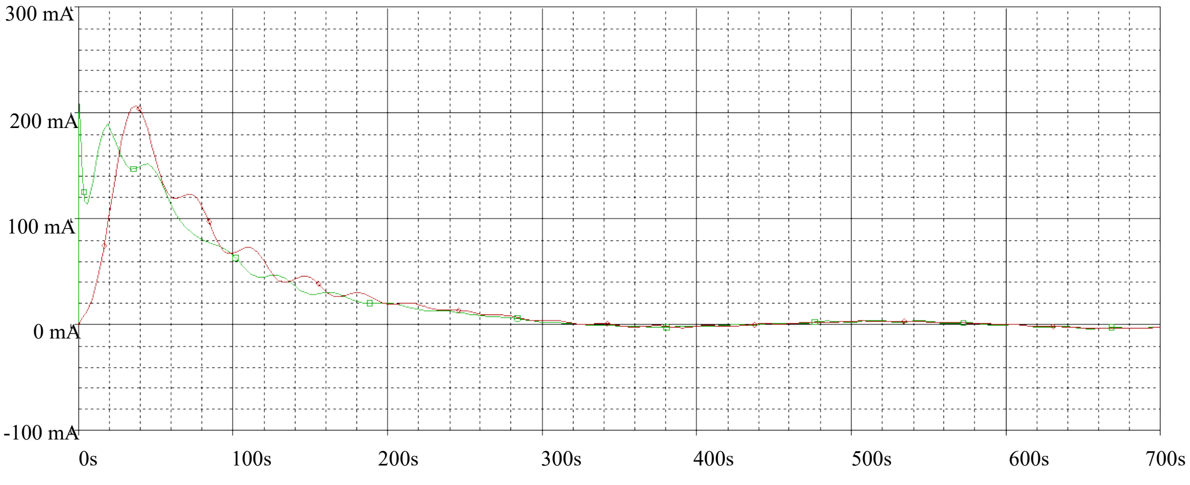
It can be seen from Table 1 that the input current increases as the capacitance increases separately at each of the five points (0.11, 0.251, 0.41, 0.51, 0.751). It is understood that the minimum value of this current corresponds to the case where the insulation is normal.



(a)



(b)



(c)

Figure 2. Curves of input and output currents of the transformer winding at damage to its insulation at point $x$=0.751
a) current curves with intact insulation; b) with increasing capacity by 10 times, c) with by 100 times

The dependence of the relative value of the input current on the frequency of change of the capacitance at the breakdown point and the distance between the breakdown point and the entrance of the circuit $I_{input}/I_{input.norm}=f(K)$ is shown in Figure 3. The input current increases at a very high rate until the capacity at the breakdown point increases by approximately 5-6 times, in the range of 6÷30 times, the rate of increase of this current decreases slightly, and when it increases more than 30 times, the current increase is very small. Increasing the capacity by more than 50 times, the input current almost does not change. So, when the insulation breakdown occurs at the 0.751 point of the circuit, the above relative value of the input current is 1.0008 mA (Figure 3, curve

5), when it occurs at the 0.5ℓ point –1.006 mA (Figure 3, curve 4) and at the 0.25ℓ point and reaching values of 1.035 mA (Figure 2, curve 2) indicates the occurrence of inter-winding short circuit at this point.

The second factor affecting input current is the distance of the insulation breakdown point from the input of the loop. As the breakdown point moves away from the loop input, the input current decreases [8]. The dependence of the current in the output (neutral) of the transformer loop on the frequency of the increase of the capacity at the insulation breakdown point shows that these current decreases when the capacity increases up to 5 times and increases when it increases more than 5 times (Table 1). As the capacity increases up to 50 times, the rate of increase of the output current becomes very large, as does the rate of increase of the input current, and after that the rate decreases considerably.

The output current increases as the insulation breakdown point moves away from the entrance to the middle of the loop and decreases as it moves away from the middle to the end of the loop [10, 13].

The largest value of the output current is obtained when the insulation breakdown point is in the middle of the loop. In cases where the insulation is broken in the parts close to the entrance and neutral of the circuit, the current in the neutral is at its lowest value, and this value is very close to the value in the case of no insulation failure. All this can be seen from the dependence of $I_{out}/I_{out.norm}=f(K)$ given in Figure 4 [3, 6, 9]. Due to such a change in the output current of the transformer circuit, although it can be said about the aging of its insulation, nothing can be said about the location of the breakdown. The location of insulation failure can be determined only by the value of the input current [9].

Table 1. Calculation results for normal insulation and for the case of insulation failure

| Location of damage | Current and oscillation period | $C_w$ | $2C_w$ | $5C_w$ | $10C_w$ | $20C_w$ | $50C_w$ | $100C_w$ | $500C_w$ | $800C_w$ | $1000C_w$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.11 | $I_{in}$, mA | 206.725 | 216.761 | 224.210 | 226.828 | 228.163 | 228.974 | 229.245 | 229.463 | 229.485 | 229.497 |
| | $I_{in}/I_{ent\ n}$ | 1.0 | 1.0485 | 1.0846 | 1.0972 | 1.1037 | 1.1076 | 1.1089 | 1.11 | 1.1101 | 1.1102 |
| | $I_{out}$, mA | 204.538 | 202.693 | 197.587 | 197.563 | 199.525 | 202.165 | 203.759 | 204.759 | 204.873 | 204.977 |
| | $I_{out}/I_{out\ n}$ | 1.0 | 0.991 | 0.966 | 0.9659 | 0.9755 | 0.9884 | 0.9962 | 1.0011 | 1.0016 | 1.0021 |
| | $T$, μ | 30 | 32 | 56 | 82 | 116 | 180 | 252 | 564 | 720 | 794 |
| | $T/T_n$ | 1.0 | 1.0667 | 1.8667 | 2.7333 | 3.8667 | 6.0 | 8.4 | 18.8 | 24.0 | 26.4778 |
| 0.25l | $I_{in}$, mA | 206.725 | 210.102 | 212.295 | 213.217 | 213.686 | 213.969 | 214.064 | 214.142 | 214.149 | 214.152 |
| | $I_{in}/I_{ent\ n}$ | 1.0 | 1.0163 | 1.0269 | 1.0314 | 1.0337 | 1.035 | 1.0355 | 1.0358 | 1.0359 | 1.0359 |
| | $I_{out}$, mA | 204,538 | 202.267 | 198.600 | 199.481 | 201.553 | 204.221 | 205.106 | 205.959 | 206.047 | 206.077 |
| | $I_{out}/I_{out\ n}$ | 1.0 | 0.9889 | 0.971 | 0.9753 | 0.9854 | 0.9985 | 1.0028 | 1.0069 | 1.0074 | 1.0075 |
| | $T$, μ | 30 | 34 | 62 | 84 | 122 | 190 | 262 | 590 | 750 | 825 |
| | $T/T_n$ | 1.0 | 1.1333 | 2.0677 | 2.8 | 4.0667 | 6.3333 | 8.7333 | 19.6667 | 25.0 | 27.5 |
| 0.4l | $I_{in}$, mA | 206.725 | 207.951 | 208.737 | 209.010 | 209.145 | 209.236 | 209.258 | 209.283 | 209.302 | 209.312 |
| | $I_{in}/I_{ent\ n}$ | 1.0 | 1.0059 | 1.0097 | 1.011 | 1.0117 | 1.0121 | 1.122 | 1.0123 | 1.0124 | 1.0125 |
| | $I_{out}$, mA | 204.538 | 201.661 | 199.050 | 201.451 | 203.167 | 205.717 | 206.642 | 207.667 | 207.715 | 207.737 |
| | $I_{out}/I_{out\ n}$ | 1.0 | 0.9859 | 0.9732 | 0.9849 | 0.9933 | 1.0058 | 1.0103 | 1.0153 | 1.0155 | 1.0156 |
| | $T$, μ | 30 | 42 | 66 | 90 | 126 | 206 | 286 | 620 | 784 | 950 |
| | $T/T_n$ | 1.0 | 1.4 | 2.2 | 3.0 | 4.2 | 6.8667 | 9.5333 | 20.6667 | 26.1333 | 31.6667 |
| 0.5l | $I_{in}$, mA | 206.725 | 207.339 | 207.732 | 207.867 | 207.935 | 207.978 | 207.991 | 208.000 | 208.001 | 208.002 |
| | $I_{in}/I_{ent\ n}$ | 1.0 | 1.003 | 1.0049 | 1.0055 | 1.0058 | 1.006 | 1.0061 | 1.0062 | 1.0062 | 1.0062 |
| | $I_{out}$, mA | 204.538 | 201.384 | 199.322 | 201.548 | 204.858 | 206.969 | 207.080 | 208.267 | 208.339 | 208.364 |
| | $I_{out}/I_{out\ n}$ | 1.0 | 0.9846 | 0.9745 | 0.9854 | 1.0016 | 1.0119 | 1.0124 | 1.0182 | 1.0186 | 1.0187 |
| | $T$, μ | 30 | 44 | 68 | 96 | 132 | 212 | 306 | 680 | 850 | 972 |
| | $T/T_n$ | 1.0 | 1.4667 | 2.2667 | 3.2 | 4.4 | 7.0667 | 10.2 | 22.6667 | 28.3333 | 32.4 |
| 0.75l | $I_{in}$, mA | 206.725 | 206.813 | 206.868 | 206.885 | 206.896 | 206.902 | 206.904 | 206.905 | 206.905 | 206.906 |
| | $I_{in}/I_{ent\ n}$ | 1.0 | 1,0004 | 1.0007 | 1.0008 | 1.0008 | 1.0009 | 1.0009 | 1.0009 | 1.0009 | 1.0009 |
| | $I_{out}$, mA | 204.538 | 202.702 | 200.494 | 201.668 | 203.351 | 205.454 | 205.524 | 206.226 | 206.265 | 206.304 |
| | $I_{out}/I_{out\ n}$ | 1.0 | 0991 | 0.9802 | 0.986 | 0.9942 | 1.0045 | 1.0048 | 1.0083 | 1.0084 | 1.0086 |
| | $T$, μ | 30 | 42 | 64 | 88 | 128 | 200 | 272 | 610 | 770 | 845 |
| | $T/T_n$ | 1.0 | 1.4 | 2.1333 | 2.9333 | 4.2667 | 6.6667 | 9.0667 | 20.3333 | 25.6667 | 28.1667 |

Figure 4 shows the dependence of the frequency of the input and output currents of the transformer circuit on the degree of insulation damage and the location of the damage in the circuit. This dependence is given in the figure $T=f(K)$ for the points mentioned above. As can be seen from Table 1 and Figure 5, as the degree of insulation breakdown increases, this period also increases monotonically in all five cases - when the breakdown is at 0.11, 0.251, 0.41, 0.51, 0.751 points. In the case of the violation, in the middle of the cycle, the values of the period are larger than the corresponding values in the other two cases [4, 5, 8].

When the degree of breakdown of the transformer loop insulation (capacity increase at the breakdown point) is up to 50, the value of the period is approximately the same regardless of the location of the breakdown point, in this case, this value is close to 200 μs. The effect of the location of the disturbance is manifested when the degree of disturbance is above 50.

It should be noted that this experiment should be carried out for all transformers in their normal condition (after the transformer has been brought to the place of installation before commissioning) and the input current should be measured.

In the event of an accident, this value of the input current should be used in the manner indicated above [8, 9]. When the degree of breakdown of the transformer loop insulation (capacity increase at the breakdown point) is up to 50, the value of the period is approximately the same regardless of the location of the breakdown point, in this case, this value is close to 200 µs.

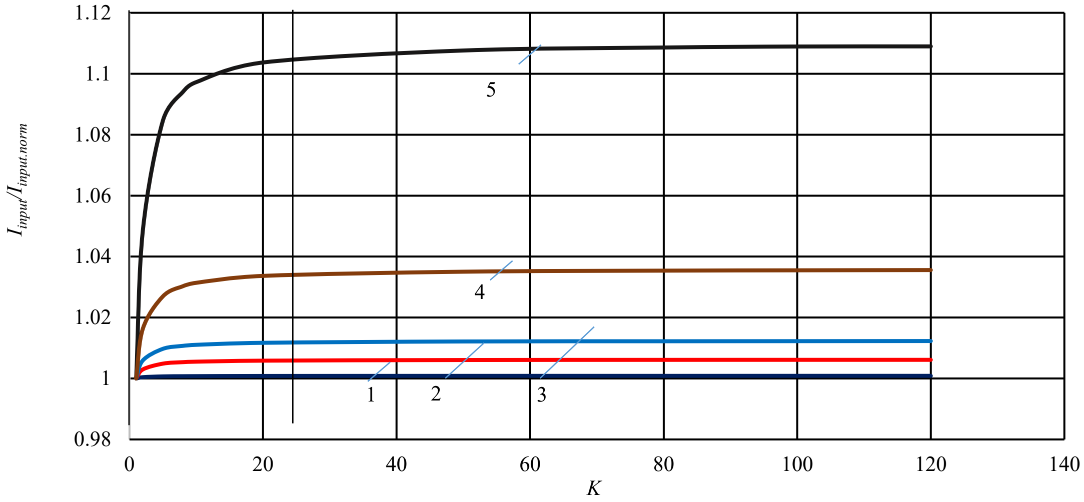


Figure 3. $I_{input}/I_{input.norm} = f(K)$ dependency

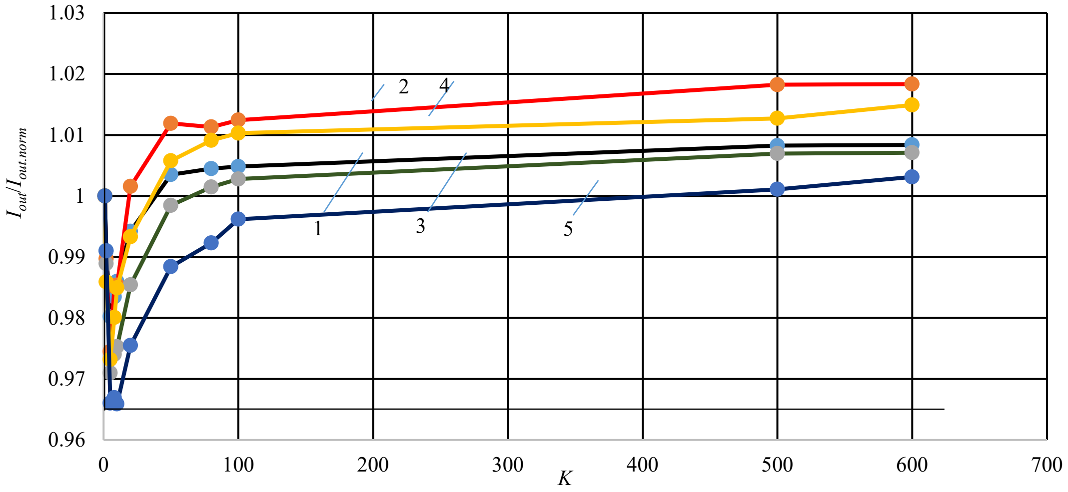


Figure 4. $I_{out}/I_{out.norm}=f(K)$ dependency

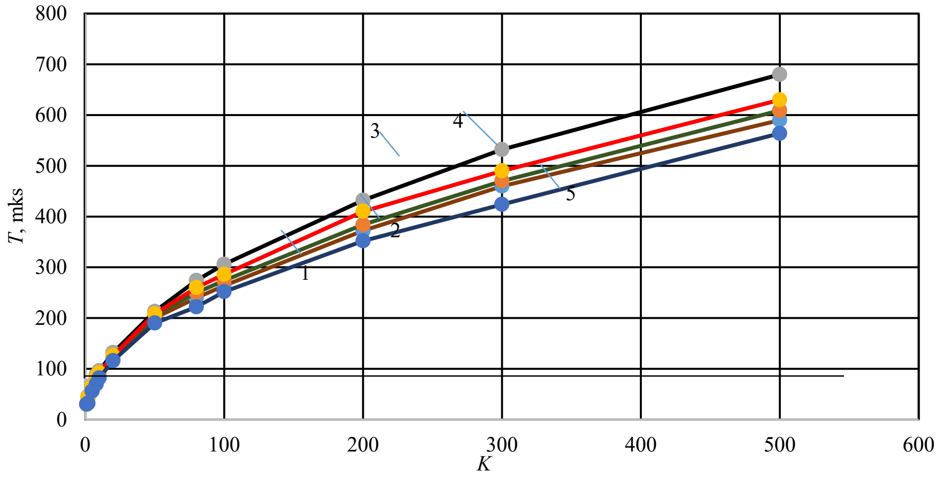


Figure 5. $T=f(K)$ dependency

The effect of the location of the disturbance is manifested when the degree of disturbance is above 50 [9]. It should be noted [11, 12] that this experiment should be carried out for all transformers in their normal condition (after the transformer has been brought to the place of installation before commissioning) and the input current should be measured. In the event of an accident, this value of the input current should be used in the manner indicated above.

## 5. CONCLUSION

1. A method with sufficient accuracy to determine the location and extent of the breakdown of only the longitudinal insulation of the transformer windings, experiments conducted at low voltage, and therefore non-destructive, is proposed. This proposed method overcomes the shortcomings of many existing methods (FRA, LVIM, SFRA) for determining the degree of breakdown of the general insulation of transformer windings - not requiring a large number of expensive equipment for conducting the experiment, conducting the experiment at high voltage, taking measurements and taking these measurements. it differs in the absence of features such as requiring a long time for its analysis.
2. In addition to the natural aging of the longitudinal insulation of the loops caused by long-term operation, the electrical scheme of the experiment and the report to determine the location and degree of damage of random defects in the loop is set.
3. In the damaged place of the loops, the effect of the degree of damage and the distance of this point from the beginning of the loop on the currents at its input and output and also on the specific frequency of the loop was determined. The dependence of these currents on the degree of insulation breakdown and the location of the breakdown in the loop is given graphically.
4. By applying impulse voltage to the damaged winding of the transformer, and from the curves of the currents at its input and output, their values and frequency values are taken, and using the dependences $I_{out}/I_{entry}=f\,(K, l)$ and $T/T_n=f\,(K, l)$, the damaged location and degree of damage in the circuit is appointed.

## REFERENCES

[1] N.A. Mufidzade, G.G. Ismayilova, E.N. Huseynov, "Effect of Line Carnation on Overvoltage in Transformers of Rated Voltage 330 kV", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 51, Vol. 14, No. 2, pp. 7-14, June 2022.

[2] E.P. Dick, C.C. Erven, "Transformer Diagnostic Testing by Frequency Response Analysis", In IEEE Transactions on Power Apparatus and Systems, pp. 2144-2153, IEEE Power and Energy Society, November 1978.

[3] E. Hanique, P.T. Vaessen, "A new Frequency Response Analysis Method for Power Transformers", In IEEE Transactions on Power Delivery, pp. 384-391, IEEE Power and Energy Society, January 1992.

[4] C.A. Sweetser, T.T. Mcgrail, "Sweep Frequency Response Analysis Transformers Applications", A Technical Paper from Doble Engineering, p. 12, 2010.

[5] A.A. Drobyshevski, "Assessment of Transformer Winding Mechanical Condition by Low-Voltage Impulse Method", In Power Tech Conference Proceedings, IEEE Power and Energy Society, pp. 112-121, Bologna, Italy, June 2003.

[6] N.A. Mufidzade, M.M. Megerbi, T.L. Otman Sherif, "Refinement of the Calculation Scheme Transformer Windings in Overvoltage Calculations", Electricity No. 1, pp. 56-57, Russia, Moscow, 2003.

[7] CIGRE Standard WG A2.26. "Mechanical-Condition Assessment of Transformer Windings Using Frequency Response Analysis (FRA)", P. Picher. CIGRE, p. 60, 2008.

[8] V.D. Razevig, "High Voltage Technique", Energy, p. 345, Moscow, Russia, 1976.

[9] A.M. Kraetge, M.N. Kruger, H.V. Viljoen, A.Z. Dierks, "Aspects of the Practical Application of Sweep Frequency Response Analysis (SFRA) on Power Transformers", The 6th Southern Africa Regional Conference, CIGRE, pp. 1-10, 2009.

[10] S.M. Jashandeep, "Novel Method for Detection of Transformer Winding Faults Using Sweep Frequency Response Analysis", In Power Engineering Society General Meeting, IEEE Power and Energy Society, pp. 1-9, June 2007.

[11] P.R. Roth, "Effective Measurements using Digital Signal Analysis", IEEE Spectrum, pp. 62-70, April 2021.

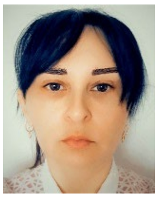
[12] R. Khalilisenobe, "Frequency Response Analysis (FRA) of Transformers as a Tool for Fault Detection and Location: A Review", Electric Power Systems Research, Vol. 155, pp. 330-345, February 2018.

[13] IEC 60076-18:2022, "Power Transformers - Part 18", Measurement of Frequency Response, p. 78, London, UK, 2022.

## BIOGRAPHIES

Name: **Nahid**
Middle Name: **Abdulla**
Surname: **Mufidzade**
Birthday: 26.07.1947
Birthplace: Ganja, Azerbaijan
Master: Power Plants, Department of Electrical Power Stations, Energy Faculty, Azerbaijan Institute of Oil and Chemistry, Baku, Azerbaijan, 1971
Doctorate: High Voltage Technology, Azerbaijan Scientific Research Energy Institute, Baku, Azerbaijan, 1980
The Last Scientific Position: Assoc. Prof., Department of Electric Networks and Systems, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, Since 1984
Research Interests: Investigation of Generation of Atmospheric Overvoltage's in Transformers and Autotransformers and Improvement of their Protection against the Overvoltage
Scientific Publications: 53 Papers, 5 Books, 1 Patent

Name: **Gulgaz**
Middle Name: **Gulaga**
Surname: **Ismayilova**
Birthday: 13.10.1977
Birth Place: Baku, Azerbaijan
Bachelor: Electric Power Engineering, Energy Faculty, Azerbaijan State Oil Academy, Baku, Azerbaijan, 1998
Master: Electric Power Engineering, Department of Electrical Power Stations, Energy Faculty, Azerbaijan State Oil Academy, Baku, Azerbaijan, 2000
Doctorate: Electric Power Engineering, Department of Electrical Power Stations, Energy Faculty, Azerbaijan State Oil Academy, Baku, Azerbaijan, 2013
The Last Scientific Position: Assist. Prof., Department of Electric Networks and Systems, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, Since 2013
Research Interests: Electrical Protection of Underground Oil and Gas Pipelines, Corrosion-Related Failure Analysis
Scientific Publications: 47 Papers, 5 Books



Name: **Samira**
Middle Name: **Alkhadi**
Surname: **Khanahmadova**
Birthday: 9.10.1967
Birth Place: Baku, Azerbaijan
Bachelor: Electrical Engineering, Department of Electrical Signal and Automation of Industrial Installations, Energy Faculty, Azerbaijan State University of Oil and Industry, Baku, Azerbaijan, 1988
Master: Electrical Engineering, Department of Electric Machines, Azerbaijan State University of Oil and Industry, Baku, Azerbaijan, 1990
Doctorate: Technical Sciences, Department of Electromechanics, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, 2014
The Last Scientific Position: Assoc. Prof., Department of Electromechanics, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, Since 2016
Research Interests: Control of Asynchronous Electric Drives, Alternative Energy Sources, Management of Various Technological Processes using Programmable Logic Controllers
Scientific Publications: 62 Papers, 14 Books, 23 Theses