Modeling the Dependence of Voltage on Ground Fault Parameters During Tests Under Load

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***Abstract*—Conducting insulation tests of electrical equipment under load in networks with a voltage of 6-35 kV is considered one of the urgent issues. For this, it is necessary to obtain artificial overvoltage in the network. It is necessary to determine the analytical dependencies between the network parameters and single-phase non-stationary ground faults in order to control the magnitude of the overvoltage. In single-phase non-stationary ground faults, the dependencies between such important parameters as overvoltage frequency, ground fault resistance, ground fault angle and network capacitance relative to the ground are subject to complex laws. Therefore, it is necessary to develop adequate mathematical models that allow knowing the interdependence of these parameters. This paper considers the problem of mathematical modeling of the relationships between the specified parameters and extreme voltage in networks with an isolated neutral as a result of non-stationary ground faults. Regression equations are obtained for the dependencies of the overvoltage frequency on the resistance and angle of the ground fault, the resistance and capacitance of the ground fault, the angle of the ground fault and the capacitance. The results confirmed the presence of strong correlations between these parameters and can be used for practical testing of equipment.**

Keywords—neutral isolated network, ground fault resistance, ground fault angle, capacity, regression equation

I. Introduction

Since the outage of electrical network equipment is related to ensuring safe working conditions for the staff, uninterrupted and reliable supply of electricity to consumers and minimizing the risks of possible accidents, in general, in order to prevent such problems in advance, special testing and adjustment works are planned or due to technical conditions is carried out. According to the construction rules of electrical installations, such tests are generally carried out when one of the following situations occurs: commissioning of the equipment or installation, after an accident, planned and unplanned repairs due to technical conditions, after the expiration of the period specified from the previous testing and inspection works, etc. At the same time, the high-voltage test of electrical equipment insulation should be carried out compulsorily for neutral-insulated distribution networks (DN) with a voltage of up to 35 kV [1, 2].

There is no doubt about the importance of carrying out high-voltage tests of insulation under load in order to obtain preliminary information about the potential damage of electrical equipment in neutral-insulated 6-35 kV distribution networks and to ensure uninterrupted electricity supply to electricity consumers [3, 4]. From the analysis of research works dedicated to this problem, it is clear that various methods and tools have been developed [5-7].

A test method of network insulation under load in 6-35 kV DN with neutral isolation was proposed [8,9]. According to this method, single-phase artificial non-stationary earth faults are created by applying the Petersen theory in PESH for organization of tests of electrical equipment and network insulation under load. From this point of view, it is possible to use the invented multifunctional high-voltage thyristor commutator device [8]. By using the mentioned test device, it is possible to create artificial single-phase non-stationary earth faults that follow Petersen's theory in neutral isolated 6-35 kV DN. Thus, by providing different values of the grounding phase angles with the help of the control unit of the device, it is possible to organize the grounding of the network phase through the switching unit. Since it is possible to control the transition processes during non-stationary single-phase earth faults in the 6-35 kV DN by changing the earthing angle, resistance and topology of the network (capacity with respect to the earth), its characterizing parameters, in other words, the earthing current, arc it is possible to adjust the voltage values. At the same time, since the parameters characterizing the transition processes at this time depend on the insulation resistance of the DN with respect to the earth, the artificial non-stationary earth faults created in the PES with the neutral isolated through the commutator following Petersen's theory can control both the insulation of the network with respect to the ground and the allows detection of damage.

Arc overvoltage values during non-stationary ground fault transition processes in 6-35 kV DN are of great importance during testing. The value of the arc overvoltage, as mentioned above, generally has an indefinite functional dependence on the ground fault resistance, the ground fault angle and the phase capacity of the network with respect to the ground. However, for the sake of simplicity, the uncertain changes of the parameters are not taken into account during the research, and it is accepted that their changes can be written by probabilistic laws. Thus, within this condition, it is necessary to pre-determine the ground fault resistance, the ground fault angle and the network capacity in order to determine the value of the voltage for non-stationary ground fault transition processes in DN, control of the arc overvoltage accordingly and for testing works. For this purpose, at the current research stage, it is an urgent issue to determine the pairwise regression dependences ($k = f(R_0, \varphi)$, $k = f(R_0, C_f)$, $k = f(\varphi, C_f)$) of the frequency of arc overvoltage generated in neutral insulated networks as a result of non-stationary earth faults in PESH, the earth fault resistance, the angle of earth fault and the phase capacity of the network with respect to earth.

Avoid these dependencies in the work under consideration - $k = f(R_0, \varphi)$ and $k = f(R_0, C_f)$ the acquisition and modeling of regression dependencies are considered.

A. Initial conditions for a non-stationary ground fault arc overvoltage regression model.

In general, between the mentioned parameters $k = f(R_0, \varphi)$ və $k = f(R_0, C_f)$ in order to model their dependence, a system of differential equations characterizing the non-stationary earth-fault transition processes subject to the Petersen theory created in the isolated neutral 6-35 kV PESH should be performed. However, the numerical solution of the problem becomes much more difficult due to the complex structure of the mentioned differential equations. In other words, since the system of differential equations is non-linear, during their numerical integration, the stability of the solution is violated in some cases and the obtained results are distorted. Therefore, the frequency of arc overvoltage to overcome such difficulties (k) with ground fault resistance (R_0), angle of closure with the ground (φ) and the phase capacitance of the network with respect to ground (C_f) it is necessary to obtain analytical regression expressions that determine the dependencies between.

It should be noted that for the considered research problem, in [10,11], the arc overvoltage ratio is determined from the grounding resistance, in [12,13], the arc overvoltage ratio is determined from the grounding angle, and in [14], the arc overvoltage ratio is determined from the grounding of the network. derivation of analytical expressions for phase capacitance dependences has already been considered. As a continuation of the conducted studies, the regression models of the dependence of single-phase arc overvoltage on the earth fault resistance and earth fault angle, the arc overvoltage resistance and the phase capacity of the DN with respect to earth are considered [15-19]. Based on the mathematical models to be obtained, it is possible to ensure the values of the arc overvoltage at the necessary values by controlling the transition processes that occur during the artificial earth-stationary earth faults created for the purpose of carrying out test-checking works under load in DN.

II. PROBLEM SOLVING METHOD AND ALGORITHMS

In this section, obtaining an analytical expression (regression model) of the dependence of the frequency of arc overvoltage during single-phase non-stationary ground faults in the neutral-insulated electric network $(C_f = const)$ on the ground fault resistance and the ground fault angle is considered.

As a result of the conducted research $k = f(R_0, \varphi)$ and $k = f(R_0, C_f)$ it was determined that their dependencies can be approximated by the following regression equations [20]:

$$k = \frac{a}{R_0} + b\sin\varphi + c, \tag{1}$$

$$k = \frac{a}{R_0} + \frac{b}{C_f} + c \tag{2}$$

here a, b, $c-$ are regression coefficients.

In order to simplify the solution of the problem, in equation (1) $\frac{1}{R_0} = x$ and $\sin\varphi = y$ and at the same time $\frac{1}{R_0} = x$ and $\frac{1}{C_f} = y$ by accepting substitutions, we can write the regression equations in the following general form:

$$k = ax + by + c \tag{2}$$

In other words, the frequency of arc overvoltage (k) with the conductance of the ground fault circuit (x) and the sine of the angle of closure to ground (or the capacitance of the grid to ground) (y) the dependence between can be approximated by a linear regression equation. In determining the type of models, such a judgment was used that if the change of the result indicator is directly proportional to the change of the factor indicators, then the linear model is considered adequate. [21].

The regression coefficients of equation (2) are determined by the following well-known expressions [21]:

$$\left.\begin{aligned} a &= \frac{\sigma_K}{\sigma_x} \cdot \frac{r_{Kx} - r_{Ky} r_{xy}}{1 - r_{xy}^2} \\ b &= \frac{\sigma_K}{\sigma_y} \cdot \frac{r_{Ky} - r_{Kx} r_{xy}}{1 - r_{xy}^2} \\ c &= \overline{K} - a\overline{x} - b\overline{y} \end{aligned}\right\} \tag{3}$$

here $\overline{x}-$ the average price of the quantity x ; $\overline{y}-$ the average price of the quantity y ; $\overline{K}-$ the average price of the quantity K ; $\sigma_x -$ of its quantity x from its average price mean square deviation $(\overline{x})$; $\sigma_y -$ of its quantity y from its average price mean square deviation $(\overline{y})$; $\sigma_K -$ of its quantity K from its average price mean square deviation mean square deviation $(\overline{K})$; $r_{xy} -$ coefficient of linear correlation between quantities x and y ; $r_{Kx} -$ coefficient of linear correlation between quantities K and x ; $r_{Ky} -$ coefficient of linear correlation between quantities K and y .

A. Formulating the initial data for the regression model $k = f(R_0, \varphi)$

In order to obtain the regression dependence $k = f(R_0, \varphi)$, the results of the experimental studies carried out in the low-voltage model of the neutral-isolated network, given in table 1, are used $(C_f = 1mkF)$ [9].

TABLE I. ADDICTION $k = f(R_0, \varphi)$

R_0, Om	φ				
	30⁰	***60⁰***	***90⁰***	***120⁰***	***150⁰***
5	2,45	3,16	3,30	3,10	2,16
10	2,29	2,91	2,96	2,86	2,03
15	2,16	2,69	2,77	2,66	1,93
20	2,05	2,51	2,62	2,49	1,84
25	1,96	2,35	2,49	2,35	1,76
30	1,88	2,22	2,38	2,24	1,69

Earth fault overvoltage factor (k) with the conductance of the ground fault circuit (x) and the sine of the angle of closure with the ground (y) the following table 2 data, based on table 1, is used for approximating the dependence between them with a linear regression equation.

TABLE II. ADDICTION $k = f(x, y)$ FOR $k = f(R_0, \varphi)$

x $[Sm]$	y				
	0,500	0,866	1,000	0,866	0,500
0,200	2,45	3,16	3,30	3,10	2,16
0,100	2,29	2,91	2,96	2,86	2,03
0,067	2,16	2,69	2,77	2,66	1,93
0,050	2,05	2,51	2,62	2,49	1,84
0,040	1,96	2,35	2,49	2,35	1,76
0,033	1,88	2,22	2,38	2,24	1,69

B. Formulating the initial data for the regression model $k = f(R_0, C_f)$

The formation of initial data is considered for obtaining an analytical expression for the dependence of the arc overvoltage ratio on the earth fault resistance and the phase capacity of the network with respect to the earth during non-stationary single-phase earth faults in the neutral insulated 6-35 kV PESH. For this purpose, the results of the experimental studies carried out in the low-voltage model of the neutral-isolated network, given in table 3, are used $(\varphi = 90^\circ)$ [6].

TABLE III. ADDICTION $k = f(R_0, C_f)$

R_0, Om	C_f, mkF						
	1	***2***	***3***	***4***	***5***	***6***	***8***
5	3,30	2,99	2,85	2,74	2,66	2,58	2,47
10	2,96	2,74	2,59	2,47	2,39	2,33	2,21
15	2,77	2,54	2,39	2,28	2,20	2,14	2,08
20	2,62	2,38	2,24	2,13	2,06	2,01	1,92
25	2,49	2,25	2,12	2,02	1,95	1,91	1,84
30	2,38	2,15	2,02	1,93	1,88	1,84	1,80

Arc overvoltage factor (k) with the values of the new (x, y) quantities for approximation by the linear regression equation between the conductance of the ground fault circuit (x) and the inverse value of the phase capacitance of the network with respect to earth (y).

TABLE IV. ADDICTION $k = f(x, y)$ FOR $k = f(R_0, C_f)$

x	y						
	1,00	***0,50***	***0,333***	***0,250***	***0,200***	***0,167***	***0,125***
0,200	3,30	2,99	2,85	2,74	2,66	2,58	2,47
0,100	2,96	2,74	2,59	2,47	2,39	2,33	2,21
0,067	2,77	2,54	2,39	2,28	2,20	2,14	2,08
0,050	2,62	2,38	2,24	2,13	2,06	2,01	1,92
0,040	2,49	2,25	2,12	2,02	1,95	1,91	1,84
0,033	2,38	2,15	2,02	1,93	1,88	1,84	1,80

III. MODELING RESULTS FOR DEPENDENCIES $k = f(R_0, \varphi)$ AND $k = f(R_0, C_f)$

The numerical values of the statistical indicators necessary for the determination of the coefficients of regression dependence and the identification of the sought model are determined according to the correlation table given in Table 5. The following markings were adopted according to Table 5.

$$A = (x_i - \bar{x})^2;\ B = (y_i - \bar{y})^2;\ C = (K_i - \overline{K})^2;$$
$$D = (x_i - \bar{x})\cdot(y_i - \bar{y});\ M = (K_i - \overline{K})\cdot(x_i - \bar{x});$$
$$N = (K_i - \overline{K})\cdot(y_i - \bar{y})$$

A data array consists of a selection $n = 30$ and the values of the statistical indicators necessary for determining the coefficients obtained as a result of calculations are given below:

$$\sum_{i=1}^{n} x_i = 2{,}45;\ \sum_{i=1}^{n} y_i = 22{,}392;\ \sum_{i=1}^{n} K_i = 72{,}26;$$

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} = 0{,}082;\ \bar{y} = \frac{\sum_{i=1}^{n} y_i}{n} = 0{,}746;$$

$$\overline{K} = \frac{\sum_{i=1}^{n} K_i}{n} = 2{,}409;\ \sum_{i=1}^{n} (x_i - \bar{x})^2 = 0{,}09830667;$$

$$\sum_{i=1}^{n} (y_i - \bar{y})^2 = 1{,}2860832;\ \sum_{i=1}^{n} (K_i - \overline{K})^2 = 5{,}390747;$$

$$\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y}) = 0;\ \sum_{i=1}^{n} (K_i - \overline{K})(x_i - \bar{x}) = 0{,}4112667;$$

$$\sum_{i=1}^{n} (K_i - \overline{K})(y_i - \bar{y}) = 1{,}998776;$$

Thus, based on the data of table 3, mean square deviations and two-dimensional correlation coefficients for individual quantities are calculated based on known formulas. The numerical values obtained are as follows:

$$\sigma_x = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n}} = 0{,}0572;$$

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \bar{y})^2}{n}} = 0{,}207;$$

TABLE V. CORRELATION TABLE FOR DEPENDENCE $k = f(R_0, \varphi)$

i	x_i	y_i	k_i	A	B	C	D	M	N
1	0,200	0,500	2,45	0,0148	0,061	0,002	-0,029	0,005	-0,010
2	0,200	0,866	3,16	0,0148	0,014	0,565	0,014	0,089	0,09
3	0,200	1,000	3,30	0,0148	0,064	0,794	0,030	0,105	0,226
4	0,200	0,866	3,10	0,0148	0,014	0,478	0,014	0,082	0,083
5	0,200	0,500	2,16	0,0148	0,061	0,062	-0,029	-0,029	0,061
6	0,100	0,500	2,29	0,0003	0,061	0,014	-0,005	-0,002	0,029
7	0,100	0,866	2,91	0,0003	0,014	0,251	0,002	0,009	0,06
8	0,100	1,000	2,96	0,0003	0,064	0,304	0,005	0,010	0,14
9	0,100	0,866	2,86	0,0003	0,014	0,204	0,002	0,008	0,054
10	0,100	0,500	2,03	0,0003	0,061	0,143	-0,005	-0,007	0,093
11	0,067	0,500	2,16	0,0002	0,061	0,062	0,004	0,004	0,061
12	0,067	0,866	2,69	0,0002	0,014	0,079	-0,002	-0,004	0,034
13	0,067	1,000	2,77	0,0002	0,064	0,131	-0,004	-0,005	0,092
14	0,067	0,866	2,66	0,0002	0,014	0,063	-0,002	-0,004	0,030
15	0,067	0,500	1,93	0,0002	0,061	0,229	0,004	0,007	0,118
16	0,050	0,500	2,05	0,0010	0,061	0,129	0,008	0,011	0,088
17	0,050	0,866	2,51	0,0010	0,014	0,010	-0,004	-0,003	0,012
18	0,050	1,000	2,62	0,0010	0,064	0,045	-0,008	-0,007	0,054
19	0,050	0,866	2,49	0,0010	0,014	0,007	-0,004	-0,003	0,009
20	0,050	0,500	1,84	0,0010	0,061	0,323	0,008	0,018	0,140
21	0,040	0,500	1,96	0,0017	0,061	0,201	0,010	0,019	0,111
22	0,040	0,866	2,35	0,0017	0,014	0,003	-0,005	0,002	-0,007
23	0,040	1,000	2,49	0,0017	0,064	0,007	-0,011	-0,003	0,021
24	0,040	0,866	2,35	0,0017	0,014	0,003	-0,005	0,002	-0,007
25	0,040	0,500	1,76	0,0017	0,061	0,421	0,010	0,027	0,16
26	0,033	0,500	1,88	0,0023	0,061	0,279	0,012	0,026	0,130
27	0,033	0,866	2,22	0,0023	0,014	0,036	-0,006	0,009	-0,023
28	0,033	1,000	2,38	0,0023	0,064	0,001	-0,012	0,001	-0,007
29	0,033	0,866	2,24	0,0023	0,014	0,028	-0,006	0,008	-0,020
30	0,033	0,500	1,69	0,0023	0,061	0,5164	0,012	0,035	0,177
Σ	**2,450**	**22,392**	**72,26**	**0,0983**	**1,286**	**5,3907**	**0,000**	**0,411**	**1,998**

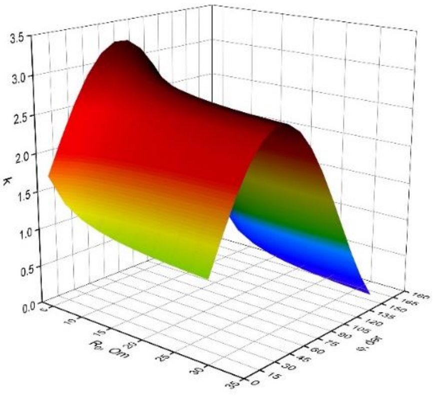

Fig. 1. Earth fault resistance times overvoltage and network overvoltage frequency 3D image of phase capacitance dependence with respect to ground

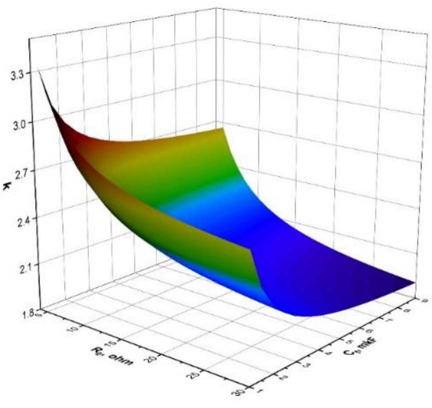

Fig. 2. Earth fault resistance and network overvoltage frequency 3D image of phase capacitance dependence with respect to ground

$$\sigma_K = \sqrt{\frac{\sum_{i=1}^{n}\left(K_i - \overline{K}\right)^2}{n}} = 0{,}4239;$$

$$r_{xy} = \frac{\sum_{i=1}^{n}\left(x_i - \overline{x}\right)\left(y_i - \overline{y}\right)}{n\sigma_x\sigma_y} = 0;$$

$$r_{Kx} = \frac{\sum_{i=1}^{n}\left(K_i - \overline{K}\right)\left(x_i - \overline{x}\right)}{n\sigma_K\sigma_x} = 0{,}5649;$$

$$r_{Ky} = \frac{\sum_{i=1}^{n}\left(K_i - \overline{K}\right)\left(y_i - \overline{y}\right)}{n\sigma_K\sigma_y} = 0{,}7591.$$

Then, based on statements (3), the calculated values of regression coefficients of equation (1) or (2) are obtained as follows: $a = 4{,}18;\ \ b = 1{,}55;\ c = 0{,}91.$

Thus, after determining the regression coefficients, the dependence (1) (or (2)) between the frequency of the arcing overvoltage generated in neutral insulated networks during single-phase non-stationary earth faults and the earth fault resistance (or circuit conductance) and the sine of the earth fault angle can be written in the following obvious form:

$$k = \frac{4{,}18}{R_0} + 1{,}55\sin\varphi + 0{,}91 \qquad (4)$$

Or

$$k = 4{,}18x + 1{,}55y + 0{,}91 \qquad (5)$$

Based on a similar algorithm, coefficients of regression dependence are found, and the following values were obtained in the considered sample: $a = 4{,}55;\ b = 0{,}76;\ c = 1{,}67.$ Thus, after determining the regression coefficients, the regression equation between the frequency of the arc overvoltage generated in neutral insulated networks as a result of non-stationary earth faults and the conductance of the earth fault circuit and the inverse value of the phase capacitance of the network with respect to earth is written in the following obvious way:

$$k = 4{,}55x + 0{,}76y + 1{,}67 \qquad (6)$$

or

$$k = \frac{4{,}55}{R_0} + \frac{0{,}76}{C_f} + 1{,}67 \qquad (7)$$

Based on the regression equations (4)-(7) obtained using computer modeling reporting methods, the 3D graph of the dependence of the arc overvoltage frequency on the ground fault resistance and the ground fault angle (Figure 1), as well as the arc overvoltage frequency on the ground fault resistance and network capacity (Figure 2) spatial images are constructed. The numerical results of the regression model obtained between the parameters mentioned in Figure 1, in other words, the existence of a strong correlation relationship between the quantities are visually confirmed.

As can be seen from the figure, the value of the arc overvoltage during artificial earth faults depending on the earth fault resistance and the capacity of the network for conducting tests of electrical equipment under load in neutral isolated networks is controlled in the range of $(1,9-3,3)\cdot U_{nom}$, depending on the nature of the test problem. can be done.

(7) regression dependence, Figure 2, and the dependences obtained in the authors' previous works [7-19] can be practically and effectively used during load tests of electrical equipment and network insulation, while the reliability of the obtained results is ensured.

IV. CONCLUSION

1. An easy-to-realize regression model was obtained between the frequency of arc overvoltage in neutral insulated networks as a result of non-stationary earth faults subject to Petersen's theory, the conductance of the earth fault circuit and the sine of the earth fault angle. The proposed analytical dependence between the mentioned parameters can be considered as a strong linear correlation relationship and based on this, the value of the test voltage can be determined.

2. An adequate hyperbolic regression model, which can be easily realized in practice, has been obtained between the frequency of the arc overvoltage generated in neutral insulated networks as a result of non-stationary earth faults, the conductivity of the earth fault circuit and the inverse value of the phase capacitance of the network with respect to earth. The model adequacy test results confirm that the mathematical model expressing the proposed analytical dependence between the mentioned location and the closure parameters has a strong linear correlation relationship.

3. The obtained results can be easily used during load tests of insulation of electrical equipment in the neutral isolated networks of Azerenergy system, and at the same time, during the investigation and analysis of the results of non-stationary ground faults that occurred in the network.

REFERENCES

[1] Khazieva, R.T., Vasiliev, P.I., Aflyatunov, R.R. Study of the installation for testing the insulation of electrical equipment with high voltage, Moscow: Electrotechnology in Industry, 2022, No. 3 (56), pp. 65-69.

[2] Patsch, R. Dielectric Diagnostics of Power Transformers and Cables - Return Voltage Measurements, Theory and Practical Results. VDE High Voltage Technology, 2018, ETGSymposium. https://www.vde-verlag.de/proceedings-en/454807130.html (дата обращения 21.07.2023).

[3] Shahmaev, I.Z., Gaisin, B.M., Shiryaev, O.V. A new method of taking management decisions at designing and developing electric power systems // 2nd International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), IEEE, 2016. doi: 10.1109/ICIEAM.2016.7911000.

[4] Mudiraj, A.N. Improvement of Power Quality by mitigating harmonics in single phase AC distribution. International Conference on Automatic Control and Dynamic Optimization Techniques (ICACDOT), - IEEE, 2016, pp. 83-88.

[5] Antonov, A.I. Study of the level of electromagnetic interference in the 10/0.4 kV network with power transformers of different capacities under an asymmetrical load. Kazan: News of higher educational institutions. Problems of energy, 2017, No. 9-10, pp. 65-76.

[6] Rajasekhar, N.V., Babu, M.N. Harmonics reduction and power quality improvement by using DPFC. International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT). IEEE, 2016, pp. 1754-1758.

[7] Akdeniz, E., Bagriyanik, M. A knowledge-based decision support algorithm to reduce the impact of transmission system vulnerabilities. International Journal of Electric Power and Energy Systems. 2016, No. 78. pp. 436-444.

[8] Orujov, N.I. Development and research of insulation test methods in neutral insulated networks based on artificial non-stationary ground faults. Dissertation submitted for the candidate of technical sciences degree, Baku, 1998, 139 p.

[9] Orujov, N.I., Orujov, A.O. Determination of the relationship between the frequency of arc overvoltage and the ground fault resistance. Baku: Scientific works. AzTU, -2013. No. 3, pp. 83-86.

[10] Orujov, N.I. Regression model of arc overvoltage dependence on ground fault resistance. "The role of engineering in the innovative development of Azerbaijan: goals and perspectives" international scientific-practical conference, Baku: BMU, November 29-30, 2019, p. 285-287.

[11] Orujov, N.I., Orujov, A.O. Determination of the dependence between the arc overvoltage and the ground closing angle. Baku: Power Engineering Problems, Science, 2014, No. 2, pp. 36-39.

[12] Orujov, N.I., Mirili, T. Regression model of the dependence of the arc overvoltage on the ground closing angle. V international scientific conference of young researchers, Baku, Book 1. BMU, April 29-30, 2021, p. 113-116.

[13] Orujov, N.I. Determination of the dependence between the frequency of arc overvoltage and the phase capacity of the network with respect to earth. Materials of the Republican Scientific-Technical Conference dedicated to the 100th anniversary of the Azerbaijan People's Republic on "Establishment of the Education-Research-Production Mechanism", Baku: AzTU, April 4-5, 2018, pp. 254-257

[14] Orujov, N.I.. The regression model of the dependence of the arc overvoltage on the phase capacity of the network with respect to the ground. II international science and technology conference, Baku: BMU, November 26-27, 2021, p.333-335.

[15] Orujov, N.I., Guliyev, H.B., Alimammadova, S.J. Regression model of arc overvoltage during single-phase non-stationary ground faults in neutral insulated networks. Scientific news of AzTU, No. 1, 2024, p.43-48

[16] Orujov N.I., Guliyev H.B., Alimammadova S.J. Regression model of arc overvoltage during single-phase non-stationary ground faults in neutral isolated networks. Reliability: Theory & Applications, Vol.20, No.2(78), USA, San Diego, 2024, p.425-433

[17] Orujov N.I., Guliyev H.B., Alimammadova S.C. 3D modeling of arc overvoltage dependence on earth fault resistance and earth fault angle. Power Engineering Problems, 2024, No. 2, pp. 11-19.

[18] Orujov N.I., Guliyev H.B., Alimammadova S.J. Arc overvoltage regression model. COIA-2024, Proceeding of he 9th International Conference on Control and Optimization with Industrial Applications, Volume 1, 27-29 August, 2024, İstanbul, Turkiye.

[19] Guliyev H.B. Fuzzy probabilistic model for managing the modes of networks with renewable energy sources. IJTPE Journal International Journal on Technical and physical problems of engineering (IJTPE), Issue 46, Vol. 13, No. 1, 2021, p.46-50

[20] Mammadov, N.R., Mammadov, B.M. Mathematical processing of the results of the experiment. Baku: Elm, 2005, 160 p.

[21] Orujov, E. Econometrics. Baku: Elm, 2018, 384 p.