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ERROR ESTIMATION OF THE DEVELOPED METHOD FOR UNGROUNDED AC SYSTEMS TO DETERMINE THE NETWORK INSULATION

Abstract. The problem of efficient and safe mining has recently become more relevant due to the intensification of production processes, for example, during the operation of electrical installations at mining enterprises, the insulation of electrical networks and electrical equipment undergoes a change in the electrical insulating properties of materials, which reduces the electrical safety. The network insulation admittance determines the safety of electrical receivers and operational personnel in mining facilities, since the current of a single-phase earth fault is directly proportional to the value of the network insulation admittance, and by controlling its active and reactive components, this will allow for a violation of the integrity of the insulation, thereby taking preventive measures.

The article depicts the analysis of the reliability of the devised method by estimating the error of insulation parameters in ungrounded AC systems which is done by indirect measurements. Graph-analytical studies of relative root-mean-square error reveal that the accuracy of the calculation in the devised method can be effectually managed by selecting the susceptance of the additional capacitor and accuracy class of measuring units.

Keywords. Network insulation, admittance, neutral shift, error estimation, zero-sequence voltage.

Introduction.

The development of the mining industry is constantly associated with an increase in the unit capacity of overburden and mining machines, and the introduction of more modern technological processes in open pits, which, in turn, is supported by the requirements for ensuring the safety and continuity of mining operations. operations. operations. internal power supply system. Ensuring an uninterrupted power supply for mining facilities and the electrical protection of their operation is one of the issues of increasing energy efficiency, where a special place is given to the development of a method for determining network insulation parameters.

Under actual operating conditions in ungrounded AC systems, it is desirable to have information about the calculated values of the single line-to-earth fault, on account of which security measures are being developed to provide the safety and uninterrupted power supply of mining facilities. All organizational and technical measures are aimed at reducing the magnitude of the earth fault current. The importance of developing a method for determining the network insulation parameters in ungrounded AC systems is its application to other enterprises with high-voltage electrical networks. [1]

There are a number of requirements for measuring network insulation parameters, namely:

- 1) Measurements must be carried out without interruptions in the supply of electrical energy to consumers.
- 2) The measurement procedure ought not to create a detriment to the insulation of consumers.
- 3) Measurements should be made using a small amount of electrical equipment and instruments.

- 4) The performance of work to determine the network insulation parameters must be electrical safety for people involved in the measurement.
- 5) Measurements of the initial values must be adequately correct and have a brief duration of measurement work.
- 6) The relative root-mean-square error of the devised method should not exceed 10%.

Materials and methods.

First of all, the requirements of the devised method for determining the network insulation parameters include the accuracy of measurements. In addition, the electrical conductivity of network insulation cannot be measured directly, so it becomes necessary to assess the accuracy of the data obtained when measuring values indirectly. As a result of the parsing of relative root-mean-square error (RMSE), useful advices are derived containing the necessary measurement accuracy and safe operation of electrical installations during measurements.

Implementation of the parsing of RMSE of the devised method, which boils down to identifying the relationship between the values of the conductivity of the network insulation and measurement data, which in our case are the maximum instantaneous magnitudes of the zero-sequence voltage, the phase voltage, and their vector angles before and after the additionally connected capacitor. The final result of the precision of deciding the desired values by the methods proposed above will be the ratio of the relative RMSE of the measured value to the error of measuring units. [2,3]

Mathematical dependencies of the devised method for determining insulation parameters are described in the article [4,5], where:

- a) network insulation conductance

$$G = \frac{B_0 U_{N1} (U_{A1} \cos(\varphi - \alpha) - U_N)}{U_{A2} U_N \sin(\varphi_1 - \alpha_1) - U_{A1} U_{N1} \sin(\varphi - \alpha)} \quad (1)$$

- b) network insulation susceptance

$$B = \frac{B_0 U_{N1} U_{A1} \sin(\varphi - \alpha)}{U_{A2} U_N \sin(\varphi_1 - \alpha_1) - U_{A1} U_{N1} \sin(\varphi - \alpha)} \quad (2)$$

- c) network insulation admittance

$$Y = \frac{B_0 U_{N1} \sqrt{U_{A1}^2 + U_N^2 - 2U_{A1} U_N \cos(\varphi - \alpha)}}{U_{A2} U_N \sin(\varphi_1 - \alpha_1) - U_{A1} U_{N1} \sin(\varphi - \alpha)} \quad (3)$$

where U_{A1}, U_{A2} – phase voltage before and after the additionally connected capacitor;
 U_N, U_{N1} – zero-sequence voltage before and after the additionally connected capacitor;
 α, α_1 – vector angles of phase voltage before and after the additionally connected capacitor;

φ, φ_1 – vector angles of zero-sequence voltage before and after the additionally connected capacitor, B_0 – susceptance of the additionally connected capacitor.

Using the main requirements of the error theory and mathematical analysis, we will analyze errors estimation. [6, 7, 8]

According to equation (1), we calculate RMSE in determining the network insulation conductance:

$$G = \frac{B_0 U_{N1} (U_{A1} \cos(\varphi - \alpha) - U_N)}{U_{A2} U_N \sin(\varphi_1 - \alpha_1) - U_{A1} U_{N1} \sin(\varphi - \alpha)},$$

where $U_{A1}, U_N, U_{A2}, U_{N1}, \varphi - \alpha = z, \varphi_1 - \alpha_1 = z_1, B_0$ – recorded data during direct determination.

RMSE of the determination function of network insulation conductance is calculated by the equation:

$$\varepsilon_G = \frac{\Delta G}{G} = \frac{1}{G} \sqrt{\left(\frac{\partial G}{\partial U_{A1}} \Delta U_{A1}\right)^2 + \left(\frac{\partial G}{\partial U_{A2}} \Delta U_{A2}\right)^2 + \left(\frac{\partial G}{\partial U_N} \Delta U_N\right)^2 + \left(\frac{\partial G}{\partial U_{N1}} \Delta U_{N1}\right)^2 + \left(\frac{\partial G}{\partial \sin(z)} \Delta \sin(z)\right)^2 + \left(\frac{\partial G}{\partial \sin(z_1)} \Delta \sin(z_1)\right)^2 + \left(\frac{\partial G}{\partial B_0} \Delta B\right)^2}, \quad (4)$$

where $\partial G \partial U_{A1}^{-1}; \partial G \partial U_{A2}^{-1}; \partial G \partial U_N^{-1}; \partial G \partial U_{N1}^{-1}; \partial G \partial \sin(z)^{-1}; \partial G \partial \sin(z_1)^{-1}; \partial G \partial b_0^{-1}$ – partial derivative functions $G = f(U_{A1}, U_{A2}, U_N, U_{N1}, \sin(z), \sin(z_1), B_0)$.

Define partial derivative functions $G = f(U_{A1}, U_{A2}, U_N, U_{N1}, \sin(z), \sin(z_1), B_0)$ with respect to variables $U_{A1}, U_{A2}, U_N, U_{N1}, \sin(z), \sin(z_1), B_0$:

$$\begin{aligned} \partial G \partial U_{A1}^{-1} &= \frac{B_0 U_N U_{N1} (U_{A2} \cos(z) \sin(z_1) - U_{N1} \sin(z))}{(U_{A2} U_N \sin(z_1) - U_{A1} U_{N1} \sin(z))^2}; \\ \partial G \partial U_{A2}^{-1} &= -\frac{B_0 U_N U_{N1} \sin(z_1) (U_{A1} \cos(z) - U_N)}{(U_{A2} U_N \sin(z_1) - U_{A1} U_{N1} \sin(z))^2}; \\ \partial G \partial U_N^{-1} &= -\frac{B_0 U_{A1} U_{N1} (U_{A2} \cos(z) \sin(z_1) - U_{N1} \sin(z))}{(U_{A2} U_N \sin(z_1) - U_{A1} U_{N1} \sin(z))^2}; \\ \partial G \partial U_{N1}^{-1} &= \frac{B_0 U_N U_{A2} \sin(z_1) (U_{A1} \cos(z) - U_N)}{(U_{A2} U_N \sin(z_1) - U_{A1} U_{N1} \sin(z))^2}; \\ \partial G \partial \sin(z)^{-1} &= \frac{B_0 U_{A1} U_{N1} (U_{A2} U_N \sin(z) \sin(z_1) - U_{A1} U_{N1} \sin(z)^2 + U_{N1} \cos(z) (U_{A1} \cos(z) - U_N))}{(U_{A2} U_N \sin(z_1) - U_{A1} U_{N1} \sin(z))^2}; \\ \partial G \partial \sin(z_1)^{-1} &= -\frac{B_0 U_N U_{N1} U_{A2} \cos(z_1) (U_{A1} \cos(z) - U_N)}{(U_{A2} U_N \sin(z_1) - U_{A1} U_{N1} \sin(z))^2}; \\ \partial G \partial B_0^{-1} &= \frac{U_{N1} (U_{A1} \cos(z) - U_N)}{U_{A2} U_N \sin(z_1) - U_{A1} U_{N1} \sin(z)}. \end{aligned} \quad (5)$$

Here $\Delta U_{A1}, \Delta U_{A2}, \Delta U_N, \Delta U_{N1}, \Delta \sin(z), \Delta \sin(z_1), \Delta B_0$ – are the absolute errors of direct determinations of $U_{A1}, U_{A2}, U_N, U_{N1}, \sin(z), \sin(z_1), B_0$ which are designated by the next equations:

$$\begin{aligned} \Delta U_{A1} &= U_{A1} \Delta U_{A1*}; \\ \Delta U_{A2} &= U_{A2} \Delta U_{A2*}; \\ \Delta U_N &= U_N \Delta U_{N*}; \\ \Delta U_{N1} &= U_{N1} \Delta U_{N1*}; \\ \Delta \sin(z) &= \sin(z) \Delta \sin(z_*); \\ \Delta \sin(z_1) &= \sin(z_1) \Delta \sin(z_{1*}); \\ \Delta B_0 &= B_0 \Delta B_{0*}, \end{aligned} \quad (6)$$

where $\Delta U_{A1*}, \Delta U_{A2*}, \Delta U_{N*}, \Delta U_{N1*}, \Delta \sin(z_*), \Delta \sin(z_{1*})$ – relative error measuring voltage circuits and in order to define the error of measuring units, we consider that $\Delta U_{A1*} = \Delta U_{A2*} = \Delta U_{N*} = \Delta U_{N1*} = \Delta \sin(z_*) = \Delta \sin(z_{1*}) = \Delta B_{0*} = \Delta$; ΔB_{0*} – is the relative error of the measuring unit that gauges the value of the additional susceptance of the connected capacitor.

Hereafter is an equation to calculate the random RMSE of the devised method, where partial derivatives of equation (4) and absolute errors (6) are substituted into equation (4), knowing that $\Delta U_* = \Delta B_0 = \Delta$ we get this equation:

$$\varepsilon_G = \Delta \left[1 + \frac{2U_N^2 U_{A1}^2 (U_{A2} \cos(z) \sin(z_1) - U_{N1} \sin(z))^2}{(U_{A2} U_N \sin(z_1) - U_{A1} U_{N1} \sin(z))^2 (U_{A1} \cos(z) - U_N)^2} + \frac{2U_N^2 U_{A2}^2 \sin(z_1)^2}{(U_{A2} U_N \sin(z_1) - U_{A1} U_{N1} \sin(z))^2} + \frac{U_{A1}^2 \sin(z)^2 (U_{A2} U_N \sin(z) \sin(z_1) - U_{A1} U_{N1} \sin(z))^2 + U_{N1}^2 \cos(z) (U_{A1} \cos(z) - U_N)^2}{(U_{A2} U_N \sin(z_1) - U_{A1} U_{N1} \sin(z))^2 (U_{A1} \cos(z) - U_N)^2} + \frac{U_N^2 U_{A2}^2 \sin(z_1)^2 \cos(z_1)^2}{(U_{A2} U_N \sin(z_1) - U_{A1} U_{N1} \sin(z))^2} \right]^{1/2} \quad (7)$$

Let's display the formulated equation (7) in relative units and use the Maple and Python.Matplotlib programs to plot:

$$\varepsilon_G = \Delta \left[1 + \frac{2U_{N*}^2 U_{A*}^2 (\sqrt{1 - \sin(z_*)^2} - \sin(z_*))^2}{(U_{N*} - U_{A*} \sin(z_*))^2 (U_{A*} \sqrt{1 - \sin(z_*)^2} - U_{N*})^2} + \frac{2U_{N*}^2}{(U_{N*} - U_{A*} \sin(z_*))^2} + \frac{U_{A*}^2 \sin(z_*)^2 (U_{N*} \sin(z_*) - U_{A*} \sin(z_*)^2 + \sqrt{1 - \sin(z_*)^2} (U_{A*} \sqrt{1 - \sin(z_*)^2} - U_{N*}))^2}{(U_{N*} - U_{A*} \sin(z_*))^2 (U_{A*} \sqrt{1 - \sin(z_*)^2} - U_{N*})^2} \right]^{1/2}, \quad (8)$$

where $U_{A*} = U_{A1} * U_{A2}^{-1}, U_{N*} = U_N * U_{N1}^{-1}, \sin(z_*) = \sin(z) * \sin(z_1)^{-1}$.

Similar calculations were made to determine RMSE of the devised method for determining network insulation susceptance and admittance using mathematical dependencies (2), (3) and we obtain:

1) RMSE of the method for determining network insulation susceptance

$$\varepsilon_B = \Delta \left[\frac{3U_{A*}^2 \sin(z_*)^2 + 4U_{N*}^2 - U_{N*}^2 \sin(z_*)^2 - 2U_{N*} U_{A*} \sin(z_*)}{(U_{N*} - U_{A*} \sin(z_*))^2} \right]^{1/2} \quad (9)$$

2) RMSE of the method for determining network insulation admittance

$$\varepsilon_Y = \Delta \left[\frac{U_{N_*}^2 (U_{A_*}^2 + 1) \left(\frac{U_{N_*} \sqrt{1 - \sin^2 z_*} - U_{A_*}}{\sin z_* (U_{N_*} - U_{A_*} \sqrt{1 - \sin^2 z_*})} \right)^2}{(U_{N_*} - U_{A_*} \sin z_*)^2 (U_{A_*}^2 + U_{N_*}^2 - 2U_{A_*} U_{N_*} \sqrt{1 - \sin^2 z_*})^2} + \frac{2U_{N_*}^2}{(U_{N_*} - U_{A_*} \sin z_*)^2} + 1 + \frac{U_{A_*}^2 \sin^2 z_* \left(\frac{\sin z_* U_{N_*}^2 - U_{A_*} U_{N_*} \sin^2 z_* + (U_{A_*}^2 + U_{N_*}^2 - 2U_{A_*} U_{N_*} \sqrt{1 - \sin^2 z_*}) \sqrt{1 - \sin^2 z_*}}{(U_{N_*} - U_{A_*} \sin z_*)^2 (U_{A_*}^2 + U_{N_*}^2 - 2U_{A_*} U_{N_*} \sqrt{1 - \sin^2 z_*})^2} \right)^2}{(U_{N_*} - U_{A_*} \sin z_*)^2 (U_{A_*}^2 + U_{N_*}^2 - 2U_{A_*} U_{N_*} \sqrt{1 - \sin^2 z_*})^2} \right]^{1/2} \quad (10)$$

where $U_{A_*} = U_{A1} * U_{A2}^{-1}$, $U_{N_*} = U_N * U_{N1}^{-1}$, $\sin(z_*) = \sin(z) * \sin(z_1)^{-1}$.

Result and discussion.

The construction of mathematical dependencies is based on the equations of random RMSE in determining network isolation parameters:

$$\begin{aligned} \varepsilon_G &= \frac{\Delta G}{\Delta} = f(U_{A_*}, U_{N_*}, \sin(z_*)); \\ \varepsilon_B &= \frac{\Delta B}{\Delta} = f(U_{A_*}, U_{N_*}, \sin(z_*)); \\ \varepsilon_Y &= \frac{\Delta Y}{\Delta} = f(U_{A_*}, U_{N_*}, \sin(z_*)), \end{aligned}$$

illustrated on the charts (Figure 1, Figure 2, Figure 3).

On Figure 1, Figure 2, and Figure 3 show the effect of connecting a capacitor on the change in RMSE of the method for determining the network insulation conductance – ε_G , the network insulation susceptance – ε_B and the network insulation admittance – ε_Y , taking into account the reliability of the desired values.

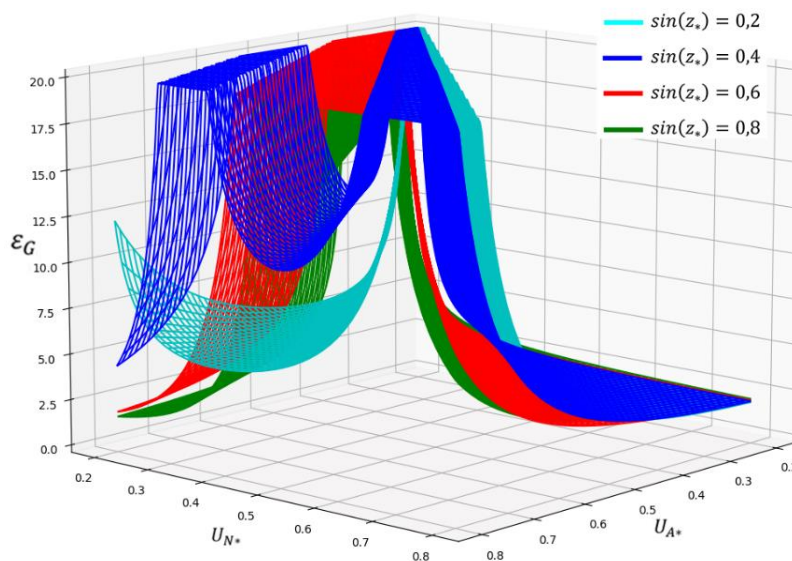


Figure 1 – RMSE of the devised method for determining network insulation conductance

When calculating the network insulation conductance based on plotted graph (Figure 1) of RMSE, the capacitor is chosen so that at: $\sin(z_*) = 0,2$ zero-sequence voltage in relative units at the limits of $U_{N*} = 0,2 - 0,62$: and $U_{A*} = 0,3 - 0,8$; $\sin(z_*) = 0,4$ zero-sequence voltage in relative units at the limits of $U_{N*} = 0,48 - 0,8$ and $U_{A*} = 0,2 - 0,54$; $\sin(z_*) = 0,6$ zero-sequence voltage in relative units at the limits of $U_{N*} = 0,51 - 0,8$ and $U_{A*} = 0,2 - 0,49$; $\sin(z_*) = 0,8$ zero-sequence voltage in relative units at the limits of $U_{N*} = 0,2 - 0,33$; $0,5 - 0,8$ and $U_{A*} = 0,6 - 0,8$; $0,2 - 0,5$.

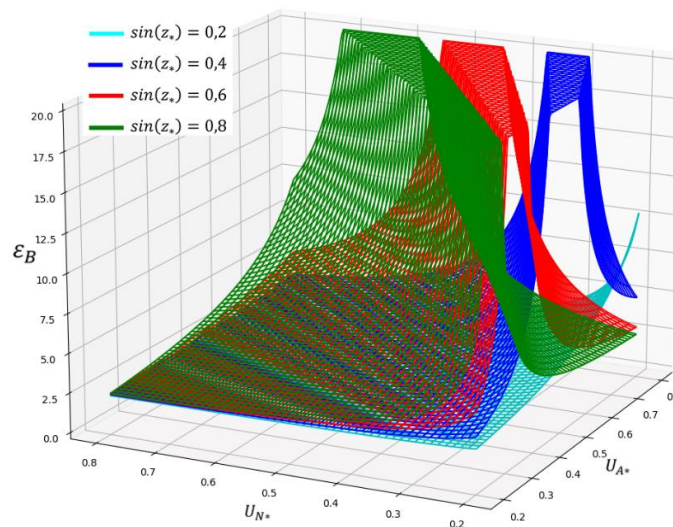


Figure 2 – RMSE of the devised method for determining network insulation susceptance

When calculating the network insulation susceptance based on plotted graph (Figure 2) of RMSE, the capacitor is chosen so that at: $\sin(z_*) = 0,2$ zero-sequence voltage in relative units at the limits of $U_{N*} = 0,2 - 0,8$: and $U_{A*} = 0,2 - 0,8$; $\sin(z_*) = 0,4$ zero-sequence voltage in relative units at the limits of $U_{N*} = 0,31 - 0,8$ and $U_{A*} = 0,2 - 0,68$; $\sin(z_*) = 0,6$ zero-sequence voltage in relative units at the limits of $U_{N*} = 0,44 - 0,8$ and $U_{A*} = 0,2 - 0,53$; $\sin(z_*) = 0,8$ HH zero-sequence voltage in relative units at the limits of $U_{N*} = 0,2 - 0,4$; $0,51 - 0,8$ and $U_{A*} = 0,6 - 0,8$; $0,2 - 0,5$.

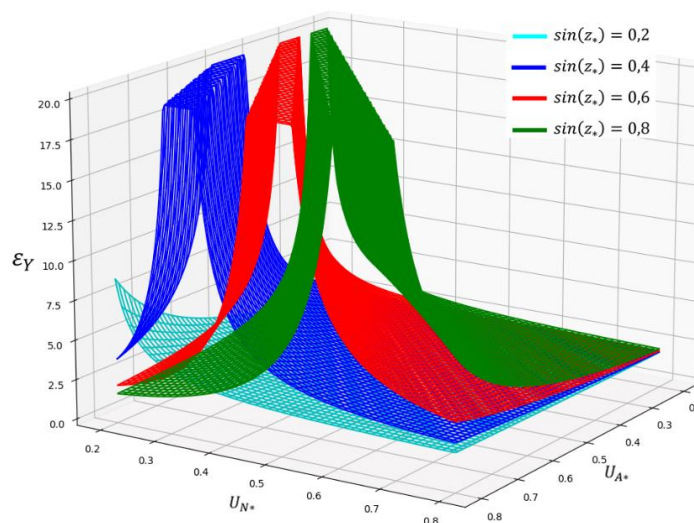


Figure 1 – RMSE of the devised method for determining network insulation admittance

When calculating the network insulation admittance based on plotted graph (Figure 3) of RMSE, the capacitor is chosen so that at: $\sin(z_*) = 0,2$ zero-sequence voltage in relative units at the limits of $U_{N*} = 0,2 - 0,8$; and $U_{A*} = 0,2 - 0,8$; $\sin(z_*) = 0,4$ zero-sequence voltage in relative units at the limits of $U_{N*} = 0,33 - 0,8$ and $U_{A*} = 0,2 - 0,69$; $\sin(z_*) = 0,6$ напряжен zero-sequence voltage in relative units at the limits of $U_{N*} = 0,2 - 0,34$; $0,46 - 0,8$ and $U_{A*} = 0,72 - 0,8$; $0,2 - 0,6$; $\sin(z_*) = 0,8$ zero-sequence voltage in relative units at the limits of $U_{N*} = 0,2 - 0,38$; $0,48 - 0,8$ and $U_{A*} = 0,6 - 0,8$; $0,2 - 0,52$.

Conclusion

These zero-sequence voltage and phase voltage variation range provide an error of indirect measurements of network insulation parameters of no more than 10% if using measuring device with class of accuracy 1.0, using a more accurate measuring device, the measurement error is proportionally reduced.

Graph-analytical studies of relative RMSE reveal that the accuracy of the calculation in the devised method can be effectually managed by selecting the susceptance of the additional capacitor and measurement accuracy.

The results show that the devised method has satisfactory accuracy in calculating network insulation parameters.

Appreciation

The work was carried out at S.Seifullin Kazakh Agro Technical University in accordance with the budget program 217 "Scientific and / or scientific and technical activities", subprogram 102 "Grant financing of scientific research" on the topic "Development of innovative technologies for improving the efficiency of power supply to power receiving devices with voltage up to 1000 V for mining enterprises" with the support of a grant MES RK AR05132692.

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ОКҚАЙЛАНҒАН БЕЙТРАЛДЫ ЖЕЛІЛЕРДЕГІ ОҚШАУ ПАРАМЕТРЛЕРІН АНЫҚТАУДЫҢ ӘЗІРЛЕГЕН ӘДІСІНІҢ ҚАТЕЛІГІН БАҒАЛАУ

Андатпа. Өндірістік процестердің қарқындауына байланысты, мысалы, тау-кен кәсіпорындарында электр қондырғыларын пайдалану кезінде, электр желілері мен электр жабдықтарын оқшаулаудың электр оқшаулағыш қасиеттерінің өзгеруіне байланысты соңғы уақытта тиімді және қауіпсіз тау-кен өндіру мәселесі өзекті бола бастады. материалдар, бұл электр қауіпсіздігінің деңгейін төмендетеді. Желілік оқшаулаудың жалпы өткізгіштігі тау-кен тораптарындағы электр қабылдағыштар мен жұмыс істейтін персоналдың қауіпсіздігін анықтайды, өйткені бір фазалы жерге тұйықталу тогы желі оқшаулауының жалпы өткізгіштігінің мәніне тура пропорционалды және оны бақылау арқылы белсенді және реактивті компоненттер, ол оқшаулаудың тұтастығының бұзылуын болжауға мүмкіндік береді, сол арқылы алдын алу шаралары. техникалық және алдын алу шаралары.

Мақалада оқшауланған бейтарапты желілерде оқшаулау параметрлерін жанама өлшеу қателігін бағалау арқылы әзірленген әдістің сенімділігін зерттеу көрсетілген. Салыстырмалы орташа квадраттық қатенің графикалық-аналитикалық зерттеулері әзірленген әдіс бойынша есептеу дәлдігін қосымша конденсатордың сыйымдылығын және өлшеу құралдарының дәлдік класын таңдау арқылы тиімді басқаруға болатынын көрсетеді.

Түйінді сөздер. Желі оқшаулауы, өткізгіштік, бейтарап ығысу, қатені бағалау, нөлдік тізбекті кернеу.

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ОЦЕНКА ПОГРЕШНОСТИ РАЗРАБОТАННОГО МЕТОДА ОПРЕДЕЛЕНИЯ ПАРАМЕТРОВ ИЗОЛЯЦИИ В СЕТЯХ С ИЗОЛИРОВАННОЙ НЕЙТРАЛЬЮ

Аннотация. Проблема эффективного и безопасного ведения горных работ в последнее время стала более актуальной в связи с интенсификацией производственных

процессов, например, при эксплуатации электроустановок на горнодобывающих предприятиях, изоляция электрических сетей и электрооборудования претерпевает изменение электроизоляционных свойств материалов, что снижает уровень электробезопасности. Полная проводимость изоляции сети определяет безопасность электроприемников и эксплуатирующего персонала в сетях горного производства, тем что ток однофазного замыкания на землю прямо пропорционально зависит от величины полной проводимости изоляции сети и контролируя ее активную и реактивную составляющие, позволит заблаговременно предвидеть разрушение целостности изоляции, тем самым предпринять упреждающие технико-профилактические мероприятия.

В статье показано исследование достоверности разработанного метода путем оценки погрешности косвенных измерений параметров изоляции в сетях с изолированной нейтралью. Графоаналитические исследования относительной среднеквадратичной погрешности показывают, что точностью расчета разработанного метода можно эффективно управлять за счет выбора емкостной проводимости добавочного конденсатора и класса точности измерительных приборов.

Ключевые слова. Изоляция сети, проводимость, сдвиг нейтрали, оценка погрешности, напряжение нулевой последовательности.
