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APPROBATION OF THE DEVELOPED METHOD FOR DETERMINING NETWORK INSULATION PARAMETERS ON AN OPERATING EXCAVATOR

One of the factors that determine the safety of electrical installations in ungrounded AC systems is the insulation resistance to earth. Early recognition and fault clearance, accompanied by a change in the active and reactive components of the insulation conductivity in ungrounded AC systems, will ensure work safety in electrical installations. Due to the fact the scale of cases of electrical injuries continues to remain significant, despite the tightening of the requirements of regulatory and technical documentation and the creation of newer effective methods and protection equipment against electric shock, therefore, increasing the level of electrical safety in the operation of mining machines and complexes is an urgent task.

The article depicts the results of the approbation of the developed method for determining network insulation parameters on an operating excavator. The developed method is based on measuring phase voltages and angles of their vectors before and after connecting an additional capacitance to the phase of the electrical network and to the earth. According to the developed method, numerical data of the insulation condition in an electrical network with a voltage up to 1000 V and the single-phase earth fault current were calculated. During the approbation of the developed method, the lack of the existing protective residual current device was identified.

Keywords: network insulation, admittance, susceptance, neutral shift, zero-sequence voltage.

Introduction

Presently, a significant amount of information has been accumulated on the research of the insulation condition of mining electrical networks, which is reflected in an increase in the level of electrical safety in open-cut mining [1–6]. However, these studies cannot serve as a standard for all types of quarries for reasons such as the location of quarries in different climatic zones, the number and capacity of electrical installations, and the length of power lines.

Due to the specific's mode of the quarry's electrical network, which is associated with the use of repeated short-term switching on energy-intensive motors, where the no-load currents rise in the shortest possible time to the latching currents [7–9]. All these oscillatory processes affect the deviations of the phase voltage values relative to the ground from the nominal values, thereby changing the zero-sequence voltage, which is directly dependent on the network insulation resistance.

Therefore, the purpose of this work was to determine the numerical parameters of insulation in an ungrounded open-pit mining electrical network by the developed method, which is described in the article [10].

Materials and methods

Approbation of the developed method on the operating excavators of «Bogatyr Coal» LLP with all auxiliary connected equipment made it possible to determine the actual data of the insulation condition.

The measurements of the network insulation parameters were carried out according to the methodology, compiled on the basis of the developed method [10], which consists of measurement data such as phase voltage – U_{A1},U_{A2}, zero-sequence voltage– U_N,U_{N1}, and angles of their vectors – α,α_1,φ,φ_1 before and after connected additional susceptance – B_0.

The measurement results are used to calculate:

– network insulation admittance

$$Y = \frac{b_0 U_{N1}\sqrt{U_{A1}^2 + U_N^2 - 2U_{A1}\,U_N cos(\varphi - \alpha)}}{U_{A2}U_N\,sin(\varphi_1 - \alpha_1) - U_{A1}U_{N1}\,sin(\varphi - \alpha)}; \quad (1)$$

– network insulation susceptance

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

– network insulation conductance

$$G = \frac{B_0 U_{N1}(U_{A1}\,cos(\varphi - \alpha) - U_N)}{U_{A2}U_N\,sin(\varphi_1 - \alpha_1) - U_{A1}U_{N1}\,sin(\varphi - \alpha)}. \quad (3)$$

To perform phase voltage measurements, a «SATEC EDL175XR» power quality analyzer with an accuracy class of 0.2S was used, and a capacitance bank shown in Fig. 1 was used as an additional susceptance.

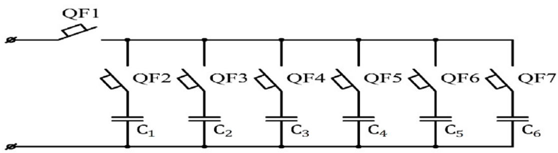

Figure 1 – Schematic diagram of a capacitor
bank with KBG-MP type capacitors:
QF1÷QF7 – switchers; C1, C2 – 0,1 μF; C3, C4 – 2 μF; C5, C6 – 4 μF;

A capacitor bank is used to connect an additional susceptance to one of the phases of the electrical network and to the earth, while the capacitor connection circuit is made in a parallel scheme, which makes it possible, to sum up, the capacitances of the capacitors, thereby achieving the necessary change in phase voltages necessary for the accuracy of calculations [11].

Discussion of results

The oscillograms (Fig. 2, Fig. 3) clearly show the change in phase voltages before and after connecting an additional susceptance (0,2 μF capacitance was used) to phase «A» (yellow color) of the ballast quarry excavator EKG-5. At this time, there is an asymmetry of the phase voltages before the connection of additional susceptance. The connection of the power quality analyzer and the capacitor bank was carried out to the 0,4 kV buses after the incoming circuit breaker.

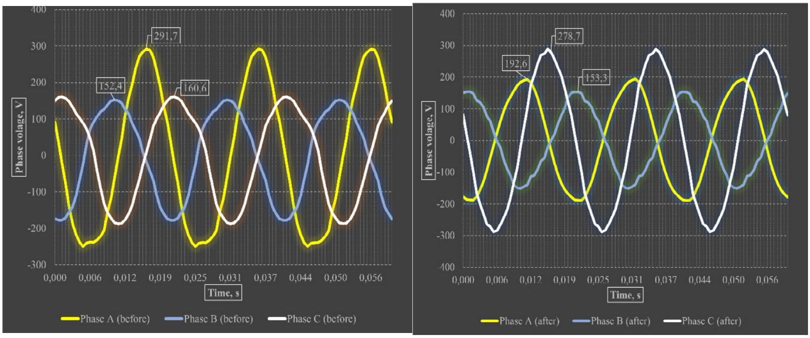

Figure 2 – Oscillograms of phase voltages before and after connecting additional susceptance on a ballast quarry excavator ECG-5

To calculate the network insulation conductance, susceptance and admittance of the ballast quarry excavator EKG-5, measurement data are used by the power quality analyzer before and after connecting additional susceptance according to the developed method, as well as test results evaluated using the small sampling method are shown in Table 1.

Table 1 – Network insulation parameters results

Network insulation param-eters	Number of measurements								
	1	2	3	4	5	6	7	8	X (Average value)
$Y \cdot 10^{-5}$, Mho	8,56	8,55	8,55	8,44	8,50	8,51	7,80	7,29	8,28
$B \cdot 10^{-5}$, Mho	0,50	0,49	0,51	0,49	0,51	0,48	0,47	0,44	0,49
$G \cdot 10^{-5}$, Mho	8,55	8,54	8,53	8,43	8,48	8,50	7,78	7,28	8,26

The results of calculations by the developed method to determine the network insulation parameters in units of measurement “Ohm” and the single-phase earth fault current are summarized in Table 2.

Table 2 – Data on network insulation parameters and single-phase earth fault current

Z, Ohm	X, Ohm	R, Ohm	C, 10^{-3} μF	Io, mA
12084/	205634/	12105/	15,48/	10,92/

11679÷13715	195342÷226955	11698÷13740	14,03÷16,29	9,62÷11,3

In table 2, the numerator shows the average value, and the denominator shows the range of deviations during the operation of the excavator.

Based on the calculation, it can be concluded that the measurements of the network insulation parameters and the single-phase ground fault current variation are within small limits, and since the excavator's electrical network does not have long cable lines, the network capacitance has small values. The range of variation of the above values is due to voltage fluctuations [7].

To protect current-using equipment on the EKG-5 excavator, a residual current device of the «UAKI» type is used, which has limited operability due to the lack of extended cable lines, since the network insulation resistance mainly consists of the active resistance of the network. In addition, when upgrading electrical equipment at mining enterprises, electrical equipment with non-linear resistances is installed, which leads to the appearance of various harmonics that adversely affect the operation of the leakage relay [9].

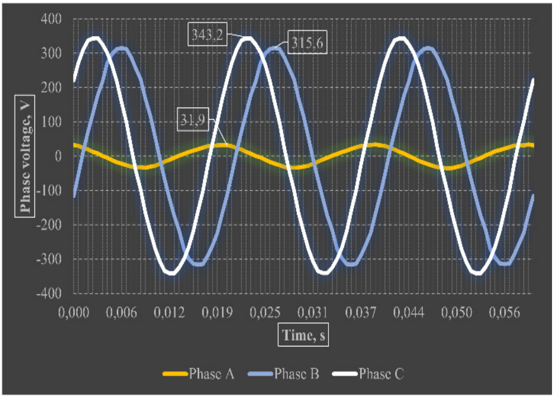

Figure 3 – Oscillogram of phase voltages on the ballast quarry excavator EKG-5when an additional capacitor with a capacity of 4 μF is connected

The test results showed that when an additional capacitor with a capacity of 4 μF is connected to the phase on the excavator, the phase voltage decreases to almost zero values, but the residual current device «UAKI» on the EKG-5 excavator did not malfunction. One of the possible reasons for the failure of residual current device is related to the tripping limit of protective devices, so according to GOST 31612-2012, the trip current of the residual current device for a voltage of 220 V is 22 mA, while the estimated current of a single-phase earth fault was 11 mA.

Due to the fact that the involved leakage relays on excavators do not function properly, which leads to non-compliance with safety requirements for the operation of current-using equipment in the mining industry, which means that there is a danger of electric shock to maintenance personnel, as well as failure of other current-using equipment. To eliminate the lack of functionality, enhancement is proposed for improvement of the effectiveness of leakage relays on excavators by increasing the capacitance of the phases relative to the earth, thereby increasing the magnitude of the single-phase earth fault current, which will exceed the tripping limit of the residual current device [7].

The enhancement to improve the efficiency of existing protective residual current device is illustrated by an electrical circuit (Fig. 4), consisting of: three phase ungrounded electrical network; input-switching device – QF1; current-using equipment; switcher designed for residual current device – QF2; protective residual current device – RCD; switcher to connect additional capacitors; susceptance of phase insulation , , ; conductance of phase insulation , , .

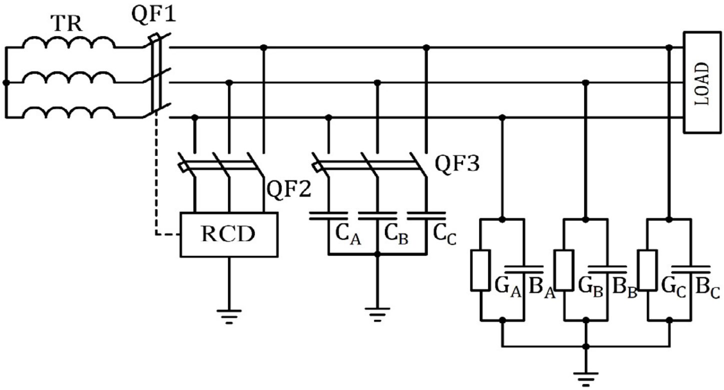

Figure 4 – Schematic diagram of residual current device on the excavator with voltage up to 1000V

To turn off the power to the excavator’s current-using equipment, the single-phase ground fault current is exceeded above the tripping limit of the residual current device by switching the QF3 switcher, which connects additional capacitors for increase network admittance and thereby gives opportunity to turn off the QF1 switcher for the safety of operating personnel and current-using equipment.

Conclusion

Measurements are made without disturbing the normal operation of electrical installations, it means, without power cutting the operating voltage and turning off current-using equipment. The developed method eliminates the need for a direct connection to the earth of any phase, which ensures the safety of measurements and eliminates the possibility of emergency situations.

The application of this method belongs to the field of safety in the operation of electrical current-using equipment with voltage up to 1000 V and allows to determine the network insulation parameters with the achievement of simplicity, convenience and safety when performing measurements. The developed method does not require the creation of a prototype, since the measuring instruments and the connected additional capacitors are available from the engineering and technical workers of the enterprise. Approbation of the developed method have shown sufficient accuracy, speed and ease of measurement.

The results of approbation the ungrounded electrical network of the EKG-5 excavator clearly show the need for a further more detailed research of the insulation condition of electrical installations by constructing a 3D map of the distribution of network conductivity, taking into account the established quarry electrical equipment.

СПИСОК ИСПОЛЬЗОВАННЫХ ИСТОЧНИКОВ

1 **Kazhekin, I. E., Finko, S. P.** Influence of Non-Linear Load on Single-Phase Fault Current in Electrical Networks with Isolated Neutral // 2022 International Ural Conference on Electrical Power Engineering (UralCon): 2022. – С. 330–335.

2 **Boboev, K., Sidorov, A., Davlatov, A.** Evaluation of Indirect Methods for Determining the Isolation Parameters of the Network Phases Relative to the Ground on a Computer Model // International Ural Conference on Electrical Power Engineering (UralCon): 2021. – С. 556–560.

3 **Fu, W., Xu, Y., Gao, Y. A** Study on Insulation Monitoring Technology of High-Voltage Cables in Underground Coal Mines Based on Decision Tree // Computational Intelligence and Neuroscience. – 2022. – DOI: 10.1155/2022/2247017.

4 **Wu, Z., Fang, M., Cai, J., Qian, W., Ji, Z.** Single-Phase Grounding Fault Identification Based on Transition Conductance Tracking Method // Mathematical Problems in Engineering. – 2022. – С. 15. – DOI: 10.1155/2022/1258565.

5 **Piesciorovsky, E. C., Morales Rodriguez, M. E.** Assessment of the Phase-to-Ground Fault Apparent Admittance Method with Phase/Ground Boundaries to Detect Types of Electrical Faults for Protective Relays Using Signature Library

and Simulated Events // International Transactions on Electrical Energy Systems. – 2022. – DOI: 10.1155/2022/1951836.

6 **Пичуев, А., Петуров, В.** Анализ причин электротравматизма на горных предприятиях // Транспортная инфраструктура Сибирского региона. – 2016. – Т. 1. – С. 637–641.

7 **Utegulov, B.** Special Issues of Ensuring Electrical Safety in Networks with Isolated Neutral Voltage up to 1000 V at Mining Enterprises / B. Utegulov // Industrial Engineering – Rijeka: IntechOpen, 2018.

8 **Fedorova S. V., Utegulov B. B., Utegulov A. B., Koshkin I. V., Kurabayev I. K.** Experimental studies of a developed method for determining the insulation parameters in a network with isolated neutral voltage up to 1000 V // Herald of Science of S. Seifullin Kazakh Agro Technical University. – 2019. – T. 1.

9 **Utegulov, B. B., Utegulov, A. B., Uakhitova, A. B.** Modeling method for measuring the admittance of insulation in a network with an isolated neutral voltage up to 1000 V in mines using Matlab/Simulink / B. B. Utegulov, A. B. Utegulov, A. B. Uakhitova // Journal of Mining Science. – 2017. – T. 53, № 2. – C. 282–290. – DOI: 10.1134/S1062739117022128.

10 **Kurabayev, I., Suvorov, I., Utegulov, A., Tatkeyeva, G.** Mathematical description of the method for ungrounded AC systems to determine the network insulation // IET Generation, Transmission & Distribution. – 2022. – T. 16, № 11. – C. 2223–2227. – DOI: https://doi.org/10.1049/gtd2.12436.

11 **Tatkeyeva, G., Kurabayev, I., Ataullaev, N., Murodov, X.** Experimental research of the developed method to determine the network insulation for ungrounded AC systems in laboratory conditions // International Conference on Electrical, Computer and Energy Technologies (ICECET): 2022. – C. 1–4.

REFERENCES

1 **Kazhekin, I. E., Finko, S. P.** Influence of Non-Linear Load on Single-Phase Fault Current in Electrical Networks with Isolated Neutral // 2022 International Ural Conference on Electrical Power Engineering (UralCon): 2022. – P. 330–335.

2 **Boboev, K., Sidorov, A., Davlatov, A**. Evaluation of Indirect Methods for Determining the Isolation Parameters of the Network Phases Relative to the Ground on a Computer Model // International Ural Conference on Electrical Power Engineering (UralCon): 2021. – P. 556–560.

3 **Fu, W., Xu, Y., Gao, Y. A** Study on Insulation Monitoring Technology of High-Voltage Cables in Underground Coal Mines Based on Decision Tree // Computational Intelligence and Neuroscience. – 2022. – DOI: 10.1155/2022/2247017.

4 **Wu, Z., Fang, M., Cai, J., Qian, W., Ji, Z.** Single-Phase Grounding Fault Identification Based on Transition Conductance Tracking Method // Mathematical Problems in Engineering. – 2022. – P. 15. – DOI: 10.1155/2022/1258565.

5 **Piesciorovsky, E. C., Morales Rodriguez, M. E.** Assessment of the Phase-to-Ground Fault Apparent Admittance Method with Phase/Ground Boundaries to Detect Types of Electrical Faults for Protective Relays Using Signature Library and Simulated Events // International Transactions on Electrical Energy Systems. – 2022. – P. 1951836. – DOI: 10.1155/2022/1951836.

6 **Pichuev, A., Peturov, V.** Analiz prichin jelektrotravmatizma na gornyh predprijatijah [Analysis of the causes of electrical injuries at mining enterprises] // Transport infrastructure of the Siberian region. – 2016. – Vol. 1. – P. 637–641.

7 **Utegulov, B.** Special Issues of Ensuring Electrical Safety in Networks with Isolated Neutral Voltage up to 1000 V at Mining Enterprises / B. Utegulov // Industrial Engineering / ed. A. A. Mokhtar, M. Muhammad. – Rijeka: IntechOpen, 2018.

8 **Fedorova S. V., Utegulov B. B., Utegulov A. B., Koshkin I. V., Kurabayev I. K.** Experimental studies of a developed method for determining the insulation parameters in a network with isolated neutral voltage up to 1000 V // Herald of Science of S. Seifullin Kazakh Agro Technical University. – 2019. – Vol. 1.

9 **Utegulov, B. B., Utegulov, A. B., Uakhitova, A. B.** Modeling method for measuring the admittance of insulation in a network with an isolated neutral voltage up to 1000 V in mines using Matlab/Simulink / B. B. Utegulov, A. B. Utegulov, A. B. Uakhitova // Journal of Mining Science. – 2017. – Vol. 53, N 2. – P. 282–290. – DOI: 10.1134/S1062739117022128.

10 **Kurabayev, I., Suvorov, I., Utegulov, A., Tatkeyeva, G.** Mathematical description of the method for ungrounded AC systems to determine the network insulation // IET Generation, Transmission & Distribution. – 2022. – Vol. 16, N 11. – P. 2223–2227. – DOI: https://doi.org/10.1049/gtd2.12436.

11 **Tatkeyeva, G., Kurabayev, I., Ataullaev, N., Murodov, X.** Experimental research of the developed method to determine the network insulation for ungrounded AC systems in laboratory conditions // International Conference on Electrical, Computer and Energy Technologies (ICECET): 2022. – P. 1–4.

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АПРОБАЦИЯ РАЗРАБОТАННОГО МЕТОДА ОПРЕДЕЛЕНИЯ

ПАРАМЕТРОВ ИЗОЛЯЦИИ СЕТИ НА ДЕЙСТВУЮЩЕМ ЭКСКАВАТОРЕ

Одним из факторов, определяющих безопасность электроустановок в электрических сетях с изолированной нейтралью, является сопротивление изоляции относительно земли. Своевременное обнаружение и устранение неисправностей, сопровождающихся изменением активной и реактивной составляющих проводимости изоляции в электрических сетях с изолированной нейтралью, позволит обеспечить безопасность работ в электроустановках. В связи с тем, что масштабы случаев электротравматизма продолжают оставаться значительными, несмотря на ужесточение требований нормативно-технической документации и создание более новых эффективных способов и средств защиты от поражения электрическим током, следовательно, повышение уровня электробезопасности в эксплуатация горных машин и комплексов является актуальной задачей.

В статье представлены результаты апробации разработанного метода определения параметров изоляции сети на действующем экскаваторе. Разработанный метод основан на измерении фазных напряжений и углов их векторов до и после подключения дополнительной емкости к фазе электрической сети и к земле. По разработанному методу рассчитаны численные показатели состояния изоляции в электрической сети напряжением до 1000 В и тока однофазного замыкания на землю. При апробации разработанного метода был выявлен недостаток существующего устройства защитного отключения.

Ключевые слова: изоляция сети, проводимость, электрическая проводимость, сдвиг нейтрали, напряжение нулевой последовательности.

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ЖҰМЫС КЕЗІНДЕГІ ЭКСКАВАТОРДА ЖЕЛІЛІК ОҚҚАУ ПАРАМЕТРЛЕРІН АНЫҚТАУ ҮШІН ӘЗІРЛЕГЕН ӘДІСТЕМЕЛІКТІ АПРАБАБАЦИЯЛАУ

Оқшауланған бейтарапты электр желілеріндегі электр қондырғыларының қауіпсіздігін анықтайтын факторлардың бірі жерге қатысты оқшаулау кедергісі болып табылады. Оқшауланған бейтарапты электр желілеріндегі оқшаулау өткізгіштігінің белсенді және реактивті компоненттерінің өзгеруімен жүретін ақауларды уақтылы анықтау және жою электр қондырғыларындағы жұмыстардың қауіпсіздігін қамтамасыз етеді. Нормативтік-техникалық құжаттама талаптарының қатайтылуына және электр тогының соғуынан қоргаудың жаңа тиімді әдістері мен құралдарының жасалуына қарамастан, электр жарақаттары жагдайларының ауқымы айтарлықтай болып қалуына байланысты, сондықтан электр тогымен зақымдану деңгейін арттыру. тау-кен машиналары мен кешендерін пайдаланудағы қауіпсіздікті қамтамасыз ету кезек күттірмейтін міндет.

Мақалада жұмыс істеп тұрған экскаватордағы желілік оқшаулау параметрлерін анықтаудың әзірленген әдісін апробациялау нәтижелері берілген. Әзірленген әдіс электр желісінің фазасына және жерге қосымша сыйымдылықты қосқанга дейін және одан кейінгі фазалық кернеулер мен олардың векторларының бұрыштарын өлшеуге негізделген. Әзірленген әдіске сәйкес кернеуі 1000 В-қа дейінгі және бір фазалы жерге түйықталу тогы бар электр желісіндегі оқшаулау күйінің сандық көрсеткіштері есептеледі. Әзірленген әдісті сынау кезінде қолданыстагы қорганыс өшіру құрылгысының кемшілігі анықталды.

Кілтті сөздер: желі оқшаулауы, өткізгіштік, электр өткізгіштік, бейтарап ығысу, нөлдік тізбекті кернеу.

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