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METHOD FOR DETERMINING THE ZERO-SEQUENCE VOLTAGE IN A THREE-PHASE ELECTRICAL NETWORK WITH ISOLATED NEUTRAL

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Annotation

At this work a method for determining the zero-sequence voltage in a three-phase electrical network with isolated neutral is proposed. It lies in measuring the values of phase-to-phase voltage modules, voltage of phase B and voltage of phase A when additional capacitive conductance connected between phase A and earth. Also in article error analysis of developed method was conducted. The error analysis has shown that the developed method provides satisfactory accuracy when determining the zero-sequence voltage as well as simplicity and safety at production of works in existing electrical installations with voltages up to and above 1000 V.

Key words: voltage, insulation, neutral, method, network.

Introduction

Three-phase electrical networks with isolated neutral by voltage up to and above 1000 V have a significant variety in length of overhead and cable lines, number of connected electrical equipment that affects the magnitude of the single-phase earth fault current. When the value of single-phase earth fault above than 5 Amperes, the use of methods for determining the insulation parameters and current of single-phase earth fault with applying of active additional active conductance leads to significant errors in determining the required quantities by an indirect method. To reduce the error, it is necessary to have an active additional conductivity with a high dissipation power.

In operation practice, there is a technique for determining the insulation parameters using additional capacitive conductance by method of Moscow Mining Institute or ammeter-voltmeter method developed in detail by the honored worker of science and technology of the RSFSR, Professor L.V. Gladilin.

The method of ammeter-voltmeter for determining the insulation parameters with using of additional capacitive conductance in the three-phase electrical networks with isolated neutral by voltage up to and above 1000 V has a significant drawback, which lies in applying experience of metallic closure of one of the phases relative to the earth. In this case the voltage on the other two phases reach the value of phase-to-phase voltage, in connection with which there is a probability of formation of emergency mode as a two phase or three phase short circuit. With the experience of metal closure of one of the phases relative to earth, the level of electrical safety is significantly reduced when operation of electrical installations with voltages up to and above 1000 V [1 – 8].

On the basis of the above, it is advisable to develop new methods for determining the insulation parameters and single-phase earth fault current with using of additional capacitive conductance in the networks with isolated neutral. Developed methods will ensure the safety at production of works in electrical installations and reliability of power supply system by excluding the experience of metallic closure of one of the phases relative to earth

Theoretical foundations of method for determining the zero-sequence voltage in three-phase electrical network with isolated neutral

Developed indirect methods for determining the magnitude of zero-sequence voltage module have complex mathematical dependencies, which do not provide satisfactory accuracy.

Given in GOST 13109-97 the method for determining magnitude of zero-sequence voltage do not provide satisfactory accuracy since the mathematical formula is not correct under condition of asymmetry of a three-phase electrical network with isolated neutral.

A known method for determining the zero-sequence voltage is based on measurement of values of phase-to-phase voltage, voltages of phase A, B and C when the additional active conductance is connected between the phase A of electrical network and earth. It is determined by the mathematical dependence [9]:

$$U_o = \frac{\sqrt{U_A^2 + U_B^2 + U_C^2 - U_{ph-ph}^2}}{\sqrt{3}}. \qquad (1)$$

In practice during operating three-phase electrical networks with isolated neutral by voltage of 6 - 10 kV with single-phase earth fault currents greater than 5 Amperes the use of an active resistance as an additional conductivity is problematic due to the thermal stability. In time of heating the resistance used has the property of changing its value and thereby introduces a significant error in determining the insulation parameters and current of single-phase earth fault. This is due to the fact that the additional conductivity is directly proportional to the unknown quantities.

To exclude influence of additional active conductance at studying of three-phase electrical networks with isolated neutral with fault currents greater than 5 Amperes it is necessary to use additional capacitive conductance.

Applying of additional capacitive conductance at determining the magnitude of zero-sequence voltage in three-phase electrical network with isolated neutral advantageously differs in that when single-phase earth fault currents greater than 5 Amperes in determining the insulation parameters and single-phase earth fault current satisfactory accuracy is ensured.

The additional capacitive conductance is different from the additional active conductance by the nature that in this case the voltages of phase C and B will be equal to each other during the additional capacitive conductance is connected between phase A of electrical network and earth. Herewith the equation (1) of determining the zero-sequence voltage will take following form:

$$U_o = \frac{\sqrt{U_A^2 + 2U_B^2 - U_{ph-ph}^2}}{\sqrt{3}}. \qquad (2)$$

Based on the above a new method for determining the zero-sequence voltage in a three-phase electrical network with isolated neutral, which consisting in measuring the magnitude of phase-to-phase voltage modules, voltage of phase B and voltage of phase A when additional capacitive conductance between phase A and earth is connected.

Error analysis of method for determining the zero-sequence voltage in a three-phase electrical network with isolated neutral

Errors analysis of method for determining the magnitude of zero-sequence voltage module in a three-phase network with isolated neutral from measured values of phase-to-phase voltage modules - $U_л$ and voltages of phases U_A and U_B is performed.

Determining the zero-sequence voltage value in a three-phase electrical network with isolated neutral by voltage up and above 1000 V based on measurement of phase-to-phase voltage module, phase B and A voltage modules relative to earth after connecting the additional capacitive conductance between phase A in electrical network and earth. Random relative mean square error is defined from the formula (2):

$$U_o = \frac{\sqrt{U_A^2 + 2U_B^2 - U_{ph-ph}^2}}{1.73},$$

where U_{ph-ph}, U_A и – values that determining the zero-sequence voltage in the network with isolated neutral, which obtaining by direct

U_B measurement.

Relative mean-square error of method for determining the zero-sequence voltage in the network with isolated neutral is found from mathematical expression [10 – 12]:

$$\Delta U_o = \frac{1}{U_o}\left[\left(\frac{\partial U_o}{\partial U_A}\Delta U_A\right)^2 + \left(\frac{\partial U_o}{\partial U_B}\Delta U_B\right)^2 + \left(\frac{\partial U_o}{\partial U_{ph-ph}}\Delta U_{ph-ph}\right)^2\right]^{1/2}, \tag{3}$$

where $\frac{\partial U_o}{\partial U_A}$, $\frac{\partial U_o}{\partial U_B}$, $\frac{\partial U_o}{\partial U_{ph-ph}}$ – partial derivatives of function

$$U_o = f\,(U_{ph-ph},\ U_A,\ U_B).$$

Here ΔU_{ph-ph}, ΔU_A, ΔU_B – absolute errors of direct measurement of values U_{ph-ph}, U_A, U_B, which are defined by the following expressions:

$$\Delta U_{ph-ph} = U_{ph-ph} \cdot \Delta U_{ph-ph*};$$
$$\Delta U_A = U_A \cdot \Delta U_{A*}; \tag{4}$$
$$\Delta U_B = U_B \cdot \Delta U_{B*}.$$

To determine the error of measuring instruments, it is assumed that $\Delta U_{ph-ph*} = \Delta U_{A*} = \Delta U_{B*} = \Delta U_*$,
where ΔU_* – relative error of measuring voltage circuits.

Partial derivatives of function $U_o = f\,(U_{ph-ph},\ U_A,\ U_B)$ on variables U_{ph-ph}, U_A, U_B are determined as:

$$\frac{\partial U_o}{\partial U_A} = \frac{U_A}{1.73\sqrt{U_A^2 + 2U_B^2 - U_{ph-ph}^2}};$$
$$\frac{\partial U_o}{\partial U_B} = \frac{2U_B}{1.73\sqrt{U_A^2 + 2U_B^2 - U_{ph-ph}^2}}; \tag{5}$$
$$\frac{\partial U_o}{\partial U_{ph-ph}} = -\frac{U_{ph-ph}}{1.73\sqrt{U_A^2 + 2U_B^2 - U_{ph-ph}^2}}.$$

Equation (3) is solved by substituting in it the values of partial derivatives from equation (5) and values of partial absolute errors (4), wherein believing that $\Delta U_* = \Delta$, then we get:

$$\varepsilon_{U_o} = \frac{\Delta U_o}{\Delta} = \frac{1}{1.73\sqrt{U_A^2 + 2U_B^2 - U_{ph-ph}^2}}\sqrt{U_{ph-ph}^4 + U_A^4 + 4U_B^2}\ . \qquad (6)$$

The resulting equation (6) is divided into equation (2):

$$\varepsilon_{U_o} = \frac{\Delta U_o}{\Delta} = \sqrt{U_{ph-ph}^4 + U_A^4 + 4U_B^2}\ . \qquad (7)$$

The resulting equation (7) is expressed in relative units, and after transformation we obtain:

$$\varepsilon_{U_o} = \frac{\Delta U_o}{\Delta} = \sqrt{1 + U_{A*}^4 + 4U_{B*}^2}\ , \qquad (8)$$

where $U_{A*} = \frac{U_A}{U_{ph-ph}}$; $U_{B*} = \frac{U_B}{U_{ph-ph}}$.

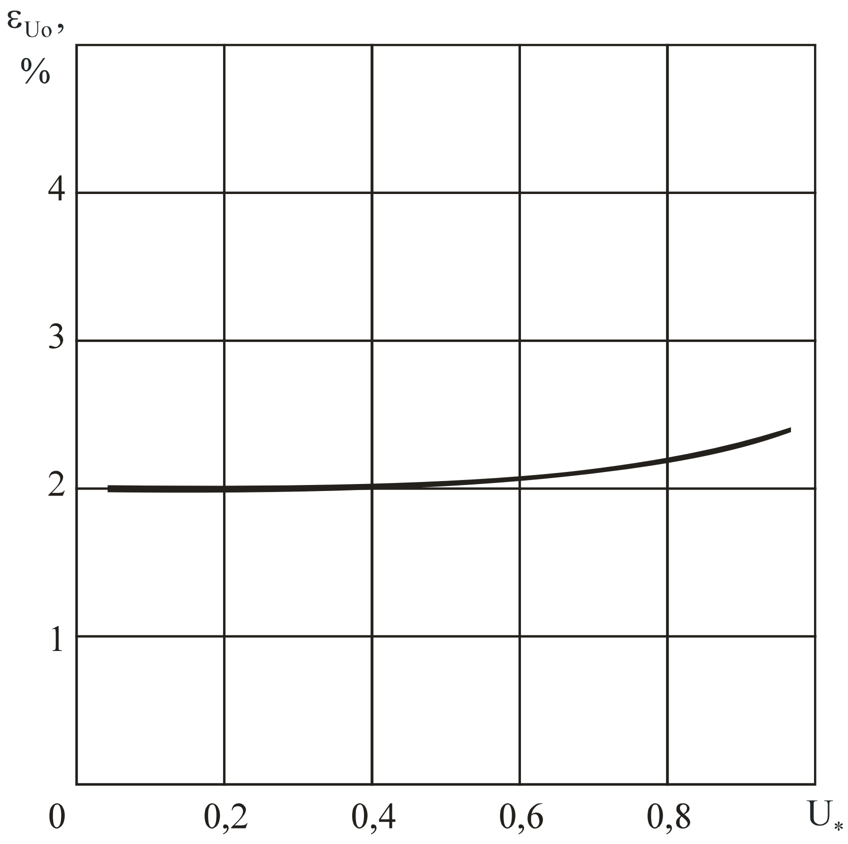
Equation (8) is transformed in connection with the fact when connecting the additional capacitive conductance between phase A of electrical network and earth the value of phase-to-phase voltage does not change:

$$\varepsilon_{U_o} = \frac{\Delta U_o}{\Delta} = \sqrt{5 + U_*^4}\ , \qquad (9)$$

where $U_* = \frac{U_{A*}}{U_{B*}}$.

Based on obtained equation (9) and results of random relative mean-square errors of determining the zero-sequence voltage in electrical network with isolated neutral, we build dependencies (picture 1):

$$\varepsilon_{U_o} = \frac{\Delta U_o}{\Delta} = f\,(U_*).$$



Picture 1 – Error analysis of determining
the zero-sequence voltage

When plotting a graph for dependence of random relative mean square error of determining the zero-sequence voltage module it is assumed that the accuracy class of measuring devices is 1.0, that is D=1.0.

In accordance with the obtained curves of dependencies it is seen that changes in the relative error of zero-sequence voltage depend on selecting values of additional capacitive conductance, which connecting between one of electrical network's phases and earth.

Under selecting additional capacitive conductance when changes U_* are within 0.2 ÷ 0.8 then the error in determining the zero sequence voltage does not exceed 2.5% in total.

Using resulting mathematical dependence for determining the magnitude of zero-sequence voltage allows us to obtain new mathematical equations for determining insulation parameters and single-phase earth fault current in a three-phase electrical network with isolated neutral by voltage up to and above 1000 V.

Wherein satisfactory accuracy for the required parameters finding by an indirect method is provided.

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Conclusions:

A method for determining the zero-sequence voltage in electrical network with isolated neutral has been developed. It lies in measuring of module values of phase-to-phase voltage, voltages of phase A and B relative to earth after connecting additional capacitive conductance between the phase A of electrical network and earth.

Studies of the relative mean-square error have shown that using this method is provided satisfactory accuracy, simplicity and safety in the manufacture of measurements. In addition, no special measuring devices are required since the measuring instruments are installed in the general industrial design. And for introduction of additional capacitive conductance, a spare cell with a load switch of the substation switchgear is applied.

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Түйін

Жұмыста кернеудің фазалық кернеуі мен фаза А кернеуінің өлшенуін қамтитын үшфазалы электр желісіндегі нөлдік тізбектік кернеуді анықтау әдісі ұсынылады, ол кернеудің фазалық кернеуі мен фазасы А және кернеу арасындағы өзара байланыспен қамтамасыз етіледі және әзірленген әдіс қателерін талдайды. Қателерді талдау нөлдік тізбектің кернеуін анықтауда, сондай-ақ 1000 В дейінгі және одан жоғары кернеулі қолданыстағы электр қондырғыларында жұмыс істеудің қарапайымдылығы мен қауіпсіздігін анықтайтын әзірленген әдіс көрсетті.

Резюме

В работе предложен метод определения напряжения нулевой последовательности в трехфазной электрической сети с изолированной нейтралью заключающийся в измерении величин модулей линейного напряжения, напряжения фазы B и напряжения фазы A при подключенной дополнительной емкостной проводимости между ней и землей и произведен анализ погрешностей разработанного метода. Анализ погрешностей показал, что разработанный метод обеспечивает удовлетворительную точность при определении напряжения нулевой последовательности, а также простоту и

безопасность производства работ в действующих электроустановках напряжением до и выше 1000 В.