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MODELING OF A SINGLE-PHASE EARTH FAULT IN DETERMINING THE LOCATION OF DAMAGE USING LINEAR ALGEBRA THEORY

The article is devoted to the analysis of emergency modes in a network with an isolated neutral of 6(10)-35 kV.. The purpose of the work is to develop a mathematical model of an electrical network with a voltage of 6(10)-35 kV when calculating a single-phase earth fault to determine the location of damage using linear algebra theory. Tasks: to analyze the emergency mode in a network with an isolated neutral; to develop a methodology for calculating an emergency event taking into account the parameters of the transient process to determine the location of accidents in the network. The result of the proposed solutions is a rational determination of the single-phase earth fault current parameter, taking into account the values of the longitudinal and transverse components of the network replacement circuit. The study of the replacement circuit and the calculation of the circuit parameters using the decomposition theory of the matrix determinant show good dynamics of accounting for all parameters of the electrical network in the event of an emergency ground fault. According to the calculated values of the frequencies under consideration, the intrinsic resistance «Z» of each of the circuits of the resulting substitution circuit is determined. After determining the intrinsic resistance of the earth fault circuit taking into account the transient resistance, the dependence

Z = f(ω) is calculated to determine the distance to the location of the defect in power transmission lines in remote devices for fixing emergency events installed in distribution networks of 6(10)-35 kV.

Keywords: Electric power industry, electric grid, isolated neutral, grounding, damage location, simulation, isolation, reliability, power quality, emergency mode.

Introduction

Ensuring high-quality and uninterrupted supply of electric receivers is the main task of energy transmission and energy distribution organizations, since power supply failures lead to negative consequences in the production process, as well as in the daily life of energy consumers. Therefore, the speed of disconnection of the emergency section of the electrical installation, as well as the determination of the defect area in the event of an accident in the electrical network, seems to be a significant component of ensuring the quality of power supply to energy consumers.

In distribution networks with a voltage of 6(10) -35 kV, the process of determining the location of damage (DLD) is associated with the peculiarity of grounding the neutral transformers and the operating mode of the network as a whole [1, 2].

According to statistics, a common type of defect in the networks under consideration is a single-phase earth fault, which is approximately in the range of 70-80% of absolutely all other types of defects [3]. The difficulty of the DLD with a single-phase earth fault (SpEF) in electrical networks of 6 (10)-35 kV consists in an insignificant value of the fault current, which often leads to failure of the fixing devices, and, in addition, in a very significant branching of the power grid. The main method of DLD used in substations of Kostanay region is topographic, implemented by bypassing the main air line together with the use of additional location equipment. In this case, the time period to search for damage increases significantly, and at the same time, the under-supply of electricity to consumers increases if the network is disconnected or works erratically [1, 2, 3].

Consequently, most of the research should be focused on the formation of new remote automatic methods and means of DLD in the event of short circuits in the 6(10)-35 kV network. For this purpose, the task of mathematical modeling of the emergency mode at the SpEF and determining the most rational mathematical apparatus, taking into account all influencing factors, is set.

Materials and methods

During the development of the methodology for the remote form of determining the location of damage in electrical networks with a voltage of 6(10)-35 kV, the following assumptions must be taken into account [2 – 4]:

1) these power grids have a large branching and length;

2) the absence in the simplified scheme of the substation of a 10 kV network and in some cases 35 kV switches at each connection, which significantly complicates the disconnection of the power line;

3) in the operating mode of the network, there is a time limit for the SpEF, due to the danger of internal overvoltages that lead to a defect in electrical equipment;

4) the presence of hard-to-reach areas of power lines where it is impossible to carry out a visual inspection of the line;

5) characteristic modes of operation of the neutral of the distribution network 6(10)-35 kV, types of emergency modes, including the presence of a transient process at the SpEF.

The principle of the method of equations of state variables when modeling an electric network in the earth fault mode is to change the energy state of the electric network, in the event of a process of its transition from one mode to another [5].

In order to create a mathematical model of an electrical network operating in an isolated neutral mode, when a single-phase earth fault occurs, the implemented modeling method is used, Figure 1 shows the network replacement scheme [2, 6, 7].

The considered substitution scheme of the electrical network can be described by a system of first-order differential equations in matrix form, where, after transformations of the parameters of the substitution scheme, the expression is obtained:

$$\frac{d}{dt} = \begin{bmatrix} C & 0 \\ 0 & L \end{bmatrix} \begin{bmatrix} u_C \\ i_L \end{bmatrix} = A \begin{bmatrix} u_C \\ i_L \end{bmatrix} + B \begin{bmatrix} u_E \\ J_C \end{bmatrix} \quad (1)$$

where C – the value of the capacity of the network parameter, F
L – the value of the inductance parameter, Gn;
u_C – voltage at the capacitances of the replacement circuit, V;
i_L – the value of the current through the inductance of the replacement circuit, A;
u_E – the value of the EMF voltage of the circuit, V;
J_C – the value of the power supply current in the branches of the replacement circuit, A;
A_1,B_1 – empirical coefficients depending on the structure of the substitution scheme [4, 5, 7].

The model of the studied electrical network with a voltage of 6(10)-35 kV using the method of differential equations of state variables, can take the following characteristics:

- the values of the active and reactive resistances of the damaged phase of the electrical network at SpEF;

- the values of the active and reactive resistances of the intact phases of the electrical network at SpEF;

- the values of the active and reactive resistances of power transmission lines that are not damaged;

- the values of the capacitances between phases in the electrical network at the SpEF;

- the values of mutual induction between phases in the electrical network at SpEF;

- types of suspension of wires on the power line.

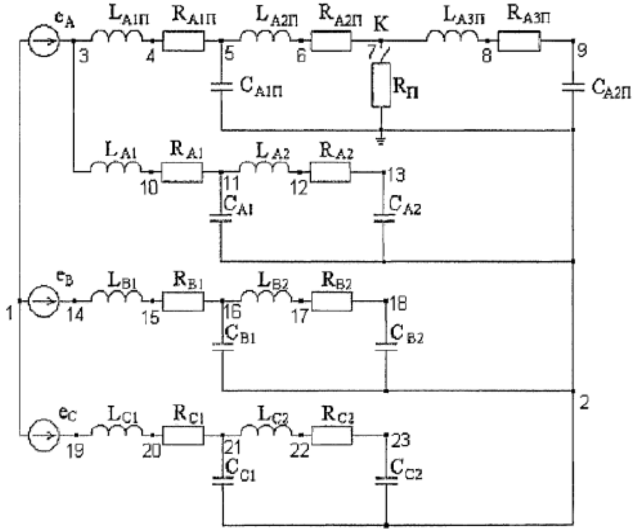

Figure 1 – Replacement diagram of a three-phase overhead power transmission line in the mode of a single-phase earth fault using the method of differential equations of state variables [2]

In addition, when modeling a network with a voltage of 6(10)-35 kV, taking into account a single-phase earth fault, it is necessary to take into account the parameters of the secondary winding of the network transformer and the value of the active longitudinal resistance of the power line as a parameter of the transient process. This conclusion is due to the fact that the parameters under consideration can significantly affect the values of the natural frequency of the current and the voltage level when a transient process occurs in the SpEF mode. In this type of accident, the capacity of the damaged phase is discharged to the resistance of the longitudinal part of the power line, and the discharge currents are closed to the low voltage winding of the communication transformer [6].

Results and discussion

During the development of a mathematical model of a 6(10)-35 kV network, when a ground fault mode occurs in one of the phases (for example, phase A), it is necessary to take into account all the longitudinal and transverse components of the replacement circuit, and additionally specify a power transformer, in the form of a T-shaped replacement circuit, and a power transmission line, which can be displayed as two T-shaped replacement circuits of each phase of the network.

The model of the line and elements of the entire network contains the following independent boundary initial values:

- eA, eB, eC – the values of the phase EMF of the primary winding of the communication transformer;
- R1, X1 – the values of the active and inductive resistances of the longitudinal part of the branch of the primary winding of the transformer;
- R0, X0 – the values of the magnetizing active and inductive resistances of the transverse part of the branch of the primary winding replacement circuit of the transformer;
- the values of the active and inductive resistances of the longitudinal part of the branch of the substitution circuit brought to the secondary winding of the transformer;
- R, XL, XC – values of active, inductive and capacitive resistances of the power line of the replacement circuit.

The method of contour currents is used to calculate the parameters that make up the transient process for SpEF in a network with a voltage of 6(10)-35 kV with an isolated neutral.

Figure 2 shows the scheme for determining the initial conditions of the transient process by the method of contour currents, compiled in accordance with the original substitution scheme.

When forming the resulting circuit, the restriction is accepted that with a single-phase earth fault, the fault current does not extend beyond the secondary winding of the communication transformer.

The value of the single-phase earth fault current of phase A in case of its damage must be calculated using the operator method of analyzing transients in emergency situations of the network using the Laplace transform.

The idea of the proposed method is to replace the resulting replacement scheme of network elements with their equivalent operator backgrounds and images:

- computational operator calculus of complex EMF and network voltage of the replacement circuit;
- Li(0) – computational operator calculation of inductance voltage;

- – the calculated operator calculation of the voltage on the capacitance of the circuit;

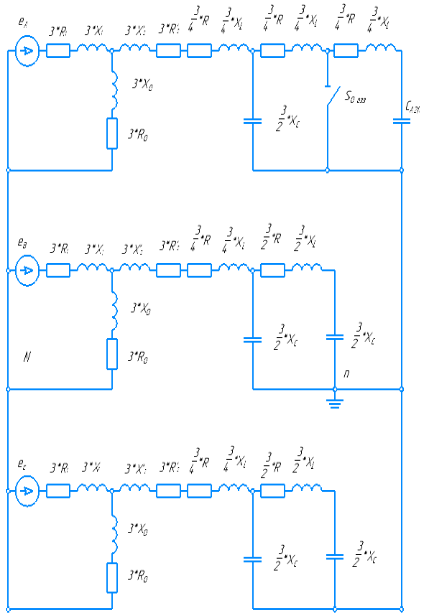

Figure 2 – The resulting network replacement scheme for determining the initial conditions of the transient process without taking into account the load power parameters

- Lp – calculated operator function of inductive resistance;
- the calculated operator function of the capacitive resistance of the circuit.

Figure 3 shows the transformed operator substitution scheme for calculating the parameters of the transient process in case of accidents in the electrical network

The matrix of parameters of the operator substitution scheme shown in the figure includes:

– operator EMF function outline;

– the function of the operator current of the circuit circuit;

– the operator resistances of the branches between the contours, as well as the intrinsic resistances of the contours in the operator form.

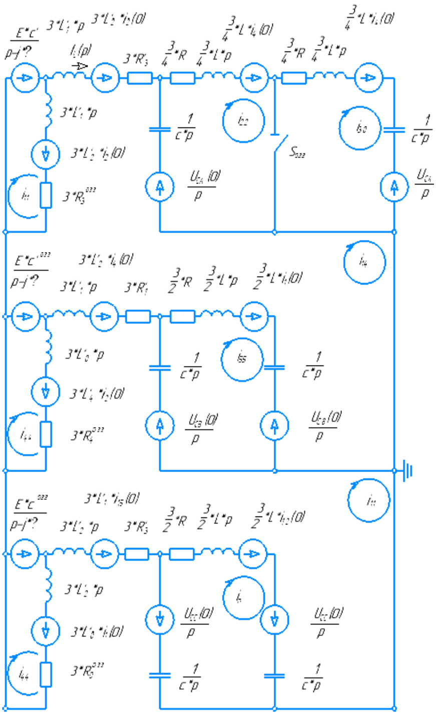

Figure 3 – Operator replacement circuit of the electrical network

Expression for determining the current value for each circuit:where

- the value is the determinant of the initial matrix of boundary values of the scheme without the i-th vector column;

- the value is the determinant of the initial matrix of boundary values of the circuit without the EMF vector.

The value of the single-phase earth fault current is determined based on the values of the current of the eighth circuit of the operator matrix: where

- the numerator polynomial of the substitution scheme operator;

- the value of the denominator polynomial of the substitution scheme operator.

In the future, when implementing the transition from the operator image of the SpEF current in the form of to the actual value of the current in the form of , the decomposition theorems of operational calculus are applied: where

- the current of a single-phase earth fault, which passes at the beginning of the damaged phase, taking into account the value of the transient resistance R;

- the roots of the equation

When solving equation (4), its roots are determined, which, in the network substitution scheme, represent the natural frequencies ω of the contour currents.

According to the values of the frequencies under consideration, the intrinsic resistance Z of each of the circuits is determined. After determining the intrinsic resistance of the earth fault circuit, the dependence is constructed in order to calculate the distance to the defect location in power transmission lines in remote emergency event recording devices installed in distribution networks of 6(10) -35 kV.

Conclusions

The construction of a mathematical operator model of an electrical network with a voltage of 6(10)-35 kV with an isolated neutral in the event of a single-phase earth fault, using the integral Laplace transform as an element of linear algebra theory, helps to take into account the influence of the following parameters of the electrical network:

- the value of the inductance of the power transformer, which affects the values of the current and frequency of the transient process;

- the value of the active resistances of the phases of the power line.

Taking into account the considered values effectively affects the accuracy of determining the current of a single-phase earth fault and in the future, searching for an accident site in the electrical network.

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СЫЗЫҚТЫҚ АЛГЕБРА ТЕОРИЯСЫН ҚОЛДАНА ОТЫРЫП, ЗАҚЫМДАНУ ОРНЫН АНЫҚТАУ КЕЗІНДЕ БІР ФАЗАЛЫ ЖЕРГЕ ТҰЙЫҚТАЛУДЫ МОДЕЛЬДЕУ

Мақала 6 (10) – 35 кВ оқшауланған бейтарапты желідегі авариялық режимдерді талдауға арналған. Жұмыстың мақсаты - кернеуі 6 (10) – электр желісінің математикалық моделін жасау. 35 кВ бір фазалы жерге тұйықталуды есептеу кезінде сызықтық алгебра теориясын пайдаланып зақымдану орнын анықтау. Міндеттері: оқшауланған бейтарапты желідегі авариялық режимді талдау; желідегі авариялардың орнын анықтау үшін өтпелі процестің параметрлерін ескере отырып, төтенше жағдайды есептеу әдістемесін әзірлеу. Ұсынылған шешімдердің нәтижесі желінің эквивалентті тізбегінің бойлық және көлденең құрамдастарының мәндерін ескере отырып, бір фазалы жерге тұйықталу тогының параметрін ұтымды анықтау болып табылады. Эквивалентті сұлбаны зерттеу және матрицаның анықтаушысының ыдырау теориясын қолдана отырып, тізбек параметрлерін есептеу жерге тұйықталудың авариялық режимі пайда болған кезде электр желісінің барлық параметрлерін есепке алудың жақсы динамикасын көрсетеді. Қарастырылып отырған жиіліктердің есептелген мәндеріне сәйкес алынған алмастыру схемасының контурларының әрқайсысының z кедергісі анықталады. Ауыспалы кедергіні есепке ала отырып, жерге тұйықталу контурының меншікті кедергісін анықтағаннан кейін 6(10) -35 кВ тарату желілерінде орнатылған авариялық оқиғаларды тіркеудің дистанциялық құрылғыларындағы электр беру желілеріндегі ақау

орнына дейінгі қашықтықты анықтау үшін тәуелділік z=F(ω)есебі жүргізіледі.

Кілті сөздер: Электр энергетикасы, электр желісі, оқшауланған бейтарап, жерге тұйықталу, зақымдану орны, модельдеу, оқшаулау, сенімділік, электр энергиясының сапасы, төтенше жағдай режимі.

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МОДЕЛИРОВАНИЕ ОДНОФАЗНОГО ЗАМЫКАНИЯ НА ЗЕМЛЮ ПРИ ОПРЕДЕЛЕНИИ МЕСТА ПОВРЕЖДЕНИЯ С ИСПОЛЬЗОВАНИЕМ ТЕОРИИ ЛИНЕЙНОЙ АЛГЕБРЫ

Статья посвящена анализу аварийных режимов в сети с изолированной нейтралью 6(10)-35 кВ. Цель работы – разработка математической модели электрической сети напряжением 6(10)-35 кВ при расчете однофазного замыкания на землю для определения места повреждения с использованием теории линейной алгебры. Задачи: провести анализ аварийного режима в сети с изолированной нейтралью; разработать методику расчета аварийного события с учетом параметров переходного процесса для определения места аварий в сети. Результатом предлагаемых решений является рациональное определение параметра тока однофазного замыкания на землю с учетом величин продольных и поперечных составляющих схемы замещения сети. Исследование схемы замещения и расчет параметров схемы с использованием теории разложения определителя матрицы показывают хорошую динамику учета всех параметров электрической сети при возникновении аварийного режима замыкания на землю. По расчетным величинам рассматриваемых частот определяют собственное сопротивление Z каждого из контуров результирующей

схемы замещения. После определения собственного сопротивления контура замыкания на землю с учетом переходного сопротивления, производится расчет зависимость для определения расстояния до места дефекта в линиях электропередачи в дистанционных устройствах фиксации аварийных событий, установленных в распределительных сетях 6(10)-35 кВ.

Ключевые слова: электроэнергетика, электрическая сеть, изолированная нейтраль, замыкание на землю, место повреждения, моделирование, изоляция, надежность, качество электроэнергии, аварийный режим.

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