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DEVELOPMENT OF SIMULATION MODEL OF SINGLE-PHASE CIRCUIT LOCK IN THE DIGSILENT POWERFACTORY PROGRAM

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Abstract: The most common types of damage in distribution networks with a voltage of 6-35 kV have been analyzed. It is shown that the majority of them are single-phase circuits, which can cause overvoltages at the point of damage and negatively affect electrical equipment, which can lead to a decrease in economic indicators. The methods of increasing the reliability of distribution networks with a voltage of 6-35 kV have been analyzed. The main attention is focused on the method of increasing reliability due to grounding of the neutral through an arc reactor, the main advantage of which in operation is the continuation of single-phase ground fault operation without disconnection of consumers. A simulation model of the distribution network in single-phase ground fault mode was developed and its main parameters were calculated. The DiGSILENT PowerFactory software complex is used as a simulation environment. A concrete example of parameter calculation when using the proposed simulation model in the DiGSILENT PowerFactory program, which contains 5 overhead and 5 cable power transmission lines with a voltage of 35 kV with a length of 10 to 100 kilometers. The use of this model will make it possible to study transient processes in the mode of single-phase grounding, to prevent emergency situations in distribution networks.
The goal of the work ist development of the simulation model of the distribution network in the mode of single-phase circuit to land and the calculation of its basic parameters.
Keywords: DIgSILENT PowerFactory, single-phase earth fault, modeling of electrical networks.

1. INTRODUCTION

One of the most common types of damage in distribution networks with a voltage of 6-35 kV is a single-phase fault to the ground (SPG). The prevalence of SPG accounts for about 90% of the total damage in these networks (Pignati et al., 2017, Salehiand and Namdari, 2018, Kim and Aggarwal, 2003, Pazyi et al., 2020). Such faults can escalate into multi-phase short circuits, especially under high currents, causing breakdowns in air line wires and potentially leading to step voltage occurrences (Shevchenko et al., 2019, Qawaqzeh et al., 2020). SPG also adversely impacts electrical equipment, resulting in diminished economic performance. In the context of increasing energy demand and the shift towards sustainable energy sources, understanding the selection of renewable energy sources, particularly in the industrial sector, becomes crucial (Ulewicz et al., 2021). Furthermore, the need for resilient and efficient energy distribution systems aligns with the broader goals of sustainable energy development across the European Union, where economic and demographic potentials play significant roles (Tutak et al., 2020). One method to enhance the reliability of 6-35 kV distribution networks is the grounding of neutrals through an arc gauge reactor. This method enables continued operation during SPG incidents without disconnecting consumers, thereby maintaining operational stability and efficiency (Shevchenko et al., 2022, Eremenko et al., 2016, Borghetti et al., 2010, Power Factory, 2019, Britel and Cherkauoi, 2022).

2. ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The complexity of implementing this mode of operation of the neutral is due to the fact that the capacitive current changes depending on the network configuration, resonance can be maintained only automatically, using smoothly regulated arc extinguishing reactors and an automatic control system (Danylchenko et al., 2019, Al_Issa et al., 2021, Shevchenko et al., 2020). In the practice of operation, there is an incorrect use of compensation of capacitive currents because the instructions and recommendations for compensation of capacitive currents, set out in (Tymchuk and Miroshnyk, 2015, Rubanenko et al., 2020), are not followed. Thus, the benefits of compensation are nullified. This gives some experts a reason to draw conclusions about the shortcomings of compensation and even about its harmfulness (a high level of arc overvoltages and the possibility of transition of SPG to interphase short circuits with significant settlement) (Shevchenko et al., 2022, Trunova et al., 2019, Shevcheno and Danylchenko, 2015).

3. SETTING OBJECTIVES

In the power engineering there are devices for assurance of electricity quality. Such devices use an active current filtration. This is a complex (volumetric) electrical system. Analysis, as well as experimental verification of such systems is a very costly and labor-intensive work. In this case, in order not to carry out such expensive procedures, solved the problem by replacing the device to a virtual computer model.

In order to increase the efficiency of the distribution network with compensated neutral and eliminating compensation shortcomings, it is recommended to use smoothly adjustable reactors with automatic adjustment. Much attention should be paid to the control system of an arc reactor, because it depends on the correctness of the compensation current for various electrical network configurations. Evaluate different control systems may use simulation simulation. Modeling a distribution network with compensated neutral allows you to study transient processes that occur in different operating modes and make an analysis of the impact of transient processes on the performance of automatic adjustment systems (Tymchuk and Miroshnyk, 2015, Rubanenko et al., 2020).

4. BASIC MATERIAL AND RESULTS

4.1. Research methods

PowerFactory environment, a scheme for replacing the distribution network was implemented (Eremenko et al., 2016).

DIGSILT POWERFACTORY is an engineering tool for analyzing industrial, transmitting and commercial electrical systems. It has been developed as an improved integrated and interactive software system designed for electrical systems and analysis of management systems to achieve the main tasks of planning and optimizing modes. The accuracy and reliability of the results obtained with this software have been confirmed by a multitude of implementations performed by organizations that are engaged in planning and operating of electric power systems (Borghetti et al., 2010, Shevchenko et al., 2022, Trunova et al., 2019, Shevcheno and Danylchenko, 2015, Mora-Flòrez et al., 2008, Khasawneh et al., 2021).

To meet modern requirements for analyzing electrical systems, the DIGSILENT software package is designed as an integrated engineering tool, provides easy access to all available features, instead of a set of different software modules. The following main features of PowerFactory are presented in a single executable program (Miroshnuk and Tymchuk, 2013, Bezruchko et al., 2019, Qawaqzeh et al., 2023, Minakova and Zaitsev, 2022):

- determination, change and ordering of research options, the main numerical methods, functions of output and documentation,
- integrated interactive one-line graphic and information software shell,
- database of elements of electrical systems and output parameters,
- integrated calculation functions (for example, calculating the parameters of transmission lines (pulp) and electric machines based on geometric dimensions or passport data),
- configuration of an electrical network based on an interactive or prompt request to the SCADA system,
- multifunctional interface for dynamic display using a computer.

With a single database that contains all the necessary information on the equipment of the electrical system (for example, the parameters of the transmission line, generators, protective devices, oscillations, controllers), PowerFactory will easily perform any or simultaneously all available features in one and the same software environment. Some of these functions are the calculation of the established mode, calculation of short-circuit currents, harmonious analysis, coordination of protective devices, calculation of stability and modal analysis (Buinyi et al., 2019, Al_issa et al., 2022, Krasnozhon et al., 2016).

PowerFactory includes an impressive and ever-growing list of modeling features:

- analysis of the established mode and short-circuit currents for all types of electric networks, including complexified 1-, 2-, and 3-phase variable and DC systems,
- analysis of low voltage networks,
- optimization of distribution networks,
- choice of intersection of cable lines,
- modeling of dynamic and electromagnetic transitional processes,
- analysis of own numbers,

- identification of the system,
- analysis of emergency situations and protection,
- harmonious analysis,
- analysis of reliability and voltage resistance,
- simulation of power electronics devices,
- grounding modeling,
- analog-to-digital interfaces, the interface for SCADA/GIS/NIS.
- compatibility with other software products such as PSS/E and PSS/U.
- optimization of the established mode.

4.2. Results of modeling

Let's consider in more detail the calculation of the main parameters of the distribution network model in the OZS mode. In fig. 1 shows a model of a three-phase electrical network. To determine the average value of the phase capacity relative to the air line, we will use the expression (Borghetti et al., 2010, Kopach et al., 2016, Krasnozhon et al., 2020, Ren et al., 2014, Khrypunov et al., 2018):

$$C_{PL} = 0{,}4884 \cdot 10^{-9} K_{tr} \cdot K_{kil} \cdot K_{rozm} \times ln\ (3{,}4 \cdot 10^{3}\, r + $$

$$+ 3{,}56 \cdot 10^{3}) \times ln\ (-\ 0{,}02\ PK_{U1} + 2{,}97\ K_{U2}) \quad (1)$$

where:
Ktr – is a coefficient depending on the presence of a lightning protection rope,
Kkil – coefficient, which depends on the number of circles of the line that is suspended in one resistance,
Krozm – a coefficient that depends on the placement of wires on the support,
r – radios of phase spinning, mm,
P – the amount of interphase distances between phases (if the two-circuit line is only one circle), m,
KU1, KU2 – coefficients that depend on the voltage of the line (with *U = 6-10 kV KU1 = 5,29, KU2 = 1,175, with U = 35 kV KU1 = KU2 = 1*).
The coefficient of *Ktr* acquires the following values:
- in the absence of a cable *Ktr = 1*,
- with a single-letter line and the presence of a cable *Ktr = 1,082*,
- with a two-wheeled line of the presence of a cable Ktr = 1,037.

The coefficient of *Kkil* acquires the following values:
- with a single-wheel line *Kkil = 1*,
- with a two-wheel line Kkil= 1.15.

The average phase capacity relative to the ground for the cable line will find according to the following expression (Danylchenko et al., 2019, Kopach et al., 2016, Ren et al., 201411):

$$C_{ku} = K_{vyk} \cdot 10^{-7} \cdot \left(ln\left(K_f + \frac{K_U}{\sqrt{F}}\right)\right)^{-1} \quad (2)$$

where:
Kvyk is a coefficient of cable usage,
Kf – coefficient of form lived,
Ku – coefficient of nominal cable voltage,
F – section lived, mm2.

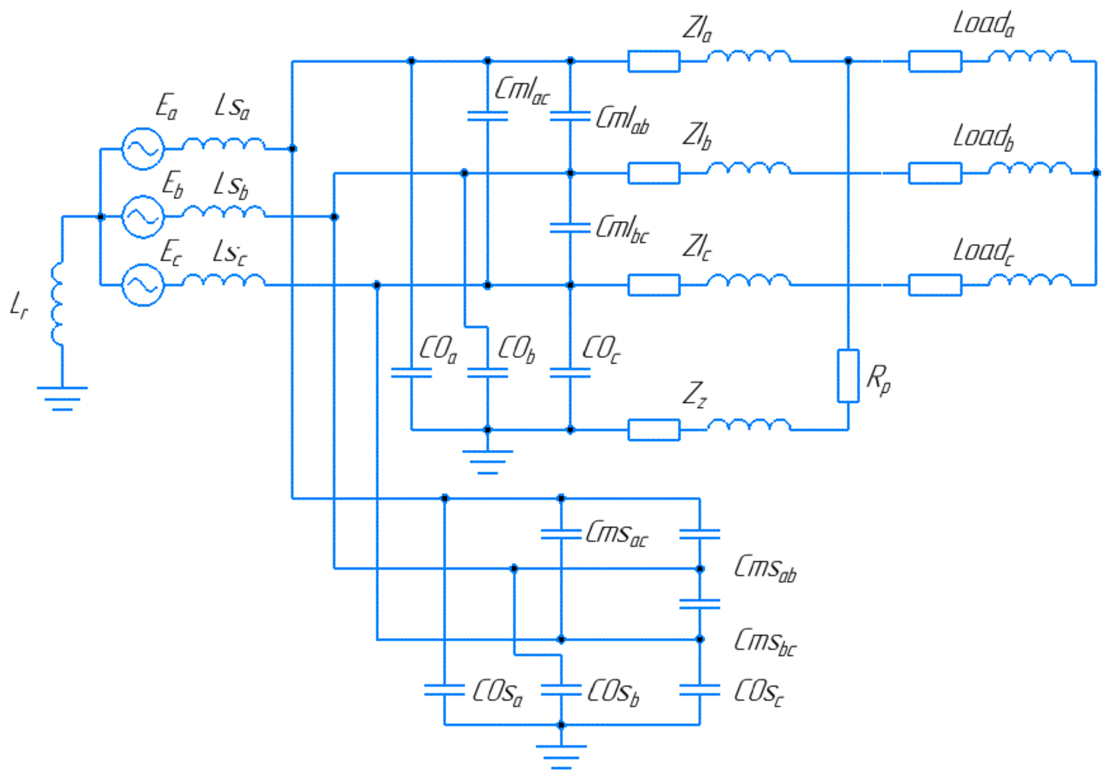

Fig. 1. Simulation model of three-phase electric network

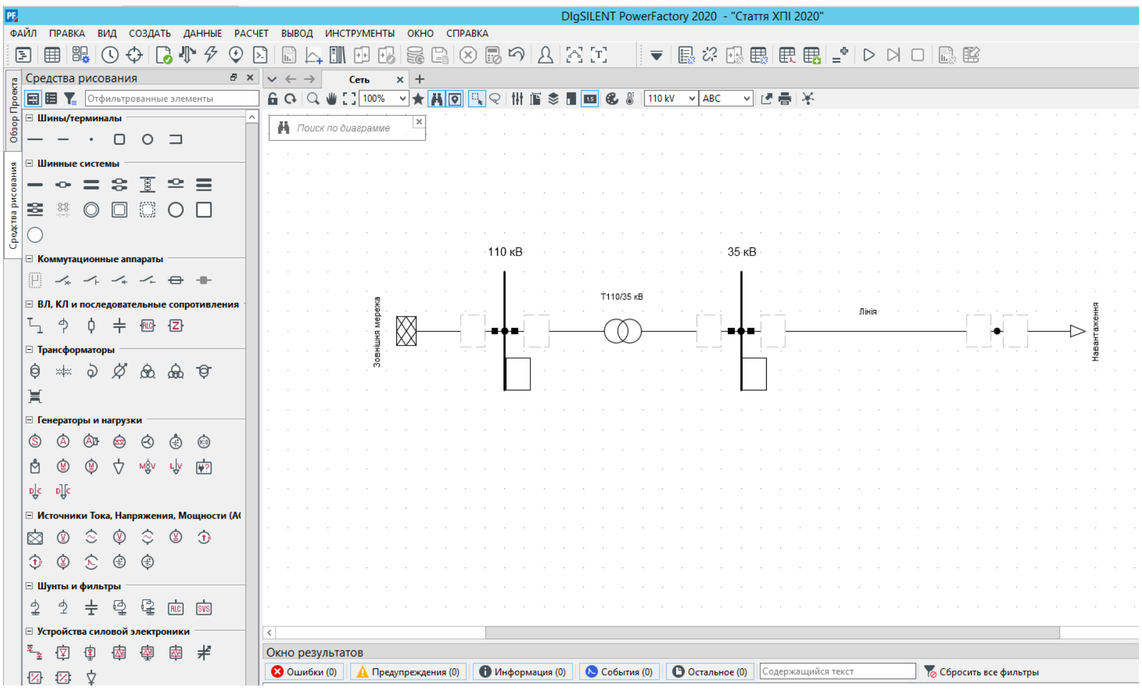

Fig. 2. A model of three-phase electric network in the DIgSILENT PowerFactory program

Consider a specific example of calculating parameters when using the simulation model. To do this, we will be built in a Digsilent PowerFactory model model and define replacement schemes. To find the parameters of the substitution scheme, consider a specific example. To do this, take 5 air (AC 70/11, AC 95/16, AC 120/19, AC 150/19, AC 185/24) and 5 cable (PvP70/11, PvP95/16, PvP120/16, PvP150/19, PvP185/24) [10, 31) Transmission lines of 35 kV and from 10 to 100 km long. The results are given in Table. 1.

With the help of such a simulation model, calculations with high accuracy are possible, as well as at low time spending.

Table 1
Lines parameters in the simulation model

A wire section, mm^2		70	95	120	150	185
Air line	*L*, Hn	0.0138	0.0134	0.0132	0.0129	0.0129
	C, mkF/km	0.049	0.05	0.05	0.051	0.051
Cable line	*L*, Hn	0.00436	0.00443	0.00424	0.00404	0.00389
	C, mkF/km	4.567	5.231	5.644	5.822	6.377

5. CONCLUSION

When using the DIgSILENT PowerFactory software complex, there is an opportunity to achieve a higher and fast result in the calculations. Compared to other specialized applied packages, the main advantage of DIgSILENT PowerFactory is an electric settlement orientation, the availability of built-in functions and algorithms for calculating and compliance with their adopted standards and the possibility of selecting the standard and calculation methodology, which allows you to reduce the time of calculation and ensure high reliability. Creation and use of the virtual model of devices allows: to confirm the main theoretical positions in the development of devices management systems that provide the quality of electricity, to evaluate the quality of the current curve filter when using various third-party factors that creates a load.

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