Advanced Methods for Boosting Operational Efficiency in Telecommunication Systems Subject to External Pulse Interference

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Abstract—the purpose and objectives of this research is to develop methods to improve the efficiency of the protection devices of telecommunications systems when exposed to external pulsed electromagnetic interference. Develop requirements for the speed of protection devices of telecommunication networks, consistent with the volt-second characteristics of the protected equipment. Develop recommendations on drawing up diagrams of cascades of telecommunications equipment protection devices.We used the methods of statistical analysis, graph theory, methods for calculating and converting electrical circuits with complex variables, direct and inverse Fourier transforms, numerical methods for solving differential equations and simulation modeling of dynamic characteristics and SPD start-up circuits. High efficiency of the telecommunications network elements can be ensured only under the condition of their uninterrupted operation. In this regard, the task of improving the reliability of the existing means of protection equipment transmission systems when exposed to external electromagnetic fields is relevant. A developed method for calculating the amplitude-time characteristics of induced voltages and currents in a line with distributed parameters of a finite length, loaded with time-varying resistance of an SPD, is proposed for use in designing networks, systems and telecommunications devices to improve performance, under the influence of external pulsed electromagnetic fields.

Keywords *- unified telecommunication networks, power supply circuit, external pulse, surge protection devices.*

I. INTRODUCTION

In the plans for the development of the telecommunications network, it is planned to continue the creation of the Unified Telecommunication Network (UTN), to expand work on organizing a nationwide data transmission system and to increase the length of long-distance telephone channels. Solving the set tasks without reliable means of protection against the pulsed electromagnetic effect of various electronic boards of telecommunications equipment (EBTE), which are one of the main elements of telecommunication networks, is not possible.

Experience in the operation of modern telecommunications transmission systems shows their low protection from the effects of impulse over voltages and currents that occur during thunderstorms and during non-stationary operation of power lines and the contact network of railways. In this case, the most frequently damaged semiconductor elements of input devices, directly connected to the extended metal structures (rails, signal circuits, longitudinal power supply lines, and wires of communication lines). The currently used surge protection devices (SPD), in some very important cases, do not give the desired effect. Developed devices and protection schemes are often recommended for implementation without detailed laboratory and field studies, which does not improve the situation.

Currently, the most urgent task is to determine the dynamic characteristics of the operation of protection devices for elements (nodes and lines) of a telecommunication network under pulsed electromagnetic effects. Demands are increasing on the reliability of communication channels, and especially in emergency situations, when exposed to lightning discharges and other sources of a pulsed electromagnetic field, when communication is especially necessary.

II. RESEARCH METHODOLOGY

The paper used the methods of statistical analysis, graph theory, methods for calculating and converting electrical circuits with complex variables, direct and inverse Fourier transforms, numerical methods for solving differential equations and simulation modeling of dynamic characteristics and SPD start-up circuits. In additional and according to the used methodologies lead to scientific valuable methods and models of developments such as:

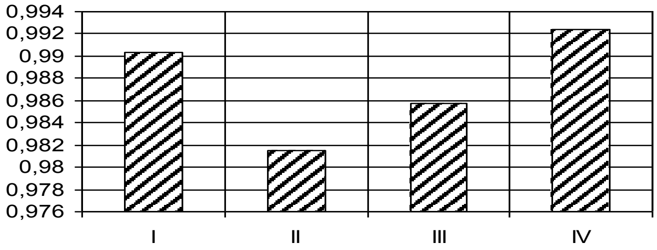
1. A method is proposed for analyzing the real data of failures of telecommunications network elements, which makes it possible to identify the sources of exposure to external interference causing telecommunications equipment damage, and to determine the ratio between the failure of individual elements of a commercial establishment and the availability factor.

2. A mathematical model of the effect of an external pulsed electromagnetic field on a line with distributed parameters of a finite length loaded on time-varying resistances of an SPD has been compiled, taking into account the speed of protection devices and the complex nature of the resistances of grounding equipment TSP.

3. A method has been developed for determining the amplitude-time characteristics of induced voltages and currents, which makes it possible to carry out numerical and simulation modeling of wave processes taking into account the dynamic change in the resistance of protection devices against time, which makes it possible to develop requirements and select devices and protection schemes.

4. The method for determining the availability of telecommunications networks has been improved, which, unlike the known ones, allows us to take into account the availability of SPDs in conjunction with the protected telecommunications equipment.

III. PROPOSED SYSTEM MODELS AND METHODOLOGIES



The proposed recommendations for testing, modeling and selecting protection devices and grounding devices that take into account dynamic characteristics can be used by organizations operating and designing telecommunication devices and systems.

A developed method for determining the availability of a telecommunications network, taking into account the availability of the protection circuit and equipment to be protected, to ensure the necessary stability of the EBTE and thereby increase the availability of a telecommunications network when exposed to external electromagnetic fields.

According to the operational statistics for technological failures, the availability factor was calculated, which showed that pulsed electromagnetic fields had a significant effect on the reliability parameters of the nodes and edges.

Table 1 shows the results of the calculation of the availability ratio of the technological TSP, taking into account failures of elements of the telecommunications network, which shows that only in one area the availability ratio corresponds to the norm.

Table 1: The results of the calculation of the availability ratio (Kg) areas technological TSP, taking into account the types of failures.

In fig. 1 shows a histogram of the availability factor by quarters of the year, in order to identify the influencing factors affecting the availability ratio of the CTP.

The histogram shows that the lowest availability factor falls in the second and third quarters, and allows us to conclude that the main influence of the damage to the TSC is the electromagnetic effect of lightning discharges.

The percentage distribution of damages shows that 17% of the total number of damages to the TSP equipment falls on power supplies, 18% on the fees of remote PBX subscribers, and 65% are damage to highly sensitive microprocessor boards of TSP devices (modems, converters, multiplexers, etc.).

Figure 1: Histogram of availability factor by year quarters

In the research was conducted of the influence of the dynamic characteristics of protection devices on the occurrence of over voltages on the elements of telecommunication systems. Based on the physical equivalent circuit of the communication line, which takes into account its own and mutual parameters, a heterogeneous system of differential equations "wire-earth" was obtained, the general solution of which is as follows:

$$\begin{cases} \dot{U} = \dot{N}(j\omega)e^{-\gamma_1(j\omega)x} + C_1(j\omega)e^{\gamma(j\omega)x} + C_2(j\omega)e^{-\gamma(j\omega)x} \\ \dot{I} = \dfrac{1}{Z_B(j\omega)}(-C_1(j\omega)e^{\gamma(j\omega)x} + C_2(j\omega)e^{-\gamma(j\omega)x}) + M(j\omega)e^{-\gamma_1(j\omega)x} \end{cases} \tag{1}$$

Where,

$$N(j\omega) = \frac{\gamma_1 \cdot 2E_{ih}(\dfrac{1}{\alpha + j\omega} + \dfrac{1}{\beta + j\omega})\sin\psi\sin\varphi\sqrt{j\omega\dfrac{\varepsilon_0}{\sigma}}e^{-(1+j)\frac{d}{\delta}}}{\gamma_1^2 - \gamma^2} \tag{2}$$

The number of the site technological TSP	Norm Kg	Elements of a telecommunication network				Total availability	
		Cable line	Fiber optic communication line	Analog equipment	Digital equipment		
1	0,996	0,9984	0,9998	0,9987	0,9984	0,9953	-
2	0,9992	0,9941	0,9999		0,9999	0,9939	-
3	0,9999	0,9996				0,9996	-
4	0,9994	0,9999				0,9999	+

And

$$M(j\omega) = \frac{\gamma \cdot 2E_{ih}(\dfrac{1}{\alpha + j\omega} + \dfrac{1}{\beta + j\omega})\sin\psi\sin\varphi\sqrt{j\omega\dfrac{\varepsilon_0}{\sigma}}e^{-(1+j)\frac{d}{\delta}}}{\gamma_1^2 - \gamma^2} \tag{3}$$

$\dot{Z}_B(j\omega) = \sqrt{\dfrac{\dot{R}(j\omega) + j\omega\dot{L}(j\omega)}{\left(\dot{G}(j\omega) + j\omega C\right)}}$ - Wave resistance;

$\dot{\gamma}(j\omega) = \sqrt{(R(\omega) + j\omega L(\omega))(G(\omega) + j\omega C)}$ - Coefficient of propagation of the affected circuit, 1 / km;

$\dot{\gamma}_1(j,\omega)$ - The distribution coefficient of the wave for the influencing effect, 1 / km; x is the current coordinate km; ℓ is the length of the line, km;

R(ω), L(ω), C, G(ω),- Own parameters of the conductor calculated in the frequency spectrum;

R(ω), L(ω), C, G(ω),- Own parameters of the conductor calculated in the frequency spectrum;

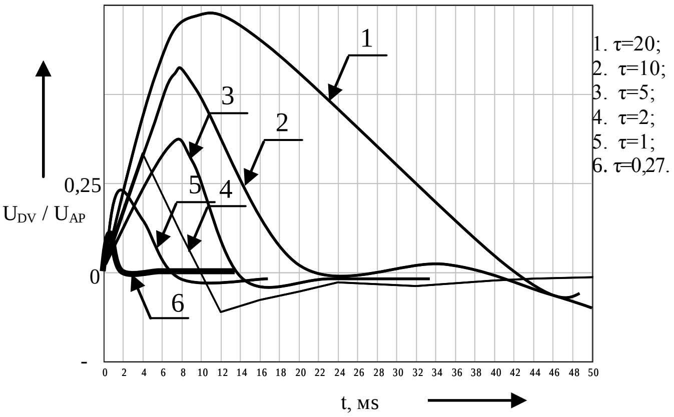
$E_{ih}(j\omega)$ - The longitudinal intensity of the external electromagnetic field in the frequency domain.

The dependence is derived for finding the initial values of currents and voltages when solving a system of differential equations in the frequency domain.

To calculate the time dependences of induced voltages and currents acting on telecommunications devices, we use the inverse Fourier transform.

$$\begin{cases} U(t)=\frac{2}{\pi}\int_0^\infty \mathrm{Re}\left(\begin{array}{l} \dot N(i\omega)\cdot e^{-\gamma 1\cdot x}+\left(\frac{\dot U_H(j\omega)-\dot N(j\omega)}{2}-\frac{\dot Z_B(j\omega)(\dot I_H(j\omega)-\dot M(j\omega))}{2}\right)\cdot e^{\dot\gamma\cdot x}+\\ +\left(\frac{\dot U_H(j\omega)-\dot N(j\omega)}{2}+\frac{\dot Z_B(j\omega)(\dot I_H(j\omega)-\dot M(j\omega))}{2}\right)\cdot e^{-\dot\gamma\cdot x}\end{array}\right)\cdot\cos(\omega t)d\omega \\ I(t)=-\frac{2}{\pi}\int_0^\infty \mathrm{Re}\left(\frac{1}{\dot Z_B(j\omega)}\left(\begin{array}{l} -\left(\frac{\dot U_H(j\omega)-\dot N(j\omega)}{2}-\frac{\dot Z_B(j\omega)(\dot I_H(j\omega)-\dot M(j\omega))}{2}\right)\cdot e^{\dot\gamma\cdot x}+\\ +\left(\frac{\dot U_H(j\omega)-\dot N(j\omega)}{2}+\frac{\dot Z_B(j\omega)(\dot I_H(j\omega)-\dot M(j\omega))}{2}\right)\cdot e^{-\dot\gamma\cdot x}\end{array}\right)+M\cdot e^{\gamma_1\cdot x}\right)\cdot\sin(\omega t)d\omega \end{cases} \tag{4}$$

The study of induced over voltages occurring in the power supply circuits and information circuits at different response times of protection devices was conducted. The paper shows the algorithms of methods for determining the influence of anexternal pulsed electromagnetic field for air power supply circuits and for cable lines.

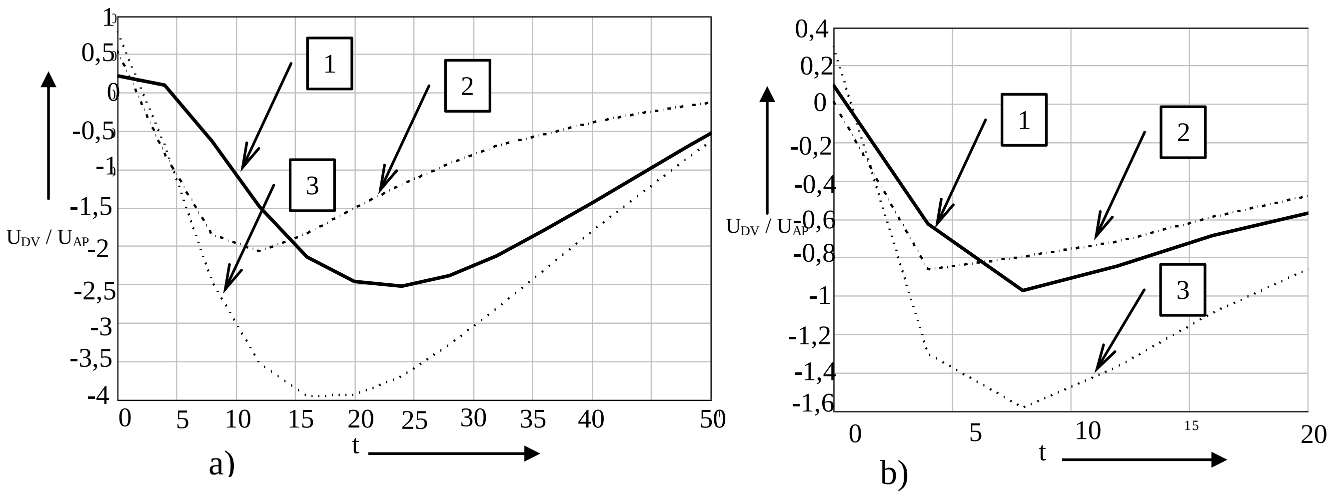


In fig. 2 shows the dependence of the relative induced voltages U_{DV} / U_{AP} in the circuit located above the ground at different time of the SPD, where U_{DV} is the dynamic voltage of operation of SPD, U_{AP} - the acting pulse voltage.

Figure 2: Voltage on the core at different time of operation of SPD With $E(t)=E_0\left(e^{-\alpha t}-e^{-\beta t}\right)$, where E_0 = 1000 V / m, $\sigma_3=10^{-2}$ Sm / m; α и β - coefficients that determine the rate of change of the electromagnetic field, 1 / s.

An increase in the response speed of protection devices from 20 to 0.27 µs reduces the level of over voltages by 10 times, while the rise time of the overvoltage impulse decreases 6 times (Fig. 2).

Figure 3: Results of mathematical modeling of the occurrence in two-wire circuits above the ground with non-simultaneous operation of two SPDs



1– differential voltage in a two-wire line; 2– residential potential with SPD 1; 3– residential potential with SPD 2.

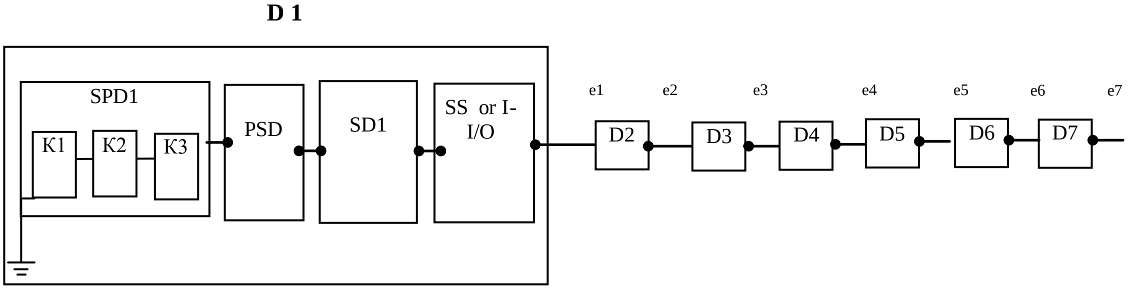
IV. EXPERIMENTS AND RESULTS DISCUSSIONS

According to the results of mathematical modeling, we can draw the following conclusions:

1)The speed of the protection device affects the amplitude-time parameters of the surge voltage pulse.

2) The non-simultaneous operation of protection devices (τ) leads to an increase in voltage in two-wire circuits by 2.5 times when τ is changed from 0.15 to 2 µs, which goes to power supplies and elements of telecommunications networks (Fig. 3).

Figure 4: Protection of the elements of the switching node included in the linear topology of the



telecommunications network along the power supplycircuit

Using the example of a network topology consisting of seven nodes, we studied the effect of dynamic characteristics of arresters on the TSP readiness ratio. On Fig. 4.

SPD 1-7 - communication center protection device (D1-7), consisting of 3 stages of protection K1-3, E1-7 - edges of the telecommunications network, PSD - power supply device, SD - switching device, SS - subscriber set, I-I/O - interface I / O.

The recommendations for the improvement of methods for diagnosing devices protecting against impulse effects of telecommunications equipmentand conducting simulation will be illustrated in this part of the research.

Methods for measuring and monitoring dynamic parameters of an SPD set GOST 21107.7-75, 51317.4.4-99, 51317.4.5-99,which contain structural diagrams for testing protection devices. However, the diagrams do not indicate the values of the elements that form the time parameters of the test pulses, and no recommendations are given on their determination. For this purpose, a technique has been developed for determining the temporal forms of test pulses and parameters of installation elements for obtaining the dynamic characteristics of protection devices and telecommunication device boards.

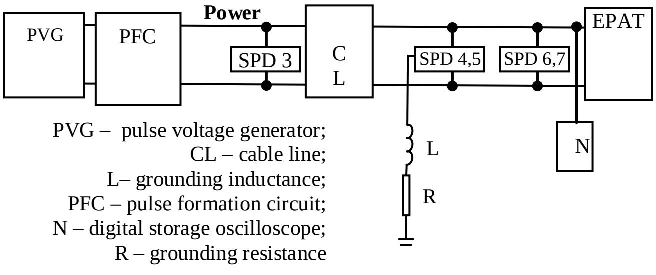


Figure 5:. Scheme for simulation modeling of the influence of dynamic characteristics of an SPD of an EBTE against pulsed electromagnetic effects, with the combination of an SPD of 4.5 into one protection device

Using simulation modeling, the values of the forming elements were obtained, which are listed in Table.2 and the shape of the test pulses in Fig. 6.

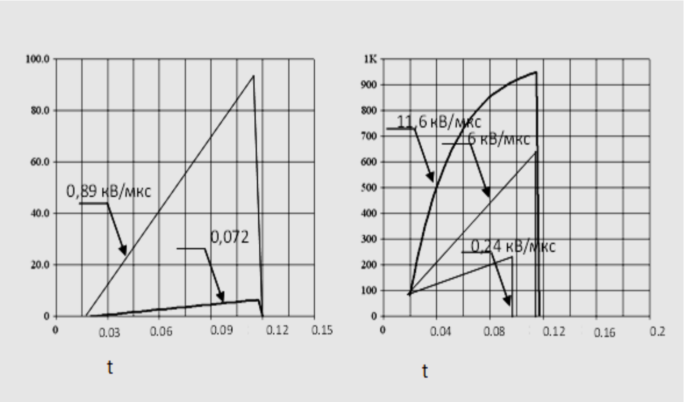


Figure 6: Test pulse shape

Table 2: The values of the elements in the scheme and the steepness of the pulse

Parameters	Parameter values						
C_1	35.5	35.5	35.5	35.5	35.5	35.5	35.5
R_1, Ом	5	5	2	2	1	2	1
C_2	3	1	0.6	0.5	0.2	0.2	0.1
ΔU/Δt, кВ/ µs	0.069	0.215	1	1.27	1.9	2.24	2.4

The simulation results are summarized in table. 3 with different resistances and inductances of the grounding circuit.

Table 3: Relative voltage values obtained at different values of the lag time of the operation of the SPD4 with different resistances and inductance of the grounding circuit

Relative stress	L=10 R= 2 Ом			L=0 R= 2 Ом			L=0 R= 0,5 Ом		
	τ, μs			τ, μs			τ, μs		
	0,2	0,5	2	0,2	0,5	2	0,2	0,5	2
U_{DV} / U_{AP}, with ℓ =0 км	0,91	0,93	0,96	0,62	0,81	0,99	0,61	0,75	0,81
U_{DV} / U_{AP}, with ℓ=3 км	0,52	0,53	0,65	0,42	0,44	0,44	0,17	0,25	0,34

As follows from the table 3, a significant voltage reduction is achieved with a lag time of 0.2 μs, and not only the active value of the ground resistance, but also the inductance of the ground loop and lead wires have a significant effect on the voltage values.

Using the method of simulation, the voltages arising in linear circuits with different dynamic parameters of SPD and grounding resistance are obtained. The simulation results coincide with the results of mathematical modeling in the range of 5-7%, depending on the accuracy of determining the primary parameters of the linear structure. So the following conclusions were made on this stage of the developments:

1) The developed method for determining the parameters of elements that form test pulses of standard and other temporary forms allows us to make recommendations on the use of GOST 21107.7-75, 51317.4.4-99, 51317.4.5-99 schemes for measuring dynamic parameters of protection devices.
2) The obtained parameters of the elements forming test pulses allowed us to create a simulation model that allows us to develop requirements for the dynamic characteristics of protection devices and complex grounding resistance parameters.
3) Comparison of the results of mathematical and simulation modeling allows us to more accurately determine the dynamic characteristics of the arresters and grounding resistances and evaluate the parameters of the protected parts of the electrical technology.

V. CONCLUSIONS

A mathematical model of the influence of an external pulsed electromagnetic field on a line with distributed parameters of a finite length, loaded on time-varying resistances of an SPD, allowing taking into account:

- Amplitude-time parameters acting pulsed electromagnetic field;
- Performance of SPDs of TSP devices
- The complex nature of the resistances of grounding equipment TSP.

2. A method has been developed for determining the availability factor of a telecommunications network, taking into account the availability factor of the protection circuit and the equipment being protected, allowing to ensure the required stability of the EBTE and thereby increase the availability ratio of the telecommunications network when exposed to external electromagnetic fields.
A calculation method has been developed that allows assessing the availability factor of a developing telecommunications network, taking into account the damage of telecommunications equipment from pulsed electromagnetic effects and the dynamic parameters of TSP protection devices.

3. Requirements for the dynamic characteristics of protection cascades have been developed, providing a standardized availability factor.
4. A method has been developed for simulating the influence of dynamic characteristics and SPD on circuits on the voltage level at the EBTE input in order to determine the speed requirements of protection and grounding devices that meet the volt-second EBTE parameters.

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