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ANALYTICAL REPRESENTATION OF SWITCHING CURRENT IMPULSES FOR STUDY OF METAL-OXIDE SURGE ARRESTER MODELS

Запропоновано аналітичні кусочні функції опису комутаційних імпульсів струму для дослідження нелінійних обмежувачів перенапруг. Представлені вирази функцій характеризується одним параметром і дозволяють описати типові комутаційні імпульси формою 30/60 мікросекунд, 45/90 мікросекунд або аналогічні їм. Вирази фукнцій призначені для тестування різних моделей металоксидних нелінійних обмежувачів перенапруг на персональних комп'ютерах.

Ключові слова: *нелінійний обмежувач перенапруг, залишкова напруга, комутаційний імпульс струму, кусочна функція.*

1. Introduction

Modeling of a metal-oxide surge arresters is necessary for calculating lightning and switching surges using personal computers. At the present time, there are several similar dynamic (that is, frequency-dependent) models of a metal-oxide surge arrester [1, 2]. As a rule, these models consist of two nonlinear resistances connected to each other by means of several linear elements: inductances, resistors and capacitance. Surge arresters have several main characteristics. Among others, these characteristics the residual voltage of an arrester, which is the peak value of voltage that appears between the terminals of an arrester during the passage of discharge current with given shape and amplitude. There are residual voltages of the arrester for nominal discharge current (lightning current impulse), switching current impulse and for steep current impulse. The surge arrester model should reproduce in the virtual experiment on the computer exactly these above-mentioned characteristics of a real arrester. To draw a conclusion about how well this or that model reproduces the behavior of a real arrester, it is necessary to compare the simulation results with the corresponding values that manufacturers give in the catalogs of their products. For computer simulation, a formula is needed to describe the dependence of the discharge current on time. The analytical representation of the nominal discharge current (lightning current impulse) and steep current impulse does not present such difficulties as the representation of the switching current impulse. As a rule, manufacturers indicate residual voltages at several amplitudes of the lightning current impulse and at several amplitudes of the switching current pulse. In order to be able to test the model with as many control points as possible, it is necessary to consider problems related to the analytical representation of switching current impulses of arresters.

2. The object of research and its technological audit

The object of research is an analytical expression for representing the switching current impulse of a surge arrester. Any current impulse (both lightning and switching) is characterized by such parameters as the virtual front time T_1 and the virtual time to half-value on the tail T_2. However, there are differences in the requirements for the accuracy of lightning and switching current impulse parameters of surge arresters.

According to the standard IEC 60099-4:2014, the lightning current impulse is defined as follows. Lightning current impulse is 8/20 current impulse with measured values from 7 μs to 9 μs for the virtual front time and from 18 μs to 22 μs for the time to half-value on the tail. That is, the permissible error for both T_1 and T_2, is ±10 %. Regarding the switching current impulse, the standard IEC 60099-4:2014 sets the following. Switching current impulse of an arrester has a virtual front time greater than 30 μs but less than 100 μs and a virtual time to half-value on the tail of roughly twice the virtual front time.

It is the latter requirement ($T_2 \cong 2 \cdot T_1$) that presents some difficulty for the mathematical description of switching current impulses. The existing approaches used to represent lightning current impulses are not suitable in this case, since these impulses have $T_2 = 2.5 \cdot T$. In this paper, the authors propose to solve the posed problem using analytical piecewise functions.

3. The aim and objectives of research

The main aim of the article is an analytical representation of switching current impulses of arrester in accordance with the requirements of IEC 60099-4:2014.

The following objectives are set to reach this aim:

1. Selection of a piecewise continuous function for representing the switching current impulses of an arrester that satisfies the requirements of the IEC 60099-4:2014 standard with respect to the virtual front time and the virtual time to half-value on the tail.

2. Analysis of the effect of the proposed expression of switching current impulse on the residual voltage of an arrester.

4. Research of existing solutions of the problem

In case of lightning overvoltage, currents with a much larger amplitude and a steeper front flow through surge arrester compared to the switching overvoltage. This is one of the reasons why the study of surge arrester models is sometimes limited only by the action of lightning current impulses, and also by a steep current impulse [1–5]. The methods of analytical representation of current and voltage waves, for example, described in [6–9], mainly concern impulses having $T_2 \gg T_1$. For this reason, they are not suitable for representing switching current impulses.

In practice, it is always necessary to determine the relationship between the parameters of a impulse wave and its time characteristics – the virtual front time T_1 and the virtual time to half-value on the tail T_2.

The well-known double-exponential impulse is described by the expression [10]:

$$i(t) = I_p \cdot k \cdot (\exp(-a \cdot t) - \exp(-b \cdot t)), \tag{1}$$

where a, b – damping coefficients; k – normalizing factor for the peak value of the impulse I_p. The relationships between the time parameters T_1, T_2 and the expression parameters k, a, b, are established by approximate expressions. Expression (1) describes well the aperiodic pulses having $T_2 \gg T_1$. Expression (1) describes approximately the impulses with shape 8/20 μs or 4/10 μs and it is not suitable to describe impulses having shape 30/60 μs or 45/90 μs.

In principle, the switching current impulses of the surge arrester can be represented by a damped sine wave [10]:

$$i(t) = I_p \cdot k \cdot \exp(-a \cdot t) \cdot \sin(\omega \cdot t), \tag{2}$$

where a – damping coefficient; ω – angular frequency; k – normalizing factor for the peak value of the impulse I_p. The relationships between the time parameters T_1, T_2 and the expression parameters k, a, ω are also established by approximate expressions and in a rather complicated manner [10].

In [11], to describe the switching current impulse, the following expression is used:

$$i(t) = \begin{cases} I_p \cdot \sin(\omega_1 t),\ 0 \le t \le t_1; \\ I_p \cdot \sin(\omega_2 t + \phi),\ t_1 \le t \le t_2; \\ 0,\ t_2 \le t < \infty, \end{cases} \tag{3}$$

where ω_1, ω_2, ϕ – parameters of the impulse wave; moments of time t_1, t_2, determine the boundaries of intervals of the main function's domain. One of the advantages of expression (3) is the absence of a normalizing coefficient for the peak value of the impulse. In [11] it is not shown how to calculate the parameters ω_1, ω_2, ϕ depending on the given impulse shape T_1/T_2. The research carried out by the authors showed that expression (3) can be used to obtain a new expression described by only one parameter.

5. Methods of research

To achieve the objectives such research method is applied: mathematical analysis, as well as circuit simulation on a personal computer. The main material of this research is the metal-oxide surge arrester model.

6. Research results

Preliminary studies carried out by the authors show that the following expression can be used to describe the switching current impulse of an arrester:

$$i_1(t) = \begin{cases} I_p \cdot \sin(\omega t),\ 0 \le t \le \dfrac{\pi}{2\omega}; \\ I_p \cdot \dfrac{\sin(\omega t) + 1}{2},\ \dfrac{\pi}{2\omega} \le t \le \dfrac{3\pi}{2\omega}; \\ 0,\ \dfrac{3\pi}{2\omega} \le t < \infty. \end{cases} \tag{4}$$

In spite of the fact that function (4) is piecewise, at the point $t_1 = \dfrac{\pi}{2\omega}$ the first derivative is continuous and equal to zero. At point $t_1 = \dfrac{\pi}{2\omega}$ function (4) reaches its peak value I_p, and at point $t_2 = \dfrac{3\pi}{2\omega}$ it goes to zero. The virtual front time T_1 and the virtual time to half-value on the tail T_2 depend on the value of the angular frequency.

Let's now turn to how IEC 60099-4:2014 specifies the virtual front time T_1 of current impulse. It is time in microseconds equal to 1.25 multiplied by the time in microseconds for the current to increase from 10 % to 90 % of its peak value.

Denoting time moments corresponding to 10 % and 90 % of the maximum (peak) value of an impulse by $t_{10\,\%}$ and $t_{90\,\%}$, correspondingly, it is possible to write that:

$$T_1 = 1.25 \cdot (t_{90\,\%} - t_{10\,\%}). \tag{5}$$

The key moments of time can be determined from expression (4) as:

$$t_{10\,\%} = \frac{\arcsin(0.1)}{\omega}, \tag{6}$$

$$t_{90\,\%} = \frac{\arcsin(0.9)}{\omega}. \tag{7}$$

Using expressions (5)–(7), by simple transformations, it is possible to determine the angular frequency ω in expression (4) for preset value of T_1:

$$\omega = 1.25 \cdot \frac{\arcsin(0.9) - \arcsin(0.1)}{T_1}. \tag{8}$$

The virtual time to half-value on the tail T_2 is determined from the expression [10]:

$$T_2 = t_{50\,\%} + 0.125 \cdot (t_{90\,\%} - 9 t_{10\,\%}), \tag{9}$$

where $t_{50\,\%}$ – the time on the impulse tail corresponding to 50 % of the maximum (peak) value of the impulse. Expression (9) can be obtained from simple geometric relations [10]. For example, expression (9) can also be written in this form:

$$T_2 = t_{50\,\%} + \frac{T_1}{10} - t_{10\,\%}. \tag{10}$$

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Expression (10) can be obtained from expression (9), taking into account expression (5) as follows:

$$\begin{aligned} T_2 &= t_{50\,\%} + 0.125\cdot\left(t_{90\,\%} - 9t_{10\,\%}\right) = \\ &= t_{50\,\%} + 0.125t_{90\,\%} - 1.125t_{10\,\%} = \\ &= t_{50\,\%} + 0.125t_{90\,\%} - 0.125t_{10\,\%} - t_{10\,\%} = \\ &= t_{50\,\%} + 0.125\cdot\left(t_{90\,\%} - t_{10\,\%}\right) - t_{10\,\%} = t_{50\,\%} + \frac{T_1}{10} - t_{10\,\%}. \end{aligned}$$

Let's note that for the impulse described by expression (4):

$$t_{50\,\%} = \frac{2\pi}{2\omega}. \tag{11}$$

Thus, the determination of the shape of the switching current impulse occurs as follows. For a given value of T_1, determine the angular frequency ω by formula (8). Then, using formula (11), determine $t_{50\,\%}$. Then, knowing $t_{50\,\%}$, calculate the resulting value of T_2 by the formula (9) or (10).

For example, for a 45/90 μs impulse, from formula (5) it can be obtained that $\omega = 28322.280$ rad/s. For such angular frequency value, using formula (11), it can be found that $t_{50\,\%} = 110.9$ μs (the result in seconds is converted into microseconds). Then, according to the formula (9) or (10), it is found that $T_2 = 111.9$ μs. Thus, instead of the impulse with the shape 45/90 μs, the impulse with 45/111.9 μs is obtained. That is, the relative error of the virtual time to half-value on the tail is +24.3 %.

In fact, according to the definition of the switching current impulse of the arrester already mentioned above, the current described by expression (4) can be used to determine the residual voltage of the arrester in simulation on a personal computer. Nevertheless, the authors proposed several more expressions, having reduced relative error of T_2. These impulses are described by equations (12), (14), (16), (18). Reduction of the T_2 duration is provided by increasing the angular frequency ω (by multiplying by a certain coefficient) only in the second sub-function, which describes the current on the interval starting with point $t_1 = \frac{\pi}{2\omega}$. In this case, the authors sought only those solutions, where this transformation coefficient of the analytic expression in the second sub-function represents a common fraction. That is, fraction with integer numerator and denominator.

$$i_2(t) = \begin{cases} I_p \cdot \sin(\omega t),\ 0 \le t \le \frac{\pi}{2\omega}; \\ I_p \cdot \frac{\sin\left(\frac{5}{4}\omega t - \frac{\pi}{8}\right) + 1}{2},\ \frac{\pi}{2\omega} \le t \le \frac{13\pi}{10\omega}; \\ 0,\ \frac{13\pi}{10\omega} \le t < \infty, \end{cases} \tag{12}$$

where

$$t_{50\,\%} = \frac{9\pi}{10\omega}, \tag{13}$$

$$i_3(t) = \begin{cases} I_p \cdot \sin(\omega t),\ 0 \le t \le \frac{\pi}{2}; \\ I_p \cdot \frac{\sin\left(\frac{13}{10}\omega t - \frac{3\pi}{20}\right) + 1}{2},\ \frac{\pi}{2} \le t \le \frac{33\pi}{26\omega}; \\ 0,\ \frac{33\pi}{26\omega} \le t < \infty, \end{cases} \tag{14}$$

where

$$t_{50\,\%} = \frac{23\pi}{26\omega}, \tag{15}$$

$$i_4(t) = \begin{cases} I_p \cdot \sin(\omega t),\ 0 \le t \le \frac{\pi}{2\omega}; \\ I_p \cdot \frac{\sin\left(\frac{4}{3}\omega t - \frac{\pi}{6}\right) + 1}{2},\ \frac{\pi}{2\omega} \le t \le \frac{10\pi}{8\omega}; \\ 0,\ \frac{10\pi}{8\omega} \le t < \infty, \end{cases} \tag{16}$$

where

$$t_{50\,\%} = \frac{7\pi}{8\omega}, \tag{17}$$

$$i_5(t) = \begin{cases} I_p \cdot \sin(\omega t),\ 0 \le t \le \frac{\pi}{2\omega}; \\ I_p \cdot \frac{\sin\left(\frac{3}{2}\omega t - \frac{\pi}{4}\right) + 1}{2},\ \frac{\pi}{2\omega} \le t \le \frac{7\pi}{6\omega}; \\ 0,\ \frac{7\pi}{6\omega} \le t < \infty, \end{cases} \tag{18}$$

where

$$t_{50\,\%} = \frac{5\pi}{6\omega}. \tag{19}$$

The calculation procedure given above is also valid for formulas (12), (14), (16), (18), except $t_{50\,\%}$ that is calculated by formulas (13), (15), (17), (19), correspondingly. The results of all calculations performed for impulses with the shape 45/90 μs are summarized in Table 1.

Table 1

The impulse shapes obtained by using different formulas (required shape is 45/90 μs)

No.	Formula	Obtained impulse shape T_1'/T_2', μs	Relative error ξT_2, %
1	(4)	45/111.90	+24.32
2	(12)	45/100.80	+11.99
3	(14)	45/99.09	+10.10
4	(16)	45/98.02	+8.91
5	(18)	45/93.40	+3.78

Relative error of T_2 in Table 1 is calculated using the following formula:

$$\xi T_2 = \frac{T_2' - T_2}{T_2} \cdot 100, \ \ \%. \tag{20}$$

In formula (20): T_2' – actual value of virtual time to half-value on the tail; T_2 – required value of virtual time to half-value on the tail.

Since the above-mentioned current impulses have analytically correct relation to T_1 via equations (6)–(8), the resulting value of virtual front time is equal to the required front time value ($T_1' = T_1$). Hence, the relative error of virtual front time calculation is equal to zero.

As it can be seen from the above expressions, up to the time $t_1 = \dfrac{\pi}{2\omega}$ the currents (4), (12), (14), (16), (18) are described by the same sub-function, and by the another one after it. It can also be assumed that these current impulses depend only on one parameter (angular frequency ω).

By circuit simulation, the effect of the received current impulses on the residual voltage of the surge arrester is studied. The main research circuit is shown in Fig. 1. This circuit corresponds to the metal-oxide surge arrester model proposed in [3].

In Fig. 1 R_1, L_1 and L_2 – linear, G_1 and G_2 – nonlinear elements of metal-oxide surge arrester model. The numerical values of the elements of the model are calculated in accordance with the procedure described in [3]. The nonlinear elements are modeled with a help of voltage-controlled current sources (NTIofV) in accordance with [11, 13]. In this article the metal-oxide surge arrester model with rated voltage 258 kV is used. Linear parameters of the model are the following:

$$L_1 = 1.952 \ \mu\text{H}, \ L_2 = 5.855 \ \mu\text{H},$$
$$R_1 = 1000 \ \text{M}\Omega.$$

Fig. 2 shows various switching current impulses and corresponding curves of residual voltage obtained in simulation. The curves corresponding to the expression (14) are not shown in Fig. 2, since they are almost equal to the curves obtained by formula (16).

For all the currents shown in Table 1, the same value of residual voltage maximum equal to 580.192 kV is obtained. This is a confirmation of the fact that only front time have significant effect on maximum residual voltage of the surge arrester and time to half-value on the tail is not critical in this case [13]. All current impulses in Table 1 have the same front time equal to 45 μs. It should also be noted that when $\omega = 159312.827$ rad/s, expression (4) describes the impulse with shape 8/19.89 μs. Thus, it is possible to describe the lightning current impulse of the surge arrester with the shape 8/20 μs with the tolerance of time to half-value on the tail equal to – 0.55 %.

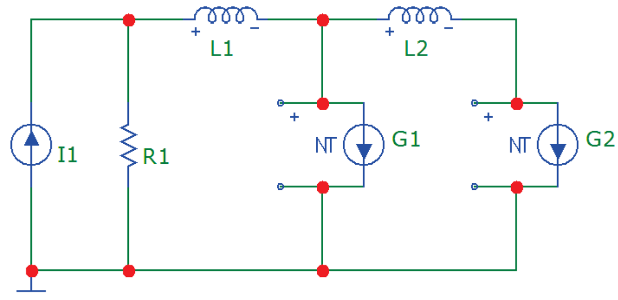

Fig. 1. Simulation of metal-oxide surge arrester in Micro-Cap 11 evaluation version [12] using voltage-controlled current sources (NTIofV) G_1 and G_2

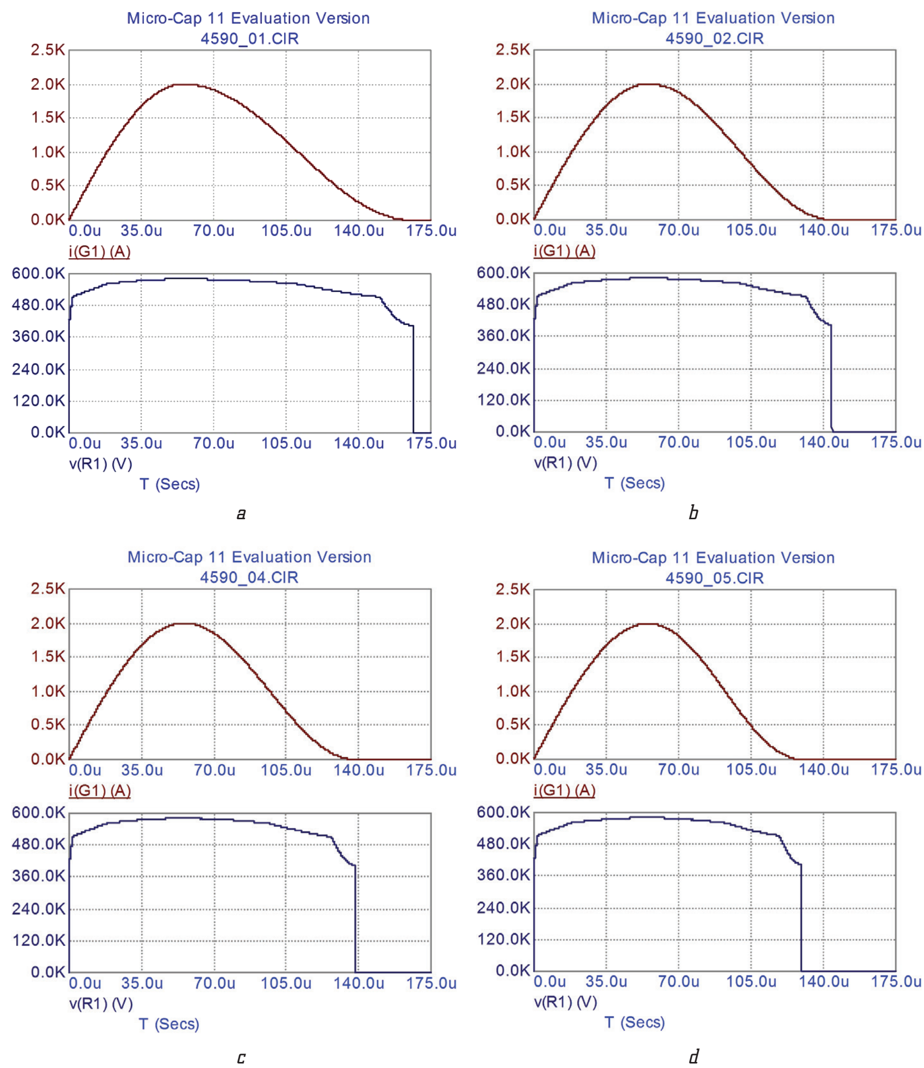

Fig. 2. Residual voltage (at the bottom) of the surge arrester during the passage of 2.0 kV switching current impulses (at the top) with various shape: *a* – 45/111.90 μs; *b* – 45/100.80 μs; *c* – 45/98.02 μs; *d* – 45/93.40 μs

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7. SWOT analysis of research results

Strengths. The strengths of this research are:
– in contrast to other expressions, the resulting expressions for the switching impulse have only one parameter (angular frequency);
– instead of approximate calculation, the front time of the resulting impulse is calculated by an analytically exact formula (which includes only one parameter of the switching impulse – the angular frequency);
– since the proposed expressions are characterized by only one parameter (rather than three), this significantly reduces the time spent on preliminary calculations.

Weaknesses. The weaknesses of this research are that:
– the time to half-value on the tail of the resulting impulses is computed with some error;
– the above error is reduced by some complication of the original expression;
– when writing piecewise functions in a linear form with the help of built-in functions, conventional and logical operators, the significant time required to enter this information.

Opportunities. The additional opportunities that this research provides include:
– the possibility of representing current impulses having virtual time to half-value on the tail of two and a half times the virtual front time with the help of expression (4). As an example, nominal discharge current (lightning current impulse) with shape 8/20 μs and high current impulse with shape 4/10 μs;
– the possibility of representing current impulses having virtual time to half-value on the tail of twice the virtual front time with the help of expression (18). As an example, switching current impulse with shape 30/60 μs and steep current impulse with shape 1/2 μs;
– possibility to study existing and future models of metal-oxide surge arresters in more detail with more control points. Thus, it is possible to identify features that, in the opposite case, would have remained unnoticed.

Threats. The resulting expression for switching current impulse has a nonzero derivative at the initial instant of time. When testing the models of surge arresters, this is not important. However, when using the resulting expression in other problems, this feature can become important and require further improvement of the expression. To apply this method in practice it is required the employee knowing the theory of linear and nonlinear electrical circuits, linear programming, as well as skills in circuit simulation.

8. Conclusions

1. Analytical piecewise continuous functions are proposed for representing the switching current impulses of surge arresters. The functions (4), (12), (14), (16), (18) satisfy the requirements of IEC 60099-4:2014 with respect to switching current impulse of the arresters. These functions allow representing discharge currents having a virtual time to half-value on the tail of roughly twice the virtual front time. For all functions the relative error of front time calculation is equal to zero. Expression (18) has minimal tolerance of time to half-value on the tail which is +3.78 %. Moreover, expression (4) allows representing current impulses having virtual time to half-value on the tail of two and a half times the virtual front time. Tolerance of time to half-value on the tail for such impulses is 0.55 %.

2. Effect of received switching current impulses on maximum residual voltage is studied with a help of dynamic metal-oxide surge arrester model. It is found that increase in time to half-value on the tail does not affect the maximum residual voltage of the surge arrester.

References

1. Meister, A. Comparison of metal oxide surge arrester models in overvoltage studies [Text] / A. Meister, R. Shayani, M. De Oliveira // International Journal of Engineering, Science and Technology. – 2012. – Vol. 3, No. 11. – P. 35–45. doi:10.4314/ijest.v3i11.4s
2. Peppas, G. D. Surge arresters models for fast transients [Text] / G. D. Peppas, I. A. Naxakis, C. T. Vitsas, E. C. Pyrgioti // 2012 International Conference on Lightning Protection (ICLP). – IEEE, 2012. – P. 1–6. doi:10.1109/iclp.2012.6344285
3. Pinceti, P. A simplified model for zinc oxide surge arresters [Text] / P. Pinceti, M. Giannettoni // IEEE Transactions on Power Delivery. – 1999. – Vol. 14, No. 2. – P. 393–398. doi:10.1109/61.754079
4. Fernandez, F. Metal-oxide surge arrester model for fast transient simulations [Text] / F. Fernandez, R. Diaz // Proceedings of 2001 International Conference on Power System Transients. – 2001. – P. 681–687.
5. Miguel, P. M. Comparison of Surge Arrester Models [Text] / P. M. Miguel // IEEE Transactions on Power Delivery. – 2014. – Vol. 29, No. 1. – P. 21–28. doi:10.1109/tpwrd.2013.2279835
6. Standler, R. B. Equations for some transient overvoltage test waveforms [Text] / R. B. Standler // IEEE Transactions on Electromagnetic Compatibility. – 1988. – Vol. 30, No. 1. – P. 69–71. doi:10.1109/15.19891
7. De Conti, A. Analytical Representation of Single- and Double-Peaked Lightning Current Waveforms [Text] / A. De Conti, S. Visacro // IEEE Transactions on Electromagnetic Compatibility. – 2007. – Vol. 49, No. 2. – P. 448–451. doi:10.1109/temc.2007.897153
8. Koehler, F. Simplified Analytical Representation of Lightning Strike Waveshapes [Text] / F. Koehler, J. Swingler // IEEE Transactions on Electromagnetic Compatibility. – 2016. – Vol. 58, No. 1. – P. 153–160. doi:10.1109/temc.2015.2493582
9. Heidler, F. Calculation of lightning current parameters [Text] / F. Heidler, J. M. Cvetic, B. V. Stanic // IEEE Transactions on Power Delivery. – 1999. – Vol. 14, No. 2. – P. 399–404. doi:10.1109/61.754080
10. Beyer, M. Hochspannungstechnik: theoretische und praktische grundlagen für die anwendug [Text] / M. Beyer, W. Boeck, K. Möller, W. Zaengl. – Berlin: Springer-Verlag, 1986. – 362 p. doi:10.1007/978-3-642-61633-4
11. Trotsenko, Y. Study of surge arrester model under influence of various current pulses [Text] / Y. Trotsenko, V. Brzhezitsky, I. Masluchenko // Technology audit and production reserves. – 2017. – Vol. 1, No. 1 (33). – P. 44–48. doi:10.15587/2312-8372.2017.92244
12. Micro-Cap 11. Electronic Circuit Analysis Program. Reference Manual. [Electronic resource]. – Ed. 11. – Sunnyvale, CA: Spectrum Software, 2014. – 1040 p. – Available at: \www/URL: http://www.spectrum-soft.com/down/rm11.pdf
13. Trotsenko, Y. Effect of piecewise linear current waveforms on surge arrester residual voltage [Text] / Y. Trotsenko, V. Brzhezitsky, I. Masluchenko // Technology audit and production reserves. – 2017. – Vol. 2, No. 1 (34). – P. 25–31. doi:10.15587/2312-8372.2017.97507

АНАЛИТИЧЕСКОЕ ПРЕДСТАВЛЕНИЕ КОММУТАЦИОННЫХ ИМПУЛЬСОВ ТОКА ДЛЯ ИССЛЕДОВАНИЯ МОДЕЛЕЙ МЕТАЛЛОКСИДНЫХ НЕЛИНЕЙНЫХ ОГРАНИЧИТЕЛЕЙ ПЕРЕНАПРЯЖЕНИЙ

Предложены аналитические кусочные функции описания коммутационных импульсов тока для исследования нелинейных ограничителей перенапряжений. Предложенные выражения функций характеризуются одним параметром и позволяют описать типовые коммутационные импульсы формой 30/60 микросекунд, 45/90 микросекунд или аналогичные им. Выражения функций предназначены для тестирования различных моделей

металоксидных нелинейных ограничителей перенапряжений на персональных компьютерах.

Ключевые слова: нелинейный ограничитель перенапряжений, остающееся напряжение, коммутационный импульс тока, кусочная функция.

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IDENTIFICATION OF THE PARAMETERS OF THE CABLE PRODUCTION PROCESS

Завдяки можливостям сучасних інформаційних систем показано шляхи удосконалення систем параметричної ідентифікації, а саме, отримання більш точних оцінок параметрів математичної моделі досліджуваного об'єкта з обмежених у часі і діапазоні, зашумлених вибірок даних. Розглянутий метод ідентифікації запропоновано використовувати в адаптивних системах керування процесом виготовлення високовольтних електричних кабелів.

Ключові слова: *параметрична ідентифікація, інтегрований метод ідентифікації, електротехнічні системи, електричні кабелі.*

1. Introduction

Technologically, leading countries transferred or are transferring to the transmission of electricity using ultrahigh-voltage cables with polymer insulation. Cable production is carried out on continuous technological lines under the influence of many destabilizing factors: transport delays, measurement noise, impossibility of exact coordination of operation of all systems, fluctuations in raw material parameters and various physical and mechanical properties of cable components.

Obtaining objective information about the parameters and the course of the technological process makes it possible to improve the quality of the systems of optimal control, diagnostics and forecasting. A significant amount of scientific research has been devoted to the problem of parametric identification in the industrial production of cables [1–13]. However, in the modern theory of identification there is a significant gap between the theoretical part and the real situation. Owing to the natural nonstationarity of the processes, the large number theorem in practice is often not fulfilled, and in conditions of limited sampling, statistically optimal identification methods can lose not only optimality, but also correctness.

Thus, it is urgent to improve the methods of parametrical identification of the technological process of cable production and their introduction in adaptive optimal control systems. This will improve the quality of products in real conditions of parametric and signal uncertainty and will promote wider use of high-voltage cable with polymer insulation in the electricity industry.

2. The object of research and its technological audit

The object of research is the process of producing electric cables with polymer insulation for ultrahigh voltages.

Manufacture of cables with XLPE insulation is carried out on electrical complexes consisting of dozens of local systems interconnected via mobile cable products under the conditions of many undetermined disturbing factors [1–3]. The application of polyethylene insulation to a conductive core that moves at a speed of about 50 m/min is carried out using a unit of three extruders 1 (Fig. 1). The outer diameter of each insulation layer is measured with random noise by the X-ray sensor unit 2 at a distance of about 0.5 m from the exit of the extruders (Fig. 1). The thickness of each layer of insulation is regulated by automated electric drives of extruders by changing the rotation speed of worms.

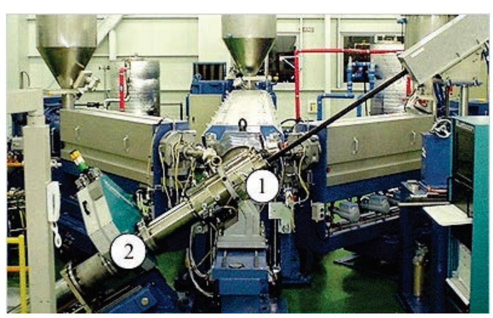

Fig. 1. Units: 1 – extruders; 2 – sensors