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FEATURES OF ASYMMETRIC SHORT CIRCUIT CURRENTS CALCULATION IN THE ELPLEK SOFTWARE PRODUCT

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Abstract. *In order to simplify the analysis of the electrical networks operation modes , specialized software tools for mathematical modeling of processes in them are used. There are many software products, but most of them are paid. To carry out research in complex power systems and obtain results in certain sections when performing practical and course work, as well as at certain stages of research, the authors actively use the free software product «Elplek», but in a deeper study of the software encountered certain features some parameters, which differ slightly from the generally accepted domestic method, which led to an error in the calculations in some versions of the schemes of power systems.*

The purpose of the research is to study the peculiarities of calculating the characteristics of asymmetric short circuits in the software product "Elplek" and to check the adequacy of the formed models. At the first stage, the object of research was chosen – this is a segment of the electrical network containing a small number of nodes and a theoretical calculation of the searched parameters of the short circuit mode in this segment of the electrical network was carried out. In the future, an approach was proposed on the task of parameters of elements in the software product "Elplek" and based on this approach, modeling was carried out as a result of which the results were obtained under the condition of the system's task, as sources of infinite power $I_{м1} = 694.9 - j3522.2\,A$ *and calculations* $I_{c1} = 694.81 - j3522.06\,A$ *for the active part differ by 0.013%, and by reactive – 0.004%; subject to the task of the system, as sources of a certain power* $I_{м2} = 654.7 - j3427.4\,A$ *and calculations on the active part differ by 0.0046%, and* $I_{c2} = 654.67 - j3427.25A$ *on the jet - 0.0044%, which makes it possible to assert the feasibility of using the proposed approach in the analysis of indicators of emergency modes of complex schemes of electrical supply to consumers of certain segments of electric power systems.*

Features of calculation of characteristics of asymmetric short circuits in the Elplek *software product are considered and the adequacy of the generated models is checked.*

Key words: ***power system segment modeling, Elplek software product, element parameter setting, single-phase short-circuit currents***

Introduction. Quite often when performing standard calculations there is a need to use automated software products, one of which is «Elplek». The author of the program is Ilkka Leikkonen (Kokkola, Finland). According to the author: «Elplek is the result of some discussions that I once had with a big company. Their idea was to have a tool, or a program that shows what happens when there is a fault in a network. The program should answer the question: if there is a fault in a given position in the network, which relay will react first, which next, and so on? … Elplek is the result of one of my discussions with a very large company. The idea was to have a tool or program that would show what happens in power outages. The program had to answer the question: if there is damage to the network, which relay will work first, which second, etc.» [12] Many problems involve determining the parameters of the emergency mode of the electrical network in case of asymmetric short circuits and the study of related processes with the stability of electrical equipment. In the framework of this scientific work there is a need to analyze the methods and models used in the analytical and hardware-software calculation of asymmetric short-circuit currents.

Analysis of recent research and publications. Analyzing the information provided in the appendix to the software product "Elplek" [12], no clear information was found, which would unambiguously state the correctness for the calculation of the some elements' parameters, which periodically led to erroneous results obtained by students in course and graduation works. In a number of articles [15], the authors propose to consider the issue of determining the emergency mode on the transmission line as a classification task using the parameters of the transmission line as classification features. To solve this problem, it was proposed to use an artificial neural network, and in some cases [10] to apply specialized software products.

In many materials [13,7] authors analyze the circuit features of the electrical networks structure, which determine the magnitude of the short-circuit current, as well as investigate the conditions under which this current has a maximum or minimum.

In [2,4] the asymmetric voltage dips caused by single-phase short circuits in electric networks are investigated and the worst failure conditions are determined and their influence on the stability of high voltage synchronous motors is shown, and the influence of short circuits [1] on cable lines is estimated, which are laid in the same trench with power cables.

In [14] various models for calculation of single-phase short-circuit currents are presented. For example, [11] presents an accurate multiphase model and its simplification to a single-phase model, and [9] presents a method of analysis of general transients for a multi-loop overhead transmission line, which takes into account the influence of mutual connections between conductors. In addition, there is a series of materials that describe measures to limit single-phase short-circuit currents [16,8].

The analysis of the information showed that this software product is interesting for researchers, but, at this stage, more in terms of review [18,5,21], but not for solving partial problems, which in the software product are presented in a fairly wide range .

The research aim is to study the peculiarities of calculating the characteristics of asymmetric short circuits in the software product "Elplek" and to check the adequacy of the formed models**.**

Materials and research methods. "Elplek" is one of the best free programs designed to calculate all types of short-circuit currents (three-phase, interlinear, earth fault, interline earth fault), to find residual voltages in the network, as well as to simulate the operation of relay protection devices.

In the software product "Elplek" the choice of the short circuit location is there where the short circuit component is installed (Fig. 1, a). This component can be moved and installed as a normal element anywhere in the circuit. In order to select the appropriate mode of calculation of short-circuit currents, it is necessary to choose one of the four proposed options, namely: calculation of the three-phase short-circuit mode (Fig. 1, b); calculation between phase short circuit or two-phase (Fig. 1, c); calculation of short circuit to ground or single-phase short circuit (Fig. 1, d); calculation between a phase short circuit through the ground or a two-phase short circuit to ground (Fig. 1, e). It is also possible to calculate the impedance of the short-circuit circuit ZTh and the impedance of the sequences Z0, Z1, Z2 at the location of the short circuit (Fig. 1, f).

a *b* *c* *d* *e* *f*

Fig. 1. Components for determining the short-circuit current in the software product "Elplek"

The total impedances are calculated based on three approaches: using "normal" full impedances , using transient full impedances and using super-transient full impedances. "Normal" impedance of asynchronous machines is calculated as the rated voltage divided by the current at a given power or slip (asynchronous).

The impedance of the impedance reverse sequence Z2 is assumed to be the same in all three cases (normal, transient, supertransient). Since asynchronous machines are neglected in the case of a transient process and Z2 is calculated in a transient process without asynchronous machines. In addition, the following components are not included in the calculations: asymmetric load, PQ - bus generation.

Short circuit and impedance look like in a single-line circuit (Fig. 2, a) and show how short circuit and impedance are modeled in the software product in different cases of short circuits, namely: three-phase short circuit with full resistance (Fig. 2 , b); interphase short circuit with full resistance (Fig. 2, c); single-phase earth fault with full supports (Fig. 2, d); line to line to earth fault with the impedances. interphase earth fault with full resistance (Fig. 2, e).

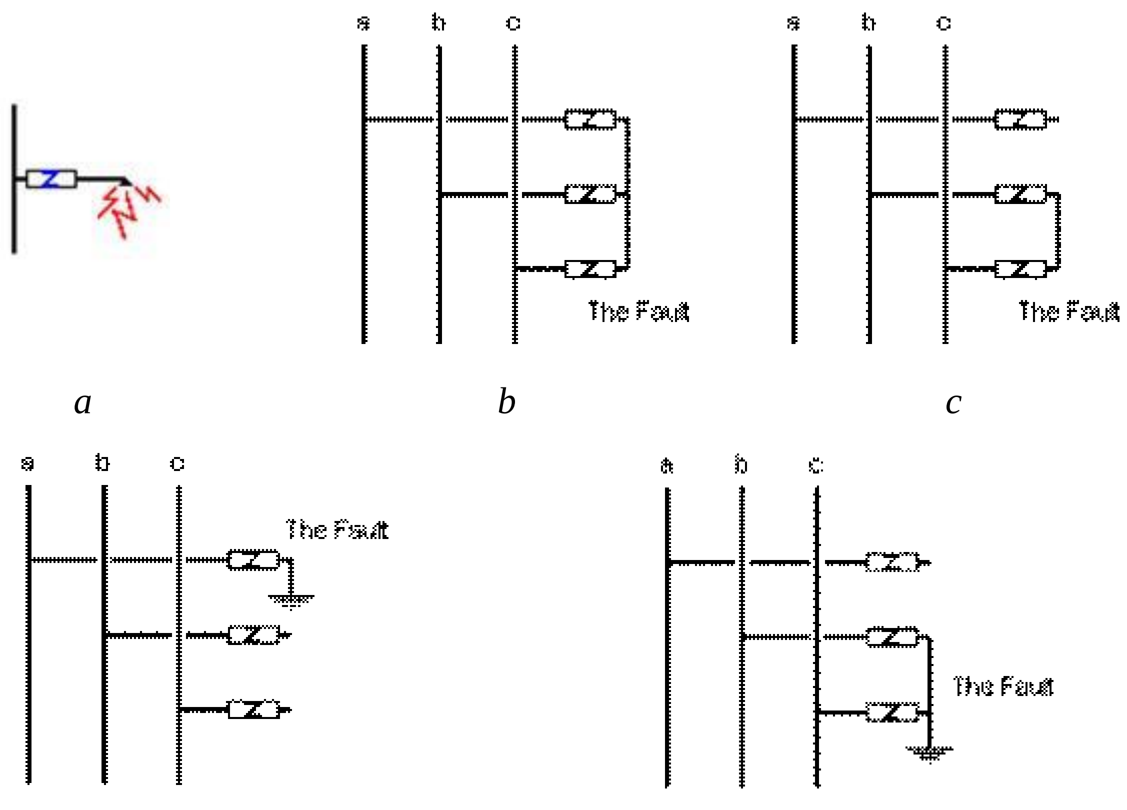
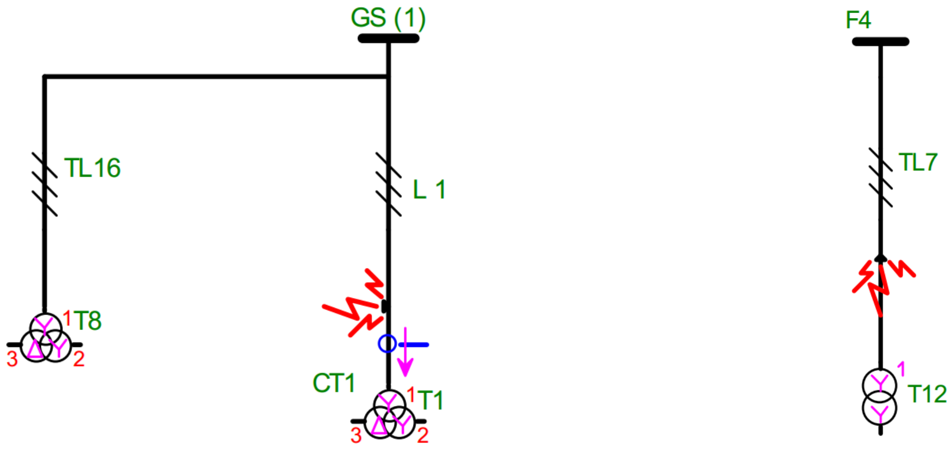


Fig. 2 Single-line electrical circuit in the software product "Elplek" and built-in simulation mechanism for different types of short circuits

It should be noted that the software product uses one of two calculation methods, namely: the method according to the standard 60909-IEC and the overlay method. There is a third method, denoted Z012, and is used to calculate the resistance of the circuit. It is worth noting that if the overlay method is selected, the user can select the initial state (as in the normal calculation of the short circuit): use the pre-calculated initial state, if you click "old init. State" or "New" initial state, which is obtained direct definition of network indicators, at the pressed button "old init. State".

Investigate the current levels in asymmetric short circuits in the structure of the substitution scheme, which is presented in Fig.3.



а *б*

Fig. 3. Equivalent circuits in the software product «Elplek»

Before the beginning of calculations it is necessary to define initial information, according to [6, 17, 19, 12] for a three-phase overhead line without a cable the characteristic ratio:

$$\underline{Z}_0 = R_c + 0.15 + j0.4351 \cdot \lg\left(\frac{D_e}{kR_a}\right),$$

where $\underline{Z}_0$ is the total line resistance; R_c is the active conductor resistance; D_e is depth of laying the return conductor; k is coefficient taking into account the part of the magnetic flux closed through the conductor (for solid round conductors of non-magnetic material k=0.779, for steel-aluminium conductors k=0.724...0.771); R_a is the actual radius of the conductor.

For three-phase overhead line with a cable:

$$\underline{Z}_{0,T} = \underline{Z}_0 - \frac{3\underline{Z}_{C,T}^2}{\underline{Z}_{T,0}},$$

where $\underline{Z}_{0,T}$ is the total resistance for the zero sequence of the power line with the cable; $\underline{Z}_{C,T}$ is mutual induction resistance between line conductor and equivalent cable; $\underline{Z}_{T,0}$ is intrinsic electrical resistance of the equivalent cable.

Accordingly, the intrinsic electrical resistance $\underline{Z}_{T,0,ek}$ of the equivalent cable, Ohm/km,

$$\underline{Z}_{T,0,ek} = \frac{r_T}{2} + 0.05 + j0.145 \cdot \lg\left(\frac{D_e}{R_{T,ek}}\right),$$

where r_T is active resistance of a cable; $R_{T,ek}$ is intrinsic electrical resistance of the equivalent cable.

Resistance of mutual induction between line conductor and equivalent cable, Ohm / km,

$$\underline{Z}_{C,T} = 0.05 + j0.145 \cdot \lg\left(\frac{D_e}{D_{C,T,a}}\right),$$

where $D_{C,T,a}$ is geometric mean distance between phase conductors and cable.

If we analyze the dependence of the impedance for a three-phase overhead line with a cable, then after the transformations it is seen that the active component of the resistance of the zero sequence will not depend on the presence of the cable, and will be equal to:

$$R_0 = R_c + 0.15\,.$$

The active resistance of the "conductor-ground" line is equal to the sum of the active conductor resistance R_c (according to reference data) and the resistance r_{gr} (taking into account the loss of active power from the current in the ground). Resistance r_{gr} (Ohm / km) practically does not depend on the conductivity of the earth and at *f* = 50 Hz we have $r_{gr} = 0{,}05\,Ом/км$.

Due to the fact that we study not a specific object, but a generalized one, so in the calculations we use the average values of the ratios between the inductive resistances x_1/x_2 for the aerial line:

Single-chain transmission line 110 ... 220 kV without cable or with steel cable ………3,5

Same with a grounded, well-conducting cable ………………………………………...2,0

Two-chain transmission line 110… 220 kV without cables or with steel cables ………5,5

Same with grounded, well-conducting cables ……..…………………………………3,0

Single transmission line 330 kV ..……………………………………………………4,1

Single transmission line 500 kV....................……………………………………..4,2

Two parallel transmission lines 330 kV on one route …………………………………5,9

Two parallel transmission lines 500 kV on one route .…………………………………6,2

In the process of modelling in the software product "Elplek" there were some features of the task and the calculation of certain elements. To simplify the understanding of the specifics of specifying these elements, a mathematical experiment was carried out according to the scheme in Fig. 3, b in the software product of symbolic mathematical calculations, the results of which are presented in Fig. 4. It should be noted that when setting the parameters of the transformer, it is necessary to pay attention to the fact that the transformer has an additional magnetizing circuit, which, as a rule, is not taken into account when calculating short-circuit currents and it is this that can introduce a certain insignificant error (0.1-0.3 %) into the simulation results. According to [17,12] Io1 - rated no-load current of the primary winding, (secondary winding is open), should be> 0, and if the value of Io1 is unknown, then it can be assumed that Io1 = 0.001 * In. Io1 should not be too small, as this can lead to inaccurate calculations.

$X0 := 0.6 \qquad Xgs := 0 \qquad x0x1 := 3.5$

$X011 := 0.42 \qquad r011 := 0.118 \qquad X010 := x0x1 \cdot 0.42 = 1.47 \qquad r0110 := 0.15 + 0.118 = 0.268$

$X2 := X011 \cdot 47 = 19.74$

$r2 := r011 \cdot 47 = 5.546$

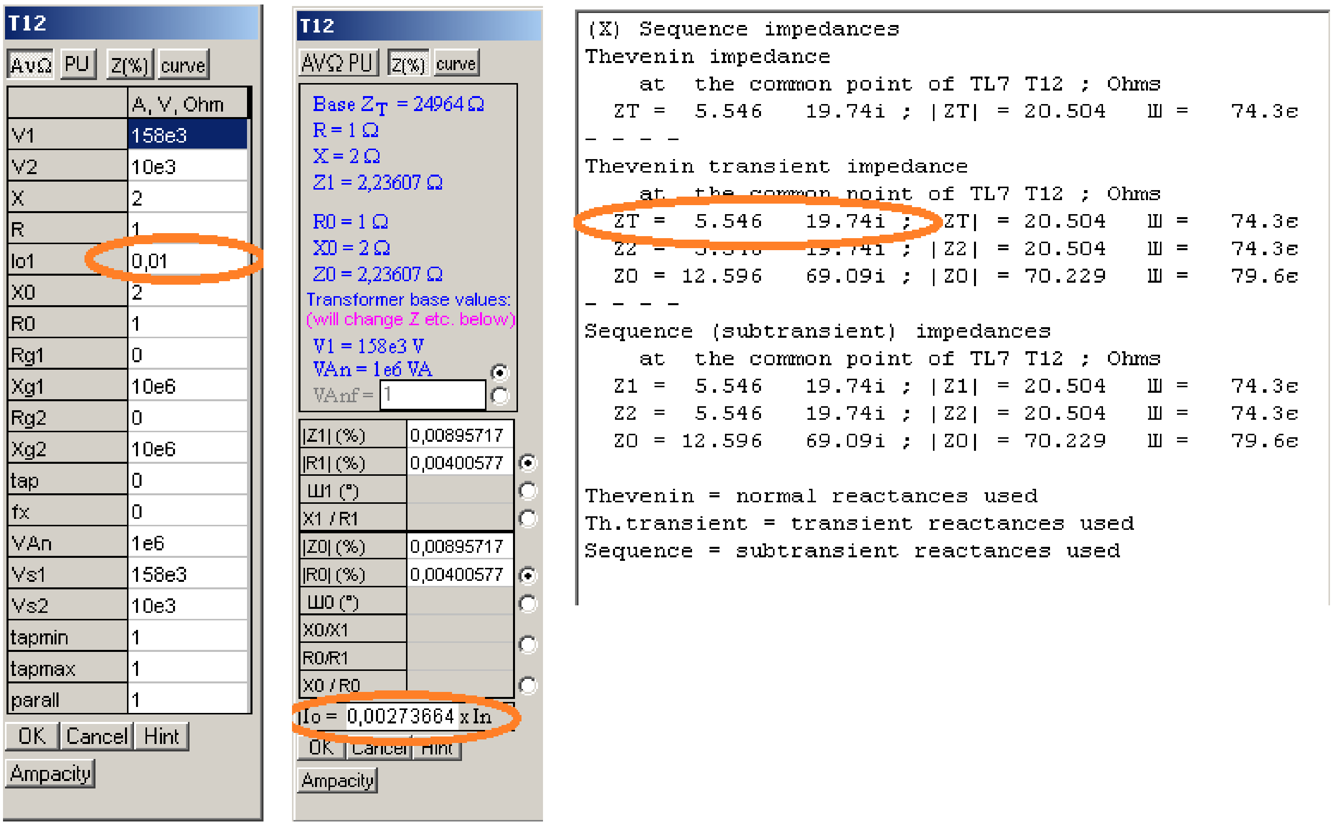
$X0111 := X2 \cdot 3.5 = 69.09$

$r0111 := (r011 + 0.15) \cdot 47 = 12.596$

$$rt2 := \frac{285000}{2 \cdot 63 \cdot 10^6} \cdot \frac{(158000)^2}{63 \cdot 10^6} = 0.896$$

$Z\Sigma1 := Xgs \cdot i + r2 + X2i = 5.546 + 19.74i$

Fig. 4 Results of symbolic calculations in a mathematical software product

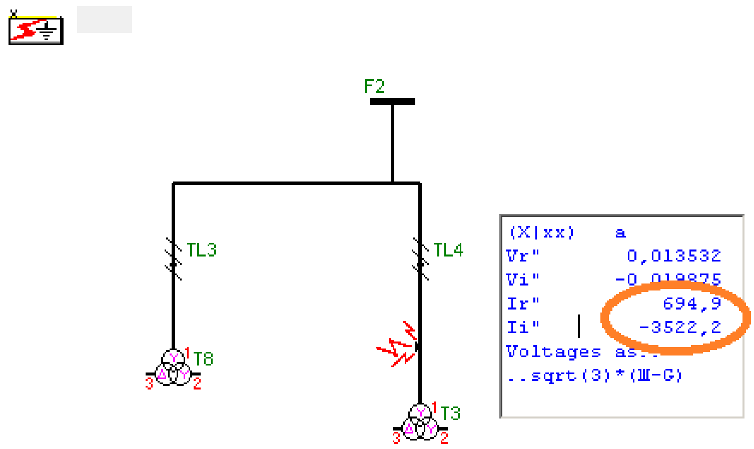


a *b* *c*

Fig. 5 Simulation results in the software product "Elplek"

Analyzing the information shown in Fig. 4 and fig. 5, b, we see the full correspondence of the results of modelling and symbolic calculation in the mathematical software product.

Subsequently, the value of single-phase asymmetric short-circuit current in the circuit shown in Fig. 3, a had been analyzed in two cases: 1) provided that the internal resistance of the power source is zero; 2) provided that the internal resistance of the power source is a positive number, for example, we assume that the internal resistance of the system of forward, reverse and zero internal sequences is equal to 1 Ohm. The results of analytical calculation and calculation in the software product "Elplek" are shown in Fig. 6.



a

Розрахунок несиметричних КЗ

$X0 := 0.6 \quad Xgs := 0 \quad x0x1 := 3.5 \quad X011 := 0.42 \quad r011 := 0.118$

$X010 := x0x1 \cdot 0.42 = 1.47 \quad r0110 := 0.15 + 0.118 = 0.268 \quad X2 := X011 \cdot 47 = 19.74$

$r2 := r011 \cdot 47 = 5.546 \quad X0111 := X2 \cdot 3.5 = 69.09 \quad r0111 := (r011 + 0.15) \cdot 47 = 12.596$

$Z\Sigma 1 := Xgs \cdot i + r2 + X2i = 5.546 + 19.74i \qquad Xc := 0$

$$rt2 := \frac{285000}{2 \cdot 63 \cdot 10^6} \cdot \frac{(158000)^2}{63 \cdot 10^6} = 0.896 \qquad Xb := \frac{(18 + 10.5 - 6)}{200} \cdot \frac{158000^2}{63 \cdot 10^6} = 44.579$$

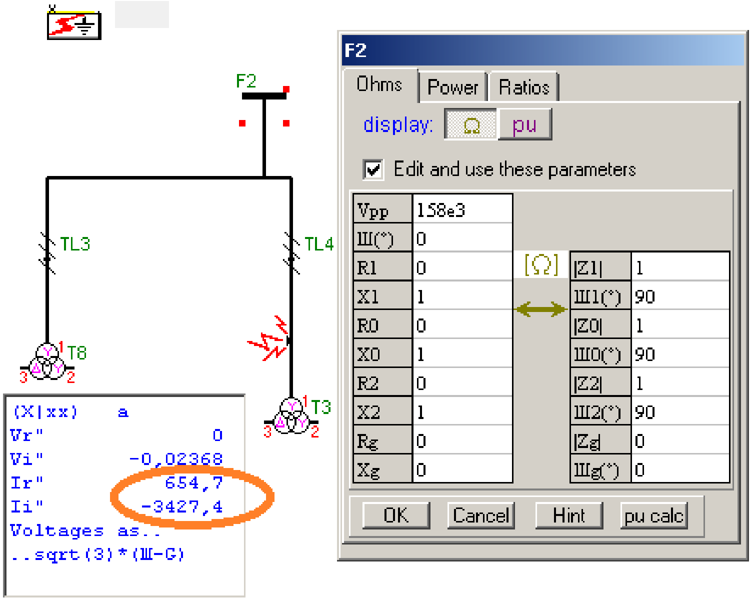
$$Xn := \frac{[(18 - 10.5) + 6]}{200} \cdot \frac{158000^2}{63 \cdot 10^6} = 26.747 \qquad Z3 := 2rt2 + Xni + Xbi = 1.793 + 71.326i$$

$$Z4 := Z3 + (r0111 + X0111i) = 14.389 + 140.416i \quad Z5 := Xgs \cdot i = 0 \quad Z5\_ := Z4 \cdot \frac{Z5}{Z4 + Z5} = 0$$

$$Z6 := (r0111 + X0111i) + Z5\_ = 12.596 + 69.09i \qquad Z\Sigma 0 := \frac{Z3 \cdot Z6}{Z3 + Z6} = 3.662 + 35.309i$$

$$Ip1 := \frac{3 \cdot \frac{158 \cdot 10^3}{\sqrt{3}}}{Z\Sigma 1 + Z\Sigma 1 + Z\Sigma 0} = 694.813 - 3522.055i \qquad |Ip1| = 3589.936$$

b



c

Розрахунок несиметричних КЗ

$X0 := 0.6 \quad Xgs := 1 \quad x0x1 := 3.5 \quad X011 := 0.42 \quad r011 := 0.118$

$X010 := x0x1 \cdot 0.42 = 1.47 \quad r0110 := 0.15 + 0.118 = 0.268 \quad X2 := X011 \cdot 47 = 19.74$

$r2 := r011 \cdot 47 = 5.546 \quad X0111 := X2 \cdot 3.5 = 69.09 \quad r0111 := (r011 + 0.15) \cdot 47 = 12.596$

$Z\Sigma 1 := Xgs \cdot i + r2 + X2i = 5.546 + 20.74i \qquad Xc := 0$

$$rt2 := \frac{285000}{2 \cdot 63 \cdot 10^6} \cdot \frac{(158000)^2}{63 \cdot 10^6} = 0.896 \qquad Xb := \frac{(18 + 10.5 - 6)}{200} \cdot \frac{158000^2}{63 \cdot 10^6} = 44.579$$

$$Xn := \frac{[(18 - 10.5) + 6]}{200} \cdot \frac{158000^2}{63 \cdot 10^6} = 26.747 \qquad Z3 := 2rt2 + Xni + Xbi = 1.793 + 71.326i$$

$Z4 := Z3 + (r0111 + X0111\,i) = 14.389 + 140.416i \quad Z5 := Xgs \cdot i = i$

$$Z5\_ := Z4 \cdot \frac{Z5}{Z4 + Z5} = 7.121 \times 10^{-4} + 0.993i \qquad Z6 := (r0111 + X0111\,i) + Z5\_ = 12.597 + 70.083i$$

$$Z\Sigma 0 := \frac{Z3 \cdot Z6}{Z3 + Z6} = 3.624 + 35.559i$$

$$Ip1 := \frac{3 \cdot \frac{158 \cdot 10^3}{\sqrt{3}}}{Z\Sigma 1 + Z\Sigma 1 + Z\Sigma 0} = 654.669 - 3427.248i \qquad |Ip1| = 3489.214$$

d

Fig. 6. The results of analytical calculation and calculation in the software product "Elplek"

Thus, we see that the simulation results provided the system as a source of infinite power $I_{\text{mod1}} = 694.9 - j3522.2\,A$ and calculations $I_{\text{cal1}} = 694.81 - j3522.06\,A$ on the active part differ by 0.013%, and on the reactive - 0.004%; provided that the system is set as a source of a certain power $I_{\mathrm{mod}\,2} = 654.7 - j3427.4\,A$ and calculations $I_{\mathrm{cal}\,2} = 654.67 - j3427.25A$ on the active part differ by 0.0046%, and on the reactive - 0.0044%.

Conclusions and prospects, Thus, the reliability and validity of the scientific results is ensured by the coincidence of asymmetric short-circuit currents calculation results in simple power supply circuits with parallel branches, carried out on the basis of the software product "Elplek", with known analytical methods. This allows us to conclude about the possibility of using the software product "Elplek" for the calculation of complex branched power supply systems and in the emergency modes indicators analysis of their operation for consumers of power systems certain segments.

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ОСОБЛИВОСТІ РОЗРАХУНКУ НЕСИМЕТРИЧНИХ СТРУМІВ КОРОТКИХ ЗАМИКАНЬ У ПРОГРАМНОМУ ПРОДУКТІ «ELPLEK»

О. В. Гай, В. М. Бодунов, А. В. Жильцов

Анотація. *З метою спрощення аналізу режимів роботи електричних мереж застосовують спеціалізовані програмні засоби математичного моделювання відповідних процесів. Існує величезна кількість програмних продуктів, але переважна їх більшість є платною. Для проведення досліджень в складних електроенергетичних системах та отримання результатів в певних розділах при виконанні практичних та курсових робіт, а також на певних етапах наукових досліджень автори статті активно застосовують безкоштовний програмний продукт «Elplek», але при глибшому вивченні можливостей програмного продукту зіштовхнулися з певними особливостями завдання деяких параметрів, які дещо відрізняються від загально прийнятої вітчизняної методики, що призводило до отримання похибки в розрахунках в окремих варіантах схем електроенергетичних систем.*

Мета досліджень – вивчити особливості розрахунку характеристик несиметричних коротких замикань в програмному продукті «Elplek» та перевірити адекватність сформованих моделей.

На першому етапі був обраний об'єкт дослідження – це сегмент електричної мережі, що містить невелику кількість вузлів, та проведений теоретичний розрахунок шуканих параметрів режиму короткого замикання в цьому сегменті електричної мережі. У подальшому був запропонований підхід щодо завдання параметрів елементів у програмному продукті «Elplek» та ґрунтуючись на цьому підході проведене моделювання, в результаті якого отримали результати за умови завдання системи як джерела нескінченої потужності $I_{моделювання1} = 694.9 - j3522.2\,A$ *та розрахунків* $I_{розрахунки1} = 694.81 - j3522.06\,A$ *за активною частиною відрізняються на 0,013 %, а за реактивною – 0,004 %; за умови завдання системи як джерела певної потужності* $I_{моделювання2} = 654.7 - j3427.4\,A$ *та розрахунків* $I_{розрахунки2} = 654.67 - j3427.25A$ *за активною частиною відрізняються на 0,0046 %, а за реактивній – 0,0044 %, що дає можливість стверджувати щодо доцільності використання запропонованого підходу при аналізі показників аварійних режимів складних схем електрозабезпечення споживачів певних сегментів електроенергетичних систем.*

Ключові слова: ***моделювання сегмента електроенергетичної системи, програмний продукт «Elplek», завдання параметрів елементів, однофазні струми короткого замикання***

ОСОБЕННОСТИ РАСЧЕТА НЕСИММЕТРИЧНЫХ ТОКОВ КОРОТКОГО ЗАМЫКАНИЯ В ПРОГРАММНОМ ПРОДУКТЕ «ELPLEK»

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Аннотация. *С целью упрощения анализа режимов работы электрических* *сетей применяют специализированные программные средства математического моделирования соответствующих процессов. Существует огромное количество программных продуктов, но подавляющее их большинство является платными. Для проведения исследований в сложных электроэнергетических системах и получения результатов в определенных разделах при выполнении практических и курсовых работ, а также на определенных этапах научных исследований авторы статьи активно применяют бесплатный программный продукт «Elplek», но при более глубоком изучении возможностей программного продукта столкнулись с определенными особенностями задачи некоторых параметров, которые несколько отличаются от общепринятой отечественной методики, что приводило к получению погрешности в расчетах в отдельных случаях схем электроэнергетических систем.*

Цель исследований - изучить особенности расчета характеристик несимметричных коротких замыканий в программном продукте «Elplek» и проверить адекватность сформированных моделей.

На первом этапе был выбран объект исследования - это сегмент электрической сети, содержащей небольшое количество узлов и проведен теоретический расчет искомых параметров режима короткого замыкания в этом сегменте электрической сети. В дальнейшем был предложен подход к заданию параметров элементов в программном продукте «Elplek» и основываясь на этом подходе проведено моделирование, в результате которого получили результаты при задании системы как источника бесконечной мощности $I_{мод1} = 694.9 - j3522.2\,A$ *и расчетов по активной части* $I_{p1} = 694.81 - j3522.06\,A$ *, которые отличаются на 0,013 %, а по реактивной - 0,004 %; при условии задачи системы как источника определенной мощности* $I_{мод2} = 654.7 - j3427.4\,A$ *и расчетов по активной части* $I_{p2} = 654.67 - j3427.25\,A$ *, которые отличаются на 0,0046 %, а по реактивной - 0,0044 %, что дает возможность утверждать о целесообразности использования предложенного подхода при анализе показателей аварийных режимов сложных схем электроснабжения потребителей определенных сегментов электроэнергетических систем.*

Ключевые слова: ***моделирование сегмента электроэнергетической системы, программный продукт «Elplek», задание параметров элементов, однофазные токи короткого замыкания***