Methodology for Assessment the Possibility of Transfer Six-Phase Power Line into the Mode of Operation with Incomplete Number of Phases

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Abstract. In electric power systems due to various reasons: short circuits, phase breaks, ice melting, phase-by-stage repair of a high-voltage power line (transmission line), interruptions in the power supply to the consumer occur. On single-sided power lines, this leads to a prolonged shutdown of consumers, and to a significant emergency lack of electricity supply. Switching the line to operation with incomplete number of phases significantly increases the reliability of consumes power supply. For double-circuit power lines it is always possible to keep in work at least two phases out of six. Among the various options for double-circuit power lines, the so-called self-compensating and controlled self-compensating high-capacity power transmission lines (SCL and CSCL) were proposed. For unidirectional power supply lines, these cases are accompanied by a prolonged shutdown of consumers from the electrical energy and a long time with a lack of supply. The article is devoted to the methodology for calculation the throughput of SCL and CSCL, which operate with incomplete number of phases. The methodology is based on the use of six symmetric components of currents and voltage of the SCL (CSC) and can be extended and applied in principle to any six-phase power transmission lines, in particular, two-circuit conventional power lines. The equivalents substitution complex schemes in the coordinates of the six symmetrical components in the MATLAB program are modeled. This allows us to find the currents and transmitted power through the line and voltages in the nodes of the network and evaluate the possibility of its operation in this mode.

***Keywords*:** electrical lines with self-compensation and controlled self-compensation; incomplete number of phases; six symmetrical components.
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Metodologie pentru evaluarea posibilității transferului unei linii electrice cu șase faze în regim de funcționare cu numarul necomplet de faze

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Rezumat. În sistemele electroenergetice din diferite motive ca scurtcircuite, rupri a faze, topirea gheții, reparație pas cu pas a unei linii de înaltă tensiune (linie de transmisie), se produc întreruperi în alimentarea consumatorilor. Obiectivul lucrării este de a dezvolta o metodologie pentru calcularea debitului unei linii de transmisie a energiei cu șase faze, luând ca exemplu linii electrice cu autocompensare și de tip LEDA, care funcționează într-un regim de sarcină cu număr necomplet de faze. Pentru a atinge acest obiectiv, am folosit o tehnică bazată pe utilizarea a șase componente simetrice ale curenților și tensiunilor LEC (LEDA) pentru diferite regimuri asimetrice și care poate fi distribuită și aplicată în principiu la orice tip de linii de alimentare cu șase faze, în special, la liniile de alimentare convenționale cu dublu circuit. În mod similar cu metoda binecunoscută a componentelor simetrice trifazice, utilizată pentru a evalua posibilitatea transferării unei linii de alimentare trifazate într-un regim incomplet de faze, metoda componentelor simetrice cu șase faze poate simplifica semnificativ calculul. Cel mai important rezultat al acestei lucrări o prezintă metoda de calculul al parametrilor electrici (curenți și tensiuni) în cazul unui regim de funcționare ce număr necomplet de faze , utilizând condițiile de limită pentru porțiunea avariată a liniei electrice de transmisie. Semnificația rezultatelor constă în obținerea unui scheme complexe echivalente la ruperea fazei în coordonatele fazore a șase componente simetrice, ceea ce permite de a calcula curenții (puterile) și tensiunii unei linii de transmisie cu sase faze în nodurile rețelei, ce permite estimarea posibilității funcționării acestei linii în regim de fază incomplet.

Cuvinte cheie: linii electrice cu autocumpensare și linii electrice dirijate, funcționare cu număr incomplet de faze, șase componente simetrice.

Методика оценки возможности перевода шестифазной ЛЭП в неполнофазный режим работы.

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Аннотация. В электроэнергетических системах в силу различных причин: коротких замыканий, обрывов фаз, плавки гололёда, пофазный ремонт высоковольтной линии электропередачи (ЛЭП) возникают перерывы в электроснабжение потребителей. Переключение линии с односторонним питанием в неполнофазный режим существенно увеличивает надежность электроснабжения потребителей. Особенно это эффективно для двухцепных ЛЭП. Для них всегда есть возможность сохранить из шести фаз хотя бы две фазы в работе для обеспечения непрерывности энергснабжения. Среди различных вариантов двухцепных ЛЭП были предложены и так называемые самокомпенсирующиеся и управляемые самокомпенсирующиеся линии электропередачи повышенной пропускной способности (СВЛ и УСВЛ). Целью работы является разработка методики расчета пропускной способности шестифазной ЛЭП на примере СВЛ и УСВЛ, которые работают в неполнофазном нагрузочном режиме. Для достижения поставленной цели использовалась методика, основанная на использование шести симметричных составляющих токов и напряжений СВЛ (УСВЛ) при различных несимметричных режимах и которая может быть распространена и применена в принципе к любым видам шестифазным ЛЭП, в частности, к двуцхцепным обычным ЛЭП. Аналогично общеизвестному методу трехфазных симметричных составляющих использованный для оценки возможности перевода трехфазной ЛЭП в неполнофазный режим, метод шестифазных симметричных составляющих позволяет существенно упростить расчёт. Наиболее важным результатом в данной работе является рассмотренная методика расчета электрических величин (токов и напряжений) при неполнофазном режиме СВЛ на основе граничных условий для участка повреждения ЛЭП. Значимость результатов состоит в получении эквивалентной комплексной схемы замещения для обрыва фазы в координатах шести симметричных составляющих, что позволяет найти токи (мощности) шестифазной ЛЭП и напряжения в узлах сети и оценить возможность её работы в неполнофазном режиме.

Ключевые слова: самокомпенсирующиеся и управляемые самокомпенсирующиеся линии электропередачи, неполнофазный режим, шесть симметричных составляющих.

INTRODUCTION

To increase the transmission capacity of electrical lines, the use of a new generation of high-capacity transmission lines has been proposed, including electrical lines with self-compensation (SCL) and controlled electrical lines with self-compensation (CSCL) [1-4]. The introduction of these power lines in practice requires solving a whole range of problems such as relay protection (RP) from various damages, including short circuits (SC), phase ruptures (PhR) and analysis of the possibility of their operation with incomplete number of phases (INPh).

Of all the possible short circuits on the SCL or CSCL, more than 60% of the short circuits belongs to short circuits of single-phase followed by disconnecting the line. For consumers connected via SCL or CSCL to a single source of electricity, this will interrupt the supply of electricity. The power supply of the consumers can be maintained by disconnecting only the damaged phase, if each phase of the SCL or CSCL has its own switch. Operation SCL and CSCL with no-full number of phases (NFPh) can be provided as a possibility that significantly increases the reliability of the electrical system, for example, when carrying out phase-by-phase repair of power lines or step by step phase ice melting.

In order to estimate what power of electricity can be transmitted to consumers, it is necessary to study the operation of the power line (SCL or CSCL) without the disconnected phase.

For the calculations of the maximum value of the electrical power transmitted by the three-phase conventional power lines [5] in the INPh operating modes, the method of three symmetrical components 0,1,2 is used. [6-24]. Similarly, for calculating the maximum value of the electrical power transmitted by SCL or CSCL in the INPh asymmetric mode of operation, the method of six symmetrical 0,1,2,3,4,5 components can be used. This requires the following data:

- the equivalent substitution schemes of the electrical network and all its elements for the sequences 0,1,2,3,4 and 5 of the currents and voltages;
- the maximum values of the power of the consumers connected to the transformer stations of the electrical network;
- passport data for generators of the power plants.

I. DETERMINATION OF THE MAXIMUM TRANSMISSION POWER IN THE MODE OF OPERATION WITH INCOMPLECT NUMBER OF PHASES (INPh)

The methodology for assessing the maximum value of the transmitted power by SCLor CSCL is based on the following assumptions: similar to asymmetric load calculations by using three symmetrical components, it is considered, that the voltage of the second (2) and fifth (5), as well as the first (1) and fourth (4) sequences of the voltage at the terminals of all power consumers connected to the common distribution network are equal. Therefore, in most cases it is sufficient to determine the asymmetry voltage on the transformer busbars of the substations, connected to the line operating in the INPh mode. The entire load is replaced by an equivalent one and is brought to the busbars of the corresponding voltage of each of the substations connected to the line operating in the INPh. Considering SCL (CSCL) as six-phase power lines, for calculating asymmetrical short-circuits, ruptures of the phases and for calculating the maximum value of the transmitted power through them in the INPh mode of operation by using six symmetrical components it is necessary:

- asymmetric systems of voltages, currents and EMF to be present as the sum of the corresponding symmetrical components;
- the initially asymmetric equivalent circuit shall be represented by six symmetrical equivalent circuits of sequences 0,1,2,3,4 and 5 of currents. The number and types of the symmetrical components circuits depends on given analyzing type of asymmetry;
- for given type of asymmetry, according to symmetric equivalent circuits, symmetric components of currents and voltages are calculated;
- using the calculated symmetrical components, the desired currents and voltages in the original circuit are determined.

In accordance of deterioration type, equivalent circuits of individual symmetrical components can be obtained (Fig.1). Figure 1 shows the circuits of the symmetrical components of the CSC line when the phase A is ruptures and shifting angle between voltages vectors of the phases closely placed of the CSC $\theta = 0$ °

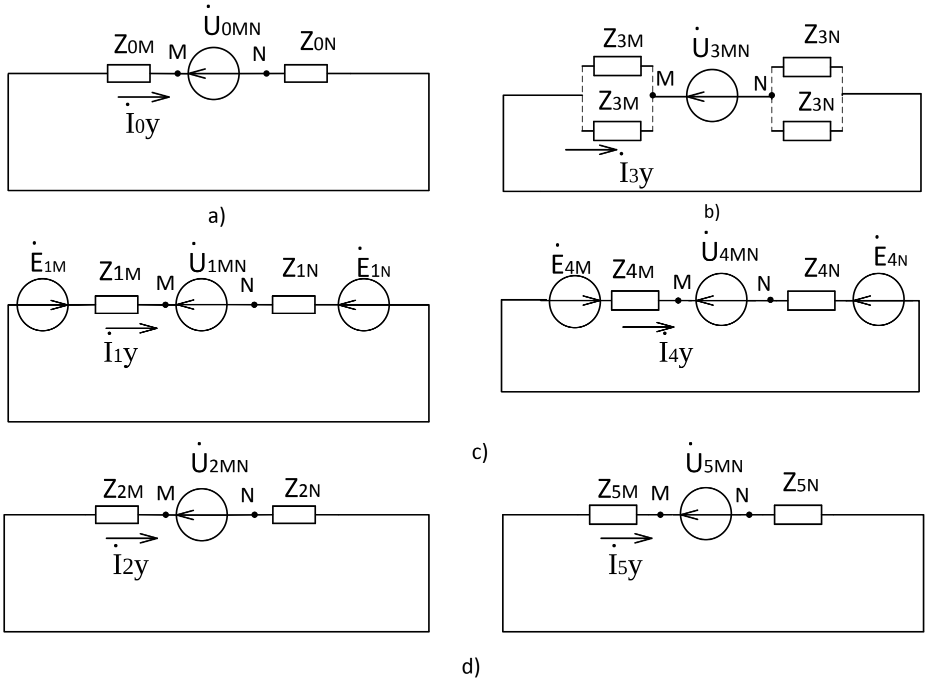

Fig. 1. The equivalent circuits of symmetrical components for ruptured phase of the CSCL with angle θ = 0 °: a- for zero sequence; b -for third sequence; c - for first and fourth sequences; d - for the twice and fifth sequences.

The ruptured phase A can be considered undamaged if a UMN source with the equivalent voltage equal to the potential difference between the rupturing points is included between the breaking points M and N. The phase components of the currents and voltages at the breaking point are characterized by the relations:

Taking into account the boundary conditions expressed in to the six symmetrical components, the equivalent schemes of individual sequences can be combined into a complex equivalent circuit. The schemes of individual components are connected in parallel to the damaged place. The individual sequence schemes need to be connected in such a way that the sum of the currents is equal to zero and the voltages of the individual sequences are equal between them. As an example, fig. 2 shows the complex equivalent scheme of the line in to the symmetric components in the MATLAB program, when phase A is ruptured.

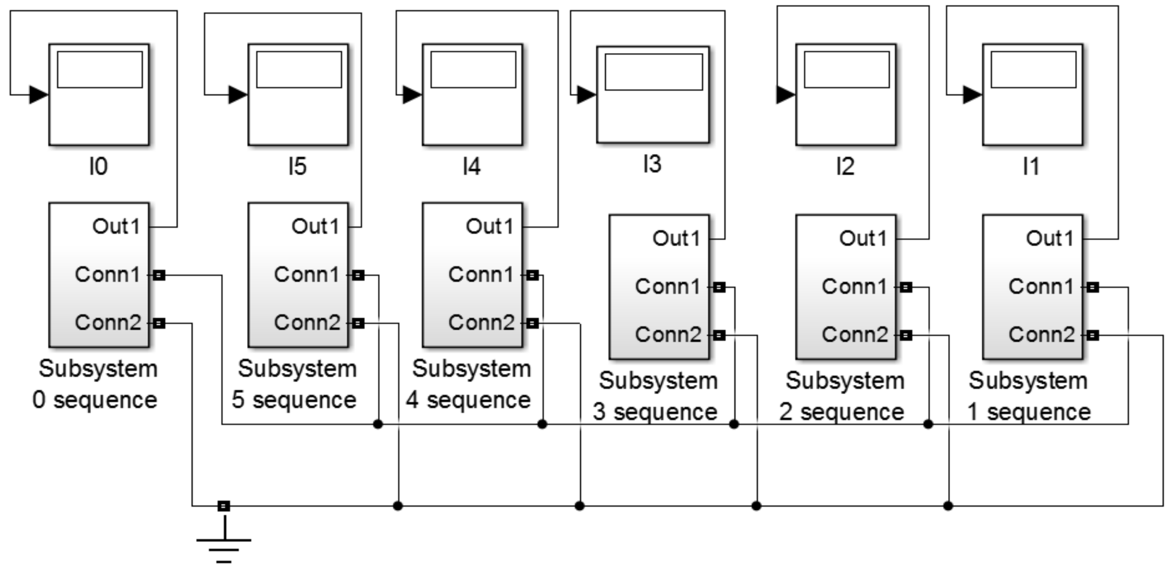

Fig. 2. Complex equivalent scheme of the line in to the symmetric components for the ruptured phase A in the MATLAB program.

II. CALCULATION THE MAXIMAL TRANSMITION POWER THROUGH HV LINE WHICH WORKS WITH INCOMPLETE NUMBER OF PHASES

Using the method of six symmetrical components, the phase and line currents and voltages according to the relations are determine

$$\begin{vmatrix} \dot{F}_A \\ \dot{F}_B \\ \dot{F}_C \\ \dot{F}_D \\ \dot{F}_E \\ \dot{F}_F \end{vmatrix} = \begin{vmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & e^{j300} & e^{j240} & e^{j180} & e^{j120} & e^{j60} \\ 1 & e^{j240} & e^{j120} & 1 & e^{j240} & e^{j120} \\ 1 & e^{j180} & 1 & e^{j180} & 1 & e^{j180} \\ 1 & e^{j120} & e^{j240} & 1 & e^{j120} & e^{j240} \\ 1 & e^{j60} & e^{j120} & e^{j180} & e^{j240} & e^{j300} \end{vmatrix} \cdot \begin{vmatrix} \dot{F}_{A0} \\ \dot{F}_{A1} \\ \dot{F}_{A2} \\ \dot{F}_{A3} \\ \dot{F}_{A4} \\ \dot{F}_{A5} \end{vmatrix} \quad (1)$$

Or in a simplified form $\dot{F} = \dot{F}_6 \cdot \dot{F}_S$

$$\dot{S}_6 = \begin{vmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & e^{j300} & e^{j240} & e^{j180} & e^{j120} & e^{j60} \\ 1 & e^{j240} & e^{j120} & 1 & e^{j240} & e^{j120} \\ 1 & e^{j180} & 1 & e^{j180} & 1 & e^{j180} \\ 1 & e^{j120} & e^{j240} & 1 & e^{j120} & e^{j240} \\ 1 & e^{j60} & e^{j120} & e^{j180} & e^{j240} & e^{j300} \end{vmatrix} \quad (2)$$

the square transition matrix from the six symmetrical components 0,1,2,3,4,5 of the vectors of current (voltage) to the six-phase coordinates A, B, C, D, E, F of the line

$$\dot{F} = \begin{vmatrix} \dot{F}_A \\ \dot{F}_B \\ \dot{F}_C \\ \dot{F}_D \\ \dot{F}_E \\ \dot{F}_F \end{vmatrix}; \qquad \dot{F}_S = \begin{vmatrix} \dot{F}_{A0} \\ \dot{F}_{A1} \\ \dot{F}_{A2} \\ \dot{F}_{A3} \\ \dot{F}_{A4} \\ \dot{F}_{A5} \end{vmatrix},$$

Where $\dot{F}$ column matrix of current (voltage) vectors in the phase coordinates, $\dot{F}_S$ column matrix of current (voltage) vectors in the six symmetrical components.

Converting the vectors using the give up matrixes is advisable for calculations in the MathCad system, because this allows for calculating the required currents and voltages without write separate formulas. On the base of the equivalent circuits of six 0, 1, 2, 3, 4 and 5 sequences (fig. 1) and complex equivalent circuit (fig. 2), following system of equations can be writes:

$$\begin{cases} Z_0\dot{I}_0 + \dot{U}_0 = 0 \\ Z_1\dot{I}_1 + \dot{U}_1 = \dot{E}_1 \\ Z_2\dot{I}_2 + \dot{U}_2 = 0 \\ Z_3\dot{I}_3 + \dot{U}_3 = 0 \\ Z_4\dot{I}_4 + \dot{U}_4 = \dot{E}_4 \\ Z_5\dot{I}_5 + \dot{U}_5 = 0 \\ \dot{I}_0 + \dot{I}_1 + \dot{I}_2 + \dot{I}_3 + \dot{I}_4 + \dot{I}_5 = 0 \\ \dot{U}_0 + \dot{U}_1 \cdot e^{-j60} + \dot{U}_2 \cdot e^{-j120} + \dot{U}_3 + \dot{U}_4 \cdot e^{-j240} + \dot{U}_5 \cdot e^{-j300} = 0 \\ \dot{U}_0 + \dot{U}_1 \cdot e^{-j120} + \dot{U}_2 \cdot e^{-j240} + \dot{U}_3 + \dot{U}_4 \cdot e^{-j120} + \dot{U}_5 \cdot e^{-j240} = 0 \\ \dot{U}_0 - \dot{U}_1 + \dot{U}_2 - \dot{U}_3 + \dot{U}_4 - \dot{U}_5 = 0 \\ \dot{U}_0 + \dot{U}_1 \cdot e^{-j240} + \dot{U}_2 \cdot e^{-j120} + \dot{U}_3 + \dot{U}_4 \cdot e^{-j240} + \dot{U}_5 \cdot e^{-j120} = 0 \\ \dot{U}_0 + \dot{U}_1 \cdot e^{-j300} + \dot{U}_2 \cdot e^{-j240} - \dot{U}_3 + \dot{U}_4 \cdot e^{-j120} + \dot{U}_5 \cdot e^{-j60} = 0 \end{cases} \quad (3)$$

Here Z_0, Z_1, Z_2, Z_3, Z_4, Z_5 are the resulting impedances of the circuits of the six symmetrical components in relation to the rupture point. The first six equations of the system are compiled according to Kirchhoff's second law (fig.1). The remaining six equations of the system are written according to the conditions at the place of asymmetry. For ruptured phase A , the boundary conditions written through the six symmetric components according to (1): $\dot{I}_A = 0$, $\dot{U}_{A'} = 0$, $\dot{U}_B = 0$, $\dot{U}_{B'} = 0$, $\dot{U}_C = 0$, $\dot{U}_{C'} = 0$. Using the known impedances of the complex equivalent circuit, the symmetric components of currents and voltages in all nodes and branches of the circuit are calculated. The phase and line currents and voltages are calculated by the relations (1). According to the phase and line values of currents and voltages, power flows for given branches:

$$S^{pq} = \dot{U}_A^p \overset{*\,pq}{I}_A + \dot{U}_B^p \overset{*\,pq}{I}_B + \dot{U}_C^p \overset{*\,pq}{I}_C + \dot{U}_{A'}^p \overset{*\,pq}{I}_{A'} + \dot{U}_{B'}^p \overset{*\,pq}{I}_{B'} + \dot{U}_{C'}^p \overset{*\,pq}{I}_{C'} \quad (4)$$

or

$$S^{pq} = 6\left(\dot{U}_1^p \overset{*\,pq}{I}_1 + \dot{U}_2^p \overset{*\,pq}{I}_2 + \dot{U}_3^p \overset{*\,pq}{I}_3 + \dot{U}_4^p \overset{*\,pq}{I}_4 + \dot{U}_5^p \overset{*\,pq}{I}_5 + \dot{U}_0^p \overset{*\,pq}{I}_0 \right) (5),$$

where p. and q are the beginning and end of a given branch

The calculation is carried out for the load range from maximum to zero (for example, 100% Sl, 80% Sl, etc.), where Sl is the power on beginning of the line. The loads of the transformers substations vary in proportion to the load on the beginning of the line. At each step, currents and voltages are calculated. In the same way, changing the load in the range from 100% to 20% are built the dependences of Uf on the values of the transmitted power. Following the above calculation method, it is possible to calculate the voltage deviation at all substations of the considered network and construct for each substation the graphs Vi = f (Sl), where $\dot{V}_i = \dfrac{\dot{U} - \dot{U}_н}{\dot{U}_н}100\%$ and ε = f ($S_{пер}$), where $\varepsilon = \dfrac{\dot{U}_2}{\dot{U}_н}100\%$. The analysis of these dependencies allows us to solve the problem of the maximum value of the transmitted power, based on the criterion of voltage quality at the consumer. As a result of the analysis of these dependencies, the maximum value of the transmitted power through the line is found. Comparing the all results of the analysis is selected the power that satisfies the given technical limitations.

III.CALCULATION THE SHORT CIRCUIT CURRENTS WHEN HV LINE WORKS WITH INCOMPLECT NUMBER OF PHASES

The asymmetry that occurs during the phase rupture was characterized by the corresponding voltages and currents that can be decomposed into separate sequences. Their values depend on currents and voltages of the previous mode of operation and have a significant effect to the operation of relay protection. In order to ensure the operation selectivity of the relay protection of the line in INPh it is necessary to adjust the relay protection in such a way, that there are capable to operate correctly At the same time, the necessary sensitivity of the relay protection must be ensured during the short circuits, which can occur during operation of the line in the INPh regimes. For the lines which supplies with electrical energy the consumers from one sours, as a rule, are installed the following relay protections:

- current cut-off relay protection, connected to the phase currents and homopolar (zero) sequence currents;
- maximum current relay protections, connected to the phase currents and homopolar (zero) sequence currents.

To choose the start current of the current cut-off protection, it is necessary to know the highest short-circuit currents behind the step-down transformers. To calculate the short-circuit currents on the lines with a single tap may be used the expressions [4]. At the figure 3, the simplified scheme of six-phase line with rupture of the phase on the chain I and phase short circuit on the chain II are given.

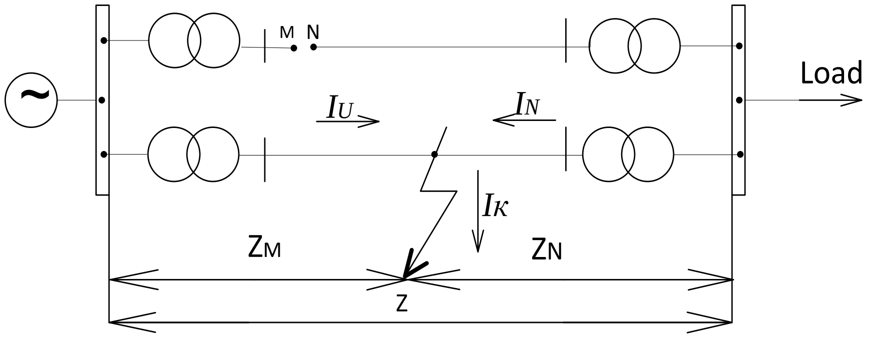

Fig. 3. The short circuit of the one phase on the ground with simultaneous rupture of another phase of the line.

To check the reliability coefficient of the protection, in most cases, it is necessary to know the currents of a single-phase short circuit of one of the working phases during the operation of the line in the INPh regime. The scheme of fig. 3 in the cases of short circuit. with the simultaneous rupture of one phase is characterized by 24 unknown currents and voltages: $\dot{I}_{1K}, \dot{I}_{2K}, \dot{I}_{3K}, \dot{I}_{4K}, \dot{I}_{5K}, \dot{I}_{0K}, \dot{I}_{1U}, \dot{I}_{2U}, \dot{I}_{3U}, \dot{I}_{4U}, \dot{I}_{5U}, \dot{I}_{0U}, \dot{U}_{1K}$, $\dot{U}_{2K}, \dot{U}_{3K}, \dot{U}_{4K}, \dot{U}_{5K}, \dot{U}_{0K}, \dot{U}_{1U}, \dot{U}_{2U}, \dot{U}_{3U}, \dot{U}_{4U}, \dot{U}_{5U}, \dot{U}_{0U}$. For each of characteristic sequences, the relationship formulas between voltages and currents it is compiled, taking into account the accepted positive direction of currents and voltages:

$$\begin{aligned}
-\dot{E}_N &= -Z_{1KK}\dot{I}_{1K} + Z_{1KU}\dot{I}_{1U} - \dot{U}_{1K};\\
-(\dot{E}_M - \dot{E}_N) &= Z_{1UK}\dot{I}_{1K} + Z_{1UU}\dot{I}_{1U} - \dot{U}_{1U};\\
0 &= -Z_{2KK}\dot{I}_{2K} + Z_{2KU}\dot{I}_{2U} - \dot{U}_{2K};\\
0 &= Z_{2UK}\dot{I}_{2K} + Z_{2UU}\dot{I}_{2U} - \dot{U}_{2U};\\
0 &= -Z_{3KK}\dot{I}_{3K} + Z_{3KU}\dot{I}_{3U} - \dot{U}_{3K};\\
0 &= Z_{3UK}\dot{I}_{3K} + Z_{3UU}\dot{I}_{3U} - \dot{U}_{3U};\\
0 &= -Z_{4KK}\dot{I}_{4K} + Z_{4KU}\dot{I}_{4U} - \dot{U}_{4K};\\
0 &= Z_{4UK}\dot{I}_{4K} + Z_{4UU}\dot{I}_{4U} - \dot{U}_{4U};\\
-\dot{E}_N &= -Z_{5KK}\dot{I}_{5K} + Z_{5KU}\dot{I}_{5U} - \dot{U}_{5K};\\
-(\dot{E}_M - \dot{E}_N) &= Z_{5UK}\dot{I}_{5K} + Z_{5UU}\dot{I}_{5U} - \dot{U}_{5U};
\end{aligned} \tag{6}$$

$$\begin{aligned}
0 &= -Z_{0KK}\dot{I}_{0K} + Z_{0KU}\dot{I}_{0U} - \dot{U}_{0K};\\
0 &= Z_{0UK}\dot{I}_{0K} + Z_{0UU}\dot{I}_{0U} - \dot{U}_{0U},
\end{aligned}$$

where $Z_{xKK} = Z_N$, $Z_{xyy} = Zx = Z_N\ Z_M$ - self impendences;

$Z_{xKU} = Z_{xUK} = Z_N$ - mutual impendences, where x is the index of the sequences (x = 0, 1, 2, 3, 4, 5) The rest of the equations are compiled according to the boundary conditions for places of short circuit and rupture. For the phase A short circuit to ground $\dot{U}_{AK} = 0$, $\dot{I}_{A`K} = 0$, $\dot{I}_{BK} = 0$, $\dot{I}_{B`K} = 0$, $\dot{I}_{CK} = 0$, $\dot{I}_{C`K} = 0$ for the phase. A in the rupture point $\dot{I}_{AU} = 0,$ $\dot{U}_{A`U} = 0,$ $\dot{U}_{BU} = 0,$ $\dot{U}_{B`U} = 0,$ $\dot{U}_{CU} = 0, \dot{U}_{C`U} = 0$.

To write the equations, we use (1)

$$\begin{aligned}
&\dot{U}_{AK} = \dot{U}_{0K} + \dot{U}_{1K} + \dot{U}_{2K} + \dot{U}_{3K} + \dot{U}_{4K} + \dot{U}_{5K};\\
&\dot{I}_{A`K} = \dot{I}_{0K} + \dot{I}_{1K}\cdot e^{-j60} + \dot{I}_{2K}\cdot e^{-j120} - \dot{I}_{3K} + \dot{I}_{4K}\cdot e^{-j240} +\\
&+\dot{I}_{5K}\cdot e^{-j300};\\
&\dot{I}_{BK} = \dot{I}_{0K} + \dot{I}_{1K}\cdot e^{-j120} + \dot{I}_{2K}\cdot e^{-j240} + \dot{I}_{3K} + \dot{I}_{4K}\cdot e^{-j120} +\\
&+\dot{I}_{5K}\cdot e^{-j240};\\
&\dot{I}_{B`K} = \dot{I}_{0K} - \dot{I}_{1K} + \dot{I}_{2K} - \dot{I}_{3K} + \dot{I}_{4K} - \dot{I}_{5K};\\
&\dot{I}_{CK} = \dot{I}_{0K} + \dot{I}_{1K}\cdot e^{-j240} + \dot{I}_{2K}\cdot e^{-j120} + \dot{I}_{3K} + \dot{I}_{4K}\cdot e^{-j240} +\\
&+\dot{I}_{5K}\cdot e^{-j120};
\end{aligned}$$

$$
\begin{aligned}
&\dot{I}_{C'K} = \dot{I}_{0K} + \dot{I}_{1K} \cdot e^{-j300} + \dot{I}_{2K} \cdot e^{-j240} - \dot{I}_{3K} + \dot{I}_{4K} \cdot e^{-j120} + \\
&+\dot{I}_{5K} \cdot e^{-j60}; \qquad (7)\\
&\dot{I}_{AU} = \dot{I}_{0U} + \dot{I}_{1U} + \dot{I}_{2U} + \dot{I}_{3U} + \dot{I}_{4U} \cdot + \dot{I}_{5U}; \\
&\dot{U}_{A'U} = \dot{U}_{0U} + \dot{U}_{1U} \cdot e^{-j60} + \dot{U}_{2U} \cdot e^{-j120} - \dot{U}_{3U} + \dot{U}_{4U} \cdot e^{-j240} + \\
&+\dot{U}_{5U} \cdot e^{-j300}; \\
&\dot{U}_{BU} = \dot{U}_{0U} + \dot{U}_{1U} \cdot e^{-j120} + \dot{U}_{2U} \cdot e^{-j240} + \dot{U}_{3U} + \dot{U}_{4U} \cdot e^{-j120} + \\
&+\dot{U}_{5U} \cdot e^{-j240}; \\
&\dot{U}_{B'U} = \dot{U}_{0U} - \dot{U}_{1U} + \dot{U}_{2U} - \dot{U}_{3U} + \dot{U}_{4U} - \dot{U}_{5U}; \\
&\dot{U}_{CU} = \dot{U}_{0U} + \dot{U}_{1У} \cdot e^{-j240} + \dot{U}_{2U} \cdot e^{-j120} + \dot{U}_{3U} + \dot{U}_{4U} \cdot e^{-j240} + \\
&+\dot{U}_{5U} \cdot e^{-j120}; \\
&\dot{U}_{C'U} = \dot{U}_{0У} + \dot{U}_{1U} \cdot e^{-j300} + \dot{U}_{2U} \cdot e^{-j240} - \dot{U}_{3U} + \dot{U}_{4U} \cdot e^{-j120} + \\
&+\dot{U}_{5U} \cdot e^{-j60}.
\end{aligned}
$$

To calculate the symmetric components of the currents and voltages using Mathcad, a matrix of coefficients and a matrix of the free members are compiled. The found currents and voltages of individual sequences in places of short circuit and rupture allow us to find currents and voltages at other points of the original circuit. The symmetrical components in the line from the power supply system N side and current of the phase A are calculated according to found currents and the corresponding equivalent circuits:

$\dot{I}_{AxN} = \dot{I}_{AxK} - \dot{I}_{AxU}$, where x is the corresponding sequence.

The calculated phase currents and voltages at all points of the network allow to analyze the operation of relay protection and of the conclusions about the need to change the settings of the operation of the relay protectio, fig. 2. complex equivalent scheme of the line for the ruptured phase a in the matlab program. (as in the usual analysis of the operation of the relay protection)**.**

CONCLUSIONS

1. The supply of the consumers with electrical energy at the single-phase short circuits of the SCL or CSCL followed by the disconnection of the failed phase can be maintained by ensuring their operation with incomplete number of phases.

2. The maximum admissible transmitted power through SCL or CSCL with INPh can be calculated by modeling at the computer the equivalent schemes of the symmetrical hex phase components

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