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Distance to a Transmission Lines Damage Place Numerical Calculation Field Method

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Transmission line, strict mathematical formulation of the field problem, transmission line (TL) 3-D symbolic model, distance to a transmission lines damage place numerical calculation, software.

1 SUMMARY. PROBLEM STATE

According to the statistical data, the considerable share of emergency operation of interconnected power systems is caused electric (isolation rupture, an overvoltage, etc.) or mechanical damages of high-voltage transmission lines (TL). Depending on a place and duration of elimination of emergency damages TL technological and economic consequences can have as local, and total character [1, 2]. Thus on efficiency and, as consequence of it, the size of an expected damage from breaks of an electrical supply of consumers is influenced by following factors:

1. Operation speed of protection and emergency control automatics means;
2. Dispatch of recognition, liquidation of power equipment emergency.

For today the problem of speed and sensitivity of remote measuring element increase solving by control and diagnostics numerical methods and functional algorithms development. In certain cases (see tab. 1) the size of an absolute error of numerical calculation of distance to a short circuit (SC) TL place can reach several kilometers (or more than 10 % concerning all length TL). In this connection the problem of decrease in the resulted error to comprehensible values ($\pm 2.5\%$) is relevant. Generally the distance to SC place (DSCP) numerical calculation error has two components – methodical (it is defined basically by adequacy (an accuracy) mathematical model air TL) and instrument which is caused by measuring part characteristics. Ways of compensation (decrease) in a instrument accuracy of current transformers are developed and investigated on «Power plants and automation of power supply systems» chair of the SEI HPE «Saint-Petersburg State Polytechnical University» (researches of differential protection results in the given edition see). The present research is devoted remote methods of DSCP numerical calculation a methodical accuracy decrease by working out of the strict mathematical description of the transients equations at the field problem in 3-D statement decision. Application of field methods of air TL electric parameters definition this new and perspective direction in a problem solution.

2 DEFINITION OF THE AIR TRANSMISSION LINE EQUIVALENT CIRCUIT ELECTRIC PARAMETERS FIELD METHODS

Modern numerical methods of calculation air TL DSCP are based on use of a electric system operating mode electric parameters, registered by digital oscillographs. The generalized algorithm procedure of calculation transmission lines DSCP is represented on fig. 1.

As it was made reference earlier, the methodical accuracy of numerical calculation substantially is caused by adequacy (strict) of the electric network including TL mathematical model. As at definition of longitudinal and cross-section parameters air TL it is necessary to consider their geometrical features (wires sag, different lines not parallel passage sites, crossings, rapprochements with others TL, etc.), widely known analytical expressions don't give the exact decision in connection with used assumptions (simplifications) set.

In turn, application of research (modeling) air-lines electromagnetic and electric field numerical methods with the strict mathematical description specified above geometrical features, inhomogeneous (non-uniform) earth structures allows to exclude the methodical accuracy of an error shown at an equivalent circuit parameters calculation.

Domestic and foreign researches experience shows that finite element method use for electromagnetic field an air-line calculation the problem decision is the most expedient[3]. It possesses advantages of program realization simplicity and a comprehensible error at a field approximation (modeling).

In work the magnetic field TL parameters numerical calculation is made with use of vector magnetic potential $\vec{A}$ projections on an rectangular coordinate system axis, and electric field parameters definition is carried out through scalar electric potential φ . For calculated region splitting into final elements the elementary three-dimensional figures – tetrahedrons with the node points only in their tops task are used. According to it, the linear polynom for required potential in a finite element distribution approximation is used.

The Galerkin method to the linear algebraic equations system concerning required potentials $\vec{A}$ and φ nodes values formation is applied. Formally it consists in volume integral of one finit element $V^{(e)}$ from product of the given element forms function transposed line on the investigated differential equation equating to zero. For example, linear equation for a vector magnetic potential projection to an axis x in tops of the e -th finite element will be fairly:

$$\left(\frac{1}{\mu} \mathbf{S}^{(e)} + j\omega \mathbf{T}^{(e)} \right) \cdot \dot{\mathbf{A}}_x^{(e)} = \mathbf{T}^{(e)} \cdot \dot{\Phi}_x^{(e)}, \quad (1)$$

and for scalar electric potential:

$$\mathbf{S}^{(e)} \Phi^{(e)} = \mathbf{0}, \quad (2)$$

where μ – environment magnetic conductivity

$\mathbf{S}^{(e)}$, $\mathbf{T}^{(e)}$ – The matrixes which elements are calculated, proceeding from considered e -th finite element node coordinates with integration use in tetrahedron coordinates natural system

$\dot{\mathbf{A}}_x^{(e)}$, $\dot{\Phi}_x^{(e)}$, $\Phi^{(e)}$ – The vector which elements are projection vector magnetic potential on an axis x node values, coordinate x from finite element electric potential in tops derivatives and e th finite element scalar electric potential node values, accordingly

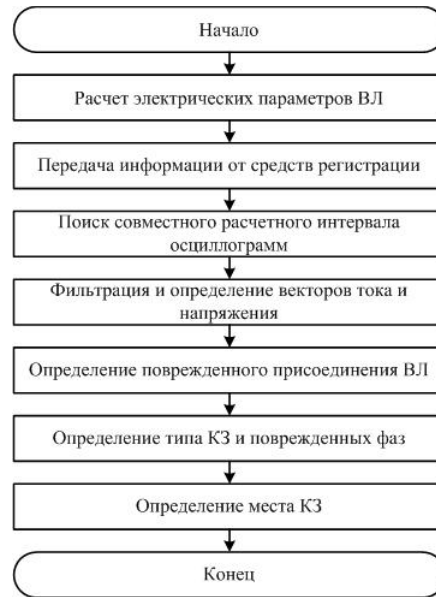


Fig. 1: Block diagram of generalized algorithm procedure of calculation transmission lines DSCP

The each finite elements equations (1), (2), should be united in the equations general system which decision is carried out concerning values of potential in all calculated region node points. Thus matrixes elements $\mathbf{S}$ and $\mathbf{T}$ are calculated as the sum of corresponding elements of local matrixes $\mathbf{S}^{(e)}$ and $\mathbf{T}^{(e)}$ all decision region finite elements.

Then, calculation of own and mutual longitudinal resistance algorithm for n air-line wires is carried out according to [3] fig. 2 taking into account an assumption about a scalar electric potential ($\text{grad} \phi$) module gradient constancy on all length of a conductor. Taking into account it a each (m -th) wire current average (on section) values definition procedure consists in the following:

1. Calculation of a scalar electric potential gradient coordinates axes projections ($\text{grad} \phi$) in all each wire node points at the set each conductor voltage decrease ($\dot{U}_m^{(1)}, \dot{U}_m^{(2)} \dots \dot{U}_m^{(n)}$).

2. The linear algebraic equations of a kind (1) systems solution concerning vector magnetic potential $\dot{\mathbf{A}}$ projections to all coordinates axes.

3. A total current in wires node points density vector calculation :

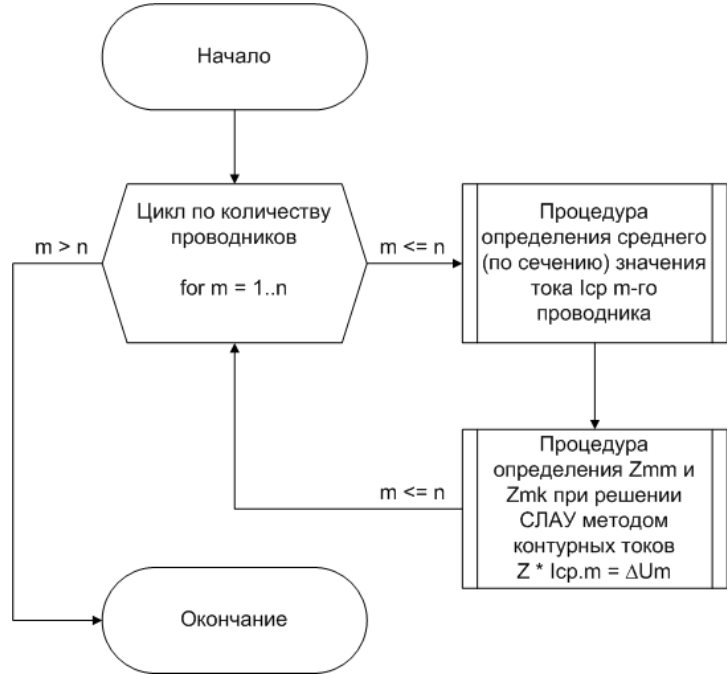


Fig. 2: Block diagram of calculation of own and mutual longitudinal resistance algorithm

$$\dot{\delta} = -\sigma \cdot (\text{grad} \phi + j\omega \dot{\mathbf{A}}), \quad (3)$$

where σ – wire specific conductivity

4. The proceeding along each wire of system average (in section) current values definition:

$$\dot{I}_{cpm} = \frac{\sum_{e=1}^N \left[(\dot{\delta}_i + \dot{\delta}_j + \dot{\delta}_k + \dot{\delta}_l) \cdot V^{(e)} \right]}{4 \cdot L_m}, \quad (4)$$

where $\dot{\delta}_i, \dot{\delta}_j, \dot{\delta}_k, \dot{\delta}_l$ – current density vector projections to a wire axis in the given section for e th finite element node points.

L_m – длина рассматриваемого m -го проводника на рассчитываемом участке considered m -th conductor on a counted site length

M - th conductor own and mutual longitudinal resistance definition is carried out at the an order n linear algebraic equations system decision

$$\left\{ \begin{array}{l} Z_{mm}\dot{\boldsymbol{i}}_m^{(1)} + Z_{m2}\dot{\boldsymbol{i}}_2^{(1)} + \dots + Z_{mk}\dot{\boldsymbol{i}}_k^{(1)} + Z_{mn}\dot{\boldsymbol{i}}_n^{(1)} = \dot{\boldsymbol{U}}_m^{(1)} \\ Z_{mm}\dot{\boldsymbol{i}}_m^{(2)} + Z_{m2}\dot{\boldsymbol{i}}_2^{(2)} + \dots + Z_{mk}\dot{\boldsymbol{i}}_k^{(2)} + Z_{mn}\dot{\boldsymbol{i}}_n^{(2)} = \dot{\boldsymbol{U}}_m^{(2)} \\ \vdots \\ Z_{mm}\dot{\boldsymbol{i}}_m^{(k)} + Z_{m2}\dot{\boldsymbol{i}}_2^{(k)} + \dots + Z_{mk}\dot{\boldsymbol{i}}_k^{(k)} + Z_{mn}\dot{\boldsymbol{i}}_n^{(k)} = \dot{\boldsymbol{U}}_m^{(k)} \\ Z_{mm}\dot{\boldsymbol{i}}_m^{(n)} + Z_{m2}\dot{\boldsymbol{i}}_2^{(n)} + \dots + Z_{mk}\dot{\boldsymbol{i}}_k^{(n)} + Z_{mn}\dot{\boldsymbol{i}}_n^{(n)} = \dot{\boldsymbol{U}}_m^{(n)} \end{array} \right. \quad (5)$$

In turn, wires TL own and mutual partial capacities β calculation is carried out according to the algorithm [4] represented on fig. 3

1. Scalar electric potential φ distribution (2) in space TL calculation by a finite elements method under conditions of m -th (investigated) wire potential equality to one and the others (including the earths) wires potentials values equality to zero;
2. Electric field intensity vector projections (E_x , E_y , E_z) in boundary with finite elements conductors a surface calculation;
3. M -th wire (investigated) charge (partial capacitor factor β_{im}) definition at neglect stream of its electric field butt components:

$$q_i = \varepsilon_0 \cdot \sum_{e=1}^N \left(\sqrt{E_x^{(e)2} + E_y^{(e)2} + E_z^{(e)2}} \cdot S_g^{(e)} \right), \quad (6)$$

where ε_0 – absolute dielectric constant;

$S_a^{(e)}$ – The e -th finite element side area, entering into a m -th wire lateral surface.

Definitively, wires TL own and mutual capacities values calculated according to expressions (7) and (8):

$$C_{ii} = \sum_{k=1}^n \beta_{ik}, \quad (7)$$

$$C_{ij} = -\beta_{ij}. \quad (8)$$

The stated above method [3, 4] of air TL with any wires and lightning-protective cables number electric parameters calculation realizes the strict mathematical description taking into account the wires in three-dimensional space (wires sag, their possible oblique-angled approachment, ground real characteristics, etc.) valid arrangement.

The TL electric parameters (mutual inductive resistance and capacity) calculation error estimation with analytical expressions use was made with reference to the computation scheme consisting of two wires in radius $R_1 = R_2 = 9.4$ mm (a dimension of first wire $G_1 = 6.0$ m, and the second $G_2 = 8.0$ m) which have sagging and oblique-angled approchement on a site (TL span) in the 285 meters length. Thus hang height wires twice more than their dimension. The minimum distance between wires a_1 makes 6.5 m.

At computation scheme with not

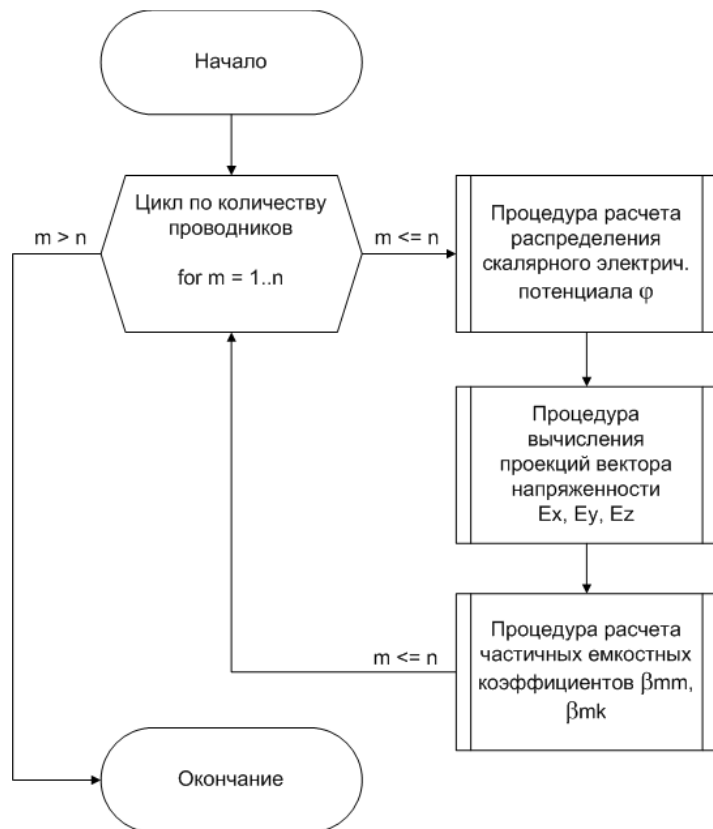


Fig. 3: Block diagram of wires TL own and mutual capacities values calculation algorithm

parallel conductors mutual inductive resistance analytical calculation [5] in expressions concepts of equivalent (average) their height hang values $h_{\text{эKB}}$ and distances between them $a_{\text{эKB}}$ [6] are used:

$$h_{\text{эKB}} = G + \frac{2}{3}h_c, \quad (9)$$

$$a_{\text{эKB}} = \frac{a_2 + 2a_1}{3} \quad (10)$$

where G – wire dimension;

h_c – maximum wire sag value;

a_1, a_2 – minimum and maximum distance between wires, accordingly

Besides, the equivalent distance between wires $a_{\text{эKB}}$, can be found as average geometrical value[7]:

$$a_{\text{эKB}} = \sqrt{a_1 \cdot a_2}. \quad (11)$$

Two wires TL passing at an angle to each other mutual capacity definition, also is carried out at average distance between them calculation:

$$a_{\text{эKB}} = \frac{a_1 + a_2}{2}. \quad (12)$$

The two wires TL mutual influence complex resistance numerical and analytical calculation on frequencies of 50 and 500 Hz (fig. 4 see, 5) at a variation of the maximum distance between wires a_2 results analysis has revealed considerable influence of an approach wires angle on a reactive component X_M calculation error with use of assumptions (9), (10) and (11).

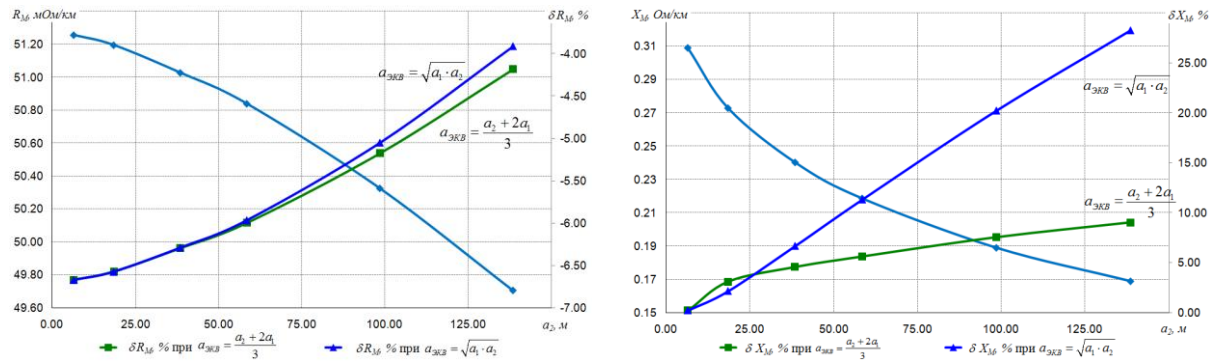


Fig. 4: Complex resistance analytical calculation error on frequencies of 50 at a variation of the oblique-angled rapprochement

In considered cases at an approach angle about 25 degrees ($a_2 = 138.5$ m) the mutual induction reactive resistance relative calculation error made more than 28 % ($f = 50$ Hz) and 46 % ($f = 500$ Hz). During too time, small influence of wires on an analytical calculation error active making R_M is established – the relative error maximum value makes about 4 % (at an approach angle no more than 25 degrees).

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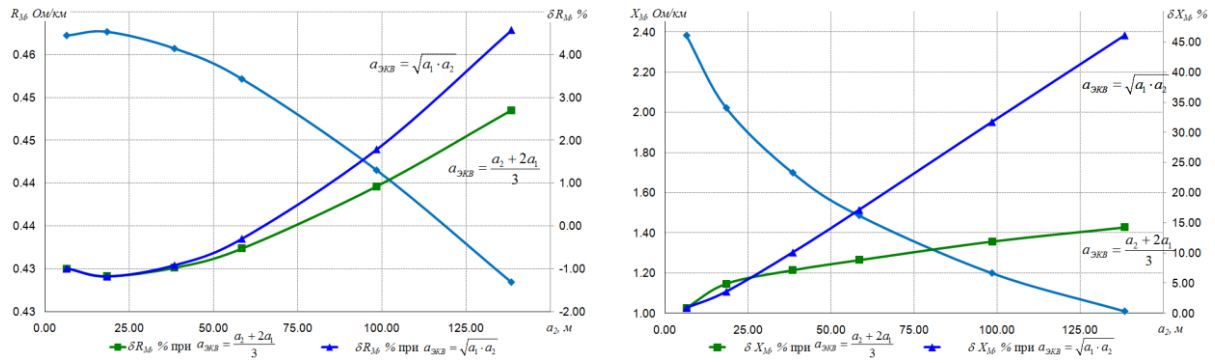


Fig. 5: Complex resistance analytical calculation error on frequencies of 500 at a variation of the oblique-angled rapprochement

Also it is necessary to note the considered scheme mutual capacity C_M analytical calculation considerable error (fig. 6 see), caused by an assumption (12). The C_M calculation relative error makes from 10 % to 50 % even at rather small corners (4. 10 degrees) rapprochements. Application of an assumption (9) at wires air TL own capacities analytical calculations negligible affects a calculation error (at the wires sag, close to real, an error makes no more than 3 %).

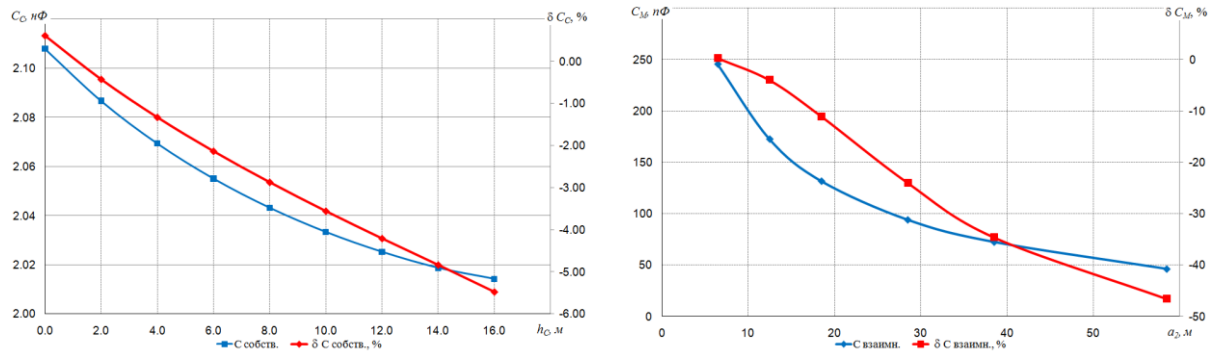


Fig. 6: Own and mutual capacities analytical calculation error at a variation of wire sag and oblique-angled rapprochement

The equivalent circuit electric parameters analytical calculation revealed error an inevitably affects multiwire TL damage place definition reliability. Thus the DSCP numerical calculation error is in a greater degree caused by an error of the initial data about TL own and mutual longitudinal resistance. In following section questions of decrease in an Northwest IPS air TL DSCP numerical calculation error at their strict mathematical description are considered.

3 DECREASE IN THE DISTANCE TO SHORT CIRCUIT PLACE NUMERICAL CALCULATION ERROR WITH THE NORTHWEST IPS AIR TL STRICT MATHEMATICAL DESCRIPTION USE

The DSCP numerical calculation error analysis was made with reference to air TL of an transmission 110 – 750 kV the Northwest IPS (the Leningrad, Kola, Karelian, Arkhangelsk and Vologda power supply systems). For research are chosen TL (tab. 1 see) for which the size resulted (by the total length) has made DSCP numerical calculation errors more than 2.5 %. Also additional criterion of emergency oscillograms with the transients caused by short circuits TL selection, was the full initial TL tracing data presence.

Tabl. 1: DSCP numerical calculation results at emergency registration only from one side

Energy object	TL Name , SC type	Length, km	Tracking, km	DSCP numerical calculation results					
				standart symbolic model			improved symbolic model		
				$l_{расч}, \text{KM}$	Δ, KM	$\delta_{np}, \%$	$l_{расч}, \text{KM}$	Δ, KM	$\delta_{np}, \%$
SS 90	Л-389, B	255.60	206.90	175.70	-31.20	-12.21	194.37	-12.53	-4.90

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	Л-389, A+C	255.60	150.00	141.70	– 8.30	– 3.25	143.90	– 6.10	– 2.39
	Л-389, C	255.60	66.30	55.50	–10.80	– 4.23	65.61	– 0.69	– 0.27
	Л-389, B	255.60	186.70	171.60	–15.10	– 5.91	190.98	4.28	1.67
SS “Leningradskay”	Л-374, C	172.08	102.30	95.20	– 7.10	– 4.13	107.69	5.39	3.13
	Л-374, B	172.08	44.60	38.20	– 6.40	– 3.72	46.74	2.14	1.24
	Л-374, B	172.08	88.50	76.60	–11.90	– 6.92	94.66	6.16	3.58
	Л-389, B	255.60	107.40	98.70	– 8.70	– 3.40	106.22	– 1.18	– 0.46
	Л-389, B	255.60	94.70	104.50	9.80	3.83	90.94	– 3.76	– 1.47
SS “Oktylovskay”	Л-361, B	134.30	34.70	22.00	–12.70	– 9.46	34.16	– 0.54	– 0.40
SS “Velikoreckay”	Л-309, C	155.60	34.20	20.90	–13.30	– 8.55	34.55	0.35	0.22

The tab. 1 generalized analysis allows to establish interrelation between an DSCP numerical calculation error and an initial information on equivalent circuit parameters representation error. In particular, according to some statistical DSCP problem data of transmission lines 110 - 330 kV the Northwest OES (tab. 1 see) the resulted and relative error has negative value (calculation distance less real). It speaks the doubtful account of phase wires mutual influence and, as consequence of it, greater (in comparison with valid) specific voltage decrease on TL length. The given fact most typical for TL distance at single-phase SC calculation results as mutual influence electric parameters, at use of modal transformations, into the zero sequence scheme are included.

It is necessary to notice that the air TL transients strict mathematical description application allows to improve essentially indicators of an distance to a short circuit place numerical calculation error. On the module value of the calculation resulted error with use of the TL equivalent circuit specified parameters has made the greatest about 5 % (at initial size more than 12 %). In some settlement cases (Л-389, Л-309 damages) the error size makes less than 0.5 %

4 CONCLUSION

1. It is shown that TL electric equivalent circuit parameters calculation analytical methods possess a considerable error. The greatest influence on DSCP numerical calculation error renders an error of the initial data about TL equivalent circuit own and mutual longitudinal resistance.
2. The developed software DoACP realizing the numerical decision field spatial problem by a finite elements method, should be applied to air TL electric parameters certification (actualization).
3. The distance to SC place numerical calculation error with initial information representation error interrelation is revealed. It is established that TL strict mathematical description application allows to lower appreciably resulted error value to comprehensible values (less than 2.5 %)

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