дуктивную связь на обоих путях с другими. В выражении (10) следует принять коэффициенты распределения тока в отключаемом проводе $\underline{K}_i = 0$. Например, для системы 25 кВ имеем:

$$\underline{Z}_0 = \underline{a}_{п1}\underline{K}_{п1} + \underline{a}_{п2}\underline{K}_{п2} - \underline{a}_{эр}\underline{K}_{эр} ; \quad (11)$$

$$\underline{Z}_{0ВПП} = \underline{a}_{п1}\underline{K}_{п2} + \underline{a}_{п2}\underline{K}_{п1} - \underline{a}_{эр}\underline{K}_{эр}. \quad (12)$$

Формулы (11) и (12) отличаются от ранее известных [5] учетом влияния наведённых токов на втором пути от нагрузки на первом пути на сопротивление одного первого пути двухпутной линии.

Расчеты для указанных исходных данных были проведены для систем электроснабжения 25 кВ, 25 кВ с УП и 25 кВ с ЭУП. Результаты приведены в таблице 2.

Анализируя результаты расчетов, видно, что доля тока в проводах контактной сети и усиливающих проводах не зависит от величины переходного сопротивления «рельс—земля». Токи в рельсах и экранирующих проводах зависят от значения переходного сопротивления. Отметим и то, что наведенные токи на втором пути в эквивалентном контактном и усиливающем проводах имеют противоположное направление.

Результаты таблицы 2 позволяют утверждать, что переход от обычной системы 25 кВ к системе с УП снижает сопротивление одного пути двухпутного участка на величину порядка 26%, а к системе с ЭУП – на 45%.

Переход от системы с УП к системе с ЭУП даст снижение сопротивления примерно на 25%.

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MULTIWIRE AC ELECTRIC TRACTION NETWORKS

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ABSTRACT

The article describes a method for calculating current distribution in wires of multiwire AC electric traction network. Formulas for determining the resistance of one track of a multiwire electric traction network of a double-track line and mutual resistance of wires of two tracks with account of induced currents in the wires of the second track are proposed, enabling in the calculation of modes of power supply to use the software for a25 kV system. The resulting equations, referring to the conditions of electric traction network with screening and reinforcing wires provide an opportunity to apply them in exclusion of any wire or several wires of available multiwire complex.

ENGLISH SUMMARY

Background. *To improve the efficiency of power supply of railways, electrified by 25 kV AC system, it has long been proposed to use a reinforcing wire (RW), connected in parallel with overhead catenary [1]. Prior to that, in the North-Caucasian railway in the late 1970s an option has been implemented with screening and reinforcing wires (SRW) [2]. It became an analogue to the system, previously developed in Japan, where in order to reduce the magnetic flow between catenary and rails (and thus induced resistance of electric traction network greatly reduces) a coaxial cable was applied. At the same time catenary is connected to a cable core and rails to its sheath.*

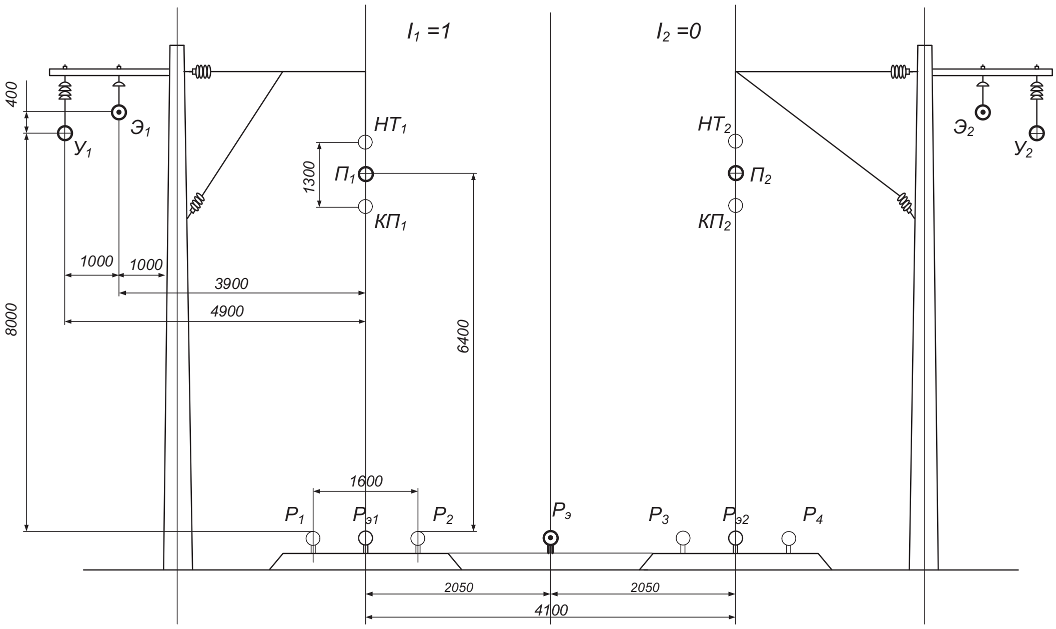
Capital cost savings involve in such cases the gradual expanding capacity of power supply system [3]. In the first phase electrification is focused on extension of the distance between substations. Depending on the traffic growth the order of the next phase of amplification (RW or SRW) and its completion date are determined [4].

Objective. *The objective of the authors is to present a method for calculating current distribution in wires of multiwire AC electric traction network.*

Methods. *The authors use mathematical methods and analysis.*

Results. *For calculation of modes of operation within RW or SRW systems it is sufficient to determine electric traction network resistance of their power systems. The task may be performed using software.*

In a system with SRW location of wires of circuit overhead catenary (K and T) is ordinary and corresponds to the used 25 kV system. Location of other wires with distances between them, adopted in the project, is shown in Pic. 1.



Pic. 1. Location of wires on a double-track line.

Keys: $У_1$, $У_2$ – reinforcing wires of the first and the second tracks; $Э_1$, $Э_2$ – screening wires of the first and the second tracks; $КП_1$, $КП_2$ – contact wires of the first and the second tracks; $НТ_1$, $НТ_2$ – suspension wires of the first and the second tracks; P_1, P_2 – single rails of the first track; P_3, P_4 – single rails of the second track; $П_1$, $П_2$ – equivalent wires of the first and the second tracks; $P_{э1}$, $P_{э2}$ – equivalent rails of the first and second tracks; $P_э$ – equivalent rail of both tracks.

A screening wire (Э) on one insulator is suspended to traverses from a land side of bearng supports (closer to them), while the reinforcing wire (У) is suspended on a garland of three or four insulators at the minimum permissible distance in terms of isolation.Screening wire is connected in parallel to the rails through zero points of track impedance bonds through two inductive bonds to the third inductive bond or through the ground if individual ground wires are used. The reinforcing wire is connected with catenary in three points on suspension points on one constant tension section.

To determine the values of the currents flowing through the wires of electric traction network, we introduce the expression for the voltage drops with account for directions of currents.

$$\Delta\dot{U}_{\text{п1}} = \underline{Z}_{\text{п1}}\dot{I}_{\text{п1}} + \underline{Z}_{\text{п1у1}}\dot{I}_{\text{у1}} - \underline{Z}_{\text{п1э1}}\dot{I}_{\text{э1}} + \underline{Z}_{\text{п1п2}}\dot{I}_{\text{п2}} + \underline{Z}_{\text{п1у2}}\dot{I}_{\text{у2}} - \underline{Z}_{\text{п1э2}}\dot{I}_{\text{э2}} - \underline{Z}_{\text{п1эр}}\dot{I}_{\text{эр}}\ ; \quad (1)$$

$$\Delta\dot{U}_{\text{у1}} = \underline{Z}_{\text{п1у1}}\dot{I}_{\text{п1}} + \underline{Z}_{\text{у1}}\dot{I}_{\text{у1}} - \underline{Z}_{\text{у1э1}}\dot{I}_{\text{э1}} + \underline{Z}_{\text{п2у1}}\dot{I}_{\text{п2}} + \underline{Z}_{\text{у1у2}}\dot{I}_{\text{у2}} - \underline{Z}_{\text{у1э2}}\dot{I}_{\text{э2}} - \underline{Z}_{\text{у1эр}}\dot{I}_{\text{эр}}\ ; \quad (2)$$

$$\Delta\dot{U}_{\text{э1}} = -\underline{Z}_{\text{п1э1}}\dot{I}_{\text{п1}} - \underline{Z}_{\text{у1э1}}\dot{I}_{\text{у1}} + \underline{Z}_{\text{э1}}\dot{I}_{\text{э1}} - \underline{Z}_{\text{п2э1}}\dot{I}_{\text{п2}} - \underline{Z}_{\text{у2э1}}\dot{I}_{\text{у2}} + \underline{Z}_{\text{э1э2}}\dot{I}_{\text{э2}} + \underline{Z}_{\text{э1эр}}\dot{I}_{\text{эр}}\ ; \quad (3)$$

$$\Delta\dot{U}_{n2} = \underline{Z}_{n1n2}\dot{I}_{n1} + \underline{Z}_{n2y1}\dot{I}_{y1} - \underline{Z}_{n2э1}\dot{I}_{э1} + \underline{Z}_{n2}\dot{I}_{n2} + \underline{Z}_{\text{п2у2}}\dot{I}_{\text{у2}} - \underline{Z}_{\text{п2э2}}\dot{I}_{\text{э2}} - \underline{Z}_{\text{п2эр}}\dot{I}_{\text{эр}}\ ; \quad (4)$$

$$\Delta\dot{U}_{\text{у2}} = \underline{Z}_{\text{п1у2}}\dot{I}_{\text{п1}} + \underline{Z}_{\text{у1у2}}\dot{I}_{\text{у1}} - \underline{Z}_{\text{у2э1}}\dot{I}_{\text{э1}} + \underline{Z}_{\text{п2у2}}\dot{I}_{\text{п2}} + \underline{Z}_{\text{у2}}\dot{I}_{\text{у2}} - \underline{Z}_{\text{у2э2}}\dot{I}_{\text{э2}} - \underline{Z}_{\text{у2эр}}\dot{I}_{\text{эр}}\ ; \quad (5)$$

$$\Delta\dot{U}_{\text{э2}} = -\underline{Z}_{\text{п1э2}}\dot{I}_{\text{п1}} - \underline{Z}_{\text{у1э2}}\dot{I}_{\text{у1}} + \underline{Z}_{\text{э1э2}}\dot{I}_{\text{э1}} - \underline{Z}_{\text{п2э2}}\dot{I}_{\text{п2}} - \underline{Z}_{\text{у2э2}}\dot{I}_{\text{у2}} + \underline{Z}_{\text{э2}}\dot{I}_{\text{э2}} + \underline{Z}_{\text{э2эр}}\dot{I}_{\text{эр}}\ ; \quad (6)$$

$$\Delta\dot{U}_{\text{эр}} = -\underline{Z}_{\text{п1эр}}\dot{I}_{\text{п1}} - \underline{Z}_{\text{у1эр}}\dot{I}_{\text{у1}} + \underline{Z}_{\text{э1эр}}\dot{I}_{\text{э1}} - \underline{Z}_{\text{п2эр}}\dot{I}_{\text{п2}} - \underline{Z}_{\text{у2эр}}\dot{I}_{\text{у2}} + \underline{Z}_{\text{э2эр}}\dot{I}_{\text{э2}} + \underline{Z}_{\text{эр}}\dot{I}_{\text{эр}}, \quad (7)$$

where $\Delta\dot{U}_{n1}, \Delta\dot{U}_{y1}, \Delta\dot{U}_{э1}, \Delta\dot{U}_{n2}, \Delta\dot{U}_{y2}, \Delta\dot{U}_{э2}, \Delta\dot{U}_{эр}$ *are voltage drops across 1km of the length of respective contours which are: equivalent wire of the first track – ground, reinforcing wire of the first track – ground, screening wire of the first track – ground, equivalent wire of the second track – ground, reinforcing wire of the second track – ground, screening wire of the second track – ground, equivalent rail – ground, V;*

$\dot{I}_{\text{п1}}$, $\dot{I}_{\text{у1}}$, $\dot{I}_{\text{э1}}$, $\dot{I}_{\text{п2}}$, $\dot{I}_{\text{у2}}$, $\dot{I}_{\text{э2}}$, $\dot{I}_{\text{эр}}$ *– currents in respective wires, A;*

$\underline{Z}_{\text{п1}}, \underline{Z}_{\text{у1}}, \underline{Z}_{\text{э1}}, \underline{Z}_{\text{п2}}, \underline{Z}_{\text{у2}}, \underline{Z}_{\text{э2}}, \underline{Z}_{\text{эр}}$ *– resistance of contours of respective wire-ground, Ohm / km;*

Methods for calculating resistance of contours wire-ground and mutual resistances between them, indicated with double suffix number, are described in [5].

To determine the currents in these wires it is necessary to formulate and solve a system of equations with seven indeterminates.

Voltage drops in parallel wires are equal. Consequently, it can be written as:
$\Delta\dot{U}_{n1} = \Delta\dot{U}_{y1}; \Delta\dot{U}_{э1} = \Delta\dot{U}_{эр}; \Delta\dot{U}_{n2} = \Delta\dot{U}_{y2}; \Delta\dot{U}_{э2} = \Delta\dot{U}_{эр}.$

Equating the right sides of these expressions and grouping similar terms, four equations are obtained. For the fifth equation we assume that the load of catenary and reinforcing wire of the first track is equal to one ($\dot{I}_1 = 1$ *).*

In this case, for separate power supply of tracks we have: $\dot{I}_{\text{п1}} + \dot{I}_{\text{у1}} = 1$.

Since the mode without load on the second track is considered ($\dot{I}_2 = 0$ *), then the sixth equation is*
$\dot{I}_{\text{п2}} + \dot{I}_{\text{у2}} = 0.$

Table 1

Coefficients of the current distribution by wires when there is a load on one track

	$Z_{\text{пер}}=\infty$	$Z_{\text{пер}}=0$
$\underline{K}_{\text{п1}}$	|0,570+j0,018|=0,570	|0,569+j0,018|=0,569
$\underline{K}_{\text{у1}}$	|0,430–j0,018|=0,430	|0,431–j0,018|=0,431
$\underline{K}_{\text{э1}}$	|0,330+j0,044|=0,333	|0,277+j0,059|=0,284
$\underline{K}_{\text{п2}}$	|–0,036–j0,016|=0,040	|–0,037–j0,016|=0,040
$\underline{K}_{\text{у2}}$	|0,036+j0,016|=0,040	|0,037+j0,016|=0,040
$\underline{K}_{\text{э2}}$	|0,166–j0,007|=0,166	|0,113+j0,008|=0,114
$\underline{K}_{\text{эр}}$	|0,504–j0,037|=0,506	|0,359+j0,012|=0,359

Type of the seventh equation depends on the taken value of transient resistance between rail and ground. The authors propose to consider two extreme cases: $Z_{пер}=0$ and $Z_{пер}=\infty$. Obviously, two systems of equations should be solved, and an arithmetic mean of two obtained values will be taken for the resulting resistance of electric traction network.

$Z_{\text{пер}}=\infty$ means that a rail is insulated from the ground and the entire traction current returns along the rails and screening wires. The seventh equation will be: $\dot{I}_{\text{э1}}+\dot{I}_{\text{э2}}+\dot{I}_{\text{эр}}=1$.

When $Z_{пер}=0$, ground serves as a return wire for traction current. Current in rails and screening wires appears due to EMF induction caused by current in other wires. Corresponding current, for example, in equivalent rail of two tracks is:

$$\dot{I}_{\text{эр}}=\frac{\underline{Z}_{\text{п1эр}}\dot{I}_{\text{п1}}+\underline{Z}_{\text{у1эр}}\dot{I}_{\text{у1}}-\underline{Z}_{\text{э1эр}}\dot{I}_{\text{э1}}+\underline{Z}_{\text{п2эр}}\dot{I}_{\text{п2}}+\underline{Z}_{\text{у2эр}}\dot{I}_{\text{у2}}-\underline{Z}_{\text{э2эр}}\dot{I}_{\text{э2}}}{\underline{Z}_{\text{эр}}}.$$

System of equations when $Z_{\text{пер}}=\infty$ takes a form:

$$\left.\begin{aligned}
&\left(\underline{Z}_{\text{п1}}-\underline{Z}_{\text{п1у1}}\right)\dot{I}_{\text{п1}}+\left(\underline{Z}_{\text{п1у1}}-\underline{Z}_{\text{у1}}\right)\dot{I}_{\text{у1}}-\left(\underline{Z}_{\text{п1э1}}-\underline{Z}_{\text{у1э1}}\right)\dot{I}_{\text{э1}}+\\
&+\left(\underline{Z}_{\text{п1п2}}-\underline{Z}_{\text{п2у1}}\right)\dot{I}_{\text{п2}}+\left(\underline{Z}_{\text{п1у2}}-\underline{Z}_{\text{у1у2}}\right)\dot{I}_{\text{у2}}-\\
&-\left(\underline{Z}_{\text{п1э2}}-\underline{Z}_{\text{у1э2}}\right)\dot{I}_{\text{э2}}-\left(\underline{Z}_{\text{п1эр}}-\underline{Z}_{\text{у1эр}}\right)\dot{I}_{\text{эр}}=0;\\
&-\left(\underline{Z}_{\text{п1э1}}-\underline{Z}_{\text{п1эр}}\right)\dot{I}_{\text{п1}}-\left(\underline{Z}_{\text{у1э1}}-\underline{Z}_{\text{у1эр}}\right)\dot{I}_{\text{у1}}+\left(\underline{Z}_{\text{э1}}-\underline{Z}_{\text{э1эр}}\right)\dot{I}_{\text{э1}}-\\
&-\left(\underline{Z}_{\text{п2э1}}-\underline{Z}_{\text{п2эр}}\right)\dot{I}_{\text{п2}}-\left(\underline{Z}_{\text{у2э1}}-\underline{Z}_{\text{у2эр}}\right)\dot{I}_{\text{у2}}+\\
&+\left(\underline{Z}_{\text{э1э2}}-\underline{Z}_{\text{э2эр}}\right)\dot{I}_{\text{э2}}+\left(\underline{Z}_{\text{э1эр}}-\underline{Z}_{\text{эр}}\right)\dot{I}_{\text{эр}}=0;\\
&(\underline{Z}_{\text{п1п2}}-\underline{Z}_{\text{п1у2}})\dot{I}_{\text{п1}}+(\underline{Z}_{\text{п2у1}}-\underline{Z}_{\text{у1у2}})\dot{I}_{\text{у1}}-\left(\underline{Z}_{\text{п2э1}}-\underline{Z}_{\text{у2э1}}\right)\dot{I}_{\text{э1}}+\\
&+\left(\underline{Z}_{\text{п2}}-\underline{Z}_{\text{п2у2}}\right)\dot{I}_{\text{п2}}+\left(\underline{Z}_{\text{п2у2}}-\underline{Z}_{\text{у2}}\right)\dot{I}_{\text{у2}}-\\
&-\left(\underline{Z}_{\text{п2э2}}-\underline{Z}_{\text{у2э2}}\right)\dot{I}_{\text{э2}}-\left(\underline{Z}_{\text{п2эр}}-\underline{Z}_{\text{у2эр}}\right)\dot{I}_{\text{эр}}=0;\\
&-\left(\underline{Z}_{\text{п1э2}}-\underline{Z}_{\text{п1эр}}\right)\dot{I}_{\text{п1}}-\left(\underline{Z}_{\text{у1э2}}-\underline{Z}_{\text{у1эр}}\right)\dot{I}_{\text{у1}}+\left(\underline{Z}_{\text{э1э2}}-\underline{Z}_{\text{э1эр}}\right)\dot{I}_{\text{э1}}-\\
&-\left(\underline{Z}_{\text{п2э2}}-\underline{Z}_{\text{п2эр}}\right)\dot{I}_{\text{п2}}-\left(\underline{Z}_{\text{у2э2}}-\underline{Z}_{\text{у2эр}}\right)\dot{I}_{\text{у2}}+\\
&+\left(\underline{Z}_{\text{э2}}-\underline{Z}_{\text{э2эр}}\right)\dot{I}_{\text{э2}}+\left(\underline{Z}_{\text{э2эр}}-\underline{Z}_{\text{эр}}\right)\dot{I}_{\text{эр}}=0;\\
&\dot{I}_{\text{п1}}+\dot{I}_{\text{у1}}+0+0+0+0+0=1;\\
&0+0+0+\dot{I}_{\text{п2}}+\dot{I}_{\text{у2}}+0+0=0;\\
&0+0+\dot{I}_{\text{э1}}+0+0+\dot{I}_{\text{э2}}+\dot{I}_{\text{эр}}=1.
\end{aligned}\right\}\qquad(8)$$

When $Z_{\text{пер}}=0$ only last equation will change:

$$-\underline{Z}_{\text{п1эр}}\dot{I}_{\text{п1}}-\underline{Z}_{\text{у1эр}}\dot{I}_{\text{у1}}+\underline{Z}_{\text{э1эр}}\dot{I}_{\text{э1}}-\underline{Z}_{\text{п2эр}}\dot{I}_{\text{п2}}-$$
$$-\underline{Z}_{\text{у2эр}}\dot{I}_{\text{у2}}+\underline{Z}_{\text{э2эр}}\dot{I}_{\text{э2}}+\underline{Z}_{\text{эр}}\dot{I}_{\text{эр}}=0.$$

Solving these systems of equations, we obtain the current distribution by wires of electric traction network with a separate power supply of tracks, provided that only one (the first) track is loaded. The coefficients of the current distribution of the first track through wires are:

$$\underline{K}_{\text{п1}}=\frac{\dot{I}_{\text{п1}}}{\dot{I}_1},\ \underline{K}_{\text{у1}}=\frac{\dot{I}_{\text{у1}}}{\dot{I}_1},\ \underline{K}_{\text{э1}}=\frac{\dot{I}_{\text{э1}}}{\dot{I}_1};$$

$$\underline{K}_{\text{п2}}=\frac{\dot{I}_{\text{п2}}}{\dot{I}_1},\ \underline{K}_{\text{у2}}=\frac{\dot{I}_{\text{у2}}}{\dot{I}_1},\ \underline{K}_{\text{э2}}=\frac{\dot{I}_{\text{э2}}}{\dot{I}_1},\underline{K}_{\text{эр}}=\frac{\dot{I}_{\text{эр}}}{\dot{I}_1}.$$

The results of calculation of the coefficients of the current distribution for distances between wires shown in Pic. 1 when suspension is ПБСМ-95 + МФ-100, rails are Р-65 and $\gamma_з$ = 0,01 Ohm/m are shown in Table 1.

To determine total resistance of electric traction network, we will use voltage drop in the contour «equivalent wire – rail»:

$$\Delta\dot{U}=\Delta\dot{U}_{\text{п}}+\Delta\dot{U}_{\text{эр}}.\qquad(9)$$

We will substitute right sides of expressions (1) and (7) in this equation. Method of superposition is used. Obviously, when there is no load on the first track and it is present on the second track currents are distributed by wires in accordance with the coefficients in Table 1, but numbers of tracks must be transposed. Moreover, the coefficients will be valid for the case when there is load on both tracks. Therefore, it can be written:

$$\dot{I}_{\text{п1}}=\underline{K}_{\text{п1}}\dot{I}_1+\underline{K}_{\text{п2}}\dot{I}_2;\qquad \dot{I}_{\text{п2}}=\underline{K}_{\text{п2}}\dot{I}_1+\underline{K}_{\text{п1}}\dot{I}_2;$$

$$\dot{I}_{\text{у1}}=\underline{K}_{\text{у1}}\dot{I}_1+\underline{K}_{\text{у2}}\dot{I}_2;\qquad \dot{I}_{\text{у2}}=\underline{K}_{\text{у2}}\dot{I}_1+\underline{K}_{\text{у1}}\dot{I}_2;$$

$$\dot{I}_{\text{э1}}=\underline{K}_{\text{э1}}\dot{I}_1+\underline{K}_{\text{э2}}\dot{I}_2;\qquad \dot{I}_{\text{э2}}=\underline{K}_{\text{э2}}\dot{I}_1+\underline{K}_{\text{э1}}\dot{I}_2;$$

$$\dot{I}_{\text{эр}}=\underline{K}_{\text{эр}}\dot{I}_1+\underline{K}_{\text{эр}}\dot{I}_2.$$

Substituting these expressions in formulas (1) and (7), after transformation instead of (9) we will obtain

$$\Delta\dot{U}=\begin{pmatrix}\underline{a}_{\text{п1}}\underline{K}_{\text{п1}}+\underline{a}_{\text{у1}}\underline{K}_{\text{у1}}-\underline{a}_{\text{э1}}\underline{K}_{\text{э1}}+\underline{a}_{\text{п2}}\underline{K}_{\text{п2}}+\\+\underline{a}_{\text{у2}}\underline{K}_{\text{у2}}-\underline{a}_{\text{э2}}\underline{K}_{\text{э2}}-\underline{a}_{\text{эр}}\underline{K}_{\text{эр}}\end{pmatrix}\dot{I}_1+$$

$$+(\underline{a}_{\text{п1}}\underline{K}_{\text{п2}}+\underline{a}_{\text{у1}}\underline{K}_{\text{у2}}-\underline{a}_{\text{э1}}\underline{K}_{\text{э2}}+\underline{a}_{\text{п2}}\underline{K}_{\text{п1}}+$$

$$+\underline{a}_{\text{у2}}\underline{K}_{\text{у1}}-\underline{a}_{\text{э2}}\underline{K}_{\text{э1}}-\underline{a}_{\text{эр}}\underline{K}_{\text{эр}})\dot{I}_2,\qquad(10)$$

where $\underline{a}_{\text{п1}}=\left(\underline{Z}_{\text{п1}}-\underline{Z}_{\text{п1эр}}\right)$; $\underline{a}_{\text{у1}}=\left(\underline{Z}_{\text{п1у1}}-\underline{Z}_{\text{у1эр}}\right)$;

$\underline{a}_{\text{э1}}=\left(\underline{Z}_{\text{п1э1}}-\underline{Z}_{\text{э1эр}}\right)$; $\underline{a}_{\text{п2}}=\left(\underline{Z}_{\text{п1п2}}-\underline{Z}_{\text{п2эр}}\right)$;

$\underline{a}_{\text{у2}}=\left(\underline{Z}_{\text{п1у2}}-\underline{Z}_{\text{у2эр}}\right)$; $\underline{a}_{\text{э2}}=\left(\underline{Z}_{\text{п1э2}}-\underline{Z}_{\text{э2эр}}\right)$;

$\underline{a}_{\text{эр}}=\left(\underline{Z}_{\text{п1эр}}-\underline{Z}_{\text{эр}}\right)$.

Expression in brackets when we use $\dot{I}_1$ can be called total resistance of one track of a double-track section with separate feeding of tracks and it can be denoted as $\underline{Z}_0$. Expression in second brackets

Table 2

Resistance of one track of a system with SRW and mutual resistance of two tracks

Electric traction network	Transient resistance	$\underline{Z}_0$, Ohm/km	$\lvert\underline{Z}_0\rvert$, Ohm/km	$\underline{Z}_{овпп}$, Ohm/km	$\lvert\underline{Z}_{овпп}\rvert$, Ohm/km
25 kV	$Z_{пер}=\infty$	0,214+j0,449	0,498	0,055+j0,175	0,184
	$Z_{пер}=0$	0,189+j0,405	0,447	0,030+j0,131	0,134
	$Z_{ср}$	0,201+j0,427	0,4725	0,042+j0,153	0,159
25 kV with RW	$Z_{пер}=\infty$	0,141+j0,348	0,375	0,054+j0,155	0,164
	$Z_{пер}=0$	0,115+j0,300	0,321	0,028+j0,106	0,110
	$Z_{ср}$	0,128+j0,324	0,348	0,041+j0,131	0,137
25 kV with SRW	$Z_{пер}=\infty$	0,121+j0,242	0,271	0,031+j0,063	0,070
	$Z_{пер}=0$	0,107+j0,228	0,252	0,017+j0,049	0,052
	$Z_{ср}$	0,114+j0,235	0,2615	0,024+j0,056	0,061

represents mutual resistance of two tracks. It can be denoted as $\underline{Z}_{овпп}$. *Then* $\Delta\dot{U} = \dot{I}_1\underline{Z}_0 + \dot{I}_2\,\underline{Z}_{овпп}$.

Knowing coefficients of current distribution by wires and values of wires' resistance and mutual induction between wires, $\underline{Z}_0$ *and* $\underline{Z}_{овпп}$ *can be calculated.*

The proposed methods for determining current distribution over wires and resistance of power supply system with SRW can be used also in case of exclusion of any wire or of several wires from a multiwire electric traction network. In order to proceed with that operation it is sufficient to remove within the system of equations (8) the columns with currents in the wires excluded on the first and second tracks and lines that take into account their inductive relation on both tracks with other wires. In the expression (10) we will take coefficients of current distribution coefficients in the deenergized wire as $\underline{K}_i = 0$. *For example, for a 25 kV system, we have:*

$$\underline{Z}_0 = \underline{a}_{п1}\underline{K}_{п1} + \underline{a}_{п2}\underline{K}_{п2} - \underline{a}_{эр}\underline{K}_{эр}\ ; \qquad (11)$$

$$\underline{Z}_{0ВПП} = \underline{a}_{п1}\underline{K}_{п2} + \underline{a}_{п2}\underline{K}_{п1} - \underline{a}_{эр}\underline{K}_{эр}. \qquad (12)$$

Conclusions. *Equations (11) and (12) differ from previously known [5] as they take into account the influence that the currents at the second track induced by the load at the first track produce on the resistance of one first track of a double-track section.*

Calculations for the specified source data were performed for power supply systems of 25 kV, 25 kV with RW and 25 kV with SRW. The results are shown in Table 2.

Analyzing the results of the calculations, it is clear that the portion of current in wires of overhead catenary and in reinforcing wires is independent of the transient resistance «rail – ground». Currents in rails and screening wires depend on the value of transient resistance. It should be noted also that the induced currents at the second track in the equivalent contact wire and in the reinforcing wire have the opposite direction.

The results in Table 2 allow declaring that the transition from a conventional 25 kV system to a system with RW reduces the resistance of one track of a double-track section by about 26%, and transition to the system with SRW reduces the resistance by about 45%.

Transition from a system with RW to a system with SRW will decrease resistance by about 25%.

Keywords: railway, multiwire electric traction network, AC, resistance of wires, current distribution, calculation methods, mathematical apparatus.

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