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Simulation model of electromagnetic compatibility of neighboring infrastructure facilities on lines with heavy trains traffic

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The continuous increase of traffic and traction loads cause the increase of loads on power supply infrastructure that leads to the growth of levels of electromagnetic emission. It results in the growth of probability of emergency functioning of overhead system because of which currents achieve very high levels that may lead to serious accidents in related circuits of signalling and remote control facilities. Such accidents often cause different failures affecting the quality and safety of railway traffic, they lead to equipment damages, as well be a reason for fire. The strongest contribution to the total number of accidents with cable lines is made by electromagnetic influence in case of heavy train movement. And as the result of such train passing along the lines with failed grounding a cable is burnt through. The requirements for EMC of infrastructure facilities are getting stricter, including the requirements for reliability and information security of communication and signalling systems. Existing methods used to define induced currents and voltages do not take into account loads that occur in today's volume of traffic, and do not allow to define the dependence on the parameters of grounding of infrastructure facilities. The parameters of lateral facilities are not taken into account as well. These facilities are located along the track on the whole length of railways. Besides, the grounding parameters change in the course of heavy train moving in different areas. That has become very important to simulate electromagnetic processes in multi-wire systems with consideration of inherent and mutual parameters of lines, as well as ground parameters. But mathematical models of electromagnetic compatibility on railway transport due to its complexity do not always help to obtain the numerical values of induced currents and voltages in the communication circuits and signalling. This article describes an application method of simulation modeling that helps to define the levels of induced currents and voltages in the lateral lines of communication and signalling on the sections of heavy train movement. The paper offers the procedure of simulation modeling, simulation results for a line of heavy train movement and the analysis of the impact of grounding parameters on induced voltages. The simulation results were correlated with the experiment data and admitted to be consistent. The calculations made by the suggested procedure helped to reveal the key dependences of induced currents and voltages on ground parameters, as well as nonlinear dependencies of the induced voltage on ground resistance that forms the basis for further studies and correlation of the obtained data with the statistics accumulated during operation.

Keywords: *electromagnetic compatibility, heavy train movement, simulation modeling.*

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Measures to improve reliability on the sections of heavy train movement

Introduction of trains with weight of 6 000 -12 000 t for regular traffic causes the increase of traction loads on power supply system on railway sections by times. Such loads often lead to the defects of equipment and power supply lines and lateral facilities. It is the reason for improvement of traction configuration that includes:

– the creation of power equipment with higher capacity, the extend of cross-section of overhead feeders (up to 5A-185);

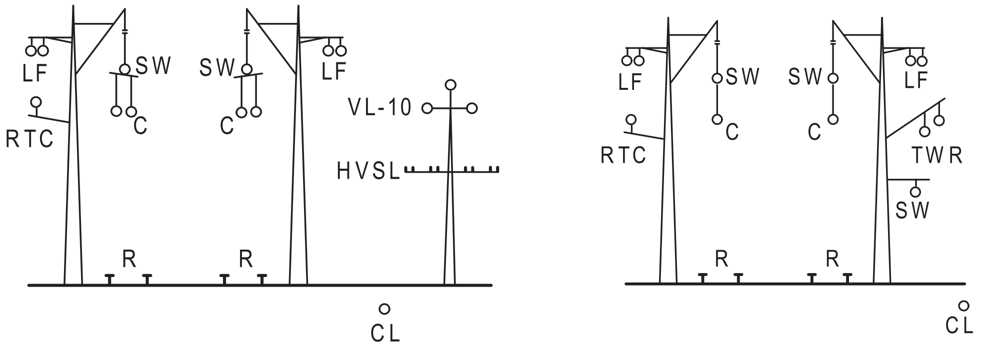
– the development of systems of traction power supply with a higher loading capacity;

– the increase of nominal power of a three-phase short circuit at the inputs of traction station up to 1500 MB*A;

– the development and application of effective devices of automation, control and protection of traction stations and overhead equipment from short circuit currents and inadmissible loads (CZAF-3,3kV, CZAF-27,5 kV).

– the application of overhead structures for the sections of heavy train movement including the replacement of contact wires (PBSM-95 on M-120), suspension of line feeders (A-185, 2A-185, M-120) and screening wires.

With consideration of the above listed requirements the overhead system configuration over each main track of open lines consists of [1,2]:



a b

Fig. 1. Schemes of arrangement of linear infrastructure facilities on the sections of heavy train movement, electrified by a) – direct current, b) – alternating current.

– on the sections with direct current – two contact wires with a cross-section not less than 120 mm^2 per each in accordance with GOST 2584-86 [3], one copper span wire with a cross-section not less than 120 mm^2 and two aluminum (aluminum-steel) line feeders with a cross-section not less than 185 mm^2 per each in accordance with GOST 839-80 [4];

– on the sections with alternating current – one contact wire with a cross-section not less than 100 mm^2,], one copper span wire with a cross-section not less than 120 mm^2, one aluminum (aluminum-steel) line feeder with a cross-section not less than 185 mm^2, one aluminum (aluminum-steel) screening wire with a cross-section not less 185 mm^2.

Schemes of arrangement of linear infrastructure facilities on the sections of heavy train movement are shown in figure 1.

The legend of figure 1 is as follows: C – contact wire, SW – span wire, LF – line feeder, R – rails, RTC – guide line of radio train communication 2,13 MHz, VL-10 – overhead line 10kV, HVSL – high-voltage signalling lines, TWR – line "two wires – rail", SW – screening wire, CL – cable line.

The mathematical model that describes the expansion of currents and voltages caused by overhead magnetic interference is represented in each line by the differential equation system whose order depends on the number of the lines forming the part of single electromagnetic system:

$$\begin{cases} -\dfrac{dU_K}{dx} = \left(R_K + j\omega L_K\right)\cdot I_K + \sum\limits_{i=1}^{n} I_i \cdot j\omega M_{iK} - j\omega M_{K-\text{кс}} \cdot I_{\text{кс}} \cdot e^{-\gamma x} \\ -\dfrac{dI_K}{dx} = \left(G_K + j\omega C_K\right)\cdot U_K + \sum\limits_{i=1}^{n} \left(G_{iK} + j\omega C_{iK}\right)\left(U_i - U_K\right), \end{cases}$$

where R_k, L_k, G_k, C_k are inherent parameters of the k-th wire,

M_{ik}, G_{ik}, C_{ik} are mutual parameters between the i-th and k-th wires of the system calculated in a frequency spectrum;

$M_{K\text{-кс}}$ is mutual induction between the k-th wire and overhead system,

U_k, I_k, U_i, I_i are currents and voltages in the i-th and k-th wires of the system,

$I_{\text{кс}}$ is the overhead current.

With permanent parameters and geometrical relationships in linear infrastructure facilities, the strength of induced currents and voltages depends on boundary conditions defined by the load at the beginning and at the end of the line. That is why an important task is to construct a simulation model to define boundary conditions with consideration of the parameters of grounding of cable lines and ground conductivity on the sections of heavy train movement.

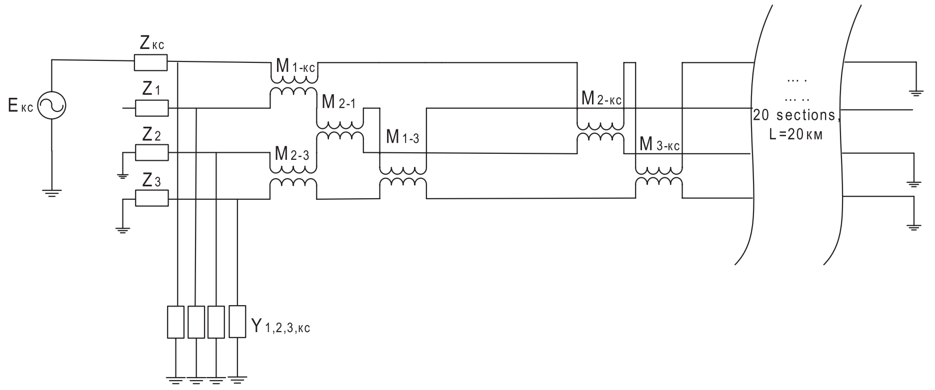


Fig. 2. Simulation modeling scheme

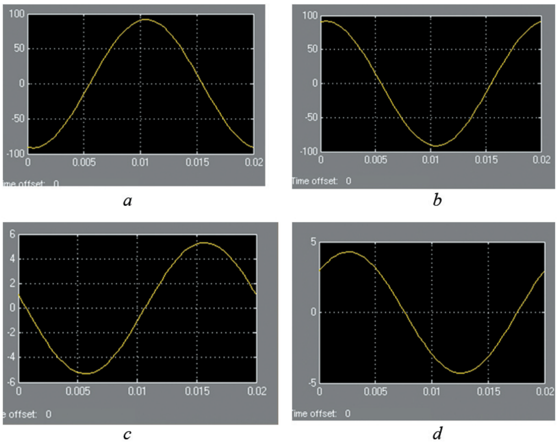
Construction of a simulation model

Simulation modeling of the expansion of currents and voltages in linear facilities was carried out in software environment Simulink (Matlab) in accordance with the scheme as per figure 2.

The modeling was carried out with consideration of linear infrastructure facilities – overhead system, rails, strand and sheath of cable lines.

In accordance with the requirements to heavy train movement [1,2], the railway infrastructure should ensure passing of the group of 3 heavy trains 6300-9000-6300t with the interval of 10 minutes provided there are trains with scheduled weight moving on the adjacent track. In accordance with technical specification of locomotives VL-80 (S,K) [5] under operation in the mode of multiple units maximum current is 110A for a train with scheduled weight, 155A – for a train 6300t, 192A – for a train 9000t. The current of starting of all trains on the section 932 A was accepted as the maximum equivalent current of the overhead system. As the result the values for the currents and voltages at 50Hz frequency were obtained.

Figure 3 shows waveforms of currents and voltages at the end of the cable strand and sheath in case of heavy train movement.



a *b*

c *d*

Fig. 3. Waveforms of currents and voltages in case of heavy train movement: a) voltage of the strand at the beginning of the line $U_{S\text{-}B}$; b) voltage of the strand at the end of the line $U_{S\text{-}E}$
c) current of the sheath at the beginning of the line $I_{S\text{-}B}$;
d) current of the sheath at the end of the line $I_{S\text{-}E.}$

Analysis of the influence of grounding parameters on the value of induced voltages

A special feature of heavy train movement sections in the test area of the West Siberian railway is that the bottom in these sections has a higher ground resistance (300-1500 Ohm·m). Besides, heavy traffic is year-around, and during a year the ground parameters change over wide range. Let us perform a simulation for the section of heavy train movement with a length of 20 km, with a total current 932A (50Hz) taking into account the special features of linear facilities grounding.

For calculation we shall take the grounding of metal coatings of the cable in form of four vertical dowel bars sunk into the ground by 5m. For calculation we shall use formulas to define ground resistance. The resistance of current spreading of one vertical ground conductor (bar) [6,7]:

$$R_0 = \frac{\rho_{eqv}}{2\pi L}(\ln(\frac{2L}{d}) + 0,5\ln(\frac{4T+L}{4T-L}))$$

where – ρ_{eqv} is equivalent ground resistance, Ohm·m;

L is a bar's length, m;

d is a bar's diameter, mm;

T is a distance from the ground surface to the middle of a bar, m.

Digging-in of the horizontal ground conductor can be found by formula [6,7]:

$$T = \left(\frac{L}{2}\right) + t,$$

where t is a digging-in of the vertical ground conductor.

Total resistance of spreading of vertical ground conductors are defined by formula [6,7]:

$$R_0 = 4R_B \cdot \eta$$

η is a demand factor of vertical ground conductors.

Let us obtain a value of induced voltage in the circuit "strand-sheath" ($U_{s\text{-}sh}$) at the beginning of the line under the change of ground resistance (with consideration of the change of the value of mutual induction among the circuits).

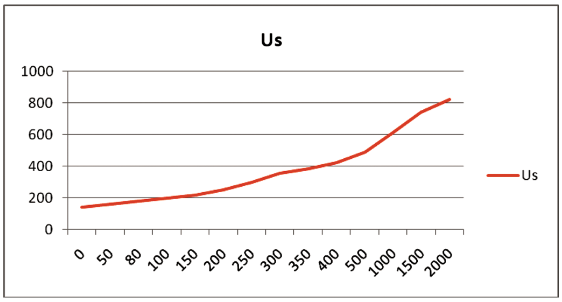


Fig. 4. The graph of dependence of voltage in a cable strand on ground resistance

Apart from fround resistance we need to consider the features of the strcture of the sheath grounding at the place of pulling to buildings. Normative documents [8] regulate the value of resistance of the grounding of a cable line sheath – 4 Ohm, as well as the resistance of metal-on-metal connec-

Table 1 – Dependence of the voltage in a cable strand on ground resistance

ρ, Ом*м	0	50	80	100	150	200	250	300	350	400	500	1000	1500	2000
$U_{s\text{-}sh}$, В	160	210	221	229	259	289	316	343	370	400	438	600	710	783

R_{met}, Ohm	0,1	1	2	3	4	5	10	50	**100**	**1K**	**10Кк**	**100K**	**1M**
$U_{s\text{-}sh}$, В	245	260	277	293	310	325	396	674	776	900	915	919	919

tion of the circuit "metal coatings-GZS-ground" – 0,1 Ohm. The parameters are measured twice a year. However, during a year the value of resistance and metal-on-metal connection may change over wide range. It is connected with climatic factors and electrical and chemical corrosion that accompany the functioning of cable lines. Often the overboost of potentials on cable lines is caused by the damage of conductin parts or bending of metal-on-metal connection.

Let us perform the si,ulation with consideration of the features of cable arrangement. Value $U_{s\text{-}sh}$ was measured at the beginning of the line at the change of resistance of grounding and metal-on-metal connection at the beginning of the line (at the end of the line the value is equal to the norm – 4,1 Ohm).

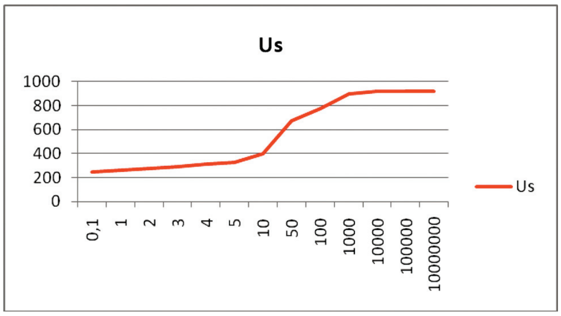


Figure 5. Dependence of the voltage "strand-sheath" on the grounding resistance of cable metal coating

This figure shows that under the growth of ground resistance by higher than 10 Ohm there begins the apparent growth of voltage in the strand ending at 0,9 kV. Very high values of resistence of grounding (higher than 1kOhm) correspond to the cases when grounding conductors or arrangement was damaged or broken.

Conclusion

Based on the constructed simulation model of electromagnetic compatibility, the levels of induced currents and voltages on the sections of heavy train movement are calculated. We have revealed the key dependences of induced currents and voltages on ground parameters of within the range of specific resistance 0 – 2000 Ohm*m with 932A (50Hz) of influencing current. We have performed the simulation depending on the resistance of the ground conductor and metal coatings and determined that the excess of the norm equal to 4 Ohm will lead to nonlinear growth of induced voltage, and the excess of 10 Ohm shall cause a great voltage growth. It helps to form clear requirements to the quality of arrangment and to the parameters of grounding of communication and signaling facilities and to improve the reliability of their functioning.

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