Simulation of induced voltages created by the 25 kV traction network across the pipeline in ice melting mode

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Abstract. Long metal structures and facilities can be located along the routes of electrified railways with 25 kV traction networks. A typical example of such facilities is pipelines designed to transport liquid or gaseous products. Due to the electromagnetic effects of electric traction networks, induced voltages can occur on structural parts, which are dangerous for the operating personnel. A set of special measures is needed to improve electrical safety and protect people from the influence of induced voltages. In the context of digitalization of the electric power industry, the choice of such measures requires the use of computer technologies, which can be implemented on the basis of methods and tools for simulation of railway power supply systems developed in Irkutsk State Transport University [18].

1. Introduction.

Metal structures and facilities along electrified railway tracks can be located in the areas of noticeable electromagnetic influences of electric traction networks (ETN). An example of such facilities is pipelines [1-3] designed to transport liquid or gaseous products. Due to the electromagnetic influences of traction networks, induced voltages [4-17] may occur on the parts of their structures, which are dangerous for operating personnel.

Special measures are used to protect people from the effects of induced voltages. In the context of digitalization of the electric power industry, the choice of such measures should be based on computer technologies which can be implemented on the basis of methods and tools for simulation of railway power supply systems developed in Irkutsk State Transport University [18].

The induced voltages at certain points of the grounded metal structure are determined mainly by the mechanism of magnetic influence; at the same time, the voltage levels depend on currents flowing through the wires of the electric traction network. Significant currents in the wires of contact suspensions take place in short circuit modes (SC) and ice melting modes. Damaged sections with short circuits are quickly turned off by relay protection, so the degree of negative impact of voltages induced in such modes is small. Ice melting is carried out for a long time (up to several hours), so in these situations the probability of electrical injuries increases due to exposure to induced voltages.

Below are the results of research aimed at implementing the method of computer simulation of
induced voltages on the ground-laid pipeline in the modes of melting ice on the wires of the electric traction network.

2. Simulation technique
The methods of modeling the electric traction network modes developed in Irkutsk State Transport University [18] allow one to implement a systematic approach to the modeling of the electromagnetic influences of electric traction networks on long metal structures. The consistency is ensured by the following circumstances:

1. Induced voltages are determined on the basis of calculating the mode of a complex power supply system, which includes a multi-wire electric traction network and a high-voltage network of the power supply system adjacent to traction substations (TS).
2. The simulation takes into account all significant factors that affect the levels of electromagnetic influences of the traction network: harmonic distortions in the currents and voltages of the traction network, conductivity of the ground, the presence of stationary and distributed groundings of the metal structure; in this case, the values of specific conductivity of the ground can be differently set on separate sections of the approach line of the traction network and the analyzed structure.
3. The algorithms used for calculating the mutual inductive resistances work correctly in the near, intermediate and far zones of Carson's integral [19].
4. The technique is universal and allows one to determine the induced voltages for traction networks of different constructive design.
5. The approach of the metal structure with the traction network can be carried out along parallel, non-parallel and complex trajectories.

3. Simulation results
The simulation was carried out in relation to the diagrams shown in Figure 1.
Figure 1. Ice melting diagram: a – by artificial short circuit (SC); b – by feeding contact suspensions (CS) from different phases of adjacent traction networks; c – by feeding contact suspensions from different phases of the same traction network

During the simulation it was assumed that a surface steel pipeline with a pipe diameter of 250 mm was laid parallel to the railway track at a distance of 100 m. The coordinates of the conductive parts are shown in Figure 2. The simulation was carried out on the basis of the Fazonord software complex. Computational schemes, fragments of which are represented in Figure 3, included models of the following segments of the electric power supply system:

- a high-voltage network adjacent to traction substations, made by 220 kV electric power transmission lines;
- traction transformers with a rated power of 40 MVA;
- electric traction networks of two inter-substation zones (ISZ) with a length of 50 km.

The inter-substation zone model, which provided approach to the pipeline, was divided into five sections 10 kilometers long. At the ends of the pipeline, the presence of stationary groundings with a
spreading resistance of 1 Ohm was assumed; in addition, the distributed grounding of the pipe with a specific conductivity of 0.05 reciprocal Ohm/km was taken into account. The specific conductivity of the ground on the approach line was set being equal to 0.01 reciprocal Ohm/m and was accepted as the same for all sections of the traction network.

Figure 2. Coordinates of conductive parts

Figure 3. Fragments of diagrams of design models: a - external network and traction substation 1; b - overhead contact system and pipeline

The results of modeling are shown in Tables 1–3 and are illustrated in Figures 4-7. Due to artificial short circuit or multi-phase connection, significant currents (Table 1, Figure 4), sufficient for their preventive heating in order to avoid the formation of ice, flowed along the wires of contact suspensions. The currents that flowed in the rails are presented in Table 2 and are shown in the graph presented in Figure 5.
### Table 1. Results of the calculation of currents and voltages

| Scheme                        | Track | Conductive part | Current | Voltage |
|-------------------------------|-------|-----------------|---------|---------|
|                               |       | Module, A       | Phase, deg | Module, A | Phase, deg |
| Artificial short circuit      | Down  | Cwire           | 465.54  | -81.08  | 20.44      | -5.86     |
|                               |       | CC              | 251.55  | -49.91  | 20.44      | -5.86     |
|                               | Up    | Cwire           | 464.84  | -81.10  | 20.44      | -5.86     |
|                               |       | CC              | 251.54  | -49.86  | 20.44      | -5.86     |
|                               | –     | Pipe            | 85.98   | 107.28  | 0.09       | -72.72    |
| Multi-phase power supply from two traction substations | Down  | Cwire           | 393.58  | -145.93 | 24.16      | 10.93     |
|                               |       | CC              | 212.58  | -114.78 | 24.16      | 10.93     |
|                               | Up    | Cwire           | 393.11  | -145.98 | 24.16      | 10.93     |
|                               |       | CC              | 212.65  | -114.76 | 24.16      | 10.93     |
|                               | –     | Pipe            | 72.72   | 42.44   | 0.07       | -137.56   |
| Multi-phase power supply from one traction substation | Down  | Cwire           | 493.91  | 164.92  | 26.20      | -57.46    |
|                               |       | CC              | 276.60  | -161.46 | 26.20      | -57.46    |
|                               | Up    | Cwire           | 496.09  | -14.56  | 27.60      | -4.43     |
|                               |       | CC              | 277.48  | 18.94   | 27.60      | -4.43     |
|                               | –     | Pipe            | 2.10    | 9.40    | 0.00       | -170.60   |

Note: Cwire - contact wire; CC - carrying cable; the data correspond to the beginning of the first section of the traction network adjacent to traction substation 1.

### Table 2. Results of calculation of currents flowing along the rails

| Rail number | Artificial short circuit | Multi-phase power supply from two traction substations | Multi-phase power supply from one traction substation |
|-------------|--------------------------|-----------------------------------------------------|-----------------------------------------------------|
|             | Current, A Current, deg | Current, A Current, deg | Current, A Current, deg | Current, A Current, deg |
| 1           | 234.16                   | 114.49                                               | 197.98                                               | 49.61       | 23.69     | -158.47   |
| 2           | 220.48                   | 111.96                                               | 186.42                                               | 47.08       | 11.70     | -160.50   |
| 3           | 220.38                   | 111.94                                               | 186.33                                               | 47.07       | 9.71      | 11.36     |
| 4           | 233.88                   | 114.46                                               | 197.73                                               | 49.58       | 21.65     | 17.58     |

Note: The data correspond to the beginning of the first section of the traction network adjacent to traction substation 1.

![Figure 4](image.png)

**Figure 4.** Contact suspension wire currents at the beginning of the first section of the traction network: 1 – artificial short circuit; 2 – multi-phase power supply from one traction substation; 3 – multi-phase power supply from two traction substations
Figure 5. Rail currents at the beginning of the first section of the traction network: 1 – artificial short circuit; 2 – multi-phase power supply from two traction substations; 3 – multi-phase power supply from one traction substation.

The results of determining the induced voltages are summarized in Table 3 and illustrated in the graphs in Figures 6 and 7.

Figure 6. Dependences of induced voltages on the coordinate $x$: 1 – artificial short circuit; 2 – multi-phase power supply from two traction substations.

Figure 7. Dependences of induced voltages on the coordinate $x$ with multi-phase power supply from one traction substation.
### Table 3 Induced voltages across the pipeline

| Scheme                                      | Coordinate x, km |
|---------------------------------------------|------------------|
|                                              | 0    | 10   | 20   | 30   | 40   | 50   |
| Artificial short circuit                    | 86.8 | 21.2 | 4.9  | 4.6  | 21.7 | 87   |
| Multi-phase power supply from one traction substation | 2.12 | 0.46 | 0.12 | 0.33 | 0.67 | 2.34 |
| Multi-phase power supply from two traction substations | 73.5 | 17.7 | 3.9  | 4.1  | 18.5 | 73.5 |

The results presented above allow us to formulate the following conclusions:

1. In the considered modes, significant currents flow through the contact suspension wires; the highest currents of the contact wire, reaching 496 A, are observed with a multi-phase power supply from one traction substation; the current of the carrying cable in this situation is equal to 277 A (Table 1, Fig. 4); significantly lower currents take place in the mode of a multi-phase power supply from adjacent traction substations (394 A for Cwire and 213 A for CC).

2. In multi-phase power supply schemes, only induced currents flow in the rails; with that, in Fig. 1c these currents do not exceed 24 A, which is associated with the phase opposition of currents flowing through the contact suspension of separate tracks (Figure 5, Table 2).

3. The currents, induced due to magnetic influence in the pipeline, have the greatest values in the schemes of artificial short circuit and multi-phase power supply from adjacent traction substations: 86 and 73 A, respectively. During multi-phase power supply from one traction substation, the phases of currents of contact suspension of separate tracks vary by 180º (Table 1); therefore, the induced current in the pipeline is reduced to 2 A.

4. At the inputs of traction substations, voltages of 20 ... 28 kV are maintained (Table 1), which corresponds to the permissible limits.

5. Levels of induced voltages exceed the allowable values of 60 V [20] in the modes of artificial short circuit and multi-phase power supply from adjacent traction substations (Figure 6). Such voltages are observed at the ends of the simulated section of the structure. In the mode of multi-phase power supply from one traction substation due to the phase opposition of currents flowing through the contact suspension of separate tracks, the levels of induced voltages do not exceed 2.5 V.

### 4. Conclusion

The presented technique and developed computer models can be used in practice when planning measures to ensure electrical safety in ice melting modes on the wires of contact suspensions.

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