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Determination of electromagnetic effects of electric traction networks on pipelines

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Abstract. The article presents the simulation results of electromagnetic effects of a 25 kV electric traction network on a steel pipeline with a pipe diameter of 250 mm. It is shown that a pipeline with insulating pipe coatings can induce stresses dangerous to operating personnel. At certain points of the pipeline, grounded on both sides, the magnitude of the induced voltage can reach 116 V with an approach width of 100 meters. Therefore, it is required to develop and implement special measures to protect operating personnel. With an increase in the approach width to 400 m, the maximum values of the induced voltages did not exceed the permissible level. In modes of short circuits in the electric traction network, the induced voltages in the pipeline may briefly exceed 500 V. The highest voltages are observed at points located near the short circuit point. In case of short circuits at the terminals of the traction substations, the magnitudes of the induced voltages are reduced to 75 V. To reduce the induced voltages, the following measures can be assumed: reducing the length of parallel passage sections of pipeline and railway, increasing the approach width, installing additional groundings. During the operation of the structure, the magnitude of the “pipe-to-ground” transition resistance may decrease, which will result in a decrease in induced voltages.

1. Introduction
In Russia, there is an extensive network of pipelines for transporting gas, oil, and its refinery products. In some sections of the routes, the pipelines may approach the railways electrified with alternating current [1, 2]. When sections of the pipeline with high-quality insulating coatings are placed parallel to the electromagnetically unbalanced 25 kV electric traction network [1–3], dangerous voltages to ground may occur [4–8]. To elaborate measures to improve electrical safety conditions, it is necessary to develop methods and algorithms of determining induced voltages emerging on pipelines due to the electromagnetic effect of the electric traction network.

The results of determining the induced voltages on the ground-surface pipeline, whose section runs parallel with the railway with a voltage of 25 kV in the overhead system, are described below.

2. The simulation technique
To determine the electromagnetic effects of electric traction networks on pipelines, one can use the methods of simulating modes of traction power supply implemented in the Fazonord software package developed in Irkutsk State Transport University [9]. The principles of using this software for calculating induced voltages are considered in [7, 9–12]. The mutual inductance coupling resistances, as well as the inherent resistances of the wire-to-ground circuits, were calculated using Carson formulas [13], which ensure that the return of currents through the ground is correctly taken into account.
3. Simulation results for train traffic.
For a considerably ordinary intersubstation railway area of 50 km in length (Fig. 1), electrified with 25 kV alternating current, the operation modes of the traction power supply system were modeled with a pipeline with a pipe diameter of 250 mm included in the multi-wire system. The computational scheme shown in fig. 2 included a model of three traction transformers and two intersubstation areas (ISA). The left ISA was divided into five sections with a length of 10 km. Besides, the scheme presented models of three 220 kV power supply lines. The distance from the pipeline to the axis of the road (approach width) varied from 100 to 400 m.

![Diagram](image)

**Figure 1.** A fragment of the traction power supply system scheme: A, B, C are the phases of supplying power lines

![Diagram](image)

**Figure 2.** A fragment of the computational model scheme: ISA is the intersubstation area; OS is the overhead system
The simulation considered the movement of 7 down trains weighing 6300 tons and the same number of up trains weighing 6000 tons. The movement schedule is shown in Fig. 3, and the current profiles of trains are shown in Fig. 4. The simulation took into account the distributed grounding of the pipeline with a resistance of 20 Ohm·km. In addition, presence of stationary groundings with a resistance of 1 Ohm was assumed at the edges of the structure.

The model of sections of the electric traction network with pipeline took into account the distribution of parameters and was formed as a chain-like scheme. In contrast to the results presented in [14], below there are the data on induced voltages that were obtained taking into consideration the influence of higher current harmonics and the electric traction voltage.

![Figure 3. Train movement schedule](image)

![Figure 4. Current profiles of the trains:](image)

\( a \) is a 6300 ton down train profile; \( b \) is a 6000 ton up train profile

The results of simulation are shown in table 1 and in fig. 5-7.

![Figure 5. Dependent of induced voltage on time with \( L = 10 \) km:](image)

\( L \) is the distance from the observation point to the left traction substation;
$U_z = U_1 \sqrt{1 + k_U^2}$ is the resulting induced voltage; $k_U$ is the total harmonic coefficient; $a$ is the approach width; $a$ is approach width.

**Figure 6.** Dependences of the total harmonic coefficient on time with $L = 10$ km

**Table 1.** Maximum values of induced voltages and harmonic coefficients

<table>
<thead>
<tr>
<th>Approach width, m</th>
<th>$L$, km</th>
<th>$U_1$, V</th>
<th>$U_{hg}$, V</th>
<th>$U_z$, V</th>
<th>$k_U$</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>10</td>
<td>64.00</td>
<td>17.14</td>
<td>66.26</td>
<td>86.15</td>
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<tr>
<td>400</td>
<td>10</td>
<td>29.70</td>
<td>6.11</td>
<td>30.32</td>
<td>87.62</td>
</tr>
<tr>
<td>100</td>
<td>20</td>
<td>112.80</td>
<td>25.24</td>
<td>115.59</td>
<td>58.74</td>
</tr>
<tr>
<td>400</td>
<td>20</td>
<td>50.90</td>
<td>8.79</td>
<td>51.65</td>
<td>67.27</td>
</tr>
<tr>
<td>100</td>
<td>30</td>
<td>63.80</td>
<td>10.90</td>
<td>64.73</td>
<td>28.55</td>
</tr>
<tr>
<td>400</td>
<td>30</td>
<td>28.40</td>
<td>3.76</td>
<td>28.65</td>
<td>21.83</td>
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<tr>
<td>100</td>
<td>40</td>
<td>49.80</td>
<td>13.66</td>
<td>51.64</td>
<td>38.68</td>
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<tr>
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<td>40</td>
<td>22.6</td>
<td>4.72</td>
<td>23.09</td>
<td>28.41</td>
</tr>
</tbody>
</table>

Note: $U_{hg}$ is the RMS voltage of higher harmonics.
Figure 7. Dependences of the induced voltage components and the total harmonic coefficient $k_U$ on the distance $L$

4. Simulation results for short circuits (SC) in the electric traction network

The simulation in the Fazonord software package was performed in two versions:

- the short circuit of the overhead line to the rail at the points corresponding to the terminals of the 27.5 kV traction substations (nodes 32 and 34 in Fig. 2);
- the short circuit of the overhead line to the rail in nodes 71, 65, 59 and 53 according to fig. 2;

Electric traction network was modeled on the basis of a chain-like scheme to take into account the distribution of parameters. The results of simulation are shown in fig. 8, 9.
Figure 8. Distribution of induced voltages in short circuit modes of the electric traction network along the pipeline length:

\[ L \text{ is the distance from the left traction substation to the observation point} \]

Figure 9. Distribution of induced voltages in short circuit at the terminals of the traction substations along the pipeline length

The simulation results make it possible to formulate the following conclusion: in short circuit modes in the traction network, the induced voltages in the pipeline can briefly exceed 500 V. The highest voltages are observed at points near the short circuit. In case of short circuits at the terminals of the traction substations, the magnitudes of the induced voltages decrease to 75 V.

5. Conclusion

The simulation results make it possible to conclude the following:

1. On the ground-surface pipeline, which has areas of the parallel approach to the AC railway line, there may be dangerous induced voltages to ground. In the calculated example, when the approach width is less than 100 m, the magnitude of the induced voltage reached 116 V. With an increase in the
approach width up to 400 m, the maximum values of the induced voltages did not exceed the permissible level [6].

2. To reduce induced voltages, the following measures can be assumed: reducing the length of parallel passage sections of pipeline and railway, increasing the approach width, installing additional groundings. During the operation of the structure, the magnitude of the "pipe-to-ground" transition resistance may decrease [15], which will result in a decrease in induced voltages.

3. The magnitude of the RMS values of the higher harmonics of the induced voltage in the calculated example reached 25 V. The maximum value of the harmonic coefficient was 88%. However, the values $U_1$ and $U_2$ differed slightly. Nevertheless, in a number of situations that may occur in operational practice, taking into account harmonic distortions while determining the induced voltages on the surface pipeline will make it possible to more properly plan activities for ensuring the personnel safety.

4. In modes of short circuits in the electric traction network, the induced voltages in the pipeline may briefly exceed 500 V. The highest voltages are observed at points located near the short circuit point. In case of short circuits at the terminals of the traction substations, the magnitudes of the induced voltages decrease to 75 V.

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