Electromagnetic influences of autotransformer overvoltage traction networks on pipelines

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Abstract. The article presents the results of the simulation of the electromagnetic effects of an advanced overvoltage traction network on a steel pipeline with a diameter of 250 mm, laid on the earth’s surface. Due to the electromagnetic imbalance of the traction network, at certain points of the structure, voltages with respect to the ground, dangerous for the maintenance personnel, may arise. In such situations, it is necessary to develop measures to improve electrical safety. In the conditions of digitalization of the electric power industry, the solution to this problem should be based on computer technologies that allow determining the induced stresses arising on the parts of pipelines due to the electromagnetic effect of the traction network. The simulation, performed with the help of the Fazonord software package, showed that at a distance of 100 meters from the railway route to the pipeline, the maximum induced voltage at individual points of the structure can reach 100 V, which is more than one and a half times the permissible value. This must be taken into account when designing advanced traction electric power supply systems in the areas where they are close to the main pipelines.

1. Introduction

To transport gas, oil and products of its processing in Russia, a large-scale network of pipelines has been created, the total operational length of which exceeds 250 thousand km [1]. Some of their sections can run along the lines of AC railways [2, 3]. Due to the electromagnetic imbalance of the traction network (TN) at certain points of the structure, voltages to earth, dangerous for the maintenance personnel, may arise [2–10]. In such situations, it is necessary to develop measures to improve electrical safety. In the context of digitalization of the electric power industry, the solution to this problem should be based on computer technology, which makes it possible to determine the induced voltages occurring on the parts of pipelines due to the electromagnetic influence of the traction network.

Such technologies can be implemented on the basis of methods and tools for simulating the modes of electric power systems in phase coordinates, proposed at Irkutsk State Transport University [11-12]. Below are the results of modeling the electromagnetic effects of an advanced overvoltage traction network [13, 14] on a ground surface laid pipeline.

2. The simulation technique.

The electromagnetic influences of electric traction networks on pipelines can be determined using the
Fazonord software package [12]. Simulation of induced voltages can be based on the principles proposed in [6, 8].

One of the main principles is to correctly take into account the return of currents through the ground on the basis of calculating the resistances of the mutual inductive coupling, as well as the intrinsic resistances of the "wire – ground" circuits using the relations proposed in [8]; this provides an exact definition of the Carson integral [15] for the near, intermediate and far zones.

3. Simulation results.
The Fazonord software complex simulates the operating modes of an advanced overvoltage traction electric power supply system (TEPSS) [15] (Figure 1). Such a traction electric power supply system provides for the construction of base traction substations (TS) equipped with unbalance-to-balance transformers; at the same time, the distance between the base traction substations can reach 300 ... 350 km. Power supply to the traction network is carried out from single-phase transformers with the winding voltages of 93.9 / 27.5, located at distances of 30 ... 45 km from each other.

![Diagram of traction electric power supply system (TEPSS) scheme of increased voltage with unbalance-to-balance transformers](image)

**Figure 1.** Traction electric power supply system (TEPSS) scheme of increased voltage with unbalance-to-balance transformers: SPTSS – single-phase traction substation; NI – neutral insert

A fragment of the computational model diagram is shown in Figure 2, and the train schedules – in Figure 3. The current profiles are shown in Figure 4. The movement of 6 freight trains weighing 6000 tons in up and down directions was simulated at intervals of 40 minutes.
The induced voltages were determined taking into account the influence of the higher harmonics of the current and voltage of the traction network. The results of modeling are shown in figures 5-10 and in table 1.
Figure 5. Dependences of the induced voltage $U_1$ of the fundamental frequency on time with the approach width $a = 100$ m: $x$ – distance from the observation point to the left traction substation.

Figure 6. Dependences of the effective value $U_{hg}$ of voltages of higher harmonics on time with the approach width $a = 100$ m.

Figure 7. Dependences of the resulting induced voltage $U_\Sigma = U_1 \sqrt{1 + k_U^2}$ on time with the approach width $a = 100$ m: $k_U$ is the total harmonic distortion.
Figure 8. Time dependences of the total harmonic distortions with the approach width $a = 100$ m

Figure 9. Shapes of induced voltage curves at the point corresponding to the coordinate $x = 20$ km

Figure 10. Maximum values of induced voltages
Figure 11. Average values of induced voltages

Table 1. Summary results

| Indicator       | Parameter | 0  | 10 | 20 | 30 | 40 | 50 |
|-----------------|-----------|----|----|----|----|----|----|
| Maximum         | $U_1$, V  | 34.50 | 86.40 | 91.60 | 56.50 | 88.10 | 27.60 |
|                 | $U_{hg}$, V | 11.05 | 40.03 | 39.83 | 25.49 | 38.26 | 8.51 |
|                 | $U_{Σ}$, V | 36.23 | 95.22 | 100 | 61.98 | 96.05 | 28.84 |
| Average value   | $U_{hg}$, V | 3.72 | 3.97 | 3.78 | 2.49 | 2.67 | 2.38 |
|                 | $U_{Σ}$, V | 10.77 | 12.02 | 13.06 | 9.64 | 8.17 | 7.95 |

The analysis of modeling results makes it possible to conclude the following.

1. For the considered electric traction network with a approach width of 100 meters, the maximum induced voltage reaches 100 V (Table 1), which is more than one and a half times higher than the permissible value [16]. To reduce it, it is necessary to provide for additional stationary grounding conductors or to increase the distance between the pipeline and the railway. This must be taken into account when designing advanced traction electric power supply systems in the areas where they are close to the main pipelines.

2. The magnitudes of the induced voltages change significantly over time, which is associated with the nonstationarity of the traction loads (Fig. 5-7).

3. There are significant harmonic distortions of induced voltages, the total harmonic distortion exceeds 60% (Fig. 8); therefore, the shapes of the curves differ significantly from the sinusoid.

4. During the operation of the facility, the magnitude of the "pipeline-to-ground" transition resistance may decrease [17], which will result in a decrease in induced voltages.

4. Conclusion

Computer technologies based on digital models of electric power systems in phase coordinates and allowing one to determine induced voltages on pipelines laid in electromagnetic influence zones of advanced overvoltage traction networks are proposed.

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