Determination of Electromagnetic Influence of 25 kV AC Electric Traction Network on 10 kV High-Voltage Overhead Line

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Abstract. Electrified railways include a system of cable and overhead lines. An analysis of the operation of alternating current (AC) electrified railways sections shows that the value of the induced voltage caused by the operation of the traction network can significantly exceed the permissible level on adjacent disconnected high-voltage overhead lines. As a consequence, this leads to serious injuries to operating personnel, including deaths, failure of electrical equipment. From this point of view, 1x25 kV 50 Hz AC railway system networks are considered the most dangerous. The electromagnetic influence of the traction network of a double-track section of an AC railway on an adjacent 10 kV high-voltage overhead line for power supply of automatic block signalling is investigated in the offered paper. Emergency cases of traction network operation are considered: short-circuit situation and forced state. The calculations of short-circuit currents in the influencing inter-substation zone, as well as estimation of the induced voltage on the wires of the 10 kV disconnected high-voltage overhead line for various schemes of grounding, have been performed. The investigations were carried out on models built using the ATP-EMTP program.

1. Introduction

The electromagnetic influence of electric traction network depends on many factors that can contribute to the occurrence of induced voltage on the overhead lines located in the vicinity. The most important are the level of current in the catenary system wires, the geometrical location of influencing and influenced conductors, and soil resistivity [1-8].

A 1x25 kV AC electric traction network has mainly a dangerous influence. The induced voltages in this case are an order of value higher than for a DC electric traction network. A 2x25 kV AC traction systems are intermediary position in terms of the degree of danger [9-13]. The research is carried out for the 1x25 kV traction network in this work.

For calculate the induced voltage caused by magnetic influence it is necessary to determine the influencing current flowing in the catenary system. The worst possible option is considered from the point of view of work safety when the induced voltages will be the highest.

The most dangerous are thus the following two modes in the traction network: short circuit and forced state. In the first case, the greatest currents flow. The maximum voltages are induced when a short circuit occurs at the end of the influenced zone. The induced voltages will be less due to a
decrease in the zone length at a short circuit in the middle of influenced zone. Compensation is also possible when short-circuit current flows from the side of second traction substation. In the case of a forced state, one of the traction substations supplying the inter-substation zone is switched off and the currents flow in one direction over a greater length compared to the normal operating state.

2. Structure of traction network and 10 kV overhead lines
Assessment of the electromagnetic influence of 25 kV AC electric traction network was carried out on the example of one of the 10 kV high-voltage overhead line. Figure 1 shows configuration of the objects under study. The traction network between TSS1 and TSS3 was divided into seven sections. Conductor transpositions on the line were taken into account when constructing the scheme.

The following data of objects under study were taken into account when constructing calculation model. Length of traction network section is 57 km. Length of 10 kV high-voltage line is 19 km. It is installed on common towers with contact network. The contact network wire type is M-120 + 2MF-100 and the line wire type is AC-50. Suspension height of the contact wire is 6 m, the catenary wire is 7 m, the 10 kV overhead line wire is 9.5 m. Distance between contact wire and nearest overhead line wire is 5.25 m. The investigated section of the railway is double-track with double-sided power supply by two traction substation TSS1 and TSS3. Each traction substation has two three-phase 40 MVA, 110 kV transformers. One of them is reserved. The high-voltage line is supplied from the TSS1.

3. Main cases of investigation
The parameters of all elements of the railway power supply system under normal operating conditions are below the maximum permissible values according to the norms [14]. The system provides power to the catenary system at the calculated value of movement and for the conditions of greatest resistance to movement of rolling stock and the highest electricity consumption. However, in practice, this is not always the case. There are fault situation and forced state also [15].

3.1. Fault situation
This is situation where the catenary system is grounded to the rails or the ground. The operation of power supply system due to disturbance of technical standards taking into account the estimated traffic volumes becomes impossible at the same time. In this regard, the traffic on the sections is partially or completely stopped.

In this case, the influencing short-circuit current can be determined by the well-known formula [16]:

$$I_{sc} = U_n 10^3 \left( \frac{2U_n^2}{S_{sc}} + \frac{U_n 96}{100S_n} \right) 10^3 + x_{sc} L_{sc} + \left( r_{sc} L_{sc} \right)^2 \right)^{3/2}$$

where the $U_n$ is rated voltage on the traction substation buses, $S_{sc}$ is short-circuit power on the primary voltage side of the traction substation, $S_n$ is rated power of traction substation, $U_{sc}$ is short circuit voltage of traction transformer, active resistance of 1 km of catenary system, $r_{sc}$ is active resistance of 1 km of catenary system, $x_{sc}$ is reactance of 1 km of catenary system, $L_{sc}$ is distance from substation to fault.

3.2. Forced state
The situation when one of the traction substations is temporarily disconnected. Its load is taken over by one or two additional substations with it. This results in a change in the normal catenary system scheme on the considered section of railway.

This paper describes two variants of the forced state. Traction substations TSS1 и TSS3 were disconnected alternately and currents in the catenary system along the entire length of section flowed in the same direction.
Figure 1. The configuration scheme of the 10 kV high-voltage overhead line and electric traction network.
4. Induced voltage design models

Figure 2 shows a calculation model that built in the ATP-EMTP program to estimation the short-circuit currents in the catenary system [17-19]. For ease of reference, the distance between substations TSS1 and TSS3 has been divided into fifteen sections. The contact wire was closed to the rail network.

![Figure 2](image)

**Figure 2.** The calculation model to investigation the short-circuit currents in the catenary system.

The calculation models were also built in the ATP-EMTP program for the forced state. In the first case, the TSS3 substation was turned off and the section was powered from the TSS1 substation. The section under consideration was powered from TSS3 in the second case. One of models is shown in Figure 3 (TSS3 only works).

![Figure 3](image)

**Figure 3.** The calculation model for studying the forced state in the traction network.
The calculations of induced voltage were carried out on the 10 kV high-voltage overhead line at an average load in the overhead line of a double-track line is 1000 A. Since the Murmansk region is characterized by grounds with low conductivity, the ground resistivity was taken equal to 1000 Ωm. The line was grounded at ends on resistance is 0.5 Ω and in the point of repair is 30 Ω (all three phases were grounded).

5. Results of Induced Voltage Calculation on 10 kV Overhead Lines

5.1. Fault situation

The calculation of the values of short-circuit current in the catenary system was carried out over the total investigated distance of the railway at various points. Figure 4 shows the results of calculation studies (these are rms values). Analysis of calculation results showed that the highest short-circuit currents occur at the ends of traction network section.

The calculations of the values of hazardous voltages were thus carried out on the disconnected line during short circuits in the vicinity of the traction substations TSS1 and TSS3. The case was also considered with the minimum value of the current Isc, typical for the middle of railway distance [20, 21]. Figure 5 shows the calculations results of induced voltage on the 10 kV high-voltage overhead line.

Figure 4. Values of short-circuit currents depending on the place of occurrence of short-circuit in the inter-substation zone.

Figure 5. The induced voltage on the 10 kV high-voltage overhead line for the following cases:
1 – short circuit near TSS3;
2 – short circuit in the middle of the traction network section (28 km from TSS3);
3 – short circuit near TSS1.
Analysis of calculation results showed that the induced voltage reaches the highest values on the disconnected and grounded line at its ends twelve km from TSS3, when the short circuit occurs at the end of supply zone near TSS1. This phenomenon is associated with the location of investigated line relative to the influencing section of railway. The line is established along the railway track from the traction substation TSS1 to 1/3 of the railway section.

High levels of induced voltage are also observed in the case of a short circuit near the TSS3. But because the short-circuit place relative to the investigated line is at a more distant distance, the maximum level of induced voltage in this case will be 1.6 times lower.

The level of induced voltage on the high-voltage overhead line wires also takes on significant values at the minimum short-circuit current in the traction network is 1.6 kA. Maximum value of induced voltage reaches 2.9 kV on the overhead line at the ninth kilometer from substation TSS2 in this case. As can be seen from figure 5, the induced voltage distribution on the disconnected line is uneven, which is also associated with the line location relative to the railway section.

5.2. Forced state

The theoretical study of an induced voltage was carried out for three cases of locomotive location in the railway section:

- near substation TSS1;
- on the ninth km of the railway section;
- near substation TSS2.

The 10 kV high-voltage overhead line was disconnected and grounded on both sides at substations in the study.

Figures 6 and 7 shows the results of calculations of induced voltage on the line for two variants of forced state of catenary system of influencing railway section.

**Figure 6.** The level of the induced voltage on the high-voltage overhead line when only the TSS3 substation is operating

1 – the locomotive is located opposite the middle of the high-voltage overhead line;
2 – the locomotive is located near the TSS1 substation.

**Figure 7.** The level of the induced voltage on the high-voltage overhead line when only the TSS1 substation is operating

1 – the locomotive is located near the TSS2 substation at the distance of 19 km;
2 – the locomotive is located opposite the middle of the high-voltage overhead line.

Analysis of the calculation results showed that the highest values of the induced voltage on the overhead line are observed when the locomotive is opposite the middle of the line (the ninth km of the railway section). The maximum value of the induced voltage was 293 V when the railway section was powered from the TSS3 substation and 421 V is substation TSS1.
The value of the induced voltage does not exceed the permissible level 25 V on the wires in the place that is the middle of overhead line in two cases: when the locomotive is at the beginning of railway section (near the TSS1 substation), and the section is powered from the substation TSS3, or when the locomotive is located near the substation TSS2 and only the substation TSS1 is operating.

Calculation study showed that the distribution of induced voltage on the wires depends on the location of the line relative to railway section and the corresponding distribution of the current in the catenary system. So, for example, the induced voltage on overhead line does not exceed the value of several volts in the forced state of catenary system when the locomotive is near the supply substation.

6. Conclusion
On the base of the carried out analysis can be concluded that the induced voltage on the wires of 10 kV high-voltage overhead line reaches dangerous values during the operation of catenary system in the short circuit situation regardless of where it arose on the railway section. This can lead to serious injuries or death due to electric shock to the operating personnel, and damage to the electrical equipment.

In the forced state of the traction network, the distribution of the induced voltage on the overhead line directly depends on the load on the section relatively to the supply traction substation. When the locomotive is located near the supply traction substation, the value of the induced voltage along the entire length of the disconnected and grounded at the place of repair and at the ends of the 10 kV high-voltage overhead line is several volts. In other cases, the induced voltage can significantly exceed the safe threshold value (tens of times) as in the short circuit situation in catenary system.

The electromagnetic interaction between the 25 kV AC railway catenary systems and the nearby overhead power lines must therefore be taken into account when working on 10 kV lines in order to avoid accidents. Work must be carried out with the use of basic and additional protective means in accordance with all work safety.

7. References
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