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A bridge between science and innovation

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# Computer model that allows assessing the electromagnetic effect of traction transformers on adjacent lines and systems

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Abstract: In the article, a computer model was developed that allows assessing the influence of traction transformers on surrounding electrical systems in various modes. According to the results of the computer model, it was established that when the same high-power load is connected to the windings AC and BC, the most dangerous electromagnetic process occurs, adjacent systems are exposed to maximum electromagnetic influence in this mode, and dangerous disruption of electromagnetic compatibility occurs in adjacent systems. Also, according to the conducted research, the difference between the computer model and the results of the experiment did not exceed 5-7%.

Keywords: electromagnetic effect, induced voltage, adjacent line, traction transformer, electromagnetic compatibility, computer model

## 1. Introduction

The increase in the number of freight trains and high-speed passenger trains supplied by the railway traction power supply system is causing a sharp increase in the requirements for the traction power supply system. Traction transformers, which are the main element of this power supply system, operate in an asymmetrical mode in most cases. This, in turn, leads to the emergence of negative electromagnetic effects in traction transformers relative to adjacent systems. Also, electromagnetic effects arising in traction transformers can negatively affect the operation of the longitudinal, communication power supply systems and automated devices adjacent to the traction system or lead to their malfunction.

It is known that traction transformers operate in different operating modes, and in each of these modes, electromagnetic influences on adjacent systems are different. Therefore, it is impossible to obtain complete and accurate results by examining electromagnetic effects only in one mode. To fully assess the electromagnetic effects arising in adjacent lines in different operating modes of traction transformers, it is necessary to conduct a complete analysis, taking into account all circumstances. For a complete assessment of the electromagnetic effects of traction transformers, experimental studies are the most reliable. However, since these processes are associated with a lot of time and dangerous situations, it is important to analyze current research mainly through computer modeling of systems. Using models developed using the Matlab program for analyzing these systems, it is possible to accurately and completely calculate electromagnetic processes, analyze the influence of various parameters, and quickly assess them.

## 2. Research methodology

When studying the available literature, we can see that most research in this area is aimed at obtaining or evaluating results based on the theory of the electromagnetic field or experimental studies. However, there are insufficient studies aimed at assessing the electromagnetic effects of models developed on the basis of the Matlab program on adjacent systems, taking into account various operating modes of the traction transformer. Taking these processes into account, this article develops a computer model that allows assessing the electromagnetic effects occurring in adjacent systems in different operating modes of tension transformers, and we compare the results obtained using this model with experimental results.

Despite the fact that a number of works have been carried out to identify or assess the electromagnetic processes occurring in traction transformers and their influence on adjacent systems, in these studies, issues related to the modeling of electromagnetic processes in them in various operating modes of traction transformers remain insufficiently scientifically solved. Research conducted in this area was conditionally divided into theoretical analysis of electromagnetic fields, experimental, computer modeling, comparison of methods, and verification of the correctness of the results of the developed model.

In classical studies, in most cases, methods of Maxwell's equations and the theory of magnetic circuits were used in the analysis of magnetic fields arising in traction transformers, as well as analytical methods for determining the occurring electromagnetic effects were proposed, however, it is observed that the introduction of certain boundary conditions in the development of these methods leads to a significant decrease in the accuracy of the results obtained from them, and the results differ from the practical results.

Currently, there are several computer programs for designing electromagnetic processes in traction transformers, such as Matlab, PsCad, ANSYS Maxwell, and FEMM, on the basis of which a number of studies are being conducted aimed at modeling these processes. Among the above-mentioned programs, Matlab is considered superior to other programs due to its speed, easy change of transformer parameters, the ability to model various operating modes, and the ability to add models of adjacent lines.

In this article, we will consider the problem of modeling electromagnetic effects arising in adjacent lines and systems

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due to traction transformers and comparing its results with experiments.

It is known that when modeling electromagnetic processes occurring in various modes of traction transformers used in the railway power supply system and their influence on adjacent lines, taking into account the technical and geometric parameters, structure, and operating modes of traction transformers is one of the most important issues. As a traction transformer, we choose a TDTNJ-40/110/27.5/10 traction transformer with a three-phase three-winding magnetic core of cold-processed silicon steel with a connection scheme Y/Δ/Δ. In the modeling process, we also take into account systems that can be located near the traction transformer.

For modeling, we use the Matlab software. We select the Three-Phase Transformer (Three Windings) block to serve as the traction transformer and input its parameters, which are calculated based on the TDTNJ-40/110/27.5/10 model transformer, as follows: for 110 kV - 0.35 Ω, 12 mH; for 27.5 kV - 0.01 Ω, 0.65 mH; for 10 kV - 0.005 Ω, 0.2 mH; and for magnetizing resistance and magnetizing inductance - 200 kΩ, 320 H. As consumers for the 27.5 kV and 10 kV windings of the traction transformer, four identical electric locomotives are selected, represented by the Series RLC Load and Three-Phase Series RLC Load blocks, respectively. The following technical parameters are entered for them: for 27.5 kV - 6120 kW, 2160 kVAR; for 10 kV - 1 MW, 484 kVAR. A PI Section Line block is used for the adjacent system, with the following parameters: 0.4 Ω/km, 1.2 mH/km, 10 nF/km. For modeling the electromagnetic effect of the traction transformer on adjacent systems, the Mutual Inductance block was selected, which included the following parameters: first winding - 1.1 Ohm, 12 mGn, second winding - 1.1 Ohm, 1.2 mGn, mutual inductance - 1 Ohm, 0.12 mGn. Additionally, the Current Measurement, Voltage Measurement, Scope, Complex to Magnitude-Angle, RMS Measurement, Display, and Spectrum Analyzer blocks are used for analyzing measurements and processes.

After connecting the above-mentioned blocks in a certain sequence, a computer model is created that allows determining the electromagnetic effect of the traction transformer on adjacent systems (Figure 1).

To verify that the results from the developed computer model correspond with practical results, we will analyze the induced voltages, their harmonic components, and the spectral composition of the induced voltage that occurs in the system adjacent to the traction transformer. This analysis is conducted under conditions where a three-phase consumer is connected to the 10 kV winding, while identical and varied loads are applied to the 27.5 kV AC and BC windings of the traction transformer. To achieve this, we obtain research results by connecting both identical (AC = 6120 kW, BC = 6120 kW) and varied loads (AC = 12240 kW, BC = 6120 kW) to the 27.5 kV AC and BC windings (the reactive powers of the consumers are also entered accordingly) (Figure 3).

For obtaining the results of the oscillogram, a time of 0÷0.02 s was selected. Since it is possible to observe 10 oscillatory processes during this time, it allows for a complete analysis of the results of the system's stable operation.

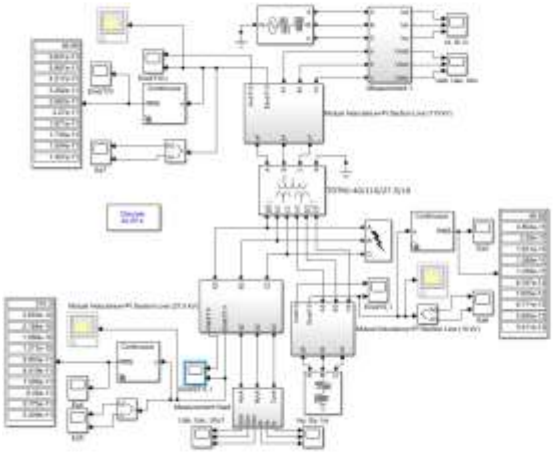

**Fig. 1. Computer model that allows determining the influence of a traction transformer on adjacent systems**

In the developed computer model, the Mutual Inductance+PI Section Line (27.5 kV) section is formed as follows (FFigure 2):

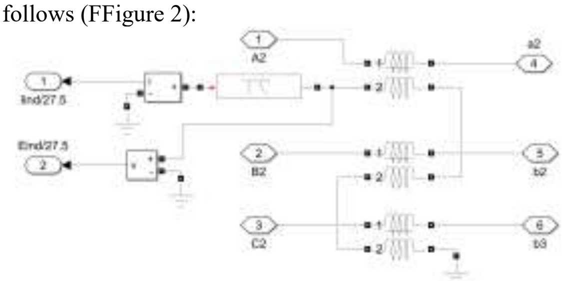

**Fig. 2. Model for determining the voltage induced by a 27.5 kV winding of a traction transformer**

According to the obtained results, when the same load is connected to the windings AC and BC, the value of the induced voltage is approximately 420÷450 V. We also see that the signal shape is almost sinusoidal and the value of the fundamental harmonic is sufficiently high. When various loads are connected to the windings AC and BC, the value of the induced voltage is approximately 230÷250 V. We can see that this value is 1.8-2 times lower compared to the case when the same load is connected to the windings AC and BC. When comparing the results of the computer model and the results of the experiment, it was found that the difference between them does not exceed 5-7%.

With the help of the RMS Measurement block of the Matlab program, curves of the harmonic components of the induced voltage were obtained, according to which the amplitude of the 3rd harmonic is significantly greater when the same load is connected to the AC and BC windings, and the amplitude of the 3rd harmonic is significantly lower when different loads are connected to these windings (Figure 4).

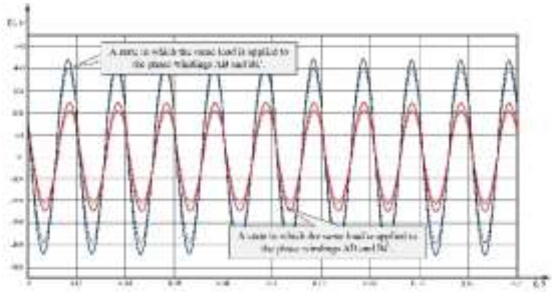

**Fig. 3. Electromagnetic effects arising in adjacent systems under the influence of a traction transformer: continuous line-computer model; discontinuous line-experimental**

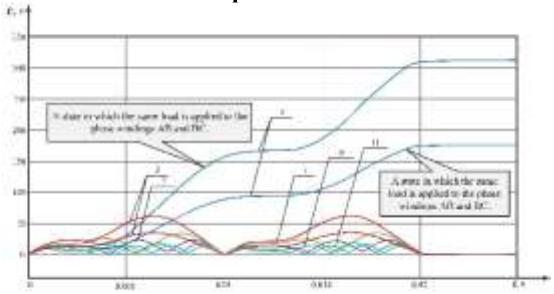

**Fig. 4. Harmonic components of induced voltage**

We can show that the main reason for the emergence of high-voltage harmonics in the induced voltage structure is the nonlinearity of the traction transformer consumers.

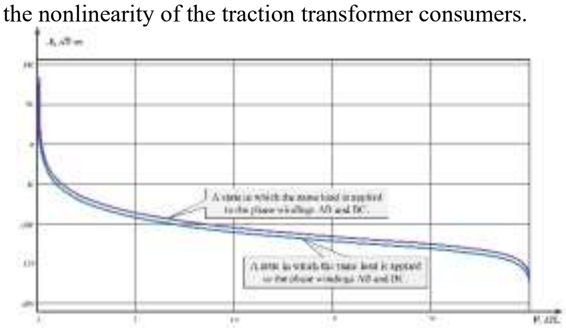

**Fig. 5. Spectral analysis of induced voltage**

Using the Spectrum Analyzer block of the Matlab program, a graph of spectral analysis of the induced voltage was obtained (Figure 5). According to the obtained results, we can see that the spectral amplitude reaches a maximum in the low-frequency region (0÷1 kHz). Reaching the maximum spectral amplitude can cause malfunctions in the system's relay protection elements, lead to incorrect operation in communication systems, and generate excessive currents in grounding circuits. In the mid-frequency range (1-10 kHz), it can also pose a threat to modern electronic control systems by causing electromagnetic interference in microprocessor-based relays and disrupting the operation of SCADA and telemechanics lines. Furthermore, according to the results obtained, the probability of a threat in the high-frequency range (10-25 kHz) is very low due to the small spectral amplitude and its filtration through various systems.

Graphs of changes in the amplitude of the induced voltage and the phase shift angle were obtained using the Complex to Magnitude-Angle block of the Matlab program (Figure 6).

According to the obtained results, we can see that the change in the displacement of the winding is significantly higher when different loads are connected to these windings compared to when the same load is connected to the windings AC and BC.

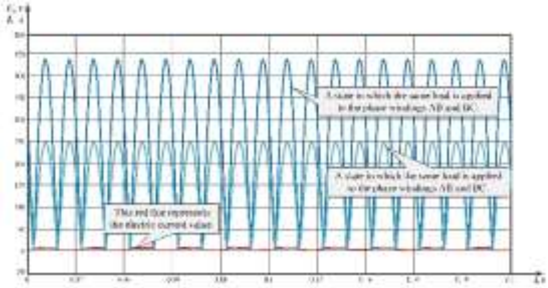

**Fig. 6. Graphs of changes in the amplitude of induced voltage and the phase shift angle**

This, in turn, leads to a change in the conditions of resonance of the adjacent system, disruption of the operation of relays designed for operation relative to the phase, and malfunction of the signaling system.

# 3. Conclusion

Based on the results of the conducted research, it was established that the developed computer model allows for a general assessment of the electromagnetic effect of traction transformers on adjacent lines and systems, and also, based on the obtained results, it was established that the most dangerous electromagnetic process occurs when the same high-power load is connected to the windings of AC and BC, adjacent systems are subjected to maximum electromagnetic influence in this mode, and dangerous violations of electromagnetic compatibility occur in adjacent systems. It was found that the difference between the computer model and the experimental results does not exceed 5-7%.

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