**Investigation of Interphase Short Circuit at The Neutral Section of The Railway Traction Network Using a Mathematical Model**

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**Abstract.** The article examines the distinctive features of the steady-state operating mode of a traction power network following the occurrence of a short circuit at the neutral section of a railway traction network. A specific operational section of the traction network is selected. Information on the electrical parameters of this network has been collected. An equivalent circuit diagram is constructed to visually represent the electrical circuit. The possibility of determining branch currents using a matrix method is considered. Additionally, based on the available data, a mathematical model of the network is created in the MATLAB Simulink environment. To simulate the operation of relay protection, Stateflow functional blocks are used. An analysis of current vector changes before and after the short circuit at the neutral section is performed. The distinctive features of current variations in the branches are identified.

**Keywords:** Neutral section, traction network, short circuit, contact line, electric locomotive, electric arc, relay protection, traction substation.

**INTRODUCTION**

In an alternating current traction power supply system, the load currents consumed by electric locomotives are unevenly distributed among the phases [1]. To reduce the asymmetry of phase loads in the power system, the sections of the contact network (CNS) between traction substations are alternately powered from phases A, B, and C (Fig. 1). Typically, CNS sections are separated by insulating joints, where, during the transition of an electric locomotive from one CNS section to another, a brief short-circuit of the CNS occurs through the pantograph [2].



**FIGURE 1.** Diagram of a traction network for a single-track section

Insulation of CNS sections with the same phase is allowed by this method. However, if CNS sections are powered from different phases, bridging of insulating joints by the pantograph causes an interphase short circuit (SC). To prevent bridging of different phase sections, neutral sections (NS) are installed at these locations [3]. NS consists of two insulating joints placed in series, which prevent simultaneous bridging by the pantograph (Fig. 2). However, to ensure reliable insulation between CNS sections, electric locomotives must pass through the NS with the load current disconnected [4]. Nonetheless, frequent wire burns and breakages occur in the NS, resulting in significant material losses due to train delays and accident recovery. The cause is often operator inattentiveness and passage through the NS without disconnecting the load.



**FIGURE 2.** Arrangement of contact wires within a neutral section

Currently, NS protection from short-circuit currents is highly dependent on human factors. To address this problem, short circuits at the NS need to be studied and new protection methods developed.

**PROBLEM INVESTIGATION**

A single-track traction network section 150 km long, powered by three traction substations (TSS), was selected for the study. Each TSS has a 25 MVA three-phase traction transformer connected to a 110 kV main power line. The distance between substations is 50 km. Feeder zones are powered from both ends and connected through sectioning posts. The traction network comprises PBSM-95 + MF-100 contact suspensions and R-65 rails. The schematic corresponds to Fig. 1.

To perform electrical calculations, a substitution diagram is necessary.

If the traction network impedances are defined as Zn1, Zn2, Zn3, Zn4; substation impedances as Zs1, Zs2, Zs3; electric locomotive impedances as Zt1, Zt2, Zt3; and the busbar voltages at the substations as Uac and Ubc, then the substitution diagram for studying SC at the NS under various network operation modes is shown in Fig. 3. The arc impedance Za depends on the wire arrangement in the NS and the physical properties of air. According to technical standards, arc resistance at the SC location is assumed to be purely active and ranges from 2 to 5 Ohms [5].



**FIGURE 3.** Substitution diagram of the traction network for a single-track section during a short circuit at the neutral section

The line voltages of the traction transformer phases are displaced by 120°, and thus the line voltage vectors can be represented as follows [6]:

(1)

(2)

(3)

Assuming equal voltage magnitudes at the TSS busbars, loop current method can be used to calculate the branch currents by solving the following system of equations [7]:

(4)

(5)

(6)

(7)

(8)

(9)

In matrix form, this system becomes [8]:

[Z] [I] = [U] (10)

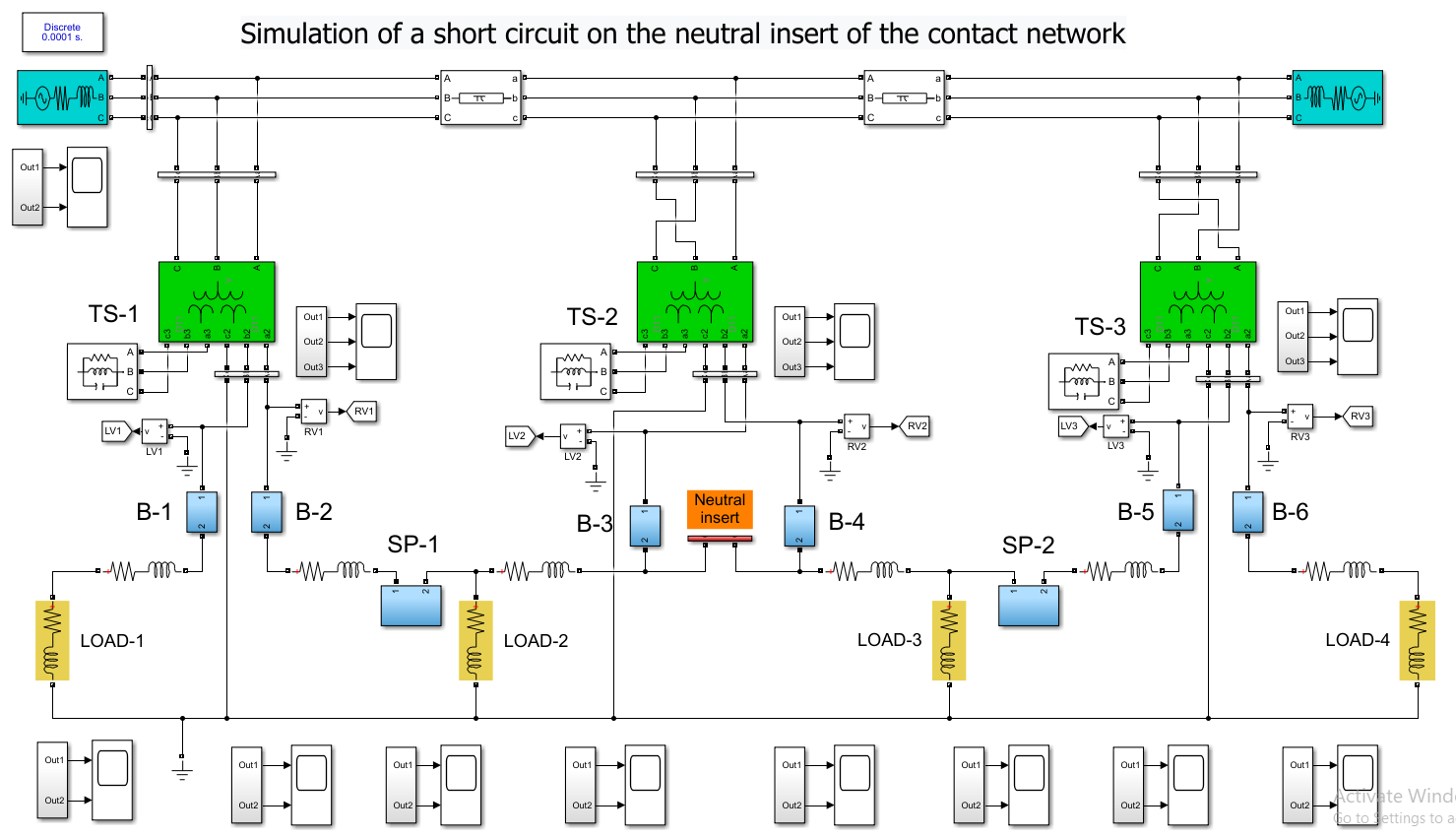
(11)

Here:

Given the known values of network, substation, and locomotive impedances, and operating voltages, the branch currents are found by:

[I] = [Z]-1[U]. (12)

Solving this problem without the use of computational tools would take a considerable amount of time and carries a high risk of calculation errors. Therefore, the most effective method for calculating the currents in this circuit is to perform mathematical modeling of the system using the MATLAB application. The MATLAB Simulink environment provides the capability to study electrical processes more quickly and accurately [9]. It allows for flexible configuration of network parameters, enabling the analysis of electrical processes under various network operating modes. To achieve this, it is necessary to create a traction network model in accordance with the substitution diagram of the studied contact network section (Fig. 4).

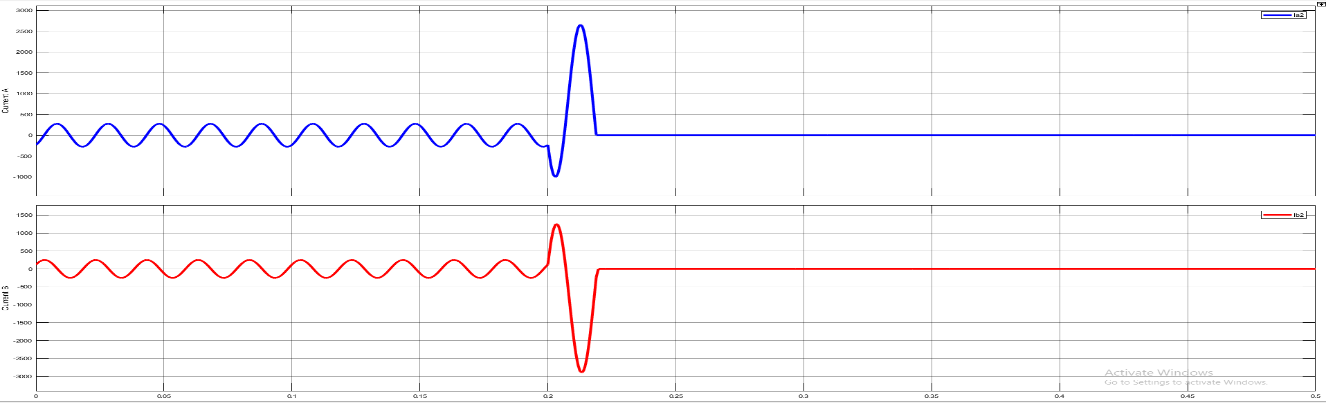


**FIGURE 4.** Model of the traction network in MATLAB Simulink

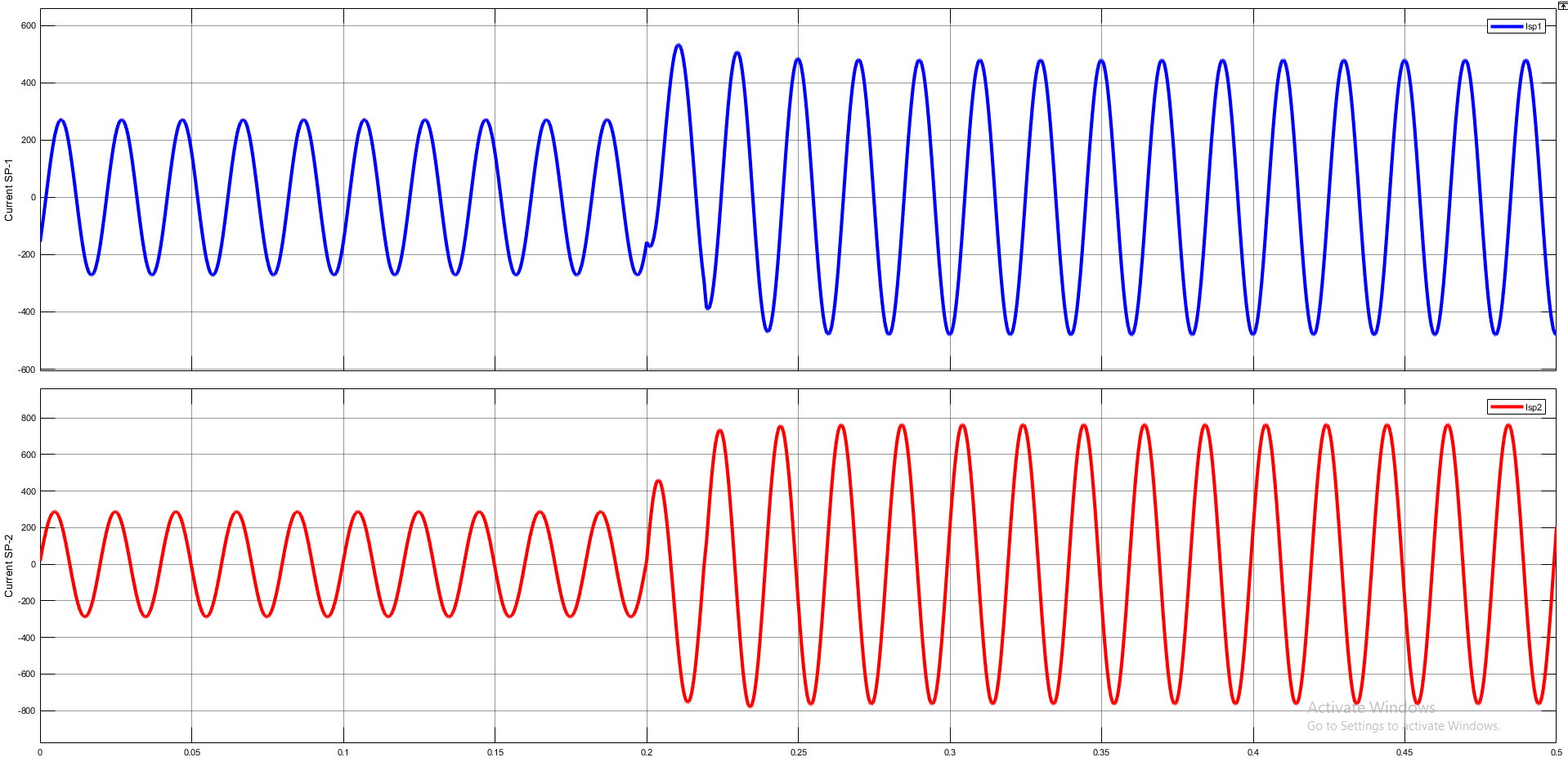
To implement the relay protection logic, Stateflow functional blocks were connected to circuit breakers B-1, B-2, B-3, B-4, B-5, B-6, SP-1, and SP-2.

The short circuit simulation was carried out under two network operating modes: one with no traction load and another where the traction load on the adjacent sections of the traction network was 6 MVA with a power factor of cosφ = 0.8. In each mode, a short circuit was simulated at the neutral section at 0.2 seconds. Measurements of current and voltage were taken at the outgoing feeders of the traction substations (B-3, B-4) and at the sectioning posts (SP-1, SP-2). The simulation was conducted in **Discrete** mode, as it was necessary to study the steady-state operating conditions. Instantaneous overcurrent protection set to 1500 A and delayed protection set to 800 A with a time delay of 0.3 seconds were applied to the outgoing feeders, in accordance with technical regulations [10].

In both operating modes, the behavior of the traction network was the same. Due to the low impedance between circuit breakers B-3 and B-4, the short-circuit current exceeded 2500 A and triggered the instantaneous overcurrent protection (Fig. 5). However, at the sectioning posts SP-1 and SP-2, due to the relatively high impedance of the traction network, the short-circuit current did not reach the protection activation threshold (Fig. 6).

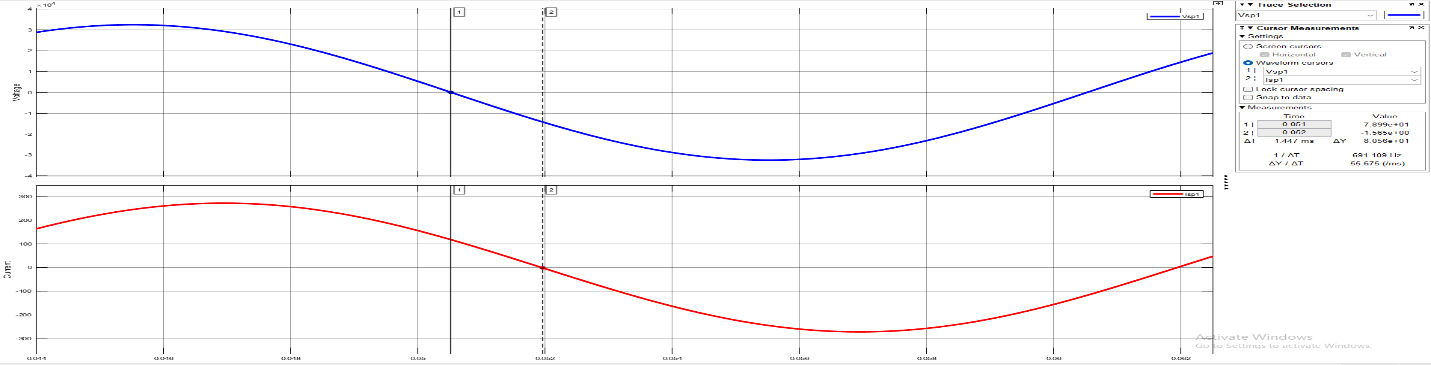


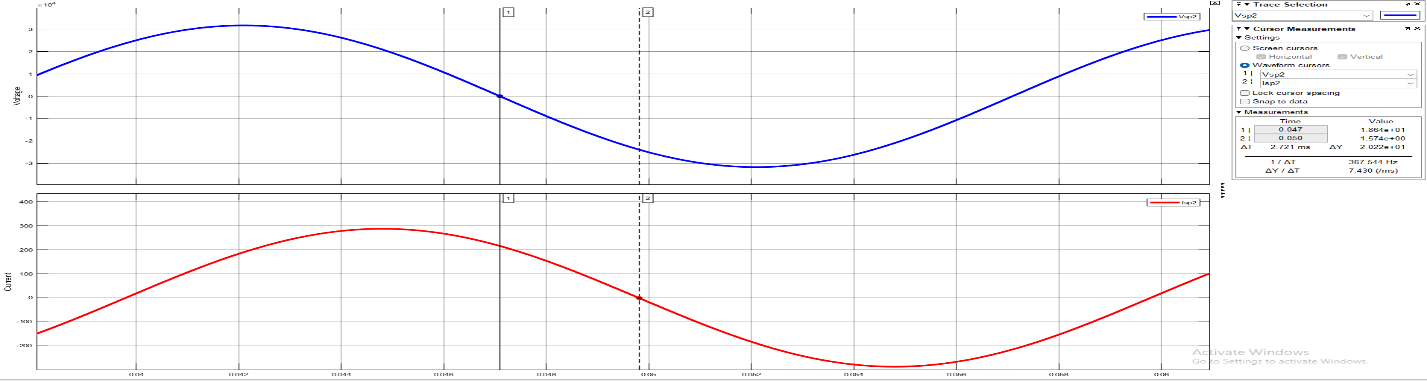
**FIGURE 5.** Current changes at breakers B-3 and B-4



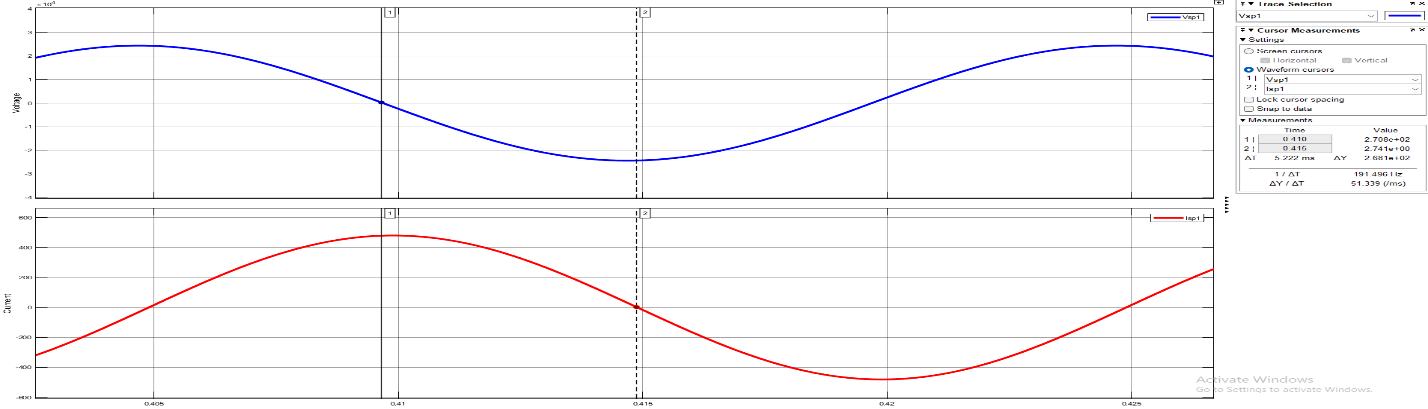
**FIGURE 6.** Current changes at sectioning posts SP-1 and SP-2

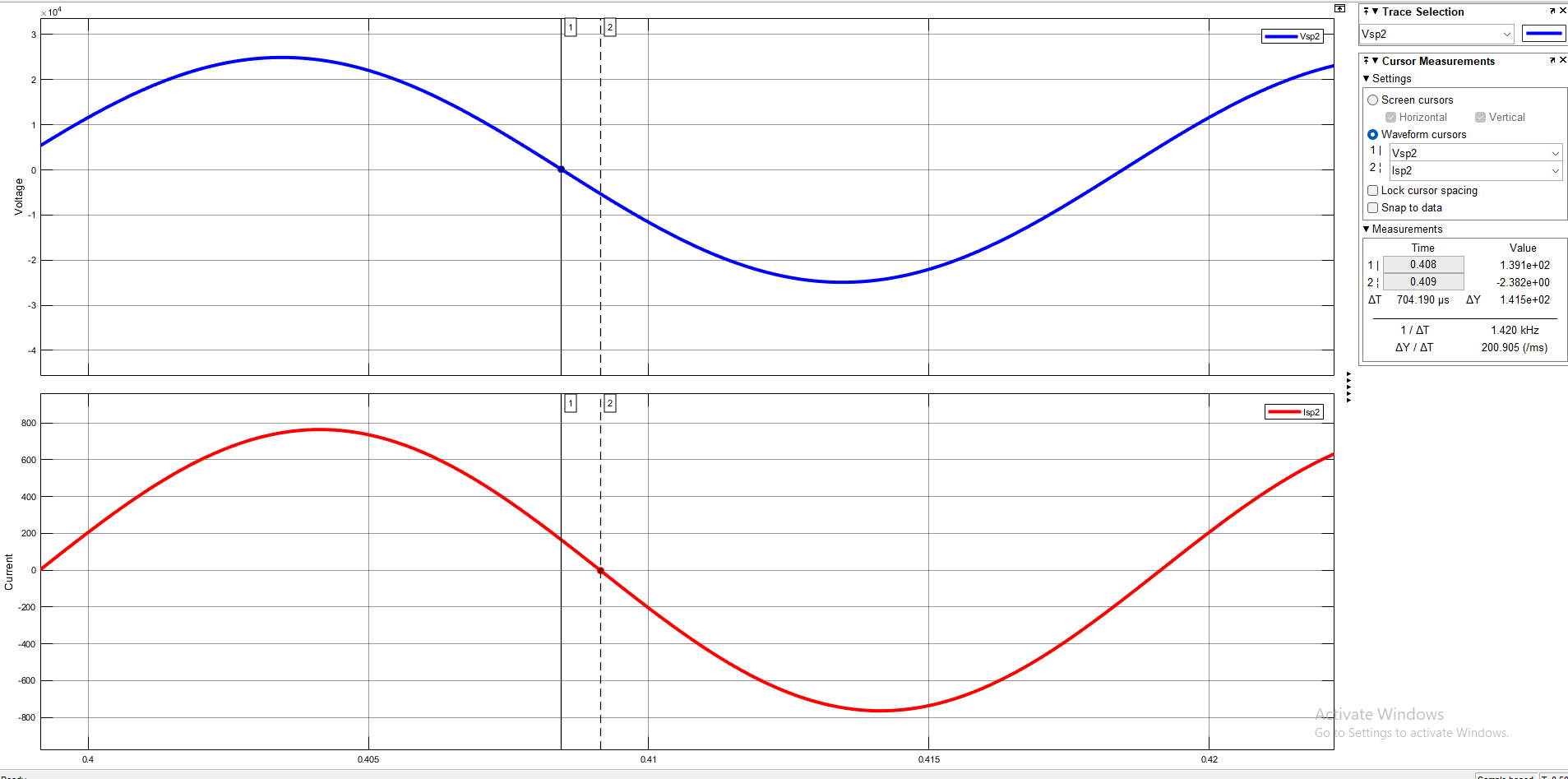
Before the short circuit, at all measurement points, the current vectors lagged behind the voltage vectors by 26° to 48°, depending on the power factor of the load (Fig. 7). After the short circuit, at SP-1 the current vector lagged the voltage vector by 94°, and at SP-2 by 12° (Fig. 8). It was found that the magnitude of the traction load had only a minor effect on the position of the current vectors after the short circuit.





**FIGURE 7.** Phase angle shift between current and voltage at SP-1 and SP-2 before the SC





**FIGURE 8.** Phase angle shift between current and voltage at SP-1 and SP-2 after the SC

**CONCLUSION**

Simulation results showed that the steady-state mode of the traction network after a short circuit at the neutral section differs significantly from the mode of a ground fault. The magnitude of the short-circuit current remains within the range of normal load current, which complicates the task of ensuring effective protection of the traction network from short circuits at the neutral section.

The most effective way to ensure the sensitivity of relay protection devices is to monitor the phase angle shift between the current and voltage vectors. This method was developed and patented by Honored Academician of the Russian Academy of Transport, E.P. Figurnov [11].

However, this method operates effectively only when electric arcs occur at both insulating joints of the neutral section, and the arc current equals the short-circuit current. Considering that relay protection does not operate instantaneously, the short-term thermal effect of the arc before the network is disconnected can significantly deteriorate the technical condition of the neutral section components.

This situation repeats every time an electric locomotive enters the neutral section without disconnecting the load, and the existing protection system is unable to prevent it.

It is necessary to develop a protection method that will disconnect the current on the electric locomotive or the voltage on the contact line if the locomotive's load is not turned off before entering the neutral section. This would prevent the formation of an electric arc at both insulating joints of the neutral section.

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