Modelling of Stray Currents Near a Railway Platform

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Abstract. *The article describes simulations of the occurrence of stray currents in the vicinity of a SUDOP-type railway platform. Stray currents occur in the vicinity of a railway platform during the passage of a railway vehicle. In a fault-free state, all metallic parts are separated from the rail by means of a surge arrester. In the case of a breakdown of the surge arrester, the full voltage which is on the rail at the time of the passing railway vehicle may also pass onto the metallic parts. The surge arresters are checked every 6 months during maintenance work on the overhead lines according to Annex No. 1 of SZDC internal regulation E 500.*

The article, therefore, carries out a simulation of stray currents in exactly this type of breakdown. In addition, to the model, we included the influence of the outdoor lighting cable which is located in the ground under the platform. For the purposes of solving the model, we are using a commercially available program which solves partial differential equations and uses the finite element method for calculation.

Keywords

Current density, finite element method, gabion, rail, railway platform, stray currents.

1. Introduction

An electric traction system includes both power and signal sources and transmitters interconnected by structure of trolley, track ballast and conductive ground. Rails are combined into parallel power conductors, and signal and communication conductors, and the entire traction system behaves like a spatial, linear distribution network [1].

The ground, therefore, constitutes an important part of the traction transmitting system. This part of the traction transmitting system is therefore in many cases (e.g. in the case of evaluating the risks of corrosion of underground equipment) a special subject of our interest. However, stray currents – we use this term to refer to escaping return currents of the electric traction – are often not the only currents flowing in the ground. The ground current fields have many causes. On the one hand, they can be created artificially, on the other hand, they can occur naturally, and they can more or less influence the energy transmission in the electric traction. Artificial current fields occur mainly in the vicinity of electric equipment powered from sources which are inadequately insulated from the ground, or they use the ground as a return conductor [1] and [5].

A stray current is a current which passes from a rail into the ground during the passage of a rail vehicle and returns back to the power supply station. These currents which also pass through concrete foundations disrupt their structure and contribute to their faster ageing. In a fault-free state, the rail is connected with the gabion by a surge arrester. In the model, we take into account the influence of a lighting cable which is located in the ground under the platform. The simulations are carried out on a model of the SUDOP-type platform. We simulate a case in which there is a breakdown of the surge arrester and the full voltage which is on the rail is present on the gabion. For the simulation, we assumed a value of 500 V.

The term "platform" refers to a part of the railway substructure (a transport area and a pathway) intended for boarding or alighting of passengers and for handling of minor consignments. A gabion or a gabion structure is an element of a cube or cuboid shape made of a hexagonal steel wire mesh, welded steel nets or possibly high-strength polymer geogrids filled with natural aggregate, quarried rock, earth, recycled material, etc. The lighting cable is laid in a concrete trough under the platform [3] and [5].

2. Mathematical Model

The basic field quantity describing current fields is the current density vector $\vec{J}$. It is a differential quantity, and it therefore determines the quantity of the current flowing through an elementary area for every place of the solved space. The current density $\vec{J}$ depends on the resistivity ρ or on the conductivity σ according to the differential form of the Ohm's law:

$$\vec{J} = \sigma \vec{E}. \tag{1}$$

In every place where it is possible to determine the intensity of the electric field $\vec{E}$ and where the conductivity is known, it is also possible to determine the current density vector. Its direction in the isotropic medium is the same as the direction of the electric field intensity vector [2].

The way to determine the current density vector is more complicated in the anisotropic medium where conductivity is in the form of a tensor. In most cases, the tensor has only diagonal components, this means that there are different conductivities in the direction of different coordinates, but the intensity of the electric field in the direction of one coordinate will not affect the current density in the direction of a different coordinate, i.e.:

$$J_x = \sigma_{xx} E_x, J_y = \sigma_{yy} E_y, J_z = \sigma_{zz} E_z. \tag{2}$$

The differential form of the Ohm's law is then

$$\vec{J} = \sigma \vec{E} = \sigma(-\mathrm{grad}\varphi), \tag{3}$$

where

$$\sigma = \begin{bmatrix} \sigma_{xx} & 0 & 0 \\ 0 & \sigma_{yy} & 0 \\ 0 & 0 & \sigma_{zz} \end{bmatrix}. \tag{4}$$

Electromagnetic problems associated with solving current fields in a railway superstructure and substructure generally work with a resulting current or current density, which is connected with intensity or potential. Forced quantities are potentials or the primary (forced) intensity of the electric field $\vec{E}_v$. The primary intensity determines the distribution of charges and currents, and it is used for specifying this distribution. For the purposes of the analysis, it is possible to accept that the primary intensity determines the secondary distribution of charges and currents and thus the secondary intensity $\vec{E}_{sec}$, i.e.:

$$\nabla \times \vec{E} = \frac{-\partial \vec{B}}{\partial t}, \tag{5}$$

$$\nabla \cdot \vec{D} = \rho_c, \tag{6}$$

$$\nabla \times \vec{H} = \vec{J}, \tag{7}$$

$$\nabla \cdot \vec{B} = 0, \tag{8}$$

where the symbol ρ_c does not stand for resistivity but for the volume density of the total charge. Similarly to the intensity $\vec{E}$, the current density $\vec{J}$ has also two components, i.e. forced current density $\vec{J}_v$ and eddy current density $\sigma\vec{E}$. Material relationships must be added to these equations on the boundary

$$\vec{D} = \varepsilon \vec{E}, \vec{B} = \mu \vec{E}, \vec{J} = \sigma \vec{E}. \tag{9}$$

A dynamic solution of Maxwell's equations includes also the influence of eddy currents, and it is advisable to use the continuous vector potential here

$$\nabla \times \vec{A} = \vec{B}, \tag{10}$$

$$\nabla \times \vec{H} = \vec{J}_y + \sigma \vec{E} = \vec{J}_y - \frac{\sigma \cdot \partial \vec{A}}{\partial t}, \tag{11}$$

$$\nabla \times \left(\nabla \times \vec{A}\right) = \mu \left(\vec{J}_y - \frac{\sigma \cdot \partial \vec{A}}{\partial t}\right). \tag{12}$$

It is often advisable to perform the solution of direct-current fields for the scalar potential of the electric field. The advantage of using the scalar potential for large ground fields resides in the replacement of the vector field $\vec{E}$, which is given by 3 components, with only a single scalar variable. The boundary value problem is therefore described with one scalar variable φ, and after its solution, we get all components of the electric field intensity and subsequently also all components of the current density. The potential has an important role in connection with converting a spatial model into a circuit model described by a node voltage method [2] and [5].

The Laplace's equation in the Cartesian system applies to the scalar electric potential in homogeneous environments without sources:

$$\nabla^2 \varphi = \frac{\partial^2 \varphi}{\partial x^2} + \frac{\partial^2 \varphi}{\partial y^2} + \frac{\partial^2 \varphi}{\partial z^2} = 0. \tag{13}$$

In modelling the 3D direct-current fields of the railway traction system, we used the duality of the stationary current field with the electrostatic or magnetostatic field. The dual equations have then the form given in Tab. 1 [2].

Tab. 1: Dual form of equations [2].

Static Magnetic Field	Stationary Current Field	Electrostatic Field
$\nabla \cdot \vec{H} = 0$	$\nabla \cdot \vec{J} = 0$	$\nabla \cdot \vec{D} = 0$
$\vec{H} = \frac{\vec{B}}{\mu}$	$\vec{J} = \sigma \vec{E}$	$\vec{D} = \varepsilon \vec{E}$
$\vec{B} = \nabla \times \vec{A}$	$\vec{E} = -\nabla \varphi$	$\vec{E} = -\nabla \varphi$
$\nabla \left(\frac{1}{\mu} \nabla A_z \right) = 0$	$-\nabla \cdot (\sigma \nabla \varphi) = 0$	$-\nabla \cdot (\varepsilon \nabla \varphi) = 0$
$\frac{1}{\mu}$	σ	ε
$\int \vec{H} \cdot \vec{B} \mathrm{d}s = \frac{1}{2} L I^2$	$\int \vec{E} \cdot \vec{J} \mathrm{d}s = \frac{1}{2} G U^2$	$\int \vec{E} \cdot \vec{D} \mathrm{d}s = \frac{1}{2} C U^2$

3. Creating the Model

We chose the Comsol Multiphysics program for the solution. Comsol Multiphysics is an engineering tool designed for modelling and simulation of physical processes. Most problems which we encounter in real life have multiphysical nature. Therefore it is often necessary to take into account the mutual interaction of several physical influences at the same time when developing products or processes and studying the behaviour of systems. Comsol Multiphysics was specially developed for solving these complex problems.

This program makes it possible to solve physical problems described by partial differential equations by the finite element method. These problems are generally solved on the basis of environment definitions which are described by partial differential equations and on boundary conditions entered in points, on edges or surfaces of a given model. The results can be obtained in several steps [4].

3.1. Geometric Layout

The first step is to select and draw a geometric form of the solution. Its layout is shown in Fig. 1.

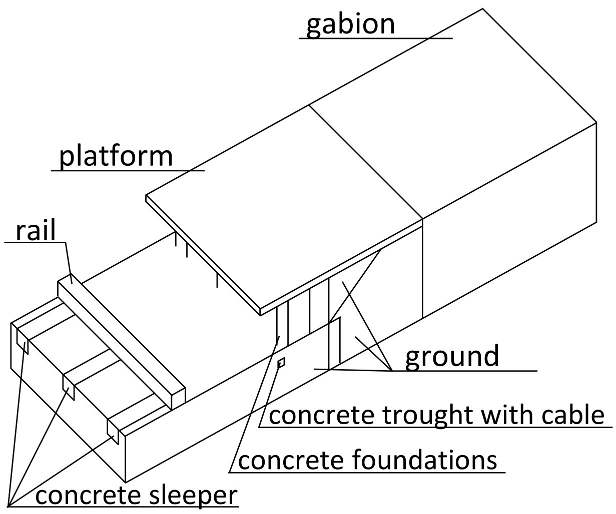

Fig. 1: Geometric layout of the model.

The model consists of a half of a track with the rail laid on concrete sleepers, of a concrete trough with a cable laid in the ground, and of concrete foundations on which there is the platform. Behind the platform, there is the gabion. The geometric layout is simplified in several points to make the solution of the model easier. The rail was drawn as a rectangle whose height and width correspond to the actual dimensions of a rail. A further simplification was made on the gabion. Although the real gabion is a mesh of wires, as was stated above, in the model it was simplified and modelled as a full surface instead of wires. This simplification was necessary in order to enter the material properties. Other components and their dimensions correspond to the reality [3].

The model simulates a situation in which there is a breakdown of the surge arrester and the rail in the model is connected with the gabion by an insulated steel conductor; we also take into account the influence of the railway lighting cable.

3.2. Definition of the Parameters

The material parameters were defined by the electric conductivity σ and the relative permeability μ_r. These are the primary parameters for calculating the model.

The conductor connecting the rail with the gabion was defined by the relative permeability $\mu_r = 4000$ and the electric conductivity $\sigma = 1.12 \cdot 10^7$ S·m^{-1}. The insulation of the conductor connecting the gabion to the rail and the lighting conductor was defined by $\mu_r = 1$ and $\sigma = 10^{-12}$ S·m^{-1}. The material properties of the rail were defined by the measured BH characteristics. Table values of $\mu_r = 1$ and electric conductivity $\sigma = 10$ S·m^{-1} were assigned to the concrete sleepers under the rail, the concrete foundations under the platform, the concrete trough and the platform itself. The gabion was defined by the values of relative permeability $\mu_r = 1$ and $\sigma = 4.1 \cdot 10^6$ S·m^{-1}. The lighting conductor was defined by the relative permeability $\mu_r = 1$ and electric conductivity $\sigma = 5.998 \cdot 10^7$ S·m^{-1}.

The most difficult task was to define the various types of earth. It is problematic to determine the exact material properties of earth because we do not know its exact composition. The resistivity of earth depends on its composition; in the case of soil it can range between $\rho = 10^{-1} \div 10^2$ Ω·m; the resistivity of clay is $\rho = 10 \div 10^2$ Ω·m and the resistivity of sand is $\rho = 10^2 \div 10^5$ Ω·m. A gravel subgrade will also have higher resistivity – in the range of $\rho = 10^2 \div 10^5$ Ω·m. The Comsol program requires entering of data by means of electric conductivity; we therefore converted resistivity to conductivity. In the present case, we selected the values for the earth in the following way: compacted antifreeze material $\mu_r = 1$, $\sigma = 0.1$ S·m^{-1}: this material is under the platform and the rail in the model, and hard surface $\mu_r = 1$, $\sigma = 0.001$ S·m^{-1}: this surface is located under the gabion in the model [6], [7] and [8].

3.3. Entering the Conditions

Another important step prior to starting the calculation is the entering of the boundary conditions. The condition of the zero electric potential $\varphi = 0$ V was entered on the bottom side of the model; this condition simulates the ground in the model. The condition of the electric potential $\varphi = 500$ V was set for the upper surface of the rail. The electric potential value is the presumed value which can occur on the rail in the case of a breakdown of the surge arrester. This value is based on measurements and on the values given in Tab. 6 in 9.3.2.3 CSN EN 50122-1 ed. 2. The connection to the return circuit is through a device for limiting voltage (a surge arrester), which will ensure a disconnection in a short time of 0.02 s in the case of voltage values which are not allowed according to Tab. 6 and which may reach up to 870 V for a short period. The surge arresters are checked every 6 months during maintenance work on the overhead lines according to Annex No. 1 of SZDC internal regulation E 500.

The lighting cable was assigned the electric potential value of $\varphi = 230$ V. Other external boundaries were assigned the condition of electric insulation $\vec{n} \times \vec{J} = 0$.

3.4. Covering the Model with a Mesh

After the boundary conditions are set, the model is prepared for generating a mesh. Covering the model with a mesh results in the creation of nodes; the required partial differential equations were calculated in these nodal points. The parameters for dividing the mesh can be set manually on the individual volumes, surfaces or lines. A further setting is the density of the mesh. The denser the mesh is, the more nodal points there are and the higher is the number of the partial differential equations, which also makes the solution more exact. However, the calculation also becomes more difficult at the same time. In our case, a fine division corresponding to the number of approx. 300000 nodal points was sufficient. As Fig. 2 shows, the program makes the mesh intuitively denser in the smaller areas.

A stationary linear solver was used for the solution.

3.5. Simulation Results

The simulations were carried out on a model of the SUDOP-type platform. We were particularly interested in how high the values of the stray currents are on the platform, in the concrete foundations and in the gabion. Figure 3 shows the distribution of the electric potential in the model.

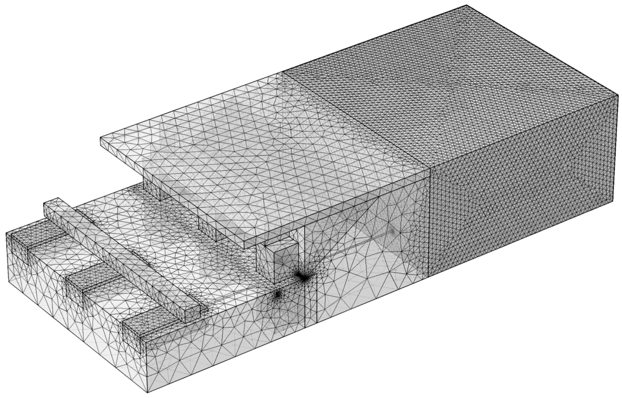

Fig. 2: Model covered with a mesh.

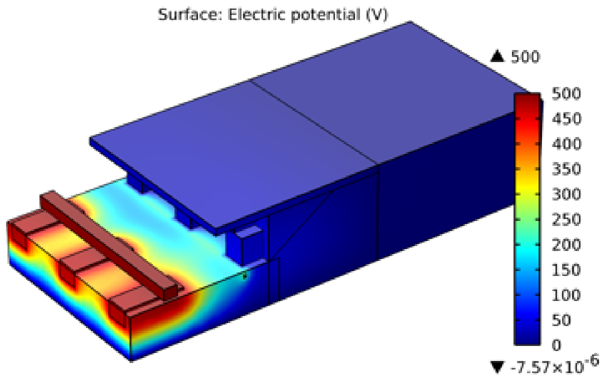

Fig. 3: Distribution of electric potential.

As presumed, the highest value of the electric potential is on the rail and in its vicinity. Its values decrease in the direction away from the rail. The value of the electric potential in the platform is approx. 30 V, the value of the potential in the concrete foundations under the platform is approx. 45 V and the value of the potential in the gabion is around 2 V.

The distribution of the current density is more reflecting (Fig. 4). The maximum value of the current density is in the rail, and because it is a faulty state in which there is a breakdown of the surge arrester, there is also a high value in the gabion. In the concrete foundations under the platform, in the part which is above the ground, the value of the current density is around 300 A·m^{-2}. In the area of the platform, the current density value is around 150 A·m^{-2}.

In the model, the conductor is anchored to the bottom of the rail, between the second and third sleeper, and it is connected to the gabion at depth of 0.5 m under the ground surface. The results are made trans-

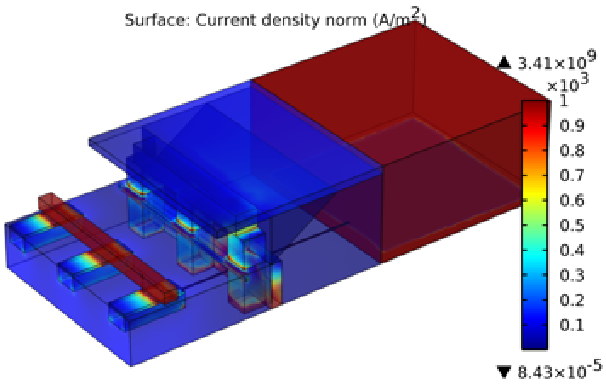

Fig. 4: Distribution of current density.

parent so that it will be possible to see the influence of the conductor on the concrete foundations.

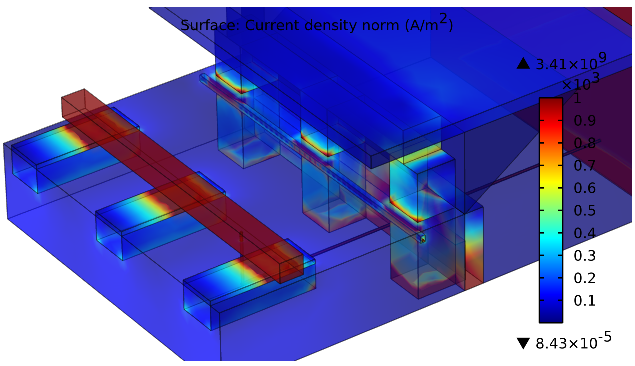

Fig. 5: Distribution of current density, concrete foundations in detail.

Figure 5 shows a detailed view of the concrete foundations laid in the ground. The figure shows that there are very high values of current density in the concrete foundations around the conductor. The value of the current density in the remotest concrete foundation is approx. 600 $\mathrm{A{\cdot}m^{-2}}$. The current density in the middle concrete foundation is approx. 1400 $\mathrm{A{\cdot}m^{-2}}$ and the highest value is in the first concrete foundation at approx. 3500 $\mathrm{A{\cdot}m^{-2}}$. This value is approx. 6 times higher than in the case of the remotest concrete foundation. This distribution is caused by the fact that the cable connecting the rail with the gabion is in the vicinity of the first foundation. Furthermore, the figure shows an increase in the current density in places where the concrete trough with the lighting cable is located.

In order to determine the direction of the current density, we used representation by means of arrows (Fig. 6). It is apparent that the current passes from the rail to the ground. Furthermore, the presence of the current in the surroundings of the lighting cable is also clear, the current passes from the cable through the concrete foundations into the ground. As presumed, we can see a higher increase in the current density also

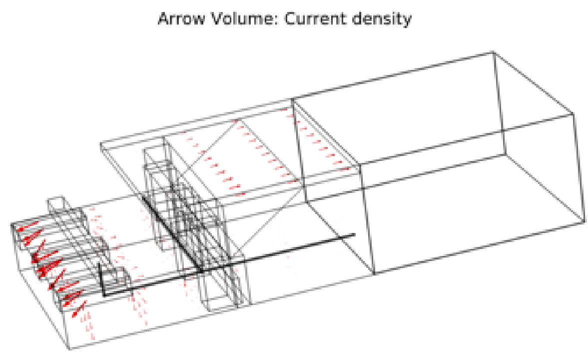

Fig. 6: Distribution of current density, arrows.

in the surroundings of the cable connecting the rail and the gabion. Higher values and the direction of the current density can be also seen in the platform.

4. Conclusion

Our aim was to determine the intensity and direction of stray currents in the model of the SUDOP-type platform. The results given above clearly show what direction and intensity the current density and electric potential have in the model. For the simulation, we assumed a value of 500 V. The surge arresters are checked every 6 months during maintenance work on the overhead lines according to Annex No. 1 of SZDC internal regulation E 500 [3].

The resulting values give us a certain idea of the distribution of the electric potential and current density and also of the flow of the current inside the concrete foundations and in the ground under the platform.

As the models given above show, the stray current passes from the rail to the concrete sleeper, and from there it passes into the ground. Then it passes through the vertical concrete foundations. A part of the current flows directly into the ground, while another part of the current flows through the surface of the platform and the gabion into the ground. The railway lighting cable which is located next to the concrete foundations is also responsible for increasing the current density in the foundations. Last but not least, the simulated breakdown of the surge arrester has also a negative influence. This fault results in up to 13 times higher values of the current density than in the case of the fault-free state.

Figure 7 shows how a stray current disrupts the concrete foundations in the vicinity of the railway substructure.

As can be seen, this fact has an adverse effect on the concrete sleepers under the rail and also on the concrete foundations of the platform. One of the pos-

Fig. 7: Illustrative photo.

sible consequences of these stray currents is that their occurrence may cause degradation of the concrete and subsequently its dusting and cracking.

In the next step, we would like to focus on how it is possible to decrease the impacts of these stray currents.

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