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Estimation of current distribution in the electric railway system in the EMTP-RV

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ABSTRACT

Current distribution in the electric traction system is an important factor regarding the electromagnetic influences on the surrounding metallic structures. The current value directly determines the magnetic field and consequently coupling of the systems. A single rail traction system can be equipped with return conductor. The return current flowing through return conductor has an opposite direction of supply current and decreases coupling and interferences.

This paper presents the AC current distribution for both designs, with and without return conductor. Also, the soil resistivity is varied. The higher the soil resistivity, the higher is the amount of return current in rails and return conductor. The different construction of return conductor results in different impedance of return path. The relations of return conductor construction and return current value are analysed.

Lightning can directly impact different traction system elements such as contact network, tower or return wire. The current distributions in several cases of lightning impacting different traction system elements are presented.

1. Introduction

Electric railway systems have very heterogeneous constructions and power supply configurations. Generally, those systems can be divided with regard to their supply voltage to DC (1.5 kV and 3 kV) and AC (15 kV, 16.6 Hz; 25 kV, 50 Hz) [1,2]. The tracks can be realized as single-track, double-track and multi-track depending on the traffic demand and intensity. The electric traction vehicles are supplied from the contact network and the return current flows through the rails, return conductors and ground. The current in the electric railway system induces voltages in the surrounding metallic structures such as telecommunication lines and pipelines, [3–7].

The paper presents a model of 25 kV, 50 Hz railway supply system. The influence of railway system construction elements on return current distribution was analysed. The developed model enables the calculation of the rail impedance [8] and current distribution with respect to the rail cross-section. The conductivity of the rails is often unknown and its value varies along the rail route. Therefore, in the simulations, the rail conductivity should be varied in the wide range [9]. The distance between the traction vehicle and traction substation also determines the value of the return current in each return path. Different return conductors were considered including different cross-sections and materials such as copper and aluminium conductor steel reinforced. Also, the case without return conductor has been analysed.

The increase of the return current in the metallic structures in the vicinity of the tracks reduces the total magnetic field of the railway line. This reduces induced voltages in the surrounding metallic structures such as telecommunication lines and pipelines [10]. Induced voltages have many negative effects on underground gas pipelines, such as the possibility of creating electric spark or increase the corrosion of material [11]. The corrosion is caused either by leakage currents or by induced voltages in case of short circuit on the electric traction system. A spark can be dangerous if it penetrates the inside of the pipeline which is used for the transportation of flammable materials, while the corrosion destroys the pipeline itself [3].

A new approach for current distribution calculation is developed including both AC and lightning current. The models have been developed in the EMTP-RV for the estimation of the current distribution in the railway system in normal operation and in case of lightning impact. The system impedances were determined for different constructions of the railway line. The electrical and geometric parameters with the most significant impact on the current distribution were determined. The parametric analysis was performed to study the impact of conductor's cross-section, conductivity and soil resistivity on the current distribution.

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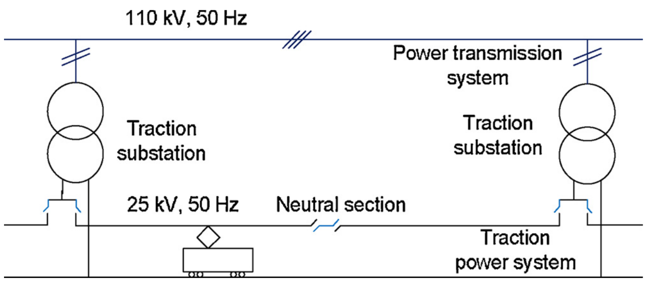

Fig. 1. Electric traction system.

2. Single rail system construction and operation

The 25 kV, 50 Hz railway supply system consists of railway traction substation, overhead contact line, bypass line, rails and return wire [1]. The grounding system of the rails is performed by connecting one or both rails to the grounded towers of contact network. Supply current flows through the contact network (contact wire and catenary conductor) and returns to traction substation. Current in each of those parts depends on numerous parameters.

Fig. 1 shows a typical 25 kV, 50 Hz electric traction system.

The electric traction system is supplied from the electric power transmission system through power transformers located at the traction substation. These transformers are connected to two phases of the power transmission system. The traction power supply network is separated by a neutral section in two parts which that are supplied from different traction substations.

The electric traction system is supplied with electrical energy through power transformers 110/25 kV. The traction supply network consists of the conductors placed above the rails (Fig. 2). Conductors are mounted on the masts next to the railway. Locomotives are supplied with electrical energy over the pantograph and the current flows back through the rails.

The overhead line consists of a catenary conductor and contact wire which are connected. The locomotive pantograph slides over the contact conductor.

Catenary conductors are kept at a mechanical tension because the pantograph causes oscillations in the conductors and the wave must travel faster than the train to avoid producing standing waves that would cause the conductors to break. Tensioning the line makes waves travel faster. The design of power traction network varies depending on the number of tracks which are electrified and the position (open or railroad station). Fig. 2 shows the cross-section of single-track line. The nominal cross section of contact conductor is 100 mm^2, and catenary conductor is 65.8 mm^2. Since the distance between those two conductors is not constant, in EMTP (transmission line model in EMTP-RV) the height of the tower is 6.5 m and vertical height midspan is 6 m. At the temperature of 80 °C, the maximum operation current for the copper wires is limited to 4 A/mm^2. Therefore, the maximum operating current for contact wire is 400 A and for catenary wire 260 A. About half of the total current returns through the rails while the remaining current flows to the ground [3].

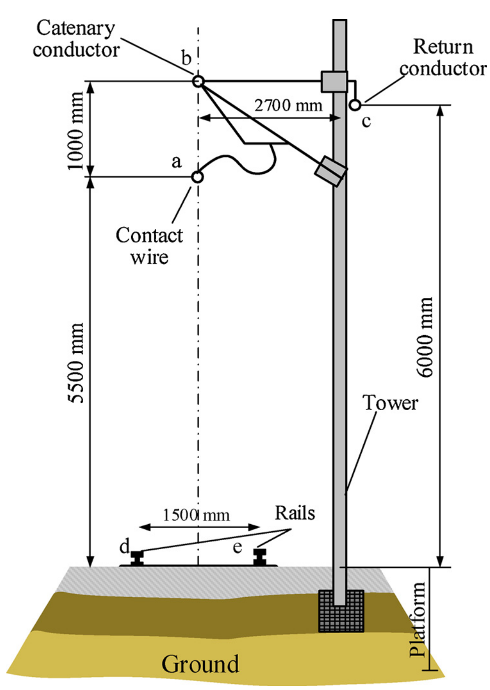

Fig. 2. Cross section of single-railed open railroad 25 kV, 50 Hz.

The electrical parameters of standard track UIC60 are used. The cross-section of each rail is 76.7 cm^2 so the diameter of equivalent cylinder is 9.88 cm.

Traction power network in the traction system consists of isolated sections in order to avoid the circulating currents that would occur between adjacent traction substations. Circulating currents could occur in the supply network when the contact sections are simultaneously connected to two substations of the electric power system. The sectioning is executed in the section switchgear by disconnectors. Also, the sectioning is performed near the traction substations at the end of radial power supply sections.

3. EMTP model of railway system

The model of single rail 25 kV, 50 Hz traction system is developed. The traction section is represented by frequency dependent (FD) line model in EMTP considering the geometry of the system and soil resistivity. Rail conductivity is taken into account based on field measurements of tower footing resistance in the contact network.

13 km long section of the electric traction system is modelled, from electric traction substation to electric traction vehicle (locomotive). FD line model in EMTP-RV includes different values of soil resistivity, with and without return conductor. The geometry of the system is presented in Fig. 2. The distance of return conductor from rail axes is 2.7 m.

The model was developed for two values of soil resistivity, 100 Ωm and 1000 Ωm. Soil resistivity and rail to ground conductivity values are parameters that are variable and have a different value in each traction part. The model is divided into segments of different lengths. Next to the traction substation and traction vehicle each segment has a length of 100 m, and in the other parts of the model the length of the segments are 1000 m.

In this paper the average ground conductivity of 1 S/km was assumed. The current source is connected directly to catenary conductor and contact wire. The nominal current is 100 A corresponding to expected current on the single track sections. Moreover, the Cigre concave lightning current source is added in the model. In the first case, it was connected to contact line and in the second case to return the conductor.

The part of model next to current source representing electric traction substation is shown in Fig. 3.

Traction substation is presented by AC current source and traction vehicle by RL element. Since in this paper only the magnetic coupling and current distribution is studied, the type of the traction vehicle is not crucial for simulations. More sophisticated models of rotating machine such as detailed winding model should be used in case when it is necessary to compute voltage distribution along the machine winding, which is not considered in this paper.

Sensitive line is incorporated in FD line model in the first kilometre next to the substation. The distance between source and load is 12 km but additional 1 km of the line is connected at both sides. The current $I_{railRO2}$ flows through the rails out of the supply segment and penetrates