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Computer Simulation of Fast Transients in Railway Systems

***Abstract**. The railway installations are particularly endangered by the direct lightning discharges in the supplying system or equipment and indirect lightning strike. Lightning overvoltages are the most unfavorable voltage stresses for the railway traction. The objective of paper is to develop modeling and digital simulations involving fast front waveforms. The creation of digital models for the analysis of work of the equipment (power system, rails, induced voltage, traction tower etc.) requires the knowledge of data organizing file and declarations used by simulation programs. The paper comprises results of calculations of overvoltages in the railway traction, performed using software package a EMTP-RV simulation software.*

***Streszczenie.** Symulacje komputerowe pełnią ważną rolę w badaniach oddziaływania elektromagnetycznego urządzeń elektroenergetycznych. Wykorzystując w symulacjach sprawdzone modele matematyczne urządzeń i zjawisk fizycznych z powodzeniem można uzupełniać badania laboratoryjne i „poligonowe" rzeczywistych układów. W referacie przedstawiono wyniki modelowania komputerowego sieci trakcyjnych przy wymuszeniach szybkozmiennymi impulsami prądowymi reprezentującymi impulsy pochodzenia atmosferycznego lub łączeniowego (**Symulacje komputerowe szybkozmiennych stanów nieustalonych w sieci trakcyjnej**).*

Keywords: railway systems, transients modelling, transmission line.
Słowa kluczowe: siec trakcyjna, modelowanie szybkozmiennych przebiegów, linia transmisyjna.

Introduction

Lightning overvoltages are the most unfavourable voltage stresses for the railway traction. These threats cause interference in the equipment services and signal transmission system. The creation of digital models for the analysis of work of the equipment (power system, rails, induced voltage, traction tower etc.) requires the knowledge of data organizing file and declarations used by simulation programs. The paper comprises results of calculations of overvoltages in the railway traction, performed using software package a EMTP-RV simulation software. The overhead lines are represented by multi-phase models considering the distributed nature of the line parameters due to the range of frequencies involved.

A possibility of the transient analysis of examples of dynamic characteristics of the selected model is presented. The equivalent model of the rail, interpolation methods and the rail conductor are presented. They will be utilized in future work during estimation of impedance of the track circuits based on the current obtained results and recognized possibility.

Surge transients

In Polish standards [1, 2] there are presented general requirements and research regarding electromagnetic compatibility (EMC) of devices, sets of devices and systems destined for automation and measurement. The range of applying these standards encompasses: designing, production, technical acceptance, installation and exploitation of the devices destined for automation and measurement. They define a group of standard surge tests waveforms.

Traditionally, the 1.2/50 μs voltage waveform was used for testing the basic impulse level of insulation (BIL). The 8/20 μs current waveform was used to inject large currents into surge-protective devices. Mathematical representations of the nominal waveforms would be convenient for engineers who wish to perform computer simulations of transient protection circuits are given by equations:

(1) $$u(t) = A \cdot U_m \cdot \left(e^{-\alpha t} - e^{-\beta t}\right)$$

(2) $$i(t) = A \cdot I_m \cdot t^3 e^{\frac{-t}{\tau}}$$

where: *A* - correction factor; α, β, τ - time constants.

These equations are useful for designing surge generators and for simulations of surge performance on computers.
In the group of standards regarding railway applications, for the network compatible with PN-EN 50163 [3], the PN-EN 50124-2 [4] standard introduces, apart from the abovementioned 1.2/50 μs and 8/20 μs surges, impulses for testing the basic impulse level of insulation. It is 4/10 μs current surge defined in the PN-EN 60099-1 and –4 standard [5, 6] and in PN-EN 50123-5 [7]. Moreover, the PN-EN 60099-4 standard also suggests applying 30/80 μs current surge with the peak value equal 40 kA for testing surge arresters in the AC networks.

In Fig. 1 there are presented the waveforms of 4/10 μs and 30/80 μs current impulses. The parameters of approximating those impulses with double exponential functions defined by (1) are A = 8.067 α=0.21•10^6 μs; β = 0.295•10^6 μs – for 4/10 μs impulse and A = 10.96; α = 0.029•10^6 μs; β = 0.038•10^6 μs; – for the 30/80 μs impulse.

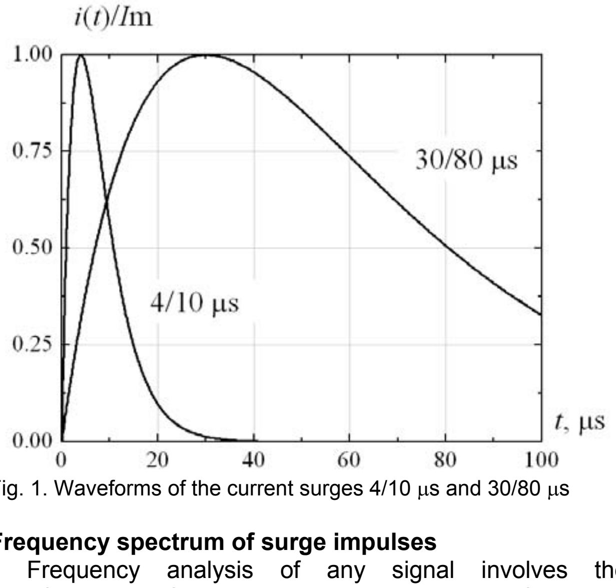

Fig. 1. Waveforms of the current surges 4/10 μs and 30/80 μs

Frequency spectrum of surge impulses

Frequency analysis of any signal involves the transformation of a time-domain signal into its frequency components. The need for describing a signal in frequency domain exists because signal processing is generally accomplished using systems that are described in terms of frequency response.

Converting the time-domain signals and systems into the frequency domain is very helpful in under-standing the characteristics of both signals and systems.

The mathematical dependencies presented with formulas (1) and (2) which are defining the shapes of impulse courses have easy to determine analytical forms of frequency characteristics. For the double exponential relation (1) we obtain the Fourier transform:

(3) $$I(\omega)=AI_m\left(\frac{1}{\alpha+\mathrm{j}\omega}-\frac{1}{\beta+\mathrm{j}\omega}\right)$$

Amplitude characteristics of impulses 4/10µs and 30/80µs presented with analytical dependence (3) with unit amplitudes I_m = 1 A are presented in Fig. 2.

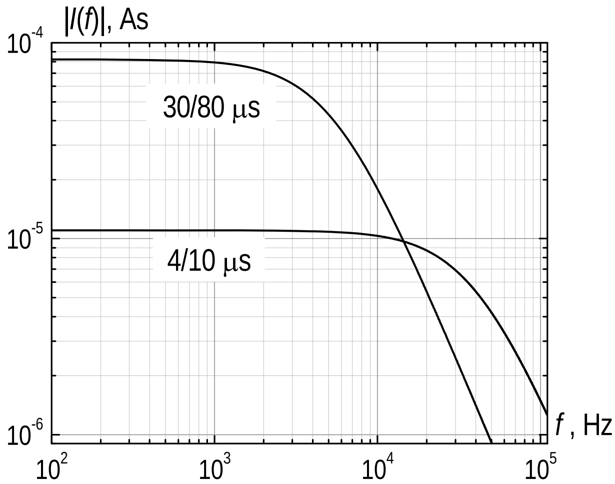

Fig. 2. Amplitude characteristics of the 4/10 µs and 30/80 µs surges

If the issue of determining electrical parameters is a linear one, it may be used for testing its frequency characteristics. Circuit frequency characteristics may be combined with any stroke with the help of weaving technology and with the help frequency analysis programs we may obtain a circuit response.

(4) $$Y(\mathrm{j}\omega)=H(\mathrm{j}\omega)X(\mathrm{j}\omega)$$

Determining of the temporal function for the response frequency characteristics consists in calculating an inverse Fourier transform.

(5) $$f(t)=\frac{1}{2\pi}\int_{-\infty}^{\infty}Y(\mathrm{j}\omega)\,\mathrm{e}^{\mathrm{j}\omega t}\mathrm{d}\omega$$

Electric traction parameters in frequency domain

The amplitude spectrum impulse characteristics presented in Fig. 2 show that for the simulation of circuits containing overhead conductor in the presence of lossy ground, one should apply models providing correct results of electrical parameters of this conductor for the frequencies reaching tens of kilohertz. A traction system in the form of a rails and contact wire may be modelled similarly to the wire of power system. On the basis of geometrical and wire data we may determine an appropriate calculating model of the analyzed circuit taking into account its own and mutual wire parameters. Computer programs based on circuit modelling, with the help of which we may test electrical properties of overhead ducts in the wide range of frequency and consideration of ground electrical parameters come from the EMTP family: EMTP-ATP or EMTP-RV [8, 9].

To analyze the frequency dependencies of the parameters of conductor located over ground there have been calculations of input impendence Z_{in} of the circuit in the form of contact wire and a single rail, with length about ten kilometres ended with resistance R_C equal characteristic impedance Z_C obtained from the equation:

(6) $$Z_C=\frac{1}{2\pi}\sqrt{\frac{\mu_0}{\varepsilon_0}}\ln\left(\frac{2h}{r}\right)\approx 60\ln\left(\frac{2h}{r}\right)$$

where: h – height conductor above ground; r – radius of conductor.

A contact wire of the cross-section equal S = 320 mm2, placed at a height equal h = 5.6 m over the ground with resistivity equal ρ_g = 100 Ωm, for which the wave impendence is Z_C = 420 Ω has been accepted. For a rail of S60 type, with a substitute radius of the cross-section equal r = 0.05 m, placed at a height of h = 0.32 m, the wave impendence is Z_C= 150 Ω. The calculation scheme of the input impendence Z_{in} determined in the EMTP-RV program is presented in Fig.3.

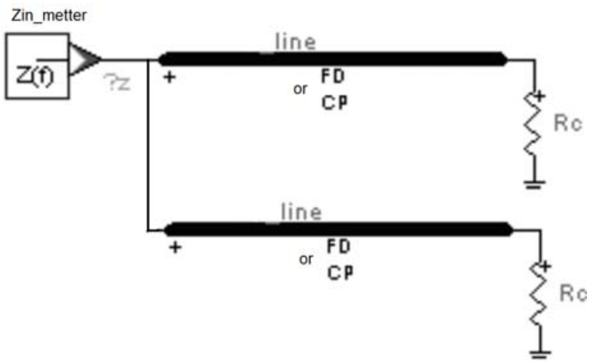

Fig. 3. Calculation scheme of the input impendence of the conductor in the EMTP-RV program

The calculation has been performed for two models of an overhead line implemented in the program: Constant Parameter (CP) line model and Frequency Dependent (FD) line model.

In Fig.4 there are presented frequency characteristics of the input impendence Z_{in} of the contact wire and in Fig.5 for the single rail track.

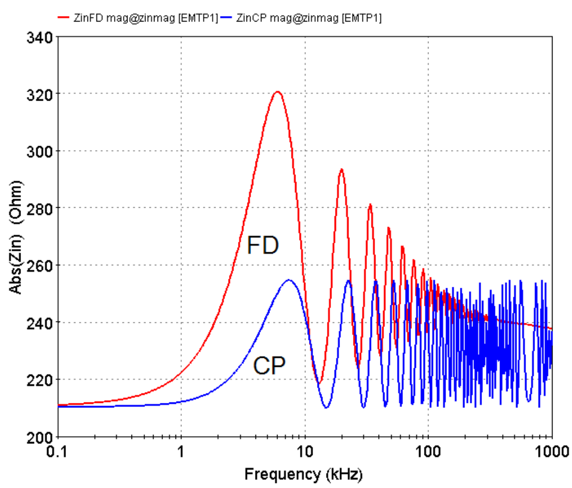

Fig. 4. Characteristics of the magnitude of the input impedance of the contact wire

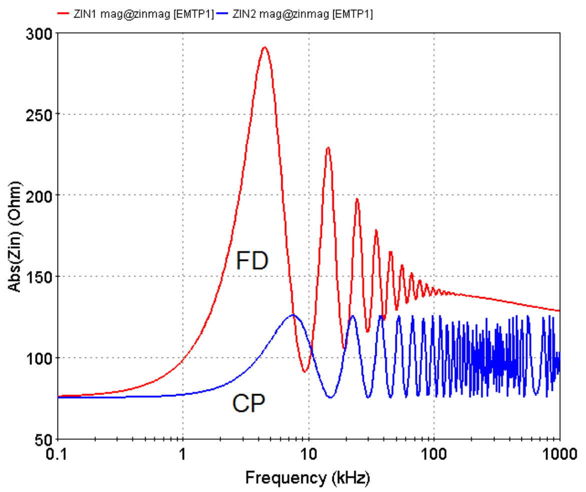

Fig. 5. Characteristics of the magnitude of the input impedance of the single rail track

Transients simulations in the traction system

The circuit model of the section of traction system is presented in Fig.6. Its represents two span 72 m long and three traction towers. System is terminated with two 10 km long traction lines on either side. The middle tower (point A) was subjected to surge current source with 4/10 μs waveform (Fig. 1) with peak current value I_m = 25 kA. Traction towers are modelled as section of transmission line with surge impedance Z_T = 280 Ω. The tower grounding is modelled by DC resistance R_g = 1000 Ω.

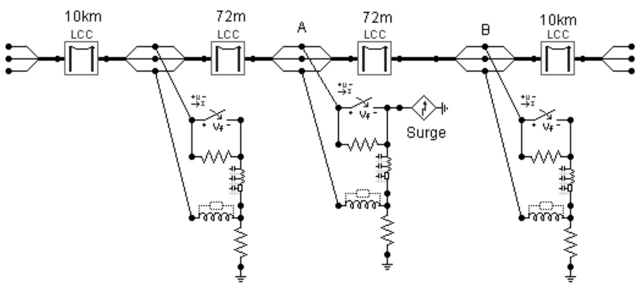

Fig. 6. Scheme of modeled section of the rail traction

Selected simulation results of overvoltages in the traction system are presented in Fig.7 and in Fig.8.

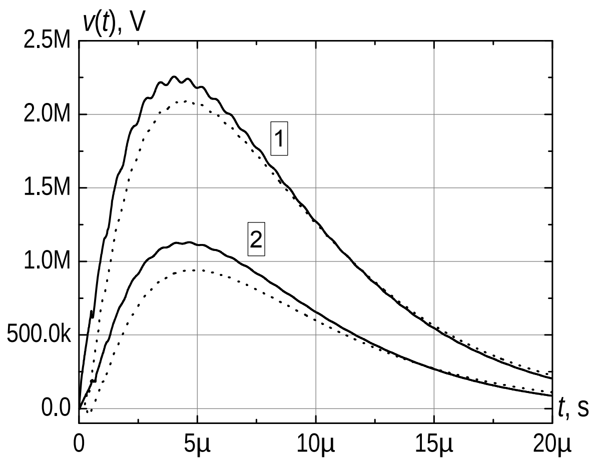

Fig. 7. Voltages on the contact wire (1) and on the outer rail (2) for CP line model: (solid line is for point A and doted line is for point B in Fig. 6 respectively)

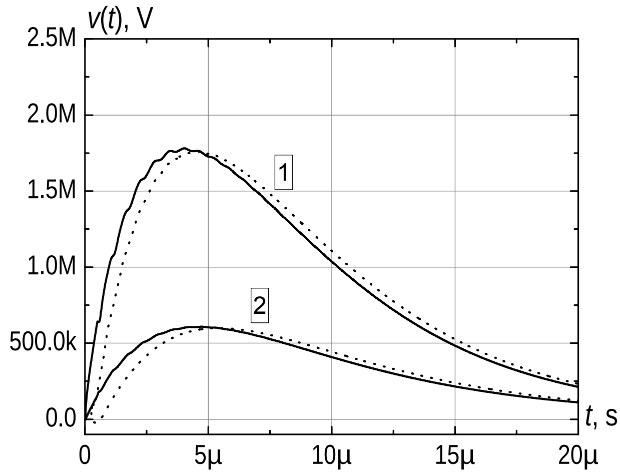

Fig. 8. Voltages on the contact wire (1) and on the outer rail (2) for FD line model: (solid line ii for point A and doted line is for point B in Fig. 6 respectively)

Conclusions

Fast surges can cause many faults and outages on traction system. The identification of the reason of voltage disturbances (particularly overvoltages) in traction system is of considerable importance. The presented examples of standard surge testing waveforms shows wide range of its parameters: rise time and time to half value on crest. Amplitude characteristics of presented impulses reach tens of kilohertz and it determines using models of elements of the analyzed system which correctly represent the electrical properties of traction system in wide range of frequencies. Fig. 7 and Fig. 8 show that the overvoltages are dependent on the line models.

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