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SIMULATIONS OF FAST TRANSIENTS IN A TYPICAL 25 kV a.c. RAILWAY POWER SUPPLY SYSTEM

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Abstract: Railway power lines as any other outdoor overhead conductors are exposed to lightning strokes. Overvoltages generated by a lightning surge may severely decrease the overall system reliability due to possible damages of powering and signalling equipment. Hence an appropriate design of lightning protection is crucial. This paper presents computer simulations of lightning phenomenon (Fast Transients) in a typical railway catenary system conducted in PSCAD software. Detailed numerical model consisted of cables, overhead catenary lines, surge arresters, transformers and rails. A few modelling approaches were used and compared. The outcome of such analysis can be helpful in determining possible overvoltages in railway system along with a proposal of ratings and locations of additional surge arresters' installation.

Keywords: railway, lightning, fast transients, PSCAD

1. INTRODUCTION

Railway transportation remains very popular despite of rapid growth of automotive and aircraft industry in recent years. This strong position of railway on the world's communication map is to be owed to innovation that often goes unnoticed. Modern equipment that is applied for traction systems, more than ever imposes the need for a careful and accurate coordination of a protection system. This also concerns the overvoltage protection, which includes disturbances of atmospheric origin.

Regardless of technology applied (AC or DC) it is evident that railway equipment is most of the time exposed to phenomena such as lightning. Therefore it is essential that lightning surge protection is configured accordingly. This is usually done by means of utilization of surge arresters. Computer simulations are very useful during this process, thus providing valuable information about the system response during abnormal, transient conditions.

2. BACKGROUND

This paper addresses only a particular type of traction system: 25 kV supply voltage [2]. Hence most elements such as tower or lightning current are modelled based on CIGRE, IEEE or IEC standards and guidelines. As reported in [2], the necessity of adopting additional protection is worth to be verified. In general, there are two ways to increase the lightning protection level: surge arresters and lightning wires. Only the first solution is addressed in this paper.

Lightning overvoltages in power systems are caused by [7]:

a) Stroke to phase conductor (shielding failure),
b) Stroke to shielding wire (backflash),
c) Stroke to ground in line proximity (induced voltage).

The phenomenon that will be investigated herein is essentially a stroke to the phase conductor as shielding is assumed to be not provided [2]. Due to unpredictable nature of lightning phenomenon it has to be represented in the standardized way, based on numerous measurements. It has been reported in [8] and [14] that the median value of the lightning current crest equals 31 kA. In CIGRE brochure this value equals 33 kA and one percentile level is approximately 130 kA [1]. This paper presents the results for two values of the lightning current: 31 kA and 130 kA. For finding the most relevant components for modelling, the reference value of 31 kA lightning current with first stroke wave shape has been used. The final configuration considered most suitable shall be then further analysed. A shape of the lightning surge waveform described by CIGRE is applied. The first and the subsequent strokes were investigated.

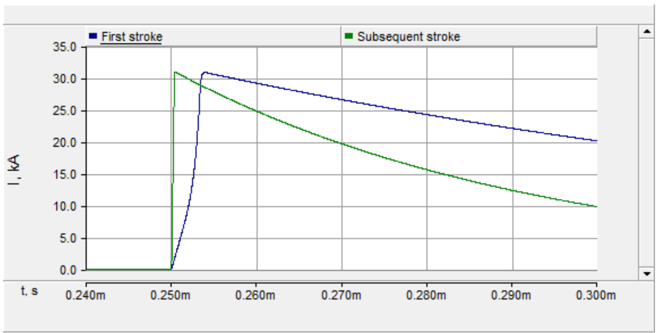

Fig. 1. CIGRE lightning current waveform implemented in PSCAD. First stroke – $t_h = 77.5$ µs, subsequent stroke $t_h = 30.2$ µs

The diagram of a considered typical system, which presents the location of lightning strokes as well as a track cross-section, is depicted in Fig. 2.

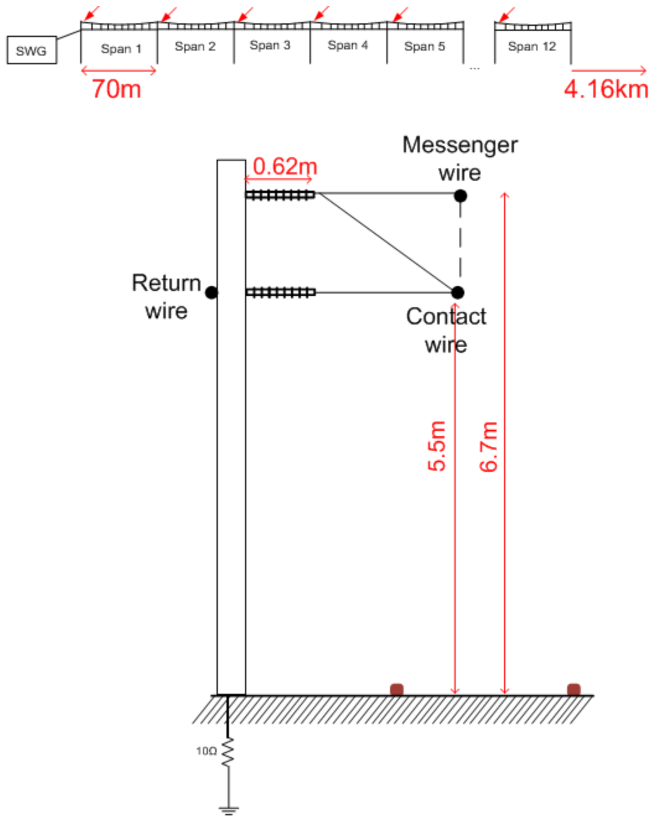

Fig. 2. Overall diagram of the modelled network. SWG stands for switchgear, including a power transformer and arresters.

3. MODELLING PRINCIPLES FOR FAST TRANSIENTS

Most of the principles of the system modelling can be adopted from the procedures for transmission or distribution power systems. Papers and standards such as [1, 5, 6, 7, 12] address this issue in detail. Therefore most of the equivalent elements needed for model preparation can be listed in a table and do not need any additional comments. However, there are certain parts, especially catenary and running rails that could be represented in several ways (or completely neglected). Thus, the paper contains an appropriate comparison between those models.

Table 1. Equipment modelling data for lightning analysis

Component	Comments
Catenary	Frequency dependent model, l = „as per layout”
Pole	Z = 220 Ω
Switchgear	C = 26 pF/m (5m)
Voltage transformer	C = 125 pF
Current transformer	C = 75 pF
Surge arrester	*IEEE model*
Voltage transformer	C = 80 pF
Oil-air bushing	C = 200 pF
HV cable	Frequency dependent model, l = „as per layout”
rails	Resistance, surge impedance or absent
Power transformer	1 nF

To ensure best accuracy [7] surge arrester model proposed by IEEE [4] has been used. This model includes arrester response in the wide range of frequencies. Hence despite its complicated structure and iterative preparation procedure it is recommended for transient analyses. The model structure is presented in Figure 3. The characteristics of nonlinear elements A_0 and A_1 are depicted in Figure 4. The data for arrester modelling were based on ABB MWK [9] air insulated surge arrester data sheet (U_r =36.3 kV). Cable screens voltage limiters were represented in a similar manner.

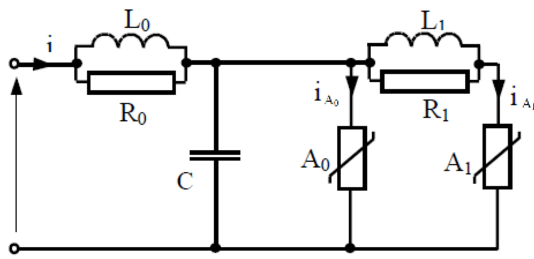

Fig. 3. IEEE surge arrester structure. L_0 = 77.4 nH, R_0 = 38.7 Ω, C = 0.2584 nF, L_1 = 2.95 μH, R_1 = 25.155 Ω

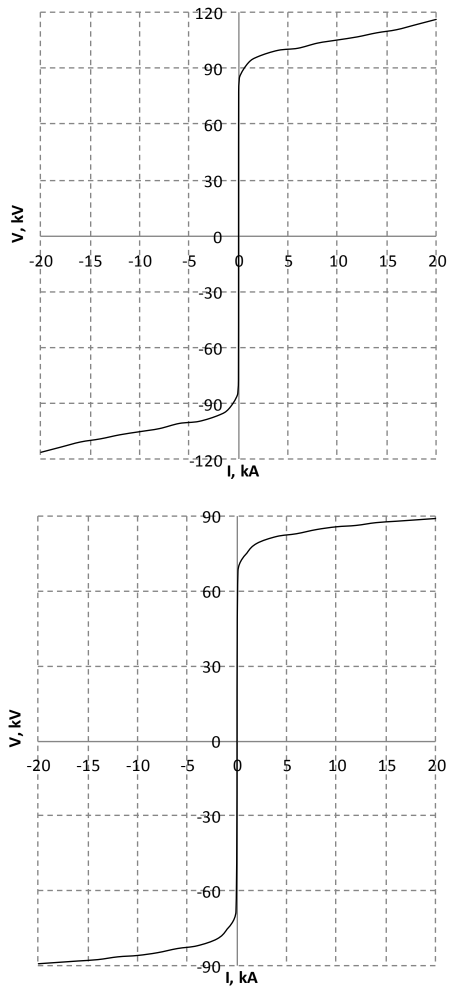

Fig. 4. IEEE surge arrester structure. Top – A_0, bottom – A_1

From the modelling point of view the most complicated element to be represented is a catenary system. This is due to the fact that it consists of a few conductors that have horizontal and vertical orientation. This may pose a numerical problem while solving the system, due to the fact that consecutive parts of catenary are very short. Such short connections require a very small simulation time step, which results in considerable computational effort. The typical catenary system consists of a contact conductor, messenger and dropper wires and a return system wire. As previously mentioned, shielding wires may be also applied [2]. Data that have been used for catenary modelling are presented in Table 2. A comparison between modelling of dropper wire as a distributed parameters element and lumped inductance 1 μH/m [7] will be presented herein. The case with dropper wire that is completely eliminated shall not be addressed.

Table 2. Catenary data

	Contact wire (Cu)	*Messenger wire (Bzll)*	*Dropper wire (Bzll)*	*Return wire (Al)*
Cross section	107 mm^2	65.8 mm^2	16 mm^2	116.2 mm^2
Diameter	12.2 mm	10.5 mm	6.2 mm	14.0 mm
Composition	solid	1X19, 2.10 mm	84 strands (d = 0.5 mm)	7x2+30x2.5 mm
Maximum resistance at 20°C	0.171 Ω/km	0.42 Ω/km	1.73 Ω/km	0.307 Ω/km

The influence of rails modelling procedure is also worth verifying. Various sources report a few ways of modelling approach [12, 13]. This is why the three approaches were investigated – rails as surge impedance ($Z = 45$ Ω, v = 69.8 m/μs), rails as lumped resistance and rails neglected. UIC 60 rail type was used for the study presented in this paper (cross section 6334 mm^2, resistivity 0.207 Ωmm^2/m).

Due to short insulators there is a high possibility of flashover and therefore these elements should also be accounted for in the model. A leader progression model has been chosen for this purpose. Additionally 8 pF lumped capacitance has been connected across each insulator [10]. The leader velocity and its propagation are described by a formula (1) given by [11]:

$$\frac{dL}{dt} = k \cdot u(t) \cdot \left(\frac{u(t)}{g-L} - E_0\right) \qquad (1)$$

- k – constant [m^2/(V^2 s)],
- E_0 – average gradient voltage [V/m],
- $u(t)$ – voltage across the gap [V],
- g – gap length [m],
- L – leader length [m].

Cantilever tube was modelled using 1 μH/m lumped inductance. Grounding resistance of the catenary pole was assumed to 10 Ω.

4. EXEMPLARY FAST TRANSIENTS ANALYSIS OF a.c. RAILWAY SYSTEM

The system that was investigated is a typical single phase 25 kV, AC power supply system that is described by standards [2]. Maximum system voltage is assumed to be 27.5 kV and all the conducted simulations were done using this value. The major components of a system are depicted in figures 2 and 5. Screens of cables are single end bonded with voltage limiters (U_r = 1.25 kV) installed at the switchgear end of each cable.

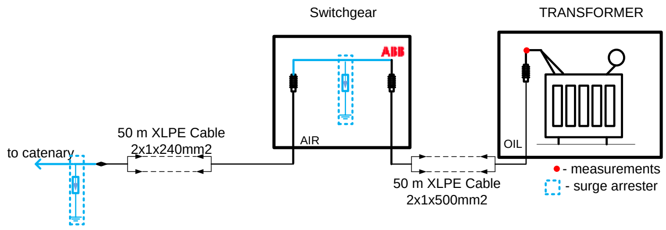

Fig. 5. General overview of the analysed system

The list of cases and configurations that were analysed is presented below:

- Evaluation of rails modelling influence (rails modelled as surge impedance and resistance are completely neglected),
- Evaluation of dropper wire influence (frequency-dependent and lumped element),
- Lightning surge influence on system performance.

All simulations were conducted in such way that the lightning surge location was also a variable. Hence there are thirteen cases per each configuration. This situation was depicted in a simplified way in Figure 2. The plotted results with appropriate descriptions are placed in the section that follows.

5. SIMULATION RESULTS

Exemplary waveform measured at the transformer winding is presented in Figure 6. The following results are presented by means of summarizing plots that are easier for comparison.

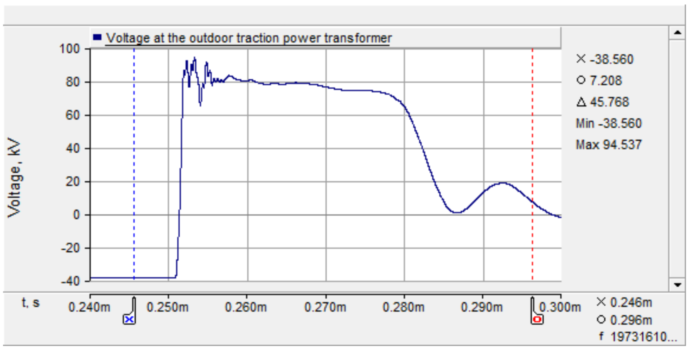

Fig. 6. Exemplary transient response at the transformer winding. First stroke, 31 kA, rails as resistance, dropper wire as inductance

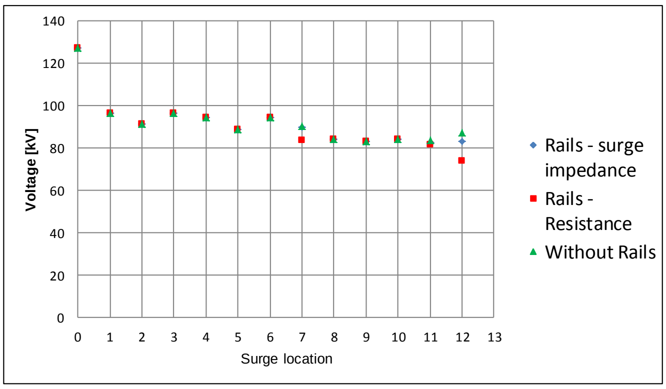

Fig. 7. Influence of rails modelling in configuration with dropper wire modelled as frequency dependent element. 31 kA first stroke applied. Voltage at the power transformer

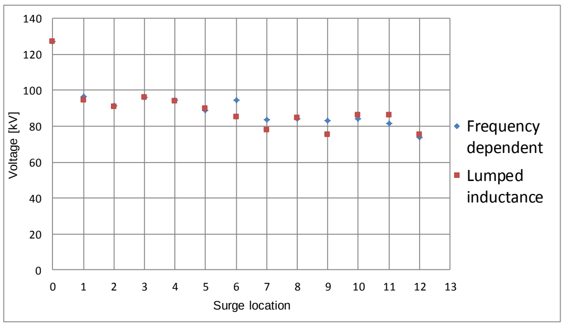

Fig. 8. Influence of dropper wire modelling in configuration with rails modelled as resistance. 31 kA first stroke applied. Voltage at the power transformer

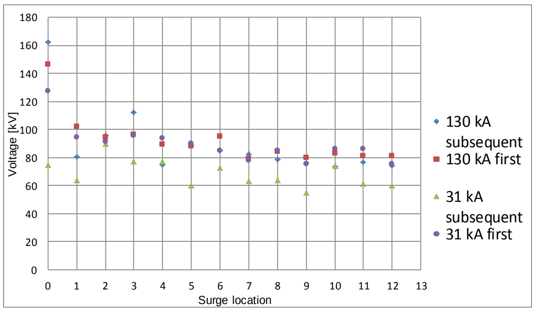

Fig. 9. Influence of lightning surge type in configuration with rails modelled as resistance and dropper wire as inductance. Voltage at the power transformer

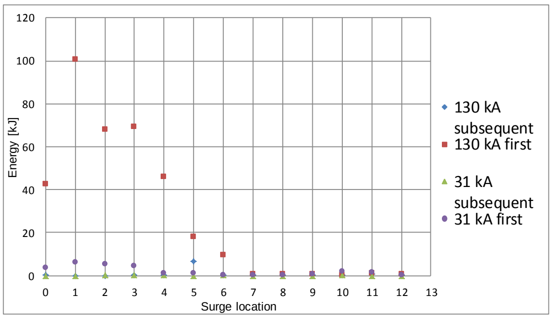

Fig. 10. Influence of lightning surge type in configuration with rails modelled as resistance and dropper wire as inductance. Energy dissipated on the line surge arrester

6. CONCLUSIONS

Paper addressed the problem of overvoltages generated during direct lightning stroke to the railway overhead catenary system. Frequency dependent models employed in the simulation allow to accurately assess the system behaviour under lightning conditions. Voltage has been measured in the most vital points of the network, such as transformer, cable bushings or switchgear. Simulations were conducted for various system configurations and values of current surge. It has been determined that a few modelling approaches of various complexity in most cases resulted in similar output. This valuable conclusion allows one to employ models of the equipment according to quality of possessed input data and resources.

7. LITERATURE

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SYMULACJE STANÓW NIEUSTALONYCH W TYPOWYM 25 kV a. c. UKŁADZIE ZASILANIA TRAKCJI

Słowa kluczowe: trakcja, przepięcia piorunowe, PSCAD

Streszczenie: Treść artykułu skupia się na symulacyjnych badaniach przepięć piorunowych w sieci zasilania trakcji elektrycznej. W oparciu o model typowego systemu 25 kV a.c., przeprowadzono porównanie odpowiedzi układu w przypadku zmiany podejścia do modelowania elementów takich jak napowietrzna sieć trakcyjna, czy też szyny.