Attenuation Measurements of Overvoltages on Contact Line

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Abstract. In paper, the problems of measurements overvoltage attenuation in a contact line have been described. The investigations have been conducted with telematics synchronization measurements on the test track of the Railway Institute and the Railway Institute Laboratory in Warsaw. The investigations consisted in the introduction of voltage kicks directly to the contact line or its laboratory model with the use of a kick generator. In this publication, the measurement systems used in both the field and the laboratory investigations have been shown. The publication contains also the recorded results of the investigation. The courses of both the voltage and current impulses have been analysed. The results of this analysis allowed to elaborate the conception of the varistor protection of the contact line against overvoltages.

Keywords: measurements overvoltage, contact line.

1 Introduction

The occurrence of overvoltages in contact lines is caused mostly by commutation processes and atmospheric discharges. The first factor arises as the result of switching over in the circuits of traction substations and in the main circuits of electric locomotives and electric traction units. The second one results from a direct lightning strike in the contact line or by the induction of overvoltages caused by lightning strikes relatively close to the contact line.

In both cases, the overvoltage wave propagates in two directions from its source and it is gradually attenuated. It is known from the studies of the available literature that the contact line elementary parameters are featured with a significant non-homogeneity. Therefore, the propagating overvoltage wave will reflect from the discontinuities, such as the anchoring of the contact line, network turnouts, sectional cabin connections, etc. It should be noted that the cases presented in the literature do not describe these phenomena in the explicit and unequivocal way, and particularly the degree of the attenuation of overvoltages by the contact line versus the distance from the source.

J. Mikulski (Ed.): TST 2012, CCIS 329, pp. 211–220, 2012.

One of the main problems in studying the overvoltages propagation on the contact lines is the synchronization of measurements at various points distant from each other even up to several kilometers. Usage one of the basic tools used in telematics, namely the so-called "time stamp" made it possible to realize such measurements in the field.

Investigations were carried out within a section of the contact line of the test centre of the Railway Institute near Żmigród, Poland and in the Railway Institutive Laboratory in Warsaw. The investigations were aimed to determine the overvoltage attenuation in the contact line as the function of the distance from the source. It was the first time when such investigations were carried out in Poland.

2 Investigation Methodology

The length of the contact line section of the RI test track, where the investigations were carried out, was 7,760 m (two contact line types: 2C120-2C-1 - 9 sections 7.28 tkm with an insulation of 25 kV; YC150-2C150 - one section of 1.09 tkm with an insulation of 25kV). The measurements of the overvoltage attenuation in the contact line were carried out for two arrangements: 1) contact line section without load, and 2) contact line loaded with the resistance of 240 Ω.

The testing consisted in the introduction of electric kicks from an impulse wave generator into the contact line and then recording of both the voltage and the current impulse amplitudes at specific sites between the generator and the measurement section end (every one kilometre). The output resistance of the used generator was 2 Ω, and the maximum level of the voltage kick 6.9 kV; standard kick was 1.2/50 µs.

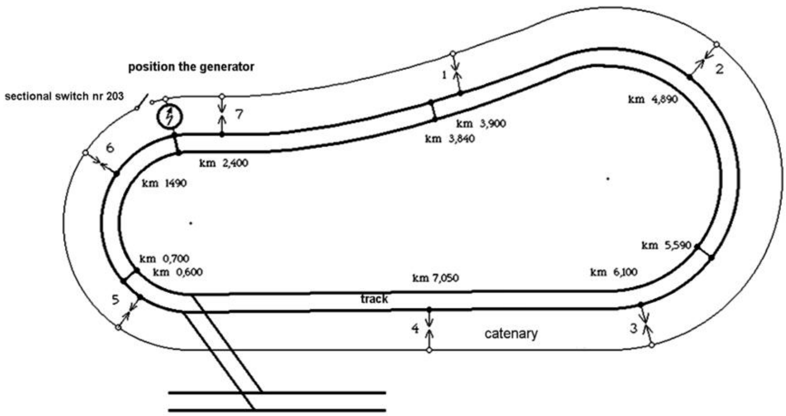

Fig. 1. The scheme of contact line of the test centre of the Railway Institute

In Fig. 1, the position of the generator in the test centre of the Railway Institute is shown. During the measurements, the contact line was open out with the sectionalising breaker No. 203, close to which the stationary station with the kick generator was located.The voltage and current impulses at the beginning of the tested contact line section were recorded with an oscilloscope, whereas at the other side of the 203 breaker, the station for the recording of the voltage impulses on the end of contact line section was located. The measurement systems are shown in Fig. 2 to 4, and the acronyms have the meaning: TEK - two-channel measuring oscilloscope, CR - Rogowski coil with the voltage-current ratio 400 mV/A, W203 - sectional breaker No. 203.

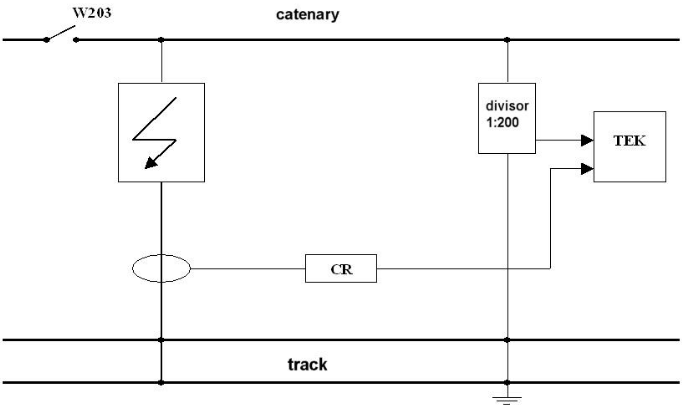

Fig. 2. Measurement system on the kick generator station

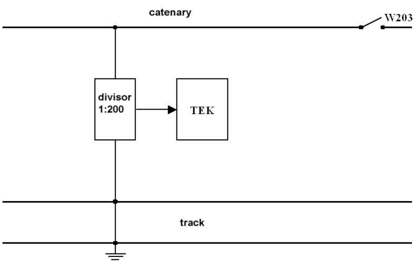

Fig. 3. Measurement system at the end of the contact line w/o load

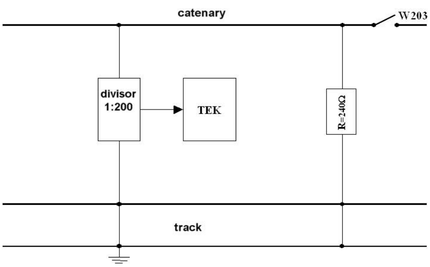

Fig. 4. Measurement system at the end of the contact line loaded with a resistor

The voltage of the electric kick for the above-mentioned arrangements of the contact line section (w/o load and with a loading resistor) was recorded every one kilometre starting from the generator up to the end of the line section. Measurements synchronization was carried out using the so-called "time stamp". This is made possible to illustrate the kick shape and its amplitude in the function of the distance from the kick generator. By using these records, the characteristics of the attenuation of the kick amplitudes on the tested contact line section versus the distance were developed.

Besides, the voltage amplitude course at the beginning of the measurement section and the surge current at the end of the contact line section loaded with the resistance of 240Ω was recorded This allowed to determine the delay of the current wave in respect to the surge voltage wave. Here the measurements were synchronized with the "time stamp" too.

Because of the necessity to reduce the field testing costs, it was decided to carry out a part of the investigations in laboratory conditions by the creation of a model corresponding with the best approximation to the contact line on the RI test track.

The following assumptions for the laboratory contact line model have been made:

- the model imitation of the contact line should be created with the elements of lumped constants,
- the model with regard to the electrical parameters should meet the asymmetric, homogenous long-line requirements,
- the contact line model should be composed of separate elements representing one-kilometre sections of the contact line,
- the resistance of the induction elements and connections within the model should be equal to the resistance of the contact line section of the test track,
- electric kicks (comparable as for their shape to the impulses occurring in actual conditions) of the maximum amplitude of 6.9 kV and the duration 1.2/50 μs and 10/700 μs will be introduced to the model circuits,
- the used elements have to meet the insulation criterion required for the interoperability with the kick generator,
- the induction and capacitance elements of the model should be arranged one to another in such a way that the possibility of arising inductive and capacitive couplings is eliminated,
- the parameters of the model components have to strictly correspond to the elementary parameters of one kilometre of the contact line,
- when introducing the kicks with an amplitude of 6.9 kV into the model, all safety conditions have to be assured for the operating teams and the measuring apparatus.

Basing on these assumptions, a laboratory model has been created, which was composed of 8 inductive elements and 8 earth capacitances. The subassemblies imitating the contact line section of 1 km in length have been carried out so that electrical parameters corresponded to the elementary parameters of the contact line used in the Żmigród test track. The following parameters of the one-kilometre module of the contact line have been assumed:

$$L = 466 \pm 5\ \mu\text{H}, \qquad R = 0.062\ \Omega, \qquad C = 10.5\ \text{nF} \pm 5\ \text{nF}.$$

The inductive element imitating the one-kilometre contact line section has been made in the form of a coil wound on an open ferrite core of a high magnetic permeability. The coil has been wound with insulated copper wire of 2 mm diameter. The inductivity of the wound coil was about 466 ± 5 μH and the resistance was 0.035 Ω. The capacitor representing the ground capacitance has been made with two metal plates separated with a dielectric. The capacitance of the capacitor made in this way was about 10.5 nF ± 5 nF and it was adjustable.

The electrical diagram of the laboratory model together with the values of the used elements is presented in Fig. 5.

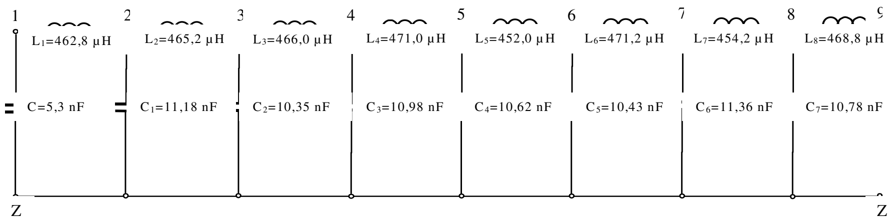

Fig. 5. Electrical system of the 8-km section of the contact line

In the investigations, the HAEFELY generator generating impulses of 1.2/50 µs (8/20 µs) and 10/700 µs shape with the maximum amplitude of the kick amounting to 6.9 kV was used.

To achieve the aim of the testing, it was necessary to establish the time relations and find out the phenomena occurring in the electrical circuit imitating the contact line as a long-line.

The laboratory investigation has been carried out on the created model, which imitated the contact line section of the length of about 7,760 km.

The kick amplitudes were recorded concurrently with two TEKTRONIX oscilloscopes of THS720 type. Fig 3 shows the basic measurement system. The measurements were carried out for two cases:

- with no load on the model output,
- with load with a resistance of 240 Ω.

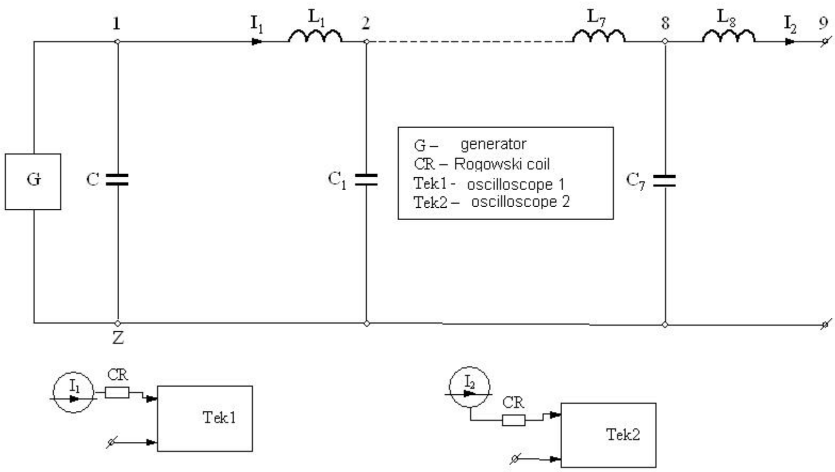

Fig. 6. Electrical measurement system used in the laboratory model of the concerned contact line section

For the creation of the model and further testing, the data related to the elementary parameters of the contact line obtained from the earlier testing [3] conducted on the Żmigród test track were used. The 240 Ω resistance corresponds approximately to the wave impedance of this contact line section.

3 Investigation Results

Fig. 7 shows the course of the recorded voltage impulse for the open-out contact line, without any load on the beginning of the line section (kick generator station), and Fig. 8 is the same, but on the end of the section. The voltage of the introduced kick was 5,900 V.

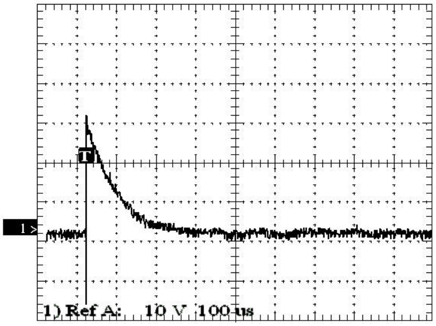

Fig. 7. The course of the voltage wave (the beginning of the open-out contact line section)

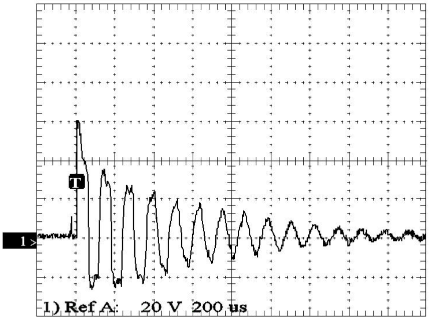

Fig. 8. The course of the voltage wave (the end of the open-out contact line section)

When comparing the amplitudes of the voltage waves presented in the above figures, it can be concluded that the tested contact line section behaves as an unloaded long-line. The amplitude of the impulse at the end of the measurement section increased from 5.6 kV up to 12.16 kV, whereas the impulse current on the kick generator output was 130 A, which proves the significant capacitance of the contact line in relation to the rails. The inductance and the capacitance of the tested contact line section formed the attenuated oscillations of the frequency of about 8.5 kHz.

In the second measurement variant (contact line loaded with a resistor), the impact of the resistance connected at the end of the measurement section on the kick amplitude measured on this resistance has been checked. The Fig. 9 shows the results of the voltage wave amplitude recording at the beginning and at the end of the section (Fig. 10) of the contact line loaded with the resistance of 240 Ω, respectively.

For the 240 Ω load resistance, the voltage wave amplitude has been measured and it amounted to 6.4 kV with the wave amplitude on the input amounting to 6.16 kV (Fig. 9 and Fig. 10, respectively). By comparing these voltage wave amplitudes, it can be stated that the 240 Ω load resistance is close to the wave impedance value for this contact line section.

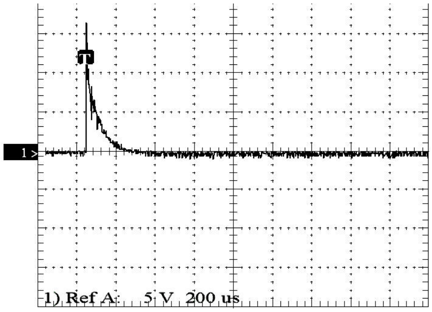

Fig. 9. The course of the voltage wave (the beginning of the contact line section loaded with the resistance of 240 Ω)

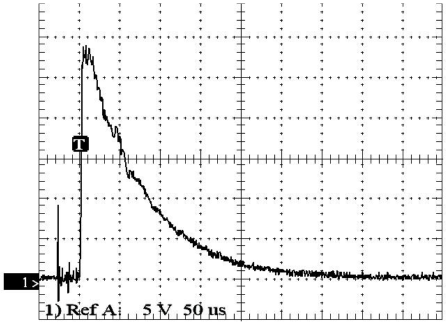

Fig. 10. The course of the voltage wave (the end of the contact line section loaded with the resistance of 240 Ω)

Within the second measurement variant, the input current amplitude values and the values of the amplitudes of the current flowing through the 240 Ω load resistance were also recorded. The amplitude of the input current was 140 A, and with the 240 Ω load resistance, it was 25 A. So significant differences between the amplitudes of the input and output currents are caused by the leakance through the capacitances between the contact line and the rails along the measurement section concerned.

4 Characteristics of the Overvoltage Attenuation on the Contact Line versus the Distance from Their Source

To select the layout of the elements of the contact line surge protection, it is necessary to know the distribution of the kick amplitudes in the function of the distance from the source of these kicks and the impact of the heterogeneity of the tested line section, such as contact line anchoring, network turnouts and viaducts, on the distribution of these kicks. Because of that, the kick amplitude distribution characteristics have been developed on the basis of the results of the investigations carried out earlier. In Fig. 11, the characteristic for the tested section of the contact line without load is presented, whereas Fig. 12 shows the same, but for the section with the load of 240 Ω.

When comparing the oscillograms, it was found that the kick amplitudes on the laboratory model output were as much as twice of the ones on the input. This was due to the reflection of the voltage wave from the open out long-line at the end. With no element constituting the load of the long-line, certain oscillations appeared on its output. Similar oscillations and the doubling increase of the amplitude were observed at the field testing on an unloaded contact line in Żmigród. This attests of the comparable electrical properties of both the laboratory model and the actual contact line section. It should be emphasised that with the developed model, similar current wave delays in relation to the voltage wave were obtained, as for the contact line section in the Żmigród test track (about 30μs).

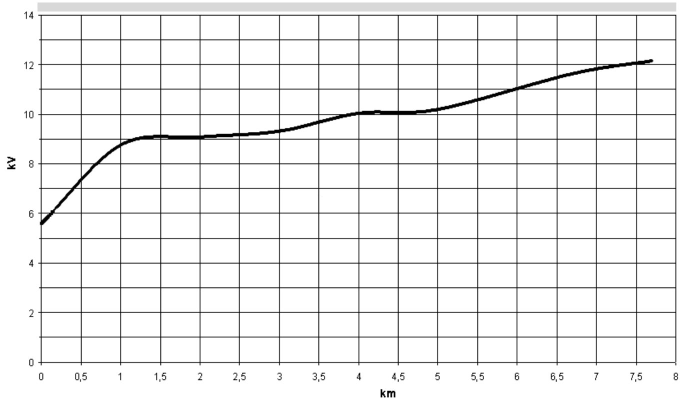

Fig. 11. The distribution of kick amplitudes versus the distance for the contact line section without load

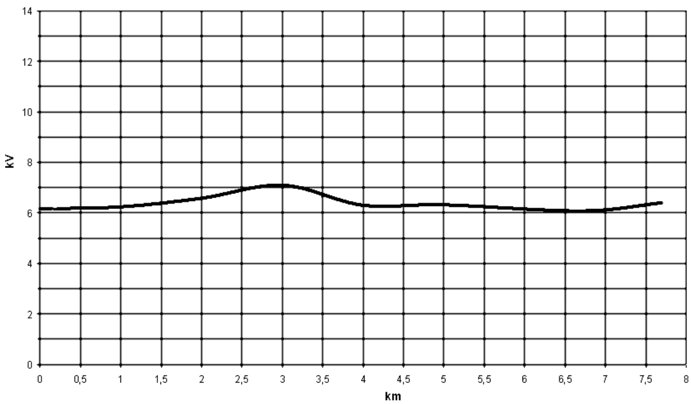

Fig. 12. The distribution of kick amplitudes versus the distance for the contact line section with 240 Ω load

Investigation on the laboratory model output loaded with the resistance of 240 Ω has also been performed. The investigation results show that no differences between the measured attenuation on the laboratory long-line model and the actual section of the Żmigród contact line were found.

The characteristics illustrating the distribution of the kick amplitudes versus the distance from the kick generator are shown in Fig. 13 and 14.

5 Conclusion

The considered section of the open-out contact line is characterised approximately with the properties identical to the homogeneous long-line. Due to the interference between the voltage impulse reflected from the unloaded end of the line section and the generator impulse, the kick amplitudes increase with the increase of the distance.

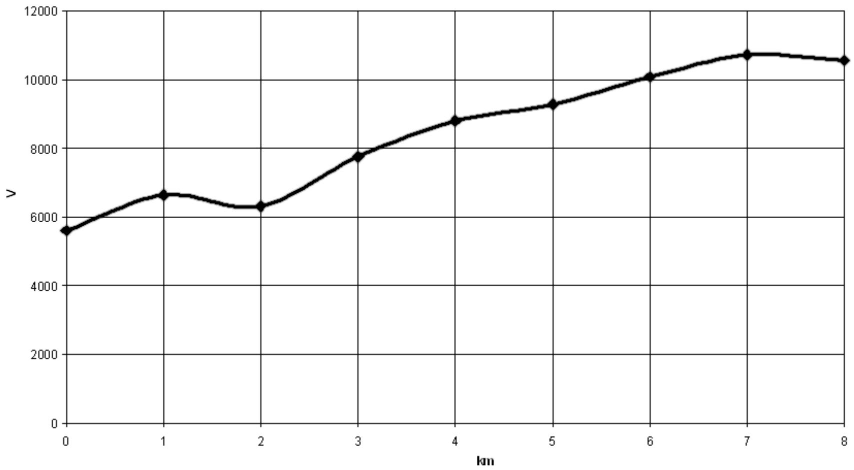

Fig. 13. Kick amplitude (1,2/50 μs) distrubution versus the distance from the generator for the model of the contact line w/o load

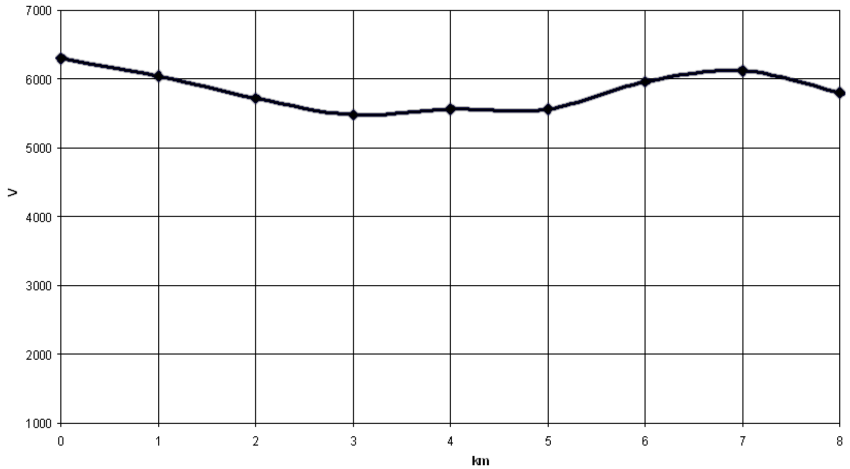

Fig. 14. Kick amplitude (1,2/50 μs) distrubution versus the distance from the generator for the model of the contact line with the load of 240 Ω

Analysing the courses, it should be noted that the characteristics of the distribution of kick amplitudes versus the distance for the contact line loaded with the resistance of 240 Ω have two specific places. In the first place (about 3 km from the generator), the voltage kick amplitutude increases. This is caused by the presence of a viaduct, which in turn contributes to the local increase of the contact line ground capacitance, and indirectly in relation to the railway rail, which causes a non-homogeneity. In the second place (at the end of the measurement section), the wave amplitude increases.

This is connected with maladjustment of the load resistance to the wave impedance value of this contact line section.

The presented results allow to state that the homogeneous contact line (i.e. without intersections, turnouts, branches, etc.) attenuates the voltage kicks to an insignificant degree only.

Carrying out field measurements were possible only by using one of the telematics tools, namely the use of so-called "time stamp to measurements synchronization".

The developed and created laboratory model of the section of the contact line as a long-line behaves within the electrical parameters as an actual section of the contact line (the section of the contact line in the test track centre in Żmigród).

The laboratory model of the contact line section has allowed to continue the investigations, which were necessary to establish the optimum distances between the varistor overvoltage limiters protecting the insulation of the contact line against overvoltages that may occur in it (including atmospheric discharges). During the laboratory investigations, the interaction of the varistor limiters at impulse waves acting on the contact line has been determined. Also, the interaction relationship between the horn gap and the varistor overvoltage limiter has been identified.

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