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Lightning current distribution in a laboratory model of lightning protection system

***Abstract**. The paper presents the results of preliminary laboratory tests of impulse current distribution in a model of the lightning protection system (LPS). The wooden frame house was prepared in a scale 1:5. It was based on the full size object subjected to lightning currents during open air experiments at the test side in Huta Poręby near Rzeszów. It was equipped with the model of the lightning protection system connected to the supplying electrical installation. The surge current injected to the tested system in the laboratory was produced with use of the lightning transient generator. Measurements were done for three varied shapes of the injected impulse current. The obtained results indicated the frequency dependent behaviour of the tested system. The current distribution in the proposed laboratory model of LPS is similar to those achieved during the tests on the real scale objects in recent years.*

***Streszczenie.** W artykule przedstawiono wyniki badań laboratoryjnych rozpływu prądów piorunowych w modelu urządzenia piorunochronnego. W skali 1:5 przygotowano drewniany szkielet budynku mieszkalnego, odwzorowujący obiekt używany do poligonowych badań rozpływu prądów udarowych w jego instalacjach piorunochronnej oraz elektrycznej, prowadzonych w Hucie Poręby niedaleko Rzeszowa. Zaproponowany model odzwierciedla istniejącą na poligonie instalację odgromową wraz z przyłączoną do niej niezasiloną typową elektryczną instalacją w postaci wewnętrznej sieci elektrycznej nn wraz z osprzętem, dochodzącej do złącza kablowego ziemnej linii kablowej nn, stacji transformatorowej i linii napowietrznej SN. Pomiarów dokonano dla trzech różnych kształtów wstrzykiwanego prądu udarowego. Uzyskane rozpływy prądów impulsowych są zbliżone do tych, obserwowanych podczas poligonowych badań pełnowymiarowych systemów przez ostatnie lata. Badany model wykazuje zależny od częstotliwości charakter. (**Rozpływ prądów udarowych w modelu laboratoryjnym urządzenia piorunochronnego**).*

Keywords: lightning, lightning protection system, grounding impedance, surge current distribution, laboratory experiments.
Słowa kluczowe: impedancja uziemienia, urządzenie piorunochronne, rozpływ prądu udarowego, badania laboratoryjne.

Introduction

The lightning discharge can cause multiple effects. The current of considerable value can flow through the structure of the building during cloud to ground discharge. A lightning protection system is designed and installed to protect from damages of objects such as residential building due to the presence of high currents and voltages. It is important to make a low impedance path to carry large currents safely from the top of the object to the ground. The theoretical and experimental research of lightning current distribution in the LPS was conducted for many years. The International Center for Lightning Research and Testing (ICLRT) at Camp Blanding, Florida is one of the centres involved with this subject [1-3]. Similar studies are carried out at the Rzeszow University of Technology in a cooperation with ICLRT since 2007 [4-8]. There is a real scale simple model of residential house, located at the test side in Huta Poręby near Rzeszów, with dedicated LPS system connected to the electrical supplying installation. The main aims of the conducted research was to verify the shape and the level of current and voltage transients measured at the different points of the tested system, while the impulse currents, produced with specially designed mobile generators, were injected to the air terminal of the LPS. Similarly like in Florida, the current distribution between the grounding systems of the LPS and the electrical installation was examined in order to verify the lightning transient propagation to remote grounding systems and the efficiency of the LPS.

The proposed model of the LPS

The purpose of the laboratory activities was to examine whether differences in a shape of current in the selected points of the LPS can be observed like at the open air test sides, even for a simple laboratory model. Attempts were made to verify how simple laboratory model is useful in assessing the distribution of impulse currents in the real size object. On the basis of the test house located in Huta Poręby, a wooden frame house in a scale of 1:5, a 1.5 m wide, 2 m long and 1.3 m high, was constructed (see Figs 1 and 2). It was placed above the reference ground plate (9) made from steel sheets with a total size of 2 m wide and 3 m long, connected to PE terminal. The lightning protection system, corresponding to the full size object tested in Florida and in Huta Poręby, was mounted to wooden parts of the frame and to the ground plane.

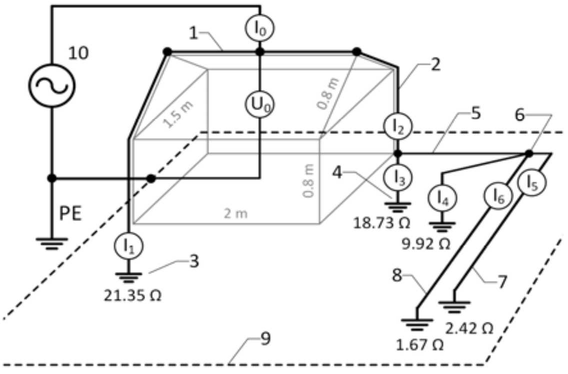

Fig. 1. The experimental setup diagram of the laboratory model of LPS and connected installations with measuring points I_0 to I_6 of impulse current distribution and U_0 voltage drop on resulting impedance of the system: 1 – horizontal conductor, 2 – down conductor, 3, 4 – grounding rod electrodes modeled by resistors, 5 – 0.6 m long conductor laid alongside above ground modeled underground connection between (4) and (6), 6 – connection point in free-standing cable termination box, 7 – grounding system of supplying underground cable line modeled by a 1.7 m long conductor laid along (8) and connected at both end to the ground by resistor, 8 – PEN conductor of underground cable line and grounding system of the transformer station modeled by a 1.7 m long conductor placed above ground plane, resistor terminated to ground, 9 – reference ground plane, 10 – surge current generator

The same type of a copper winding wire of a 18 mm^2 cross-section was used to model most of conductors of the real LPS system. The prepared model consists of horizontal conductor (1) connected to two down conductor (2) at opposite corners of the test house. They are coupled with vertical grounding rods (3, 4), modelled by inductive power resistors terminated to ground. The values showed in Fig. 1 near to all symbols of groundings are the dc resistances of each ground rod or grounding system.

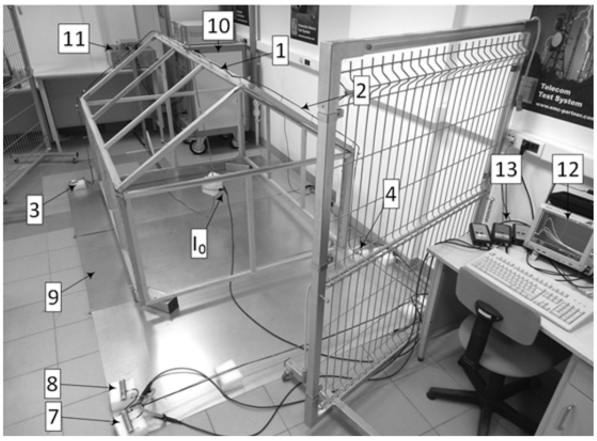

Fig. 2. The laboratory test stand: 1-4, 7-10, I_0 – as in Fig. 1, 11 – injection transformer, 12 – digital oscilloscope, 13 – current probes

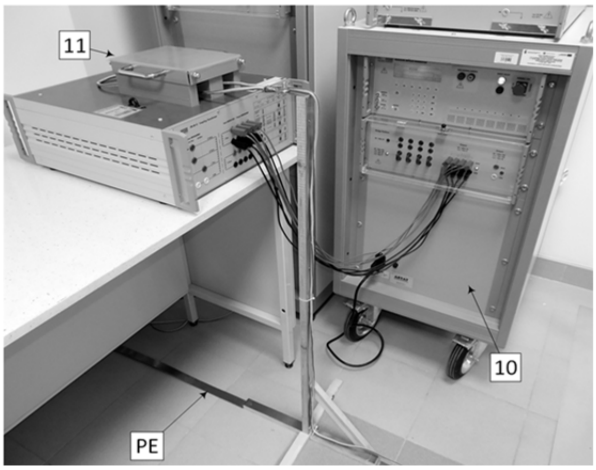

Fig. 3. The part of the test stand with visible lightning transient generator (10) and connected transformer (11)

The conductor (5) represented the uninsulated buried flat bar conductor connecting the ground rod (4) with the grounding system of supplying underground cable line (7). In addition at the open air test side they are connected with the PEN conductor of cable line at the cable termination box (6). At the other end the cable line was connected to the transformer station. The part (8) of the proposed LPS model represents the PEN wire of cable line and the transformer station grounding system.

Test-measurement system

The tested system was subjected to impulse currents generated by the lightning transients generator (10). The lightning currents were injected to the system at the middle of the horizontal conductor (1). The connection of the LPS to the generator set was implemented from bottom as shown in Fig. 2, 3 in order to reduce the inductance of a connecting 5 AWG copper wire, negative affecting the peak value and the shape of injected current. The increase of the connecting cables loop surface by separating them and suspending one of them from the top to the injection point caused reduction of peak value and increased the rise time of the injected current. A single stroke MIG 0618SS generator was used in order to simulate short duration currents with parameters corresponding to those used for tests in Huta Poręby. The repeatability of generated transients was the biggest advantage of the selected apparatus. This allowed for the measurement at multiple points of the system identified by the symbols I_0 to I_6 and U_0 in Fig. 1, by relocation of a limited number of a probes and repeating a test. The CTW Rogowski coils (13 – see Fig. 3) were used to measure the current transients. The voltage transients on the resulting input impedance of the LPS were measured by the TT-SI 9010 voltage differential probe. The 4-channel DPO5204 digital oscilloscope (12) recorded all signals with 100 μs time scale and 100 MS/s sample rate.

Results of experimental studies and discussion

The tests were carried out for three different shapes of injected lightning current in order to examine whether the current distribution in the LPS depends on the input current shape and the peak value. There were three measuring sessions named A, B, and C. The injection transformer connected to the generator output was used in the first case (A). This allowed to achieve the shortest front time of injected current waveform. The said conductor connecting the transformer output with the LPS input (5 AWG wire) was the secondary winding of the injection transformer. Its primary windings was connected to generator output (see Fig. 3). The tests were conducted at the different level of peak value and at the same shape of the current injected into the LPS. For the selected generator settings (6.4/69 μs) in this (A) variant the current rise time would be 6.4 μs, while the fall time to half of the maximum value would be 69 μs, if the connected system was in the short circuit state. Then the current peak value would be equal 4 kA. For the non-zero input impedance of the LPS model the 7.5/25 μs times and the 0.55 kA peak value were obtained. Later in the paper only the results for the maximum attainable peak level in each case were presented. In the second (B) and the third (C) cases the tested system was directly connected to the surge generator output. For this configurations the selected voltage transients the 6.4/69 μs for B and the 40/120 μs for C case would be obtained only for the open circuit condition of the generator output. The maximum of generated voltage transient was the same for both equal 3 kV at the open circuit. After connecting the LPS with a some value of impedance the rising times of main current were longer and achieved respectively the values of 25 μs (for B) and 48 μs (for C case). While the peak values of input current transients were accordingly 1.76 kA and 1.59 kA.

The test results of impulse current distribution in the proposed model of LPS, for the tree different waveforms of current injected to this system, shown in Fig. 1, are presented in Fig. 4-8. The observation of the recorded current transients in points I_0 to I_6 leads to notice, that the current I_0 flowing into the system input divides unevenly between components of the tested system. The significant part of this current (I_2) flows through down conductor on the side of the cable termination box. Then, a large amount of I_2 flows through underground conductor (5) into connection point (6) in the cable termination box. Next, the current primarily distributes to the grounding system of the transformer station (I_6) and underground cable line (I_5). It should be noted that for such resistance values of ground rods and grounding systems, which correspond in a scale to dc resistances of the grounding elements at the test side, a large portion of input lightning current was not dissipated in a local grounding system of the LPS. There is a tendency to distribution of surge transients in a remote grounding systems. Small values of currents I_1, I_3 in the ground rods and I_4 in short buried flat bar grounding are caused by the relatively high values of their impedances in comparison to the grounding impedance of the other parts of the system.

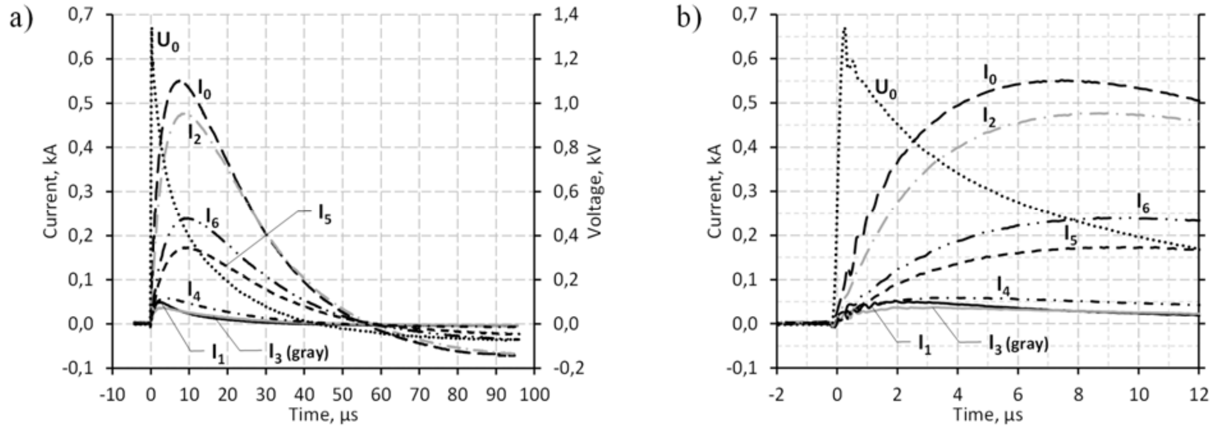

Fig. 4. The distribution of impulse current in the LPS at measuring points I_0 – I_6 and voltage transient U_0 at injection point, shown in Fig. 1, for the first measuring session (A). a) Complete waveforms displayed on the full time scale. b) Same transients, shown on the expanded scale of time

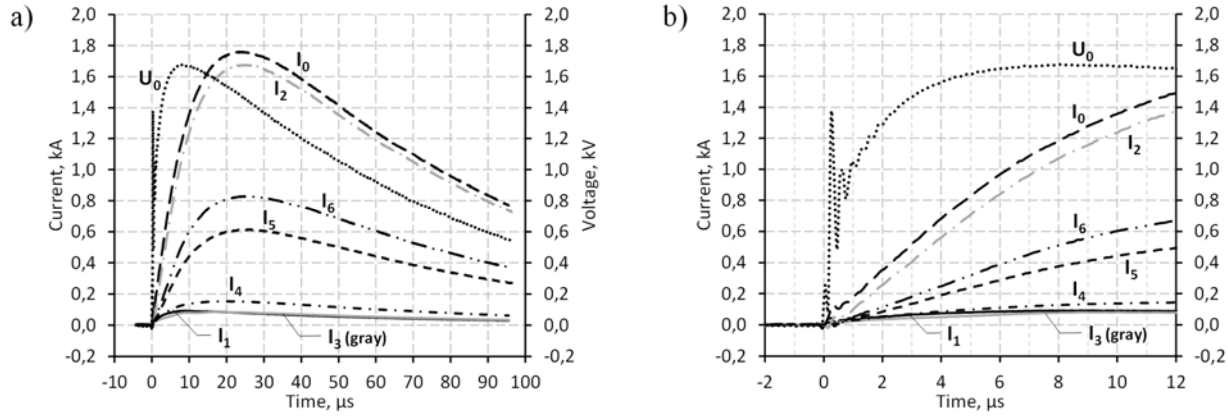

Fig. 5. The distribution of impulse current in the LPS at measuring points I_0 – I_6 and voltage transient U_0 at injection point, shown in Fig. 1, for the second measuring session (B). a) Complete waveforms displayed on the full time scale. b) Same transients, shown on the expanded scale of time

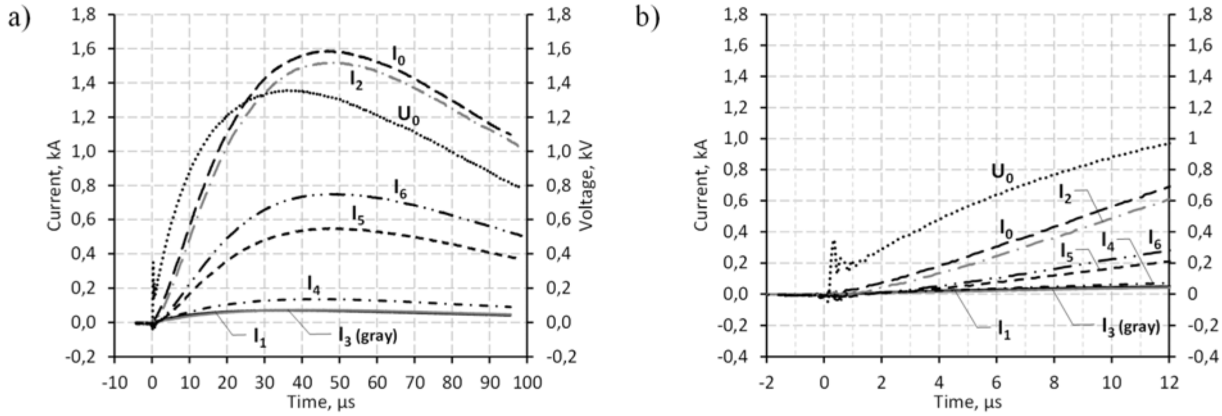

Fig. 6. The distribution of impulse current in the LPS at measuring points I_0 – I_6 and voltage transient U_0 at injection point, shown in Fig. 1, for the third measuring session (C). a) Complete waveforms displayed on the full time scale. b) Same transients, shown on the expanded scale of time

All the observed currents differ both in the peak value and in the wave shape. It is important result shows, that tested system has a frequency dependent behaviour. Also voltage drop U_0 on the resulting impedance of the lightning protection system during the main current flow was measured between the middle point of the horizontal wire (1) and the ground reference plane (9), as shown in Fig. 1. This also allows to estimate the lightning surge impedance of the tested system in a future. The inductance of the long flat bar and underground cable line models causes relatively slow fronts of currents I_5 and I_6. Moreover, the shorter rise time of currents I_1 and I_3 (three to four times) comparing with the I_0, indicates a significant proportion of the capacitive reactance in the grounding impedance of both vertical rods (3) and (4). It is quite difficult to determine the exact difference in the peak value and in the front time between current waveforms measured in the points I_0 to I_6 by observation the traces as in the Fig. 4-6. The relative scale of current value was used in order to better compare with each other the desirable features. As an example, three points I_1, I_3, and I_6 in the LPS were selected (see Fig. 7). The current values have been scaled by dividing their by I_{0_C} have the same peak value on the relative value scale equal 1. Thanks to this method it is quite easy to note, that the peak values and the front times of current surges measured in the same point of the system during three session are not comparable. At the point I_1 maximum value in the case A (I_{1_A}) is even two times greater than that in the C (I_{1_C}). They clearly depend on the front time of the injection current. The same applies to the differences observed in the rising time. The similar behaviour of the current peak value and the front time with changes in injection current I_0 shape is observed for second vertical the maximum of input current separately for each: A, B and C measuring session. All of injected currents I_{0_A}, I_{0_B}, and ground rod (4), where I_3 flows. Such changes of the current peak values may be due to the impedance increase of another part of circuit. The inductive reactance will increase because of the high-frequency current components. This happens with the impedance of transformer station and cable line grounding systems. Then the greater amount of current (I_1, I_3) can flow through the grounding (3) and (4), as is visible in Fig. 7. The current peak value in the transformer station grounding is reduced for the shorter rise time of current at the input of the tested LPS.

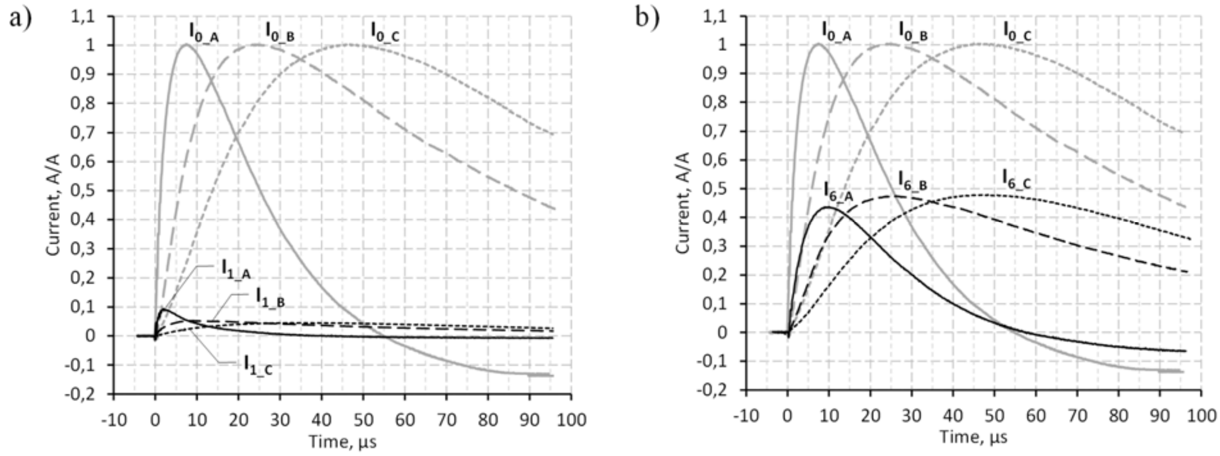

Fig. 7. Comparison of current waveforms at injection point I_0 with currents: a) I_1 in vertical ground rode (3); b) I_6 in grounding system of transformer station. Currents measured during A, B, and C sessions. Waveforms shown on relative value scale.

Conclusion

The results obtained in the form of lightning current distribution in the model of LPS system are similar to the open air experimental results received in recent years at the test sides in Rzeszów and in Florida. The peak value and the front time of current waveforms measured at several points of the system clearly depend on the rise time of injected current. The above results suggest, that the tested system has frequency dependent behaviour. The currents flowing through the vertical ground rods models of the LPS to the ground characterize by a considerably shorter rise time in relation to the impulse current from the generator, show a significant proportion of the capacitive reactance in the grounding impedance of these ground electrodes. As opposite to this, the longer front time of current in the PEN conductor of underground cable line and the transformer station grounding system arises from considerable participation of inductive reactance in these circuits. A significant part of the input lightning current not dissipates in local grounding system and distributes to remote ground. Therefore, there is a low efficiency of the proposed model of LPS, but it is comparable with the results of the tests of the full scale LPS systems, especially in Florida.

The results obtained in this study will explain in the future by making further laboratory experiments and a computer simulation.

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