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Measurements and modeling of current impulses in the lightning protection system and internal electrical installation equipped with household appliances

G. Maslowski*, S. Wyderka, R. Ziemba, G. Karnas, K. Filik, L. Karpinski

Department of Electrical and Computer Engineering, Rzeszow University of Technology, Powstancow Warszawy 12, Rzeszow 35-317, Poland

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ABSTRACT

Open air experiments were conducted of impulse current distribution in the lightning protection system, supplying cable and electrical installation of a test house equipped with electrical and electronic household appliances. Impulse currents were injected from the generator into the installation. Current distributions in elements of tested system were measured with multi-channel electro-optical system. To verify the experimental results the simulations of surge current in the test house modeled in ATP-EMTP were conducted. The obtained results show a good agreement between measured and numerically simulated currents and significant influence of frequency dependent parameters of the test house elements on both the amplitude and the shape of current waveforms.

1. Introduction

The measurements and modeling of surge current distribution in the lightning protection system (LPS) and the building electrical installation in the case of direct lightning strike have been analyzed in the literature [1–5]. The lightning induced effects and the electromagnetic environment inside a building during direct and indirect lightning strikes were also studied in detail because of the widespread use of sensitive electronic and computer devices [6–13]. Lightning over voltages can be also transferred to the building electrical system from the multi conductor transmission line through the distribution power transformer [14–17].

Experimental investigations of efficiency of lightning protection systems of small structures have been carried out for couple of years at the International Center for Lightning Research and Testing (ICLRT) at Camp Blanding, Florida, and at the Rzeszow University of Technology (RUT), Poland [18–21]. Measured surge current distribution was verified by the modeling and computer simulations [22–24]. Recently, experimental tests with the house equipped with typical electrical and electronic household appliances have been conducted at a new open-air laboratory situated 50 km far from the RUT. The inclusion of appliances allowed the testing of surge current distribution in the more realistic structure, and more accurate assessment of the hazard level of electrical and electronic devices due to lightning. In this paper, which is an extended version of the ICLP2014 paper [25], analyses of experimental results and modeling of current impulses in the lightning protection system and internal electrical installation are presented.

2. Experimental setup and obtained results

A new test site with an overall area of 50,000 m^2 situated in Huta Poreby, 50 km far from the Rzeszow University of Technology, Poland, dedicated for testing of lightning protection systems of small structures was described in detail in [21]. Examination of surge current distribution in elements of the entire test house was conducted with application of experimental setup presented in Fig. 1. The test house was equipped with LPS consisting of three vertical air terminals interconnected by a horizontal conductor on the roof ridge, two down conductors and two vertical ground rods at opposite corners of the test house. Note that in Poland 20-m long flat bar connected to the cable termination box is typically buried by power electric companies along the underground power cable. Therefore, one of the vertical ground rod was connected to this long buried flat bar in order to improve the effectiveness of the LPS (see Fig. 1).

An electrical diagram of the test house and the measuring points are presented in Fig. 2. Pearson's current probe and digital oscilloscope (see Figs. 1 and 2) were applied to measure small currents flowing in electrical and electronic appliances.

* Corresponding author. Tel.: +48 17 865 1296; fax: +48 17 854 1260.
E-mail address: maslowski@prz.edu.pl (G. Maslowski).

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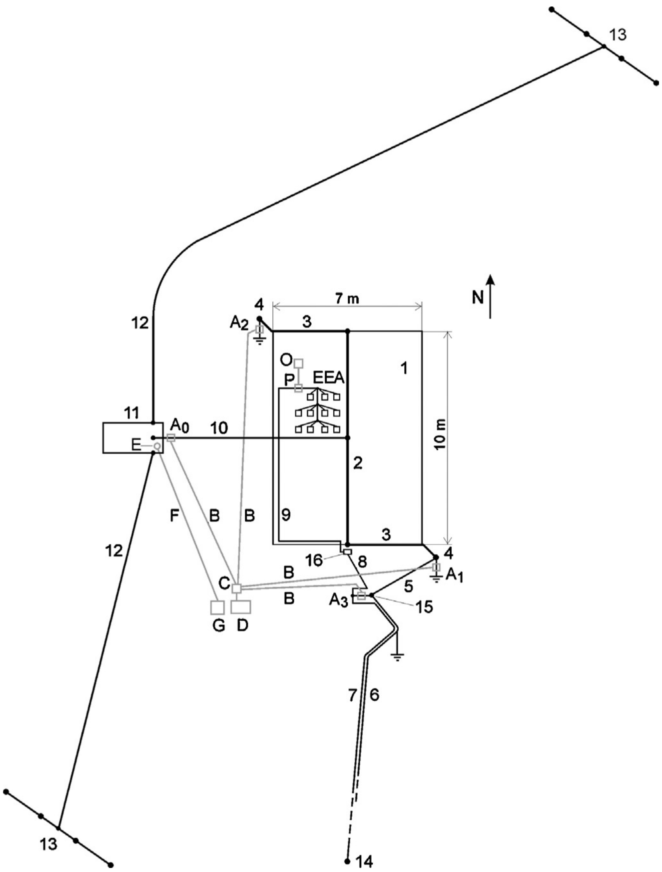

Fig. 1. Schematic diagram of the measurement system: (1) test house, (2) air termination system, (3) down conductors, (4) ground rods, (5) 4-m long buried flat bar, (6) 20-m long buried flat bar, (7) 50-m long underground cable with PEN conductor, (8) short underground cable with PE conductor, (9) main circuit of the test house electrical installation, (10) insulated copper conductor, (11) current surge generator, (12) insulated conductors of return path, (13) four interconnected ground rods, (14) grounding system of transformer station, (15) free-standing cable termination box, (16) watt-hour meter box, (A) current shunt, voltage divider, analogue-digital and electro-optical converters (located in points A0 to A3), (B) optic waveguide, (C) five optoelectronic converters and memory buffer, (D) laptop, (E) optoelectronic converter, (F) optic waveguide, (G) digital controller of generator, (O) oscilloscope, (P) current probe, EEA—electrical and electronic appliances.

Registrations of impulse currents were done with the five-channel electro-optic system showed in Fig. 3 [26]. At the same Fig. 3, the test house equipped with the LPS together with the free-standing cable termination box and typical electrical and electronic household appliances are also visible.

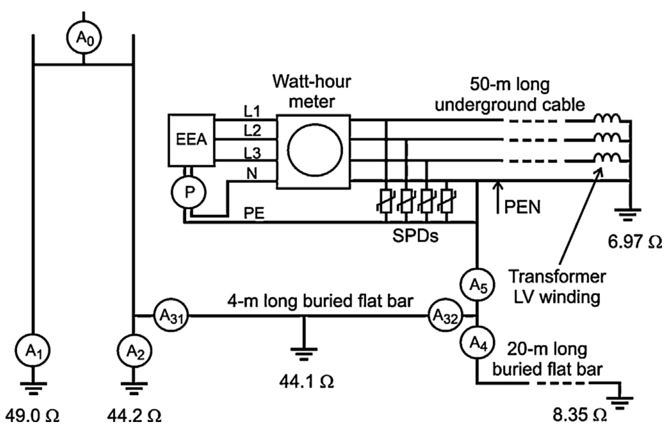

Fig. 2. Equivalent circuit of the test system with marked measuring points of surge currents; EEA—electrical and electronic appliances.

Fig. 3. Electro-optic measuring system and the test house with the LPS and typical electrical and electronic household appliances.

Current distribution in elements of the test house was measured and registered for injected current impulses from the generator charged to 30 kV. As a result, the peak values of injected currents were almost 3 kA.

The impulse current shown in Fig. 4 (point P in Fig. 2) flows in the PE conductor of underground cable and main circuit of test house electrical installation and then via loads and phase conductors it flows further through the transformer windings and station grounding system into ground. This current was two orders of magnitude smaller than input current due to relatively high impedance of transformer windings. Distinct oscillations and reflections were also registered (see Fig. 4). This is, among other things, due to complexity of input impedances of household electrical appliances.

Frequency characteristics of impedance absolute value and angle of eleven household electrical appliances were measured using the LCR meter [17]. Selected three representative frequency characteristics of input impedance absolute value and angle are presented in Fig. 5. Obtained frequency characteristics of input impedances of elementary household electrical appliances are characterized by big changes of absolute value and angle along the entire frequency range, especially for upper part of this range. Exceptions are appliances having no electronic systems in supplying circuit, e.g. electric stove. For such appliances the impedance frequency characteristic is smooth up to some megahertz.

In order to check the influence of input impedances of electrical and electronic appliances on current waveforms measured in point P additional investigations were conducted on modified electrical installation. The appliances (EEA in Fig. 2) were replaced by three.

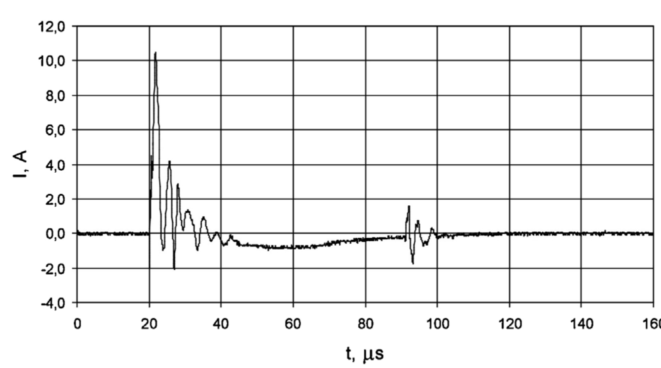

Fig. 4. Current in electrical and electronic appliances registered in point P (see Fig. 2).