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High-Frequency Grounding Impedance Measurements at Test Site in Huta Poreby, Poland

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***Abstract*— High frequency grounding impedance measurements were conducted at the test site in Huta Poreby during the summer season in 2015. The impedances seen from different locations were measured with the impedance meter AES 1002 at frequencies ranging from 100 Hz to 1 MHz. The obtained impedance vs. frequency characteristics have similar shapes. In the low-frequency range impedance values are almost constant while above tens of kilohertz their values begin to rise and reach a peak at about 200 kHz. Above this frequency impedance values begin to decrease. Additionally, the grounding resistances and surge grounding impedances were measured and analyzed.**

Keywords - lightning; lightning protection; grounding impedance; high frequency measurements.

I. INTRODUCTION

For several years experimental studies of lightning protection systems were conducted at the test site in Huta Poreby, Poland [1-3]. These investigations were related to similar tests implemented at Camp Blanding, Florida using the rocket-and-wire technique for triggering lightning [4]. In both lightning research centers we were trying to determine the distribution of an injected surge current in the lightning protection system (LPS) and connected power supply installation. In the first experiments carried out in Florida the return stroke current of triggered lightning was injected into air terminals of LPS, and then, currents in different parts of the installation were measured. In order to determine the distribution of current in the similar lightning protection system of a small residential building, an impulse current generator was used in Poland. The shapes of the injected impulses from the mobile generator were similar to those of subsequent lightning return strokes. Recently, other impulse shapes similar to those of lightning continuing currents were used as well.

The analysis of the measurements shows that parameters of individual elements of the grounding system have a significant influence on the currents flowing in different parts of the circuit. Therefore, it is desirable to test grounding systems with particular emphasis on their properties during the impact of currents containing high-frequency components. Although, high frequency grounding impedance measurement techniques are well known, they have been used only in a few cases for insightful tests of ground electrodes in the real objects. Such high frequency grounding measurements were carried out using selected frequencies up to 1 MHz at the test site in Huta Poreby during the summer season in 2015. Experimental tests conducted in Poland in 2015 were similar to those made at Camp Blanding in 2009 [5]. The obtained results are presented in this paper.

II. TEST SETUP AND RESULTS

High frequency grounding impedance testing was conducted at Huta Poreby during the summer season in 2015 (see Fig. 1).

Figure 1. Test site in Huta Poreby, Poland equipped with a test house connected to the transformer station and the 500 m long overhead power line.

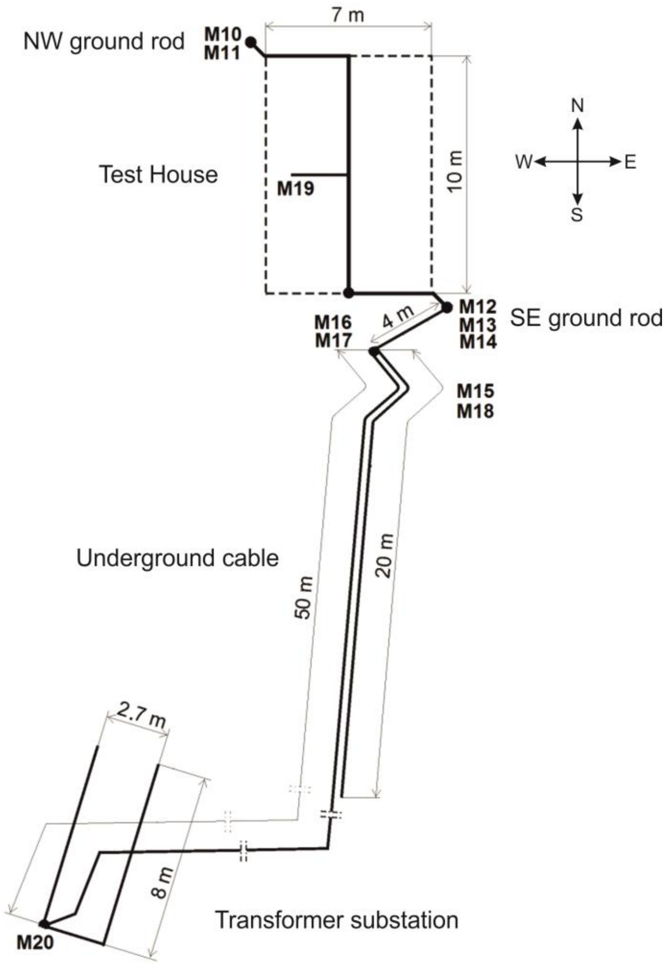

Figure 2. Schematic diagram of experimental setup and test object with measurement points M10-M20 described in the paper.

The experimental setup was described in detail in papers [2, 3]. The basic element of the test object is a physical model of 10 m long and 7 m wide building equipped with the basic elements of an electrical installation. On its southern wall there is a box with the watt-hour meter, circuit breakers and surge arresters. A five-conductor internal circuit is connected to this box. The electrical installation of the building is connected to the free-standing cable termination box with a five-conductor underground cable. A galvanized steel tape having a length of 20 m placed horizontally in the ground is the grounding of the cable termination box. The building LPS consists of air termination composed of three vertical rods and horizontal wire on the roof ridge, two down conductors and two vertical rods placed in the ground at opposite corners of the building. The ground rod at the southeast corner of the building is connected to the PEN terminal of the cable termination box with a buried 4 m long galvanized steel tape. A newly built MV/LV transformer substation is equipped with typical distribution equipment, its main device is the oil-immersed transformer TNOSCT-160/15. An unenergized 500 m long overhead line is connected to the MV transformer terminals. The low-voltage switchgear of transformer station is connected to the cable termination box near the building, with a 50 m long four-conductor cable buried at a depth of 60 cm.

The impedances seen from different locations were measured with the high frequency earth impedance meter AES 1002 using frequencies up to 1 MHz (the points marked with diamonds on the frequency characteristics in Fig. 3). The meaning of testing labels M10-M20 indicated in Fig. 2 is as follows:

M10 – impedance of entire system from the NW ground rod;
M11 – impedance of 1.5 m long NW ground rod only;
M12 – impedance of entire system from SE ground rod;
M13 – impedance of 1.5 m long SE ground rod connected to 4 m long horizontal tape and 20 m long horizontal tape (disconnected from the LPS);
M14 – impedance of 1.5 m long SE ground rod only;
M15 – impedance of 4 m long horizontal tape only (measured from the cable termination box);
M16 – impedance of 20 m long horizontal tape only (measured from the cable termination box);
M17 – impedance of PEN conductor connected to the transformer grounding (measured from the cable termination box);
M18 – impedance of 4 m long horizontal tape connected to 20 m long horizontal tape (measured from the cable termination box);
M19 – impedance of entire system from the current injection point (measured using 8 mm galvanized conductor dropped from the top);
M20 – impedance of entire system of transformer grounding; isolated (PEN conductor and 20 m long horizontal tape disconnected; measured from the transformer grounding).

The measured impedance vs. frequency characteristics shown in Fig. 3 have similar shapes. In the low-frequency range impedance values are almost constant while above tens of kilohertz their values begin to rise and reach a peak at about 200 kHz. Above this frequency, impedance values begin to decrease. The peak values of impedance of the entire system seen from the NW ground rod and 1.5 m long NW ground rod only are almost equal (M10 – 100 Ω; M11 - 112 Ω), although, values for low-frequency differ significantly (M10 - 6 Ω; M11 - 60 Ω). Comparing the characteristics of the impedance of the NW ground rod (M11) and 4 m long horizontal tape (M15) one can see that they have very similar values in the entire frequency range. However, the grounding impedance of M15 for low frequency range is greater by about 10 ohms than M11 (see also Table I). Note that in Fig. 3 the characteristic for M14 is not shown since it is almost the same as that for M11. Analyzing the characteristics of the 20 m long horizontal tape (M16) you can see that it has much better grounding properties in the entire frequency range than the short horizontal tape (M15), as expected. The connection of these two underground tapes together (M18) does not substantially change the frequency characteristic that is similar to M16. Note that the characteristic of PEN conductor connected to the transformer grounding (M17) has a little different shape than the other and its peak value is the greatest (exceeds 220 Ω) at 200 kHz.

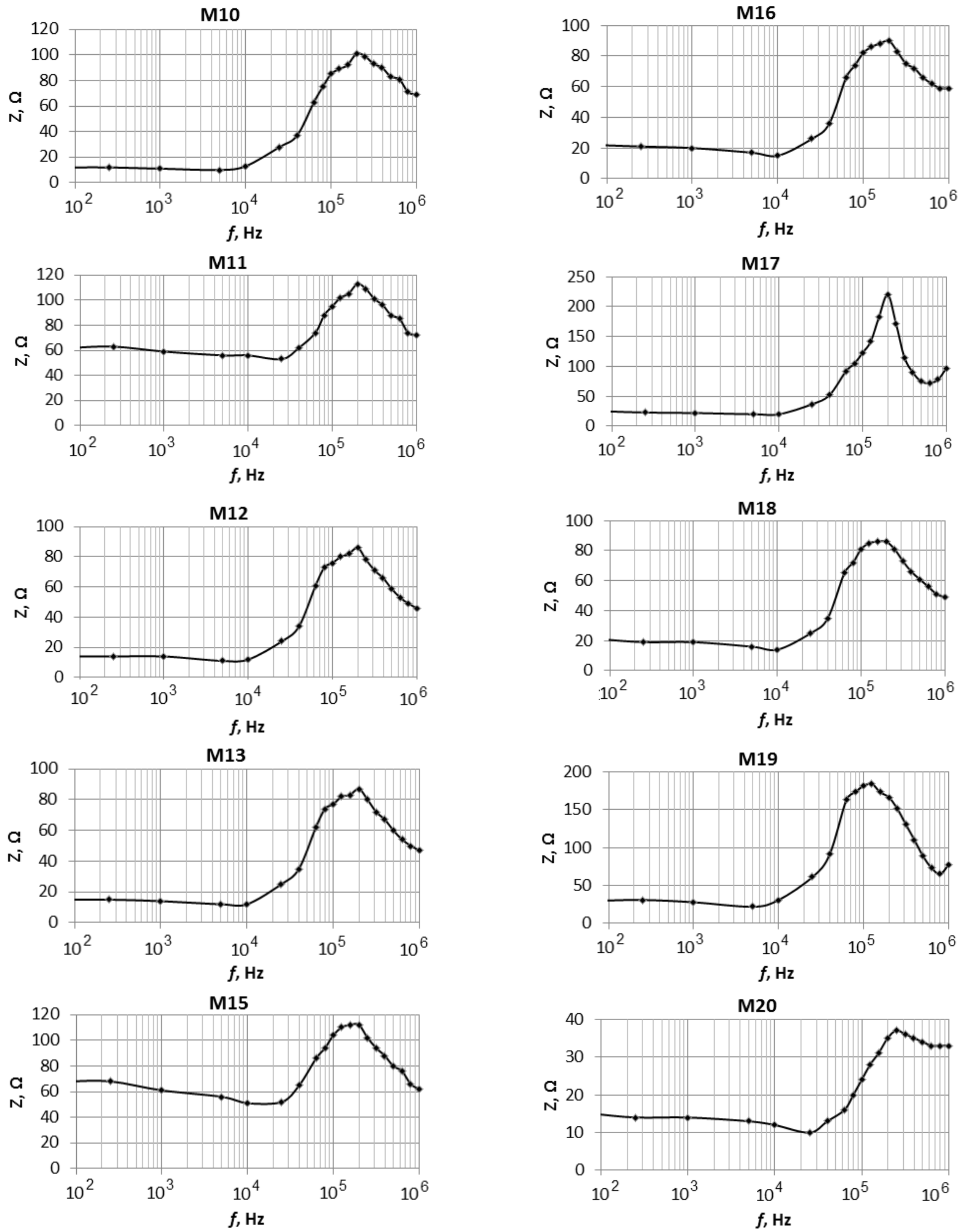

Figure 3. Frequency characteristics of grounding impedances measured at the test site in Huta Poreby during the summer season in 2015.

TABLE I. GROUNDING RESISTANCE AND SURGE GROUNDING IMPEDANCE MEASUREMENTS FOR SELECTED TESTING POINTS

Test points	R_{gnd1}, Ω 2014	R_{gnd2}, Ω Aug. 31, 2015	R_{gnd2}/R_{gnd1}	Z_{surge}, Ω Sept. 2, 2015
M10	-	8.6	-	-
M11	49.0	56.0	1.14	-
M12	-	5.6	-	-
M13	-	27.0	-	-
M14	44.2	53.0	1.20	50.0
M15	44.1	74.0	1.68	50.0
M16	8.4	11.2	1.33	13.6
M17	-	13.6	-	62.0
M18	-	9.9	-	13.1
M19	-	5.7	-	16.7
M20	7.0	12.3	1.76	-

Such frequency characteristic of the PEN conductor significantly affects the impedance of the entire system seen from the current injection point (M19). The last frequency characteristic of grounding impedance was measured at the transformer grounding system. The graph of the frequency characteristics for test point (M20) shows that the peak value at 200 kHz is relatively small compared to the other characteristics shown in Fig. 1.

The grounding resistances were also measured at the selected points (see Table I) using the standard fall-of-potential 3-point method. Listed in Table I are measurements conducted in 2014 and in 2015 on the same day as the high frequency measurements. Additionally, some measurements of surge grounding impedances were made for selected points given in the last column in Table I using the meter WG-407 in 2015. The surge impedances were determined on the basis of the surge voltage and current waveforms as the ratio of the peak values of these two quantities. The measuring method is thoroughly discussed in [6]. Comprehensive analysis of time and frequency-dependent lightning surge characteristics of grounding electrodes is presented in [7]. From Table I, it can be seen that the ratio of the change in the grounding rod resistances are both approximately 1.2, suggesting the difference in values could be related to differences in soil moisture. It is not quite as clear when reviewing the ratio of resistances from the buried tape and transformer ground. The burial depth of the tapes is much less than the driven rods, so the effect of surface moisture would be more significant for those electrodes than for the vertical rods. There was a substantial increase in the resistance of the 4 m tape but it is located at one of the highest points at the structure and has less surface area than the corresponding 20 m tape. The ratios for the buried grounding tapes range from around 1.3 to 1.7, which could also be within the expected variation due to the drought conditions experienced during the period prior to the August 2015 testing.

Note that the surge grounding impedance of vertical grounding rod and 4 m long buried tape are less than their grounding resistances (see Table I). It means that for such short ground electrodes their inductances can be neglected but the effect of capacitances should be taken into account. Since the capacitance is modelled as connected in parallel to the grounding resistance, the total impedance can be less than the grounding resistance.

CONCLUSION

The high frequency grounding impedance studies were conducted at the test site in Huta Poreby during the summer season in 2015. The impedances seen from different locations were measured with the impedance meter AES 1002 operating in the frequency range from 100 Hz to 1 MHz. The obtained characteristics have similar shapes. In the low-frequency range impedance values are almost constant while above tens of kilohertz their values begin to rise and reach a peak at about 200 kHz. Above this frequency, impedance values begin to decrease. The observed variability of the frequency characteristics was smaller and they are more regular in comparison to those obtained during the similar measurements conducted at Camp Blanding, Florida in 2009. Note that the ground resistivity of clay soil in Poland was considerably lower than for sandy soil at Camp Blanding (less than 100 Ωm for clay soil versus several hundred to a few thousand Ωm for sandy soil). Additionally, the grounding resistances and surge grounding impedances were measured and analyzed. For the short ground electrodes their inductances can be neglected, but the effect of capacitances should be taken into account, and therefore, a total impedances can be a slightly less than their grounding resistances. In order to verify obtained results we plan to repeat the high frequency measurements in the near future when the soil is wet. At the same time a thorough investigation of the soil will be conducted in order to formulate its multi-layer model. Finally, modeling of grounding system of the lightning protection system will be carried out over the entire analyzed frequency range.

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