Electric Power Systems Research 118 (2015) 69–75

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Transient grounding impedance and transient resistivity measurements using a very short current lead

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ARTICLE INFO

Article history:
Received 10 January 2014
Received in revised form 28 April 2014
Accepted 20 May 2014
Available online 13 June 2014

Keywords:
Lightning protection
Transmission line
Transient grounding impedance
Soil resistivity

ABSTRACT

This work describes a system for measurements of the transient impedance of grounding electrodes using a portable impulse generator and a new arrangement of test leads. The major innovation is the use of a physically short current reaction lead, using a transmission line with very low propagation velocity (2% of the velocity of light). The methodology for obtaining the transient impedance from the measurements is discussed and validated in field studies using a 2.4 m long vertical rod. A comparison with calculated values is also presented. Additionally, the influence of the length of the potential lead is investigated using the very short current lead and the transient soil resistivity is also calculated.

1. Introduction

The grounding impedance of transmission line towers plays an important role in the lightning performance of the lines. Usually, when poor performance is observed, a survey is carried out to measure the grounding impedance of each tower. This task is cumbersome, time consuming and expensive. Several efforts have been recently reported to facilitate the measurement of grounding impedance [1–4]. The time-domain methodology for measuring transient ground electrode footing impedance has been advancing in recent years. In this technique, current is impressed into a "reaction lead" of constant surge impedance with a length that is four or five times longer than the tower height, and thus typically 90–150 m long. It was verified that this range of lengths is sufficient to avoid that surge impedance response is free of reflections from the remote end and to characterize the transient impedance of transmission tower ground. However, this can pose a problem depending on local conditions. This work presents an improvement in this field by proposing the use of physically short current reaction leads. This makes it possible to measure the impedance even in places where the use of such long cables is inconvenient or impossible. Thus, the key point for improving the measurements is the use of a transmission line with very low propagation velocity. The new methodology uses a transmission line with around 2% of the velocity of light in vacuum *c*, for the current reaction lead.

In the study, this transmission line will be named LIA (acronym in Portuguese for Artificial Infinite Line). For the potential lead insulated copper cables 20 m long and 2.5 mm^2 cross-section were used. This new LIA methodology was first presented in Ref. [5], and now a comparison with the methodology discussed in Refs. [1,3,4] is presented.

The feasibility of the proposed methodology was verified through field tests using the developed prototype. It is a complete measuring system consisting of a portable repetitive impulse generator, four LIAs, 3 m long each, and a digital oscilloscope to record the transient waveforms. The field test consisted of measuring the transient grounding impedance of a 2.4 m long vertical grounding rod. In this experiment, the main objective was to validate the use of the very short current lead instead of a long one. The transient grounding impedance is derived from the field results and presented. A comparison with calculated values is also included. The influence of the length of the potential lead in the transient impedance value is investigated and potential leads 7 and 20 m long were used. This is an important matter because in Refs. [3,4], the transient soil resistivity is calculated using transient impedance values measured with potential leads of different lengths.

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http://dx.doi.org/10.1016/j.epsr.2014.05.014
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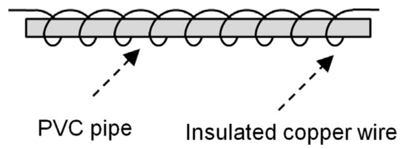

Fig. 1. Transmission line with low propagation velocity (LIA) used as current or potential leads.

2. The experimental setup

Details of each component of the measuring system and the results of the field tests are presented in the following.

2.1. Artificial Infinite Line (LIA)

The new current reaction lead – LIA – is a transmission line made with a thin insulated wire wrapped around a non-conductive polyvinyl chloride (PVC) pipe, as shown in Fig. 1. The propagation velocity can be adjusted controlling the number of turns per unit length. Benefiting from the reduced propagation speed, using the proposed current lead, the transient grounding impedance value can be evaluated for time intervals of around 10 μs, for a 20 m long LIA. For the sake of comparison, the same 10 μs observation time can only be obtained using conventional lead length of 1000–1400 m, with propagation velocity of 0.7*c*–0.9*c* depending on the underlying soil resistivity and wire height over ground.

The performance of the LIA, concerning propagation velocity and surge impedance, was first evaluated using 4 LIAs, each one 3 m long in the dipole arrangement shown in Fig. 2. The height of the LIAs with respect to the floor (h) was varied from 0 to 200 mm. The corresponding measured current and voltage waveforms are shown in Fig. 3 for $h = 0$.

From Fig. 3, the time of arrival of the reflected current at the open end is about 2.0 μs which means a propagation velocity of 6.0 m/μs, corresponding to 2% of the velocity of the light in vacuum. Fig. 4 shows that a constant surge impedance of around 1500 Ω is established within 200 ns and maintained for more than 2 μs.

The LIA characteristics can be established approximately using the inductance per unit length from the following expression:

$$L' = \mu_0 N^2 A \quad (1)$$

where μ_0 is the vacuum permeability, N is the number of turns per meter and A is the area. For a LIA made with an insulated copper cable of 0.32 mm^2 (22 AWG) wrapped around a PVC pipe with a diameter of 20 mm and 800 turns per meter, the inductance per unit-length is ∼252 μH/m. This is a very high value when compared to inductance of a line of constant surge impedance, with $Z = 500\,\Omega$ giving $L' = 1.7$ μH/m using $L' = Z/c$ per meter. While the surge impedance of the line on the ground is affected by underlying soil resistivity, the high self-inductance of the LIA reduces the sensitivity to this effect.

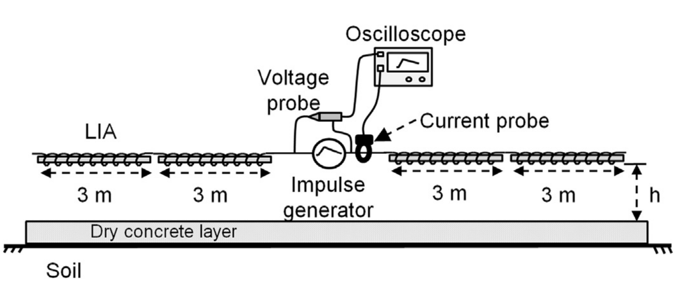

Fig. 2. Arrangement used to measure the LIA propagation velocity and surge impedance.

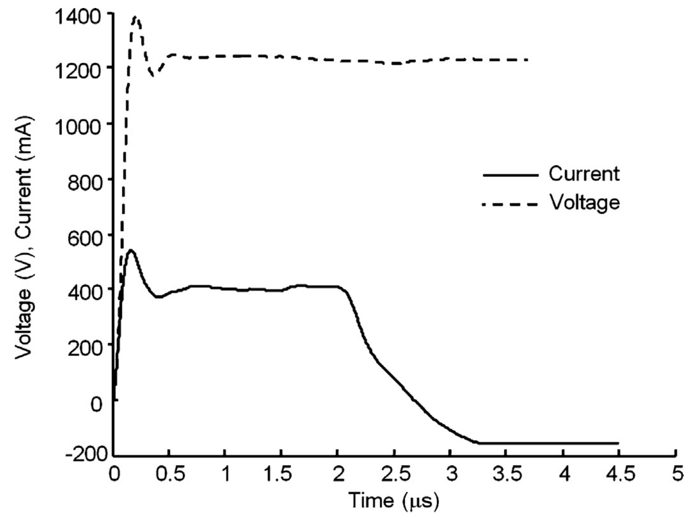

Fig. 3. Current and voltage measured at the impulse generator for two 6 m long each LIAs placed directly on the floor ($h = 0$).

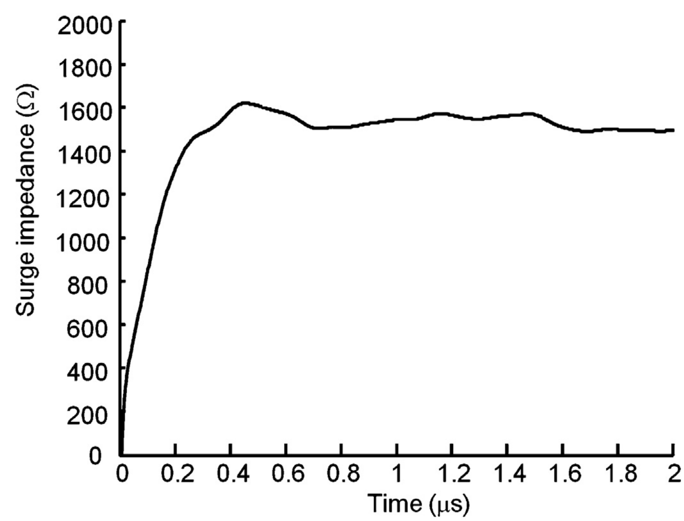

Fig. 4. Surge impedance of a 6 m long LIA placed directly on the floor ($h = 0$).

The capacitance per unit length of a wire of constant surge impedance over ground, with $Z = 500\,\Omega$, is $C' = 1/(Zc) = 6.7$ pF/m. The LIA capacitance per unit length is not so easy to calculate, as its surge impedance is sensitive to the height of the LIA over ground. To clarify this dependence, the propagation velocity and the surge impedance of the LIA was measured for different heights ($h = 0$ to $h = 200$ mm) and Table 1 shows the results.

Fig. 5 shows a photograph of the arrangement used for the measurements taken over a dry concrete floor. Additionally, the propagation velocity of a 12 m long LIA placed directly on the soil surface was measured in the outdoor test site located at the Federal University of Minas Gerais campus. Fig. 6 shows the arrangement

Table 1
LIA propagation velocity and the surge impedance for $h = 0$ to $h = 200$ mm.

Height (mm)	Surge impedance (Ω)	Propagation velocity (m/μs)	Relative propagation velocity (% of the velocity of the light in vacuum)
0	1500	6	2
20	2307	9	3
40	3300	11	3.7
200	4100	15	5