# TRANSIENT IMPEDANCE OF GROUNDING RODS

I. F. Gonos F. V. Topalis I. A. Stathopulos

National Technical University of Athens
Department of Electrical and Computer Engineering, High Voltage Laboratory

**Abstract:** The aim of this paper is the correlation of the transient impedance and its parameters with the stationary resistance of simple grounding systems. Impulse current tests of the standard form 8/20 μs were performed on several types of equilateral triangles and single driven rods of different lengths. The injected current in the grounding system and the developed potential were recorded, resulting in the determination of the time variation of the transient impedance. Further mathematical analysis of the experimental results led to simple linear relations between the parameter of transient impedance and the stationary resistance. The results provide useful information for the design of a grounding system and the measures for the protection of installations from lightning strokes.

**Key words:** Grounding system, transient impedance, stationary resistance.

## 1. Introduction

The grounding systems serve multiple purposes. Not only they do insure a reference potential point for the electric and electronic devices but also provide a low resistance path for fault currents into the earth. Such fault currents can arise either from internal sources or from external ones e.g. by lightning strokes and industrially-generated static electricity. The resistance of grounding systems has an essential influence on the protection of the grounded system. Grounding systems can consist of one or more vertical or horizontal ground rods, three or more vertical ground rods connected to each other and two or three-dimensional grids from metal rods and foundation grounding systems.

The behaviour of the grounding system under lightning determines the degree of protection provided. This makes obvious the purpose of analysis procedures predicting the transient response of grounding systems. If an equivalent circuit approach is adopted these procedure can be implemented in a simulation model [1-7].

The specific value of impulse impedance which is of main interest is the one corresponding to the beginning of the steep ascent for the wave-front. The results reveal its value to be quite higher than the stationary value of its ground resistance and reduces to this latter value [3, 5].

The work presented in this paper refers to the problem of transient analysis of practical grounding systems consisting of grounding rods under impulse lightning currents.

## 2. Fundamentals

The driven rod is one of the simplest and most economical form of electrodes. The stationary resistance $R$ of a driven rod is given by the following formula [7]:

$$R = \frac{r}{2 \cdot p \cdot l} \cdot \left( ln\left( \frac{8 \cdot l}{d} \right) - 1 \right) \tag{1}$$

where:
$r$ is the resistivity of the ground,
$l$ is the length of the rod and
$d$ is the radius of the rod.

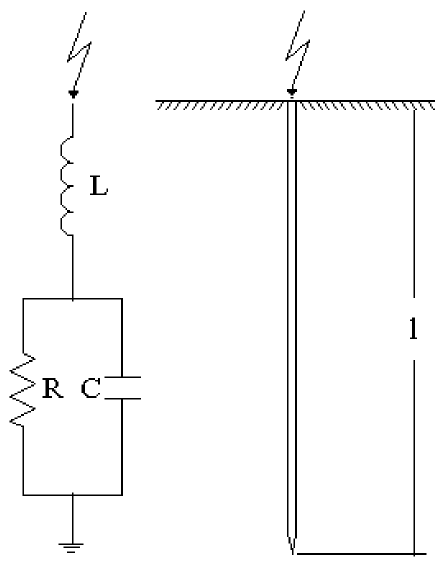


Fig. 1: Equivalent circuit for a driven rod stressed by an impulse current

When the electrode voltage changes with time, there will be a conductive current in addition to a capacitive current. The equivalent circuit of a driven rod under impulse current is shown in Fig. 1. The resistance $R$ of the rod is given by the Eq. (1) and the inductance $L$ of such a rod is equal to [7, 8]:

$$L = 2 \cdot l \cdot ln\left(\frac{4 \cdot l}{d}\right) \cdot 10^{-7} \quad (2)$$

The capacitance $C$ of the ground rod is [7]:

$$C = \frac{e_r \cdot l}{18 \cdot ln\left(\frac{4 \cdot l}{d}\right)} \cdot 10^{-9} \quad (3)$$

where $e_r$ is the dielectric constant of the soil.

The impulse impedance of a grounding system is necessary for determining its performance while discharging impulse currents to ground, as in the case of lightning and transient grounds faults. The impulse impedance is define $Z$ is defined as the ratio of the impulse voltage to the impulse:

$$Z(t) = \frac{U(t)}{i(t)} \quad (4)$$

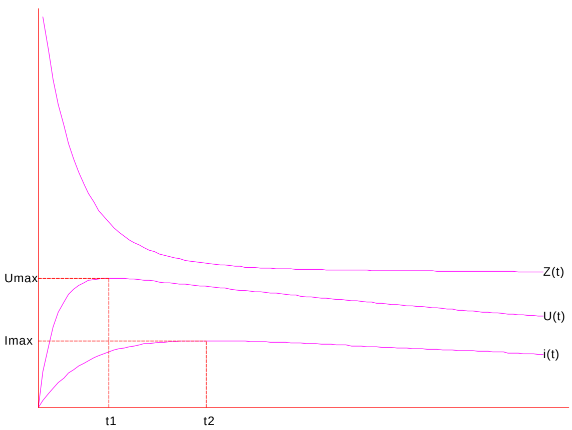


Fig. 2: Definition of the parameters of impulse impedance

Four parameters of impulse impedance (Fig. 2) are defined as follows [3]:

$$Z_1 = max(Z(t)) \quad (5)$$

$$Z_2 = \frac{U(t_1)}{i(t_1)} \quad (6)$$

$$Z_3 = \frac{U(t_1)}{i(t_2)} \quad (7)$$

$$Z_4 = \frac{U(t_2)}{i(t_2)} \quad (8)$$

where:
$Z_1$ is the maximum value of the ratio of impulse voltage to impulse current, $Z_2$ is the ratio of the maximum value of voltage to the respective value of current when voltage reaches its maximum, $Z_3$ is the ratio of maximum value of voltage to the maximum value of current and $Z_4$ is the ratio of voltage when current reaches its maximum to the maximum value of current.

It is obvious:

$$Z1 > Z2 > Z3 > Z4 > R \quad (9)$$

A lightning discharge affects the resistance of a grounding system in two ways. The current is up to 100 kA or more and has a much higher frequency spectrum than the stationary case. The transient impedance becomes greater as:

- the inductivity of the wire and of the connection becomes greater
- the high value of current can dry the ground,
- the high frequency spectrum shortens the electrical length of long grounding wires
- the skin effect rises the resistance and the inductivity of wires due to the value of the frequency.

The transient impedance becomes smaller as the electrical field strength on the surface of grounding system can reach values where predischarges in the ground start; these discharges can lead to ground ionisation that destroy layers with high resistance [4].

## 3. Experimental apparatus and test techniques

The layouts of grounding system (Fig. 3) were tested experimentally under impulse lightning current of waveshape 8/20 μs The maximum value of the current was varying up to 3 kA. The first grounding layout was a single driven rod and the second one was an equilateral triangle with three vertical rods. Cooper rods with diameter 20 mm were used. The measured value of the earth resistivity was found to be equal to 30 $\Omega \cdot$m. The waveforms of the impulse current and of the potential of grounding system were recorded directly by a data acquisition system controlled by a personal computer, with measuring bandwidth of 20 MHz.

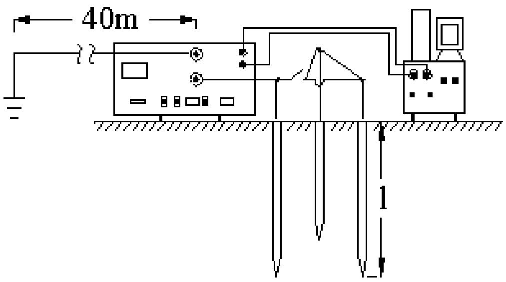


Fig. 3: Experimental set-up

## 4. Test results

The measurements values of peak voltage, peak current and impedance of ten different grounding layouts are presented in Table 1.

Table 1: Experimental results.

| Electrode | l [cm] | R [Ω] | $U_{peak}$ [kV] | $I_{peak}$ [A] | $Z_3$ [Ω] |
|---|---|---|---|---|---|
| A rod | 50 | 68.2 | 5.14 | 13.7 | 375 |
| A rod | 75 | 31.0 | 5.08 | 16.5 | 308 |
| A rod | 100 | 22.3 | 5.03 | 17.7 | 284 |
| A rod | 125 | 14.6 | 5.00 | 18.8 | 266 |
| A rod | 150 | 12.1 | 4.99 | 19.3 | 259 |
| Three rods | 50 | 27.0 | 4.91 | 16.7 | 294 |
| Three rods | 75 | 15.6 | 4.87 | 18.3 | 266 |
| Three rods | 100 | 10.7 | 4.83 | 19.3 | 250 |
| Three rods | 125 | 7.6 | 4.80 | 20.0 | 240 |
| Three rods | 150 | 6.9 | 4.79 | 20.3 | 236 |

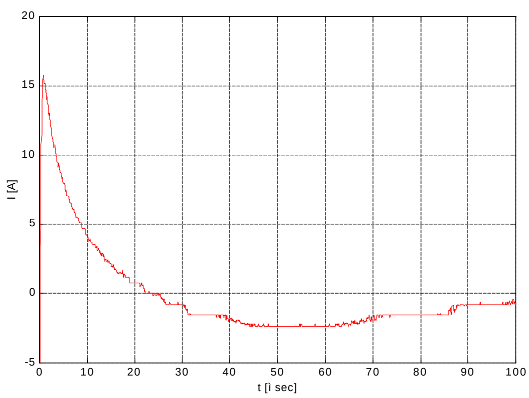


Fig. 4: Waveform of the injected current.

In these figures, the test results for the grounding system of a driven rod with diameter 20mm and length 75cm are presented. The waveforms of the injected current is shown in Fig. 4. The measured potential with reference to the ideal earth is shown in Fig 5. The transient impedance of the grounding system under this stress is the one of Fig. 6.

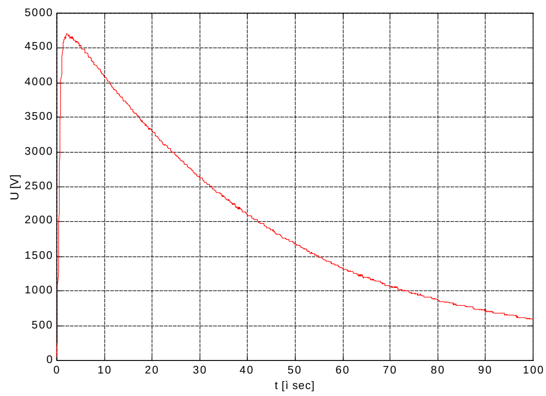


Fig. 5: Waveform of the potential.

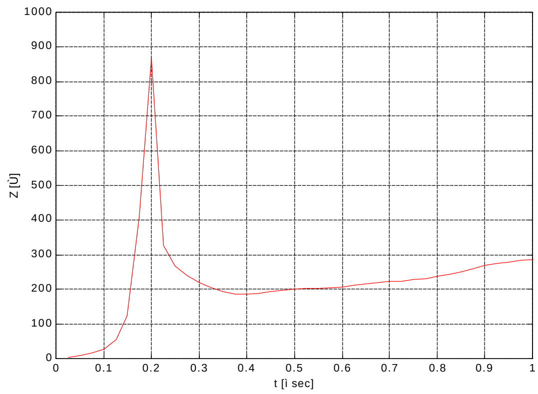


Fig. 6: Variation of the impulse impedance

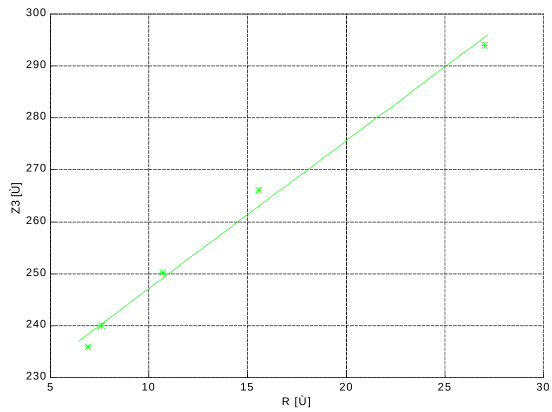


Fig. 7: Variation of the impulse impedance vs. stationary resistance for driven rod.

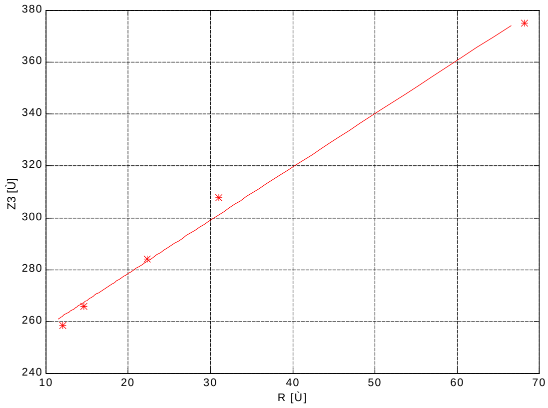


Fig. 8: Variation of the impulse impedance vs. stationary resistance

The variation of the parameter $Z_3$ of impulse impedance versus the stationary resistance of single driven rod is presented in Fig. 7. The respective variation of the equilateral triangle is presented in Fig 8. Further mathematical analysis of the experimental results leads to the following relation between Z3 and R of the single driven

$$Z_3 = 2.053 \cdot R + 237.5 \qquad (10)$$

A similar relation for the equilateral triangle, was found to be:

$$Z_3 = 2.847 \cdot R + 218.7 \qquad (11)$$

## 5. Conclusions

The performed measurements show that the transient impedance reaches its maximum value very fast (fraction of microsecond) and consecutively is reduced to the value of the stationary resistance. the one corresponding to the beginning of the steep ascent for the wave-front. The results reveal the value of the transient impedance to be quite higher than the stationary resistance. The determined analytical relations between the parameters of the transient impedance and the stationary resistance allow the limitation or even elimination of time and money consuming experiments. It will also facilitate the optimisation of any planned grounding system. The computer aided optimisation of grounding systems is very useful, since the improvement of them after their installation is a difficult task and sometimes not possible.

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## Address of Authors

National Technical University of Athens
Dept. of Electrical and Computer Engineering
42, Patission Str., GR-10682 Athens, Greece
Tel.: +30-1- 7723539, 7723627, 7723582
Fax.: +30-1- 7723628, 7723504
Email.: igonos@softlab.ece.ntua.gr
topalis@softlab.ece.ntua.gr
stathop@power.ece.ntua.gr