BEHAVIOUR OF A GROUNDING SYSTEM UNDER IMPULSE LIGHTNING CURRENT

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Abstract: *This paper deals with the behaviour of a grounding system, under impulse lightning current. The authors have made a large number of experiments in the High Voltage Laboratory of N.T.U.A. and the relevant experimental results were found to agree favorably with those obtained theoretically by using the Electromagnetic Transient Analysis Program (EMTP).*
Experimental results have been obtained by using variable peak impulse lightning current. The typical waveforms of the injected electric current and the variation of the potential and the impedance upon the time are presented using diagrams which show the compliance between theoretical and experimental data.

Key words: *Grounding system, impulse impedance, lightning current, transient current.*

1. Introduction

The resistance of grounding systems has an essential influence on the protection. Thus investigation of the transient of grounding systems shall lead to an objective interpretation [1]. The grounding systems serve multiple purposes. Not only do they insure a reference potential 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 [2]. The behaviour of the grounding system under lightning determines the degree of protection provided by them [3]. All of the above make obvious the purpose of analysis procedures predicting the transient response of grounding systems [4]. Some grounding systems are: hemispherical electrode, driven rod and grounding grids. Grounding systems can consist of one or more vertical or horizontal ground rod(s), three or more vertical ground rods connected to each other, two or three-dimensional grids from metal rods and foundation grounding systems. The specific value of impulse impedance which is of our 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 steady-state value of its ground resistance and reduces to this latter value [5].

2. Fundamentals

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

In order to validate the behavior of grounding systems the knowledge of their performance over a wide range of frequencies is required. The basic models developed so far are the following :

The Network Approach, which models an earth conductor as equivalent π-circuits involving R-L-C elements. The coupling of earth conductors can be taken into account by mutually coupled inductances.

The Transmission Line Approach, where the interconnected linear ground conductor is treated by the traveling wave technique.

The Electromagnetic Field Approach, which is strictly based on the theorems of electromagnetism and with the least neglects possible. The problems are defined in terms of retarded potentials and are solved by the method of moments[2].

All three developed models produce equations for the grounding system's impulse impedance depending on time, thus depending on the contents of the frequency spectrum.

That is of major importance as a lightning discharge affects the resistance of a grounding system in two ways. The current is up to 100 kA or more and contains a much higher frequency spectrum. The later affects the inductivities of the wires, it shortens the electrical length of long grounding wires and the skin effect which rises the resistance.

It would be useful here to define the impulse impedance *Z*. It is agreed that by the term impulse impedance is meant the ratio of the impulse voltage to the impulse current upon the time. The impulse impedance is defined in four ways (Fig. 1):

$Z_1 = max(Z(t))$: Maximum value of the ratio of impulse voltage to impulse current

$Z_2 = \frac{U(t_1)}{i(t_1)}$: Ratio of peak voltage to current when voltage peak occurs.

$Z_3 = \frac{U(t_1)}{i(t_2)}$: Ratio of peak voltage to peak current independent of the instant at which each one occurs.

$Z_4 = \frac{U(t_2)}{i(t_2)}$: Ratio of voltage (when current peak occurs) to peak current.

R : Grounding resistance.

Therefore $Z_1 > Z_2 > Z_3 > Z_4$

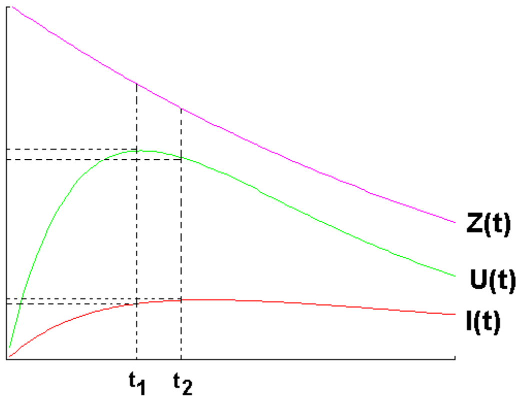

Fig. 1. Definition of impulse impedance

3. Experimental Apparatus and Test Technique

Experimental results have been obtained by using variable peak impulse lightning current at two usual grounding system configurations (a single driven rod and three parallel vertical rods forming an equilateral triangle). The experimental setup is sketched in Fig. 2. The impulse current ranging from 8/20 μs was produced by discharge of a current generator across a maximum current of 3 KA. The variation of impulse current and potential of grounding system has been recorded by means of a data acquisition system controlled by a personal computer, still having a measuring bandwidth of 10 MHz. Cooper rods with diameter 20 mm were used for the grounding system. The soil was very wet and the value of earth resistivity was measured 40 Ω-m.

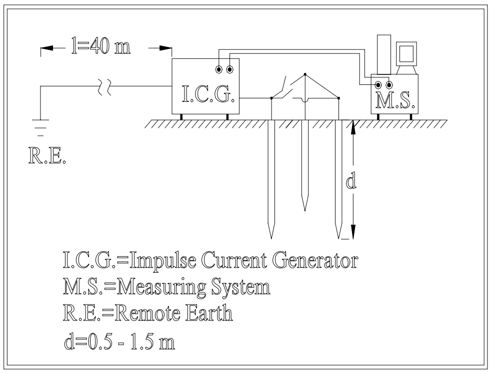

Fig. 2. Experimental setup

4. Test Results

The goal of the work is to lead to the reduction in power losses due to lightning strokes and transient ground faults. A large number of experiments has been made in the High Voltage Laboratory of N.T.U.A. and the relevant experimental results were found to agree favorably with those obtained theoretically by using the Electromagnetic Transient Analysis Program (EMTP), Fig. 3.

The test results are summarized in Table 1.

There are typical waveforms of the injected electric current which is generated by an impulse current generator. The diagrams which show the variation of voltage and impedance upon the time are depicted in Fig. 4...10.

Table 1
Experimental results

Kind of Electrode	Impedance					Voltage	Current	Figure
	Z_1 [Ω]	Z_2 [Ω]	Z_3 [Ω]	Z_4 [Ω]	R [Ω]	U_{peak} [kV]	I_{peak} [A]	
Single driven rod (length 50 cm)	342	315	221	205	33.1	3.34	15.1	Fig. 4.
Single driven rod (length 100 cm)	308	193	180	177	15.7	3.03	16.8	Fig. 5.
Single driven rod (length 150 cm)	251	177	164	161	12.0	2.82	17.2	Fig. 6.
Three rods in parallel (length 50 cm)	538	178	173	167	15.4	4.08	23.6	Fig. 7.
Three rods in parallel (length 75 cm)	411	163	159	158	9.9	4.04	25.4	Fig. 8.
Three rods in parallel (length 100 cm)	376	152	147	143	7.4	4.42	30.1	Fig. 9.
Three rods in parallel (length 150 cm)	399	144	128	127	4.7	4.25	33.1	Fig. 10.

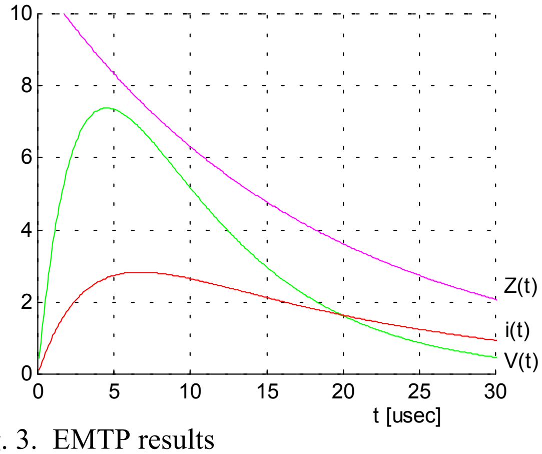

Fig. 3. EMTP results

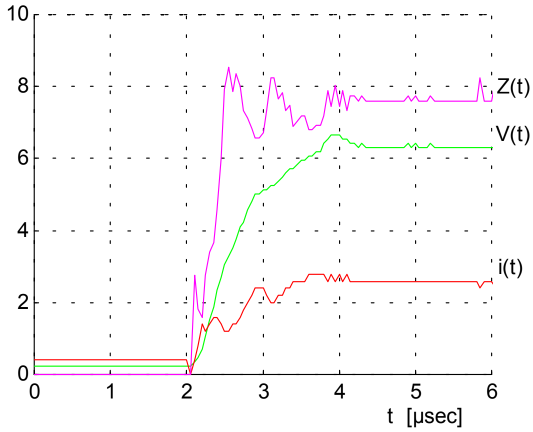

Fig. 4. Measurement of Z(t) of a single rod with 33.1 Ω grounding resistance (Zx40 Ω, Vx500 V, ix5 A)

Fig. 4. shows the variation of impulse current i(t), voltage V(t) and impedance Z(t) versus time.

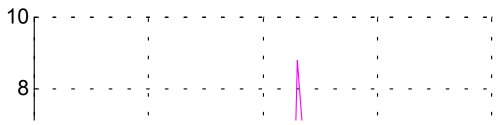

Fig. 5. Measurement of Z(t) of a single rod with 15.7 Ω grounding resistance (Zx35 Ω, Vx700 V, ix10 A)

Fig. 5. shows the variation of impulse current i(t), voltage V(t) and impedance Z(t) versus time.

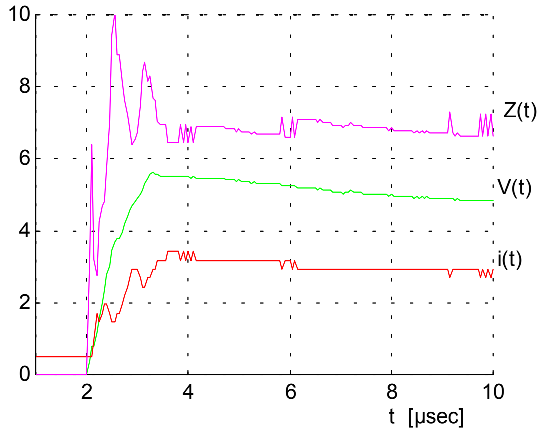

Fig. 6. Measurement of Z(t) of a single rod with 12.0 Ω grounding resistance (Zx25 Ω, Vx500 V, ix5 A)

Fig. 6. shows the variation of impulse current i(t), voltage V(t) and impedance Z(t) versus time.

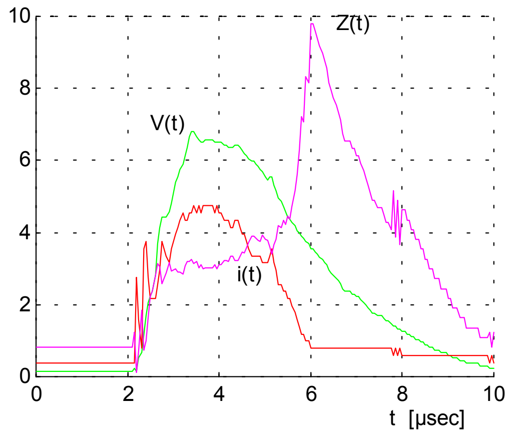

Fig. 7. Measurement of Z(t) of three rods in parallel with 15.4 Ω grounding resistance (Zx55 Ω, Vx600 V, ix5 A)

Fig. 7. shows the variation of impulse current i(t), voltage V(t) and impedance Z(t) versus time.

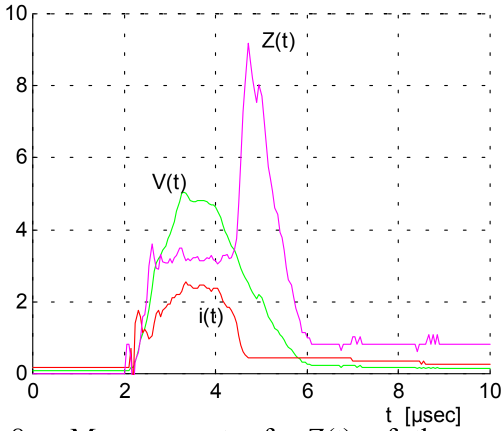

Fig. 8. Measurement of Z(t) of three rods in parallel with 9.9 Ω grounding resistance (Zx50 Ω, Vx800 V, ix10 A)

Fig. 8. shows the variation of impulse current i(t), voltage V(t) and impedance Z(t) versus time.

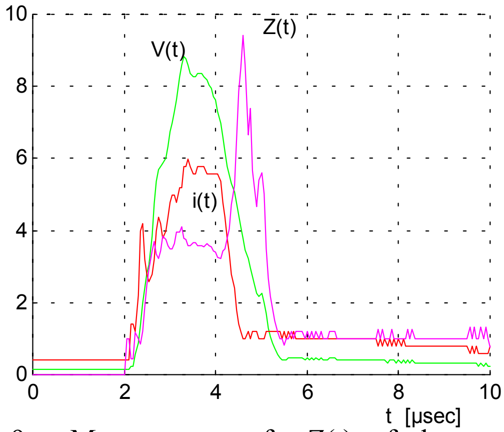

Fig. 9. Measurement of Z(t) of three rods in parallel with 7.4 Ω grounding resistance (Zx40 Ω, Vx500 V, ix5 A)

Fig. 9. shows the variation of impulse current i(t), voltage V(t) and impedance Z(t) versus time.

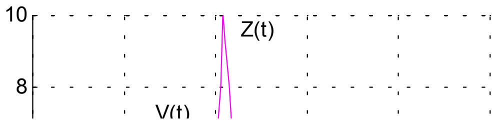

Fig. 10. Measurement of Z(t) of three rods in parallel with 4.7 Ω grounding resistance (Zx40 Ω, Vx600 V, ix10 A)

Fig. 10. shows the variation of impulse current i(t), voltage V(t) and impedance Z(t) versus time.

5. Conclusions.

The measurements and the simulation results show that the specific value of impulse impedance which is of our 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 steady-state value of its ground resistance and reduces to this latter value.

This good agreement between experimental and computed results is a very strong indication for the validity and the correctness of the developed model and allow the limitation or even the elimination of the experiments needed for the optimization of any planned grounding system. The limitation or elimination of experiments seems to be very significant since the execution of such experiments is time and money consuming and has as presupposition the availability of sophisticated and expensive equipment. On the other hand the computer aided optimization of any planned grounding system is very useful, since the improvement of grounding system after its installation is a difficult and not always successful or even possible work.

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