MODELLING OF A GROUNDING GRID USING AN ELECTROLYTIC TANK

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Abstract: The work presented in this paper refers to the problem of transient analysis of grounding grids under impulse lightning currents using scale models (an electrolytic tank). Impulse current tests were performed on several types of grids. The injected current in the grounding system and the developed potential were recorded, resulting in the determination of the variation of the transient impedance upon the time.

Key words: Grounding system, electrolytic tank, transient impedance, scale model.

1. Introduction

Grounding systems constitute one of the most important parts of building constructions. The grounding systems resistance has an essential influence on the protection of the grounded system. As it is stated in the ANSI/IEEE [1] a safe grounding design has two objectives:

- To provide means to carry electric currents into the earth under normal and fault conditions without exceeding any operating and equipment limits or adversely affecting continuity of service.
- To assure that a person in the vicinity of grounded facilities is not exposed to the danger of critical electric shock.

Grounding systems can consist of a) one or more verticals [2, 3] or horizontal ground rods [4, 5], b) three or more vertical ground rods connected to each other [2, 3] and to all equipment frames, neutrals and structures that are to be grounded. Such a system that combines a horizontal grid and a number of vertical ground rods penetrating lower soil layers has several advantages in comparison to a grid alone. Sufficiently long ground rods stabilize the performance of such a combined system making it less dependent on seasonal and weather variations of soil resistivity. Rods are more efficient in dissipating fault currents because the upper soil layer usually has a higher resistivity than the lower layers. The current in the ground rods is discharged mainly in the lower portion of the rods. Therefore, the touch and step voltage is reduced significantly compared to that of the grid alone.

The existing studies are mainly concentrating to the behavior of grounding systems in the steady state operation condition. In this particular condition the value of the grounding system resistance appears to be much lower than the value of the resistance in the transient condition. It must be paid special attention to the above event in order to avoid possible failure or damage of the protected installation due to a high value of the grounding resistance, during a transient effect (e.g. lightning discharges). For this reason an effort has been made to simulate in the high voltage laboratory the operation of a grounding system during a transient phase and to study its behaviour.

2. Fundamentals

A typical substation-grounding grid consists of a number of horizontal wires and vertical rods connected together and buried in the earth [6, 7]. Many questions may be raised concerning the best configuration for the mentioned grid. Experiments to answer such questions are both costly and difficult to perform. An alternative to full scale measurements is a numerical computation. Thus while numerical computation is a valuable tool it is not the only method and does need from time to time verification. On the contrary scale models offer a practical and inexpensive alternative solution [8]. The work presented in this paper refers to the problem of transient analysis of grounding grids under impulse lightning currents using scale models (an electrolytic tank).

Experiments on full size grid are both costly and difficult to perform. In real grounding systems it is impossible to make experiments for the improvement of the grounding grid characteristics due to its large dimensions. The atmospheric conditions change the behaviour of the grounding impedance as they change the value of soil resistivity [8]. Modelling of ground grid using an electrolytic tank is a known technique over years. The electrolytic tank presents no particular problem for a homogeneous case; water is a convenient choice. For a two-layer model (modelling of multi-layer soil stratification) a gel may be used for the lower layer with the bulk of the grid model still in the upper liquid layer [8].

The impulse impedance of a grounding system is necessary for determining its performance. There are four parameters of impulse impedance. 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 [2].

A lightning discharge affects the resistance of a grounding system. The current is up to 100 kA or more and has a very high frequency spectrum. The transient impedance becomes greater as the inductivity of the wire and of the connection becomes greater. Likewise the high value of current can dry the ground. Also the high frequency spectrum shortens the electrical length of long grounding wires. Last but not least the skin effect rises the resistance and the inductivity of wires. On the contrary the transient impedance becomes smaller as the electric field strength on the surface of grounding system can reach values where pre-discharges in the ground start; these discharges can lead to ground ionisation that destroy layers with high resistance [2].

3. Test apparatus and techniques

The test arrangement is shown in Fig. 1. It includes a high impulse current generator with maximum stored energy 1.5 kWs. It generates impulse currents of the waveform 8/20 μs and with a peak value up to 25 kA. The impulse voltage is measured by means of a resistive voltage divider (50kΩ/50Ω). The injected impulse current is measured by an impulse current shunt (1.0 mΩ) The impulse voltage divider and the current shunt are build in the impulse generator cover. The measuring instrument is a dual beam digital oscilloscope with sampling range 200MS/s. The time between successive impulse applications is at least 1 min.

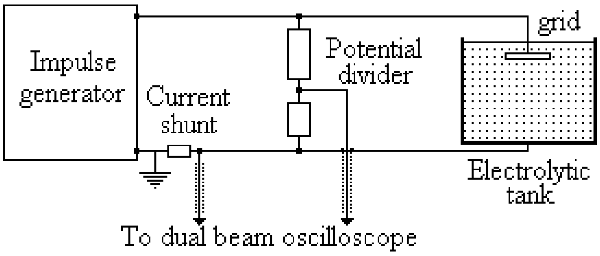

Fig. 1: Experimental set-up

Although the best shape of an electrolytic tank is the hemispherical one, due to the obvious practical difficulties, cylindrical or orthogonal tanks are more readily used [8, 9, 10]. The dimensions of the electrolytic tank which is used for the experiments are 1,5x1,5x1,0 m^3. The model grid is hung on nylon fish lines bellow the surface of the electrolyte. The hanging provides a horizontal configuration with the minimum deformation and bend. For a scale factor 100:1, a variety of grids with outside dimensions 20x20 cm^2 are modeled and tested. The grid model is located in the centre of the tank at a depth of 2 cm. The layouts of grounding systems (Fig. 2) are tested experimentally under impulse lightning current. The first grounding system is a square grid with sixteen meshes (grid-16) and the second one is an other one with the same outside dimensions and four meshes (grid-4). Cooper rods 2,5 mm^2 are used for the construction of the grounding system. The maximum dimension of the grid (the diagonal for a square mesh) must be at least two or three times less than the minimum dimension of the tank. The depth of the tank must not be less than the half side of the tank.

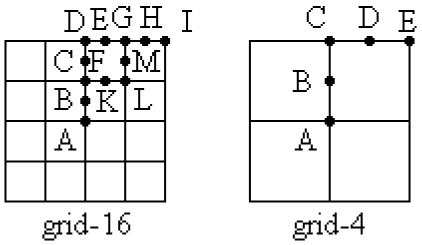

Fig. 2: Investigated grids

Salted tap water is used as electrolyte, which serves as an adequately conducting medium and represents homogeneous earth. Changing the salinity changes the liquid resistivity.

4. Test results

For both grids tested, the conductivity, the temperature of the salted water and the applied voltage and current were recorded. The measured value of the water conductivity is found to be equal to 2.5 mS/cm, (water resistivity is $4\,\Omega m$, for a scale factor 100:1 it corresponds with a soil resistivity $400\,\Omega m$; it is well known that soil resistivity takes values between 100 and $1000\,\Omega m$ [6, 7]). For each point of Fig. 2 (5 points in the first grid and 12 points in the second one) several series of measurements have been carried out. The waveforms of the injected current and the voltage at the grid are shown in Fig. 3. CH1, i.e. the negative waveform, is the voltage drop along the 1.0 mΩ current shunt caused by the injected current and CH2, i.e. the positive waveform, is the voltage measured at the low voltage arm of the (50kΩ/50Ω) potential divider.

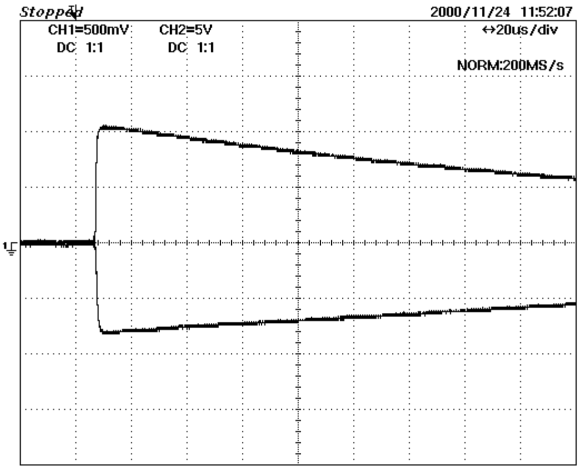

Fig. 3: Current and voltage waveform at grid-16

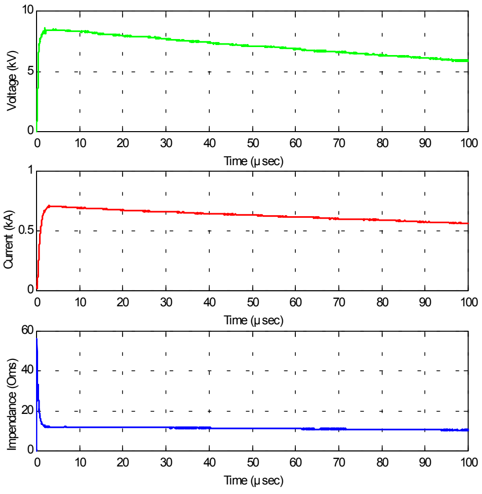

Fig. 4: Variation of voltage, current and impulse impedance upon the time

The variation of voltage, current and impulse impedance [i.e. the ratio (voltage/current)] is presented in Fig. 4. The performed measurements show that the transient impedance reaches its maximum value (Z_1) very fast (fraction of μs) and thereafter is reduced to the value of the stationary resistance. The results reveal the value of the transient impedance to be quite higher than the stationary resistance

The mean values of the impulse parameters for each point are shown in Figs. 5 and 6. The mean values of the Z_2, Z_3 and Z_4 parameters for the grid consisting of four squares (grid-4) are greater than the corresponding mean values of the Z_2, Z_3 and Z_4 parameters of the grid consisting of sixteen squares (grid-16). This is something, which was expected, since the grid-16 has lower resistance than the grid-4, due to the longer conductor that has been used.

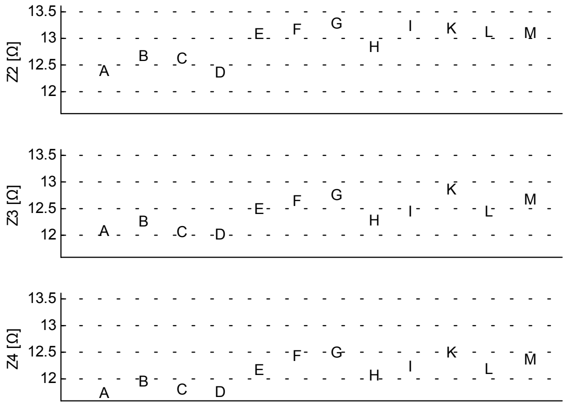

Fig. 5: Variation of the impulse parameters Z_2, Z_3 and Z_4 (grid-16)

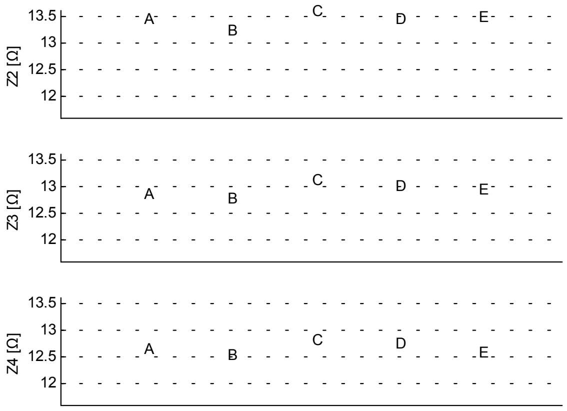

Fig. 6: Variation of the impulse parameters Z_2, Z_3 and Z_4 (grid-4)

By comparing the mean values of the parameters Z_2, Z_3 and Z_4 on external points of any one of both examined grids to the relevant values on internal points of the same grid, one can state that the Z-values are generally in the external points higher than in internal points. i.e. a grounding systems becomes more effective if the descending conductors are connected to internal points of the grounding grid.

The standard deviation of the above parameters is shown in Figs. 7 and 8; it is between 0.1 and 0.5 Ω, i.e. the relative standard deviation is less than 4%.

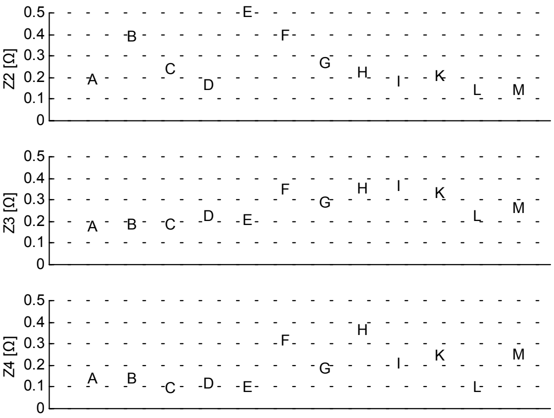

Fig. 7: Variation of standard deviation of the impulse parameters Z_2, Z_3 and Z_4 (grid-16)

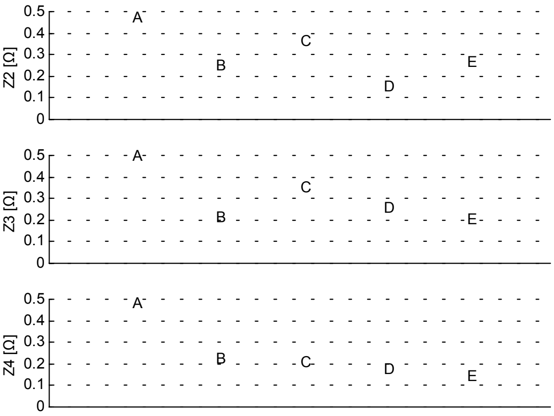

Fig. 8: Variation of standard deviation of the impulse parameters Z_2, Z_3 and Z_4 (grid-4)

5. Conclusions

The improvement and reinforcement of grounding systems after their installation is a very difficult and usually impossible task. For this reason the measurement and the analysis of grounding system parameters using electrolytic tank forms a very useful tool in designing and studying of grounding systems. The performed measured show that the Z parameters are higher on external points than on internal points in the grounding system. Therefore, a grounding systems becomes more effective if the descending conductors are connected to internal points of the grounding grid.

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