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Technique to increase the effective length of practical earth electrodes: Simulation and field test results

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ABSTRACT

Field experiments and computer simulations of two sectionalized horizontal earth electrodes are presented. The electrodes were energized using various voltage sources (dc, and transients of different shapes), and measurements of current and voltage magnitudes along the length of the electrode were examined. Furthermore, by incrementally increasing the length of the test electrodes, the effective length of the earth electrodes was determined experimentally. The experimental and simulation results show reasonably close agreement which gives confidence in predicting the effective length. A new method is proposed to increase the effective length of the horizontal earth electrode by installing an additional insulated parallel conductor which is bonded to the horizontal electrode at points along its length. Such insulated conductor allows current to be distributed further away from the injection point without high leakage as would occur with standard horizontal electrodes buried in the ground. The results show that the current and voltage distributions are modified such that a greater length of buried conductor is utilized and that this contributes to an additional reduction in the earth impedance, and hence the earth potential rise at the point of current injection. The effect of the proposed technique is simulated on a practical wind turbine earthing design, and shows significant gains.

1. Introduction

The enhancement of an earthing system using a horizontal earth electrode is limited because no further benefit is obtained by increasing its length beyond a certain distance from the main earth electrode, which is known as the effective length. It is also well known that, under impulse conditions, horizontal electrodes dissipate current to earth more rapidly than under power frequency resulting in shorter effective lengths. The effective length under impulse conditions depends on soil resistivity, impulse risetime and electrode geometry. Many investigations have been carried out on the transient performance of earth electrodes and empirical formulae and calculation techniques for determining the effective length have been proposed [1–18].

In this paper, results of experimental measurements of transient voltages and currents at points along two buried horizontal test earth electrodes are described. The impulse resistance was calculated for different conductor lengths and, from these results, it was possible to determine experimentally the effective length. The experimental results are compared with those obtained by computer simulations, and show close agreement. Also, it is demonstrated that satisfactory prediction of the effective length using a simplified analytical formula is achievable. Recently, a new method [11,13,15,16] has been proposed by the present authors to increase the effective length of the horizontal earth electrode by installing an additional insulated parallel conductor bonded to the bare underground horizontal electrode at points along its length. In this paper, the experimental tests and computer simulations when adopting this proposal have been compared. Furthermore, its application to a wind turbine earth electrode system was investigated, and it is shown that a significant reduction in earth potential rise is achievable.

2. Field tests on horizontal earth electrodes

2.1. Electrode A

2.1.1. Test arrangement

Fig. 1 shows a diagram of the experimental setup used for the current injection tests. Test Electrode A is an 88.5-m long conductor with a cross-sectional area of 25 mm^2, buried at a depth of 30 cm. The electrode follows an arc of 30 m radius as shown in Fig. 1. The earth electrode is divided into sections of different lengths with test pits located between sections to enable access for

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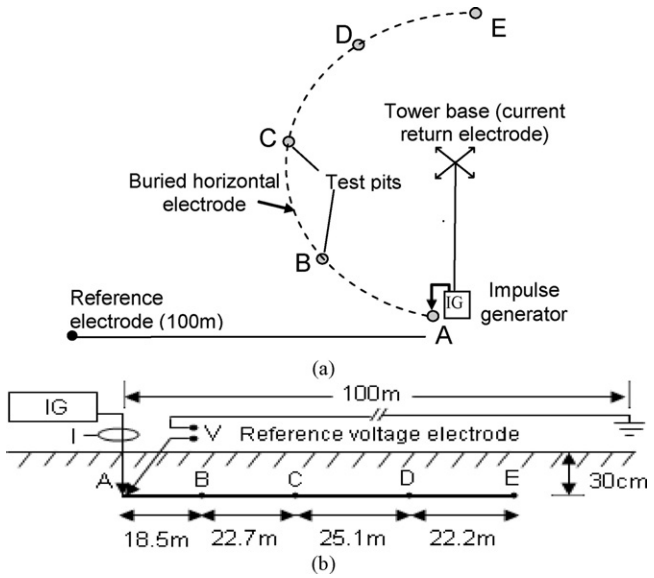

Fig. 1. Experimental set-up of horizontal earth Electrode A: (a) top view and (b) side view.

voltage and current measurements. These junctions are indicated by points A, B, C and D on the figure, and the lengths of the conductor sections are given in Fig. 1(b). Current transformers of 0.1 V/A and 0.01 V/A sensitivities, and high-bandwidth differential voltage transducers were used for the measurements. The current was circulated between one end of the electrode (point A) and a transmission tower base which was used as the auxiliary return current electrode. For the low voltage impulse tests, a HAEFELY recurrent surge generator, Type RSG 481 was used. This instrument has a maximum output voltage of 400 V and delivers double-exponential impulse voltages of variable amplitude and shape. The electrode earth potential rise (EPR) was measured with reference to a rod electrode placed at a distance of 100 m from the injection point.

2.1.2. *Impulse test results for earth Electrode A*

An example of the applied impulse current and the resulting earth potential rise at the current injection location (point A) is shown in Fig. 2. As can be seen on the figure, the current has a risetime of 5.8 μs and a time to half value of 16 μs, with a peak value of 5.4 A. The corresponding peak EPR is 44.4 V. The influence of the electrode inductance is indicated by a sharp rise in electrode potential during the front of the impulse, with its peak occurring earlier than that of the current.

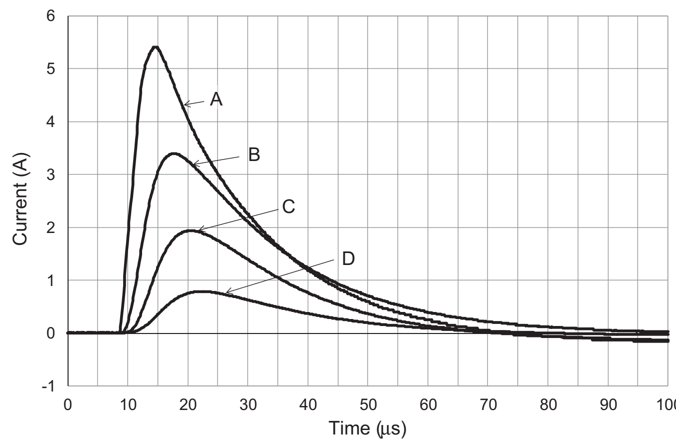

Fig. 3. Measured impulse currents along horizontal Electrode A at locations A, B, C and D of Fig. 1.

2.1.3. *Current and voltage distribution along the electrode*

The impulse currents measured at locations A, B, C and D of the horizontal electrode are shown in Fig. 3, and the corresponding electrode voltages measured at these points, and also at the end point E are shown in Fig. 4. As can be observed, the current impulse undergoes attenuation of its magnitude and a change in the rate of rise as it travels along the electrode length. This is attributed to the current leaking into the ground during propagation. The time delays seen on the current impulse shapes measured at points B (18.5 m), C (41.2 m) and D (66.3 m) correspond to the travel times along the horizontal electrode. In the first 18.5 m section of the horizontal electrode (section AB), 37% of the injected current is dissipated into the ground, whereas in the three sections AB, BC and CD together (66.3 m of electrode length), the current dissipated is 85% of the injected current. As shown in the figure, it was found that the reduction in the peak magnitude of current is not linear, with the highest proportion of current dissipated in the first section AB of the electrode which has the shortest length, compared with sections BC and CD.

Similarly, as illustrated in Fig. 4, the magnitude of the voltage along the electrode shows a significant reduction with length, and undergoes a distortion in shape both on the front and tail of the impulse. The EPR falls by 39% at point B, 62% at point C and 66% at points D and E.

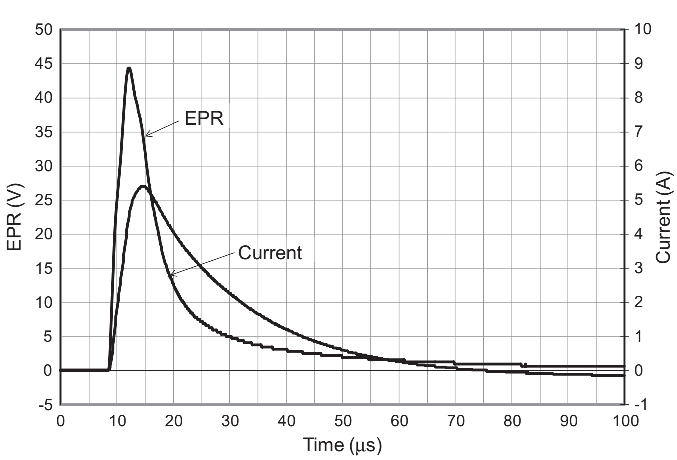

Fig. 2. Example of measured voltage and current records at injection point of horizontal earth Electrode A.

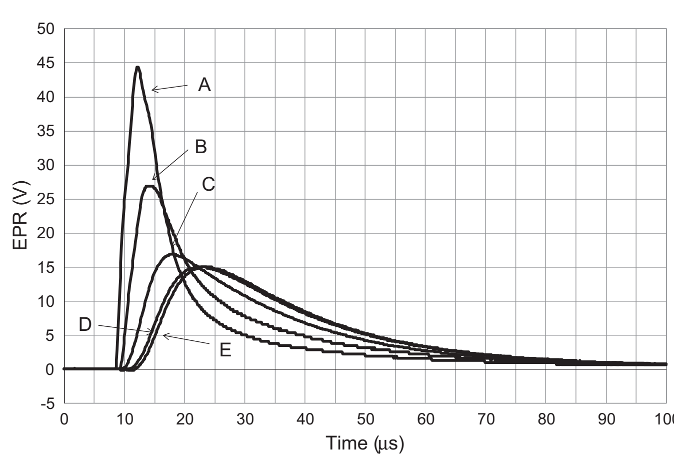

Fig. 4. Measured impulse voltages along the horizontal Electrode A at locations A, B, C, D and E.