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논문 25-8-12

Critical Length Estimation of Counterpoise Subjected to Lightning Stroke Currents

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Abstract

The conventional grounding impedance of a counterpoise is calculated as a function of the length of the counterpoise by use of the distributed parameter circuit model with an application of the EMTP(Electromagnetic Transient Program). The adequacy of the distributed parameter circuit model is examined and verified by comparison of the simulated and the measured results. The conventional grounding impedance of the counterpoise is analyzed for the first short stroke and subsequent short stroke currents. As a result, the simulated results show that the minimum conventional grounding impedance gives at a specified length of the counterpoise. The shorter the time taken to reach the peak of injected currents, the shorter the length of the counterpoise having the minimum conventional grounding impedance. We also present the critical lengths of the counterpoise for short stroke currents as a function of soil resistivity. Based on these results, it is necessary to compute the length of the counterpoise in a specified soil resistivity which satisfies both the low conventional grounding impedance requirement whilst also providing a suitable ground resistance in order to obtain an economical design and installation of the counterpoise.

Key Words : Conventional grounding impedance, Distributed parameter circuit model, EMTP, Counterpoise, Critical length

1. Introduction

Because lightning stroke currents flow through the grounding electrode, the grounding system should be evaluated in terms of the grounding impedance as well as the ground resistance because the grounding system indicates the transient grounding impedance characteristic due to the inductance of the grounding electrode and the permittivity of the soil [1]. The transient grounding impedances are influenced by various factors such as the length and diameter of the grounding electrodes and the permittivity, resistivity and structure of soils [2]. Also it is difficult to generalize the transient grounding characteristics. One of the various solutions is the concept of the conventional

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grounding impedance which shows the transient characteristics in an indirect way involving impulse currents of the grounding system. The conventional grounding impedance is defined as the ratio of the peak values of the electric potential to the peak value of the ground currents. The grounding system having low conventional grounding impedance is a fine grounding system with a low electric potential at the grounding electrode where lightning currents flow.

In this paper, in order to develop a methodology for the conventional grounding impedance calculations in designing the grounding system for protection against lightning, the conventional grounding impedance of the counterpoise is calculated by use of the distributed parameter circuit model and an application of the EMTP (Electromagnetic Transient Program). The adequacy of the distributed parameter circuit model is examined by comparison of the simulated and the measured results. The conventional grounding impedance of the counterpoise is analyzed for the first short stroke and subsequent short stroke currents.

2. Basic theory

2.1 The definition of conventional grounding impedance

The conventional grounding impedance is defined as

$$Z = \frac{V_p}{I_p} \ [\Omega] \tag{1}$$

where I_p is the peak value of the current injected at a point in the grounding system and V_p is the peak potential between the point and the remote ground[3]. So the grounding impedance shows a transient characteristic under impulse currents flowing through the grounding system and it also depends on the shape and dimension of the grounding electrode, the impulse currents.

2.2 Theory of the distributed parameter circuit model

The counterpoise may be represented quantitatively by a combination of three parameters. These are its inductance, conductance, and capacitance of soil as shown in the equivalent circuit diagram of Fig. 1.

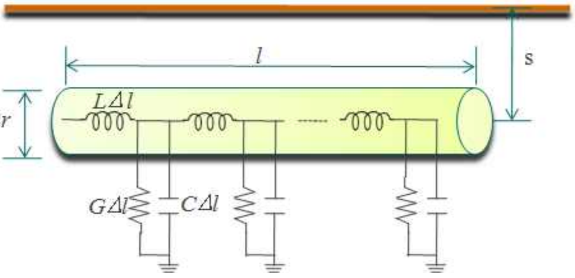


Fig. 1. An equivalent circuit diagram for the distributed parameter circuit model of a counterpoise

The distributed parameters per unit length of a counterpoise are given by Sunde's equation, as follows [4] :

$$R_0 = \frac{\rho}{\pi l}\left[ln\left(\frac{2l}{\sqrt{2rs}}\right) - 1\right] \ [\Omega] \tag{2}$$

$$G = \frac{\pi}{\rho}\frac{1}{ln\left(\frac{2l}{\sqrt{2rs}}\right) - 1} \ [\mathrm{S/m}] \tag{3}$$

$$C = \frac{\pi\varepsilon_r\varepsilon_0}{ln\left(\frac{2l}{\sqrt{2rs}}\right) - 1} \ [\mathrm{F/m}] \tag{4}$$

$$L = \frac{\mu_0}{\pi}\left[ln\left(\frac{2l}{\sqrt{2rs}}\right) - 1 \right] [\mathrm{H/m}] \qquad (5)$$

where l, r, s are the length, radius and buried depth of counterpoise, whilst ε_0 and μ_0 are the permittivity and permeability in free space, respectively. The distributed parameters G, C and L can be derived from equation (2) as shown in equations (3)-(5) [5].

3. Conditions of the counter-poise for measurement and simulation

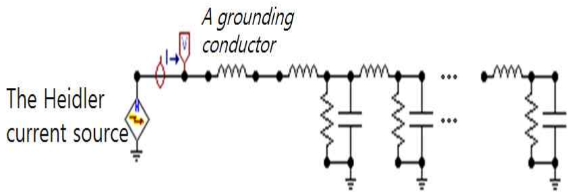


Fig. 2. An equivalent circuit in EMTP for the distributed parameter circuit model of counterpoise

In order to verify whether the distributed parameter circuit model could be applied to the grounding electrode for the conventional grounding impedance, it is necessary to compare the simulated results with the measured results. So theoretical simulation and experimental measurements should be carried out under the same conditions.

The object of the present investigation is the 30[m]-long counterpoise having a cross-sectional area of 25[mm^2]. The counterpoise conductor is copper stranded wire with the resistivity of 1.72×10^{-8}[Ω · m]. It is assumed that the counterpoise is buried at a depth of 0.5[m] in homogeneous soil. By using the Sunde's equation expressing the ground resistance of the counterpoise, the soil resistivity is calculated from the measured ground resistance of the 30[m]-long counterpoise.

The range of the relative permittivity is known to be 4~80[1]. In this paper, the relative permittivity is set to 80 because the soil at the test site had a high humidity. The 1.2[m]-long GV conductor with a cross-sectional area of 25[mm^2] is considered as a grounding conductor which is connected to the counterpoise. In the equivalent circuit shown as Fig. 2, it acts like a series inductance of 1.38[μH]. The current waveforms used in EMTP analysis act as a Heidler current source, as follows [6] :

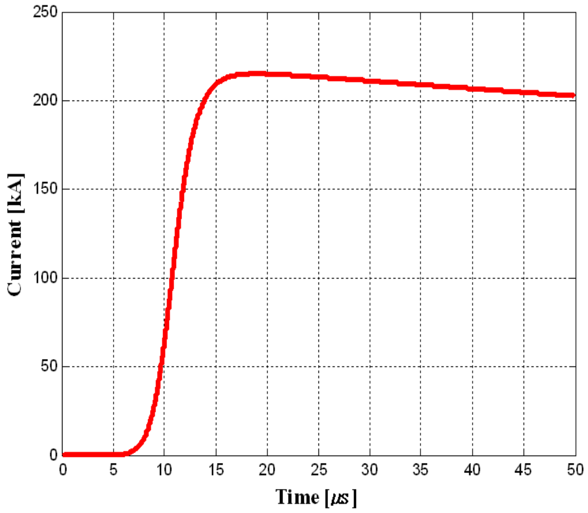
$$i(\mathrm{t}) = \frac{\mathrm{I}}{k}\frac{(\mathrm{t}/\tau_1)^{10}}{1+(\mathrm{t}/\tau_1)^{10}}\mathrm{e}^{(-\mathrm{t}/\tau_2)} \qquad (6)$$

where I is the peak of current, τ_1 is the front time constant, τ_2 is the tail time constant, k is the correction factor for the peak of current and t is the time.

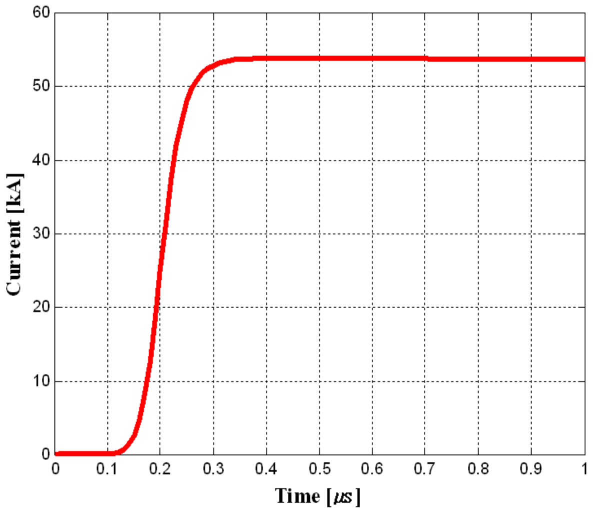
Table 1. Parameters of the short stroke currents for LPL I

Parameters	First short stroke	Subsequent short stroke
I[kA]	200	50
k	0.93	0.993
τ_1 [μs]	19	0.454
τ_2 [μs]	485	143

In the current waveforms of the first short stroke and the subsequent short strokes for Lightning Protection Level I (LPL I), the parameters are given in Table 1 [7]. Fig. 3 depicts the first short stroke and subsequent short stroke currents having the waveforms 10/350[μs] and 0.25/100[μs], respectively.

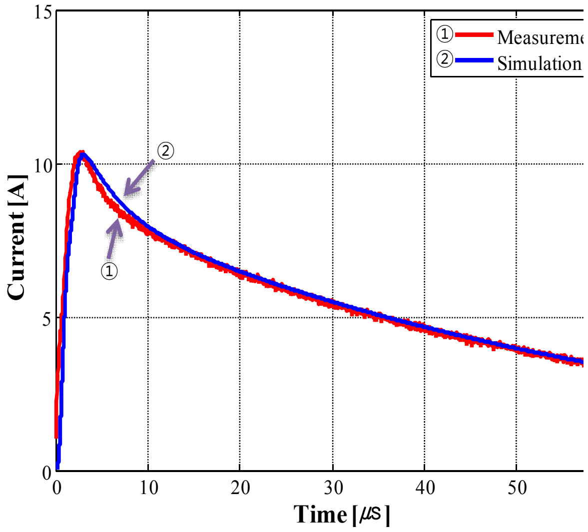


(a) The first stroke currents

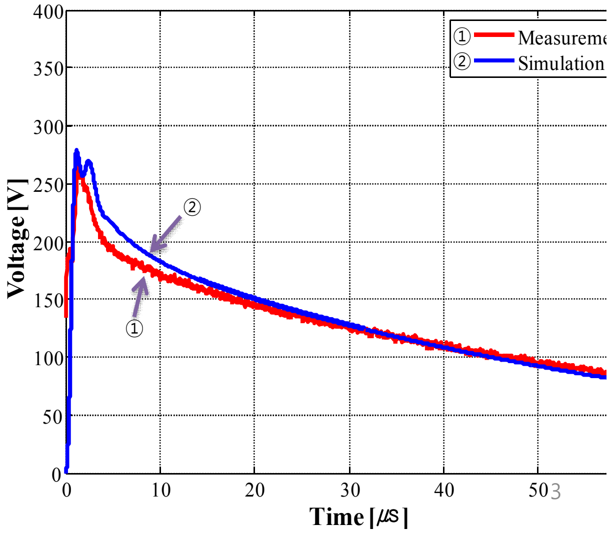


(b) The subsequent stroke currents

Fig. 3. The simulated short stroke currents for LPL I



(a) The injected current



(b) The output electric potential

Fig. 4. Comparison between the measured and simulated results for the 30[m]-long counterpoise

4. Results and discussion

4.1 Analysis of the conventional grounding impedance using the distributed parameter circuit model for a counterpoise

The conventional grounding impedance simulated for a 30[m]-long counterpoise by the application of an EMTP is compared with the measured results. The revised fall-of-potential method, recommended by the IEEE std. 81.2-1991, has been used in the measurements of the conventional grounding impedance [8-9]. In order to simulate the same impulse current waveform as the measured current waveform, the parameters of the Heidler function are adjusted.

When the injected currents are similar to the measured currents as shown in Fig. 4 (a), the resultant potentials based on the measurements and simulations for the 30[m]-long counterpoise are approximately the same as shown in Fig. 4 (b).

The measured results of the conventional grounding impedance of the 30[m]-long counterpoise are in good agreement with the data simulated by the method proposed in this work as shown Table 2. There is just a 5[%] error rate between the measurement and simulation due to differences in the injected current waveforms. The reliability of the simulation of the conventional grounding impedance calculation using the distributed parameter circuit model is verified.

Table 2. Conventional grounding impedance of the 30[m]-long counterpoise

	Conventional grounding impedance
Measurement	25.65[Ω]
Simulation	27.06[Ω]

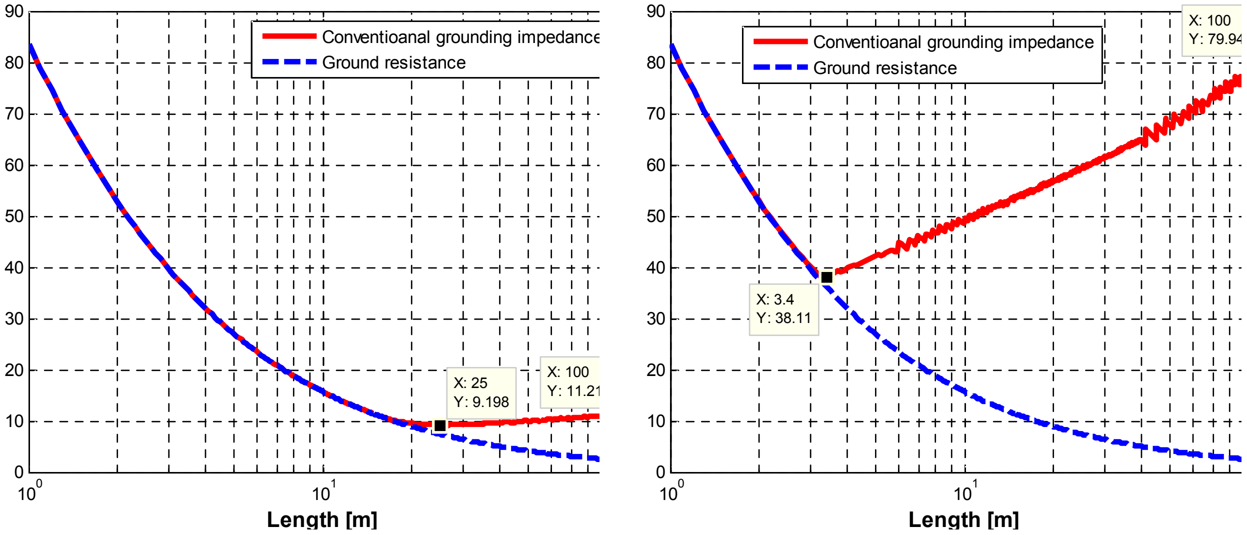
4.2 The simulation of the conventional grounding impedance as a function of length of counterpoise

The longer the length of the counterpoise is, the lower is the ground resistance. However the conventional grounding impedance of the counterpoise is different from the ground resistance because of the inductance of the counterpoise and the capacitive components of the soil.

Assuming a soil resistivity of 100[Ω·m], Fig. 5 illustrates a comparison between the ground resistance computed by the Sunde's grounding equation and the conventional impedance against the short stroke current simulated by the EMTP based on a distributed parameter circuit model, as a function of the length of the counterpoise. It can be seen that for the first stroke current the agreement between the ground resistance and the conventional grounding impedance is very good for a counterpoise of 25[m]-long, whilst for subsequent stroke currents the agreement becomes good for a counterpoise length of less than 3.4[m].. However the conventional grounding impedance is increased in the case of the longer counterpoise. So, there exists a critical length of counterpoise which has the lowest conventional grounding impedance and there is no need to install a counterpoise longer than the critical length

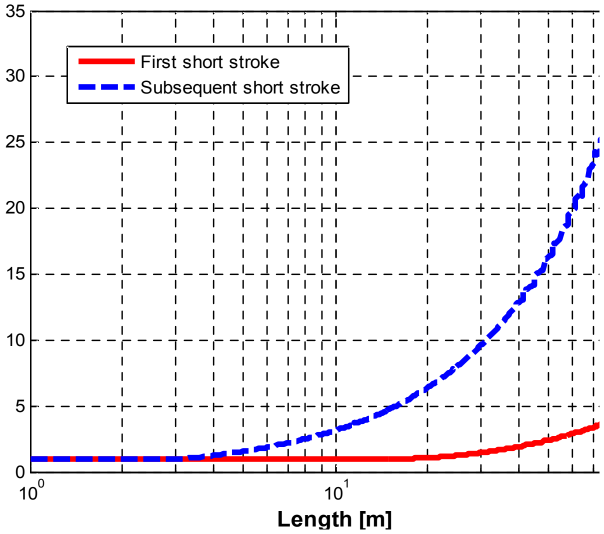
When comparing the data shown in Figs. 5 (a) and 5 (b), the length of the counterpoise having the lowest conventional grounding impedance against the subsequent stroke current is much shorter than the critical length against the first stroke current. Also the conventional grounding impedance increases significantly in the case of the subsequent stroke current in comparison with the first stroke current, for a counterpoise longer than the critical length, as shown in Fig 5 (c). The reason for this result is that the inductance effect of the counterpoise itself is more pronounced for a longer counterpoise and especially for subsequent stroke current having a faster rise time.

The critical length of counterpoise is simulated for different soils in the resistivity range from 10[Ω·m] to 5,000[Ω·m] for short stroke currents, as shown in Fig. 6. The higher the resistivity of the soil, the longer is the critical length for both short stroke currents. This result means that it is acceptable for a counterpoise to be as long as the critical length



(a) The conventional grounding impedance against the first stroke currents

(b) The conventional grounding impedance against the subsequent stroke currents



(c) The ratio of the conventional grounding impedance to ground resistance

Fig. 5. The conventional grounding impedance against short stroke currents as a function of the length of the counterpoise buried in soil having the resistivity of 100[Ω · m]

when the soil resistivity is high but the length should be reduced for lower soil resistivities so as not to increase the conventional grounding impedance dramatically. The critical length in the case of the subsequent stroke currents is shorter than the length obtaining for the first stroke current for all resistivities in the range from 10[Ω · m] to 5,000[Ω · m]. As a result, the length of the counterpoise to be buried in soil should be selected to be the critical length for subsequent stroke currents for the given soil resistivity in order to reconcile the lowest conventional impedance with the lowest ground resistance.

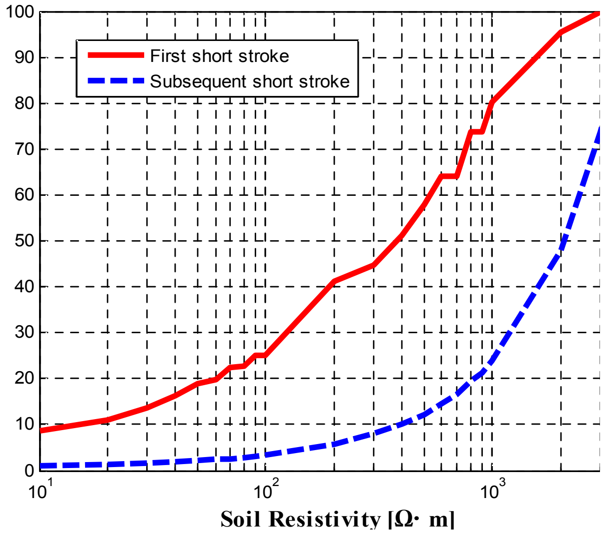


Fig. 6. Critical length computation of counterpoise against short stroke currents as a function of soil resistivity

The effective length and conventional grounding impedance of grounding electrodes for high frequency current is strongly dependent on the shape of grounding electrode and feeding point of injected current. Characteristics of the effective length of grounding impedances of such horizontal electrodes as end fed linear, center fed linear, 4 points star and 8 points star have been reported in the literature[10]. Further research on the accurate analysis of effective length and grounding impedance of horizontal grounding electrode using the method of images for satisfying the boundary conditions is under way.

5. Conclusion

This paper describes a methodology for analyzing the conventional grounding impedance characteristics of a counterpoise using the distributed parameter circuit model implemented by the EMTP. The adequacy of the simulation technique and the distributed parameter circuit model for the counterpoise was verified by comparing the simulated and the measured results. Based on these results, the conventional grounding impedance is analyzed as a function of the length of counterpoise. As a result, it is found that there exists a critical length of counterpoise which has the lowest conventional grounding impedance for a given soil resistivity and rise time of the injected impulse current. Hence in stages of the design of an actual grounding system, the length of the counterpoise having a proper conventional grounding impedance should be determined as well as the ground resistance against lightning surges. The methodology, which analyzes the conventional grounding impedance proposed in this work, could be used in the design of a grounding system for protection against lightning according to the KS C IEC 62305 standard.

Acknowledgements

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Biography

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