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Parameters affecting the charge distribution along overhead transmission lines' conductors and their resulting electric field

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ABSTRACT

There are many parameters affecting the distribution of the electric charges along the conductors of the overhead transmission lines and hence their resulting electric field, such parameters as: the conductors sag, the presence of the tower, replacing the sub-conductors of each phase with an equivalent conductor, the presence of the ground wires, the presence of another overhead transmission line (OHTL) circuit, the slope of the ground surface under overhead transmission line (OHTL) and the conductivity, permittivity and thickness of a sandy soil layer over the ground surface under overhead transmission line.

This paper presents a new methodology to investigate the effect of these parameters on the electric charge distribution along the conductors of the overhead transmission lines and hence on the calculation of their resulting electric fields.

The suggested technique is verified by comparing its results with a measurement by the other. The suggested technique is based on both the charge simulation method (CSM) and the image method (IM).

1. Introduction

High voltage overhead transmission lines (OHTLs) are used to transfer the electric energy between substations. The high voltage is used for long-distance transmission in order to reduce the ohmic losses while transmitting the electric energy. However, these overhead transmission lines are not as peaceful as they seem; a phenomenon of induced voltage between the earth and fences, vehicles, pipelines, telephone lines and other metallic objects was discovered.

Also, there are transmission line electromagnetic environment problems, such as effects of power frequency electric field intensity (EFI) and corona performance of radio interference (RI) level and audible noise (AN). All of these factors are important for design parameters of new overhead transmission lines. These design parameters include: bundle number, bundle spacing, subconductor diameter, minimum distance to the ground surface, etc. [1].

Solving problems that involve OHTL electromagnetic fields, electromagnetic interference, and grounding tends to be a complex issue, because many interrelations between them exist [2–4].

Recently, the electromagnetic fields induced by OHTLs have been a subject of great interest [5–8]. Many of these researches used computer software to simulate the electromagnetic fields induced by OHTLs [9–14]. On the other hand, in many papers, the effects of high voltage overhead transmission lines were calculated using the charge simulation method compound with the image method [15,16]. Most of these researches assume that the overhead transmission lines are horizontal and parallel to each other and to a flat ground, and the sag of each conductor due to its weight is neglected or introduced by taking the average height of the conductor [17,18].

The effect of the conductor sag on the electric field calculation was presented in [17,18], but its effect on the distribution of the electric charges along the length of the conductors was ignored. Of course, there are many other factors such as the ground wires, the terrain topography (ground surface), nearby conducting objects (towers), and the presence of another OHTL circuit affect the values and the distributions of the electric charges along the conductors of the OHTL, and hence affect their resulting electric field.

In this paper the effects of the conductor sag, the presence of the towers and the ground wires, the replacing of the phase sub-conductors by an equivalent conductor and the presence of another overhead transmission line (OHTL) circuit, the slope of the ground surface under OHTL and the conductivity, permittivity and thickness of a sandy soil layer over the ground surface under overhead transmission line on the values of the distributed electric charges along the length of the conductors of the OHTL, and hence on the calculation of their resulting electric fields are extensively investigated.

In this suggested new methodology the image method and the charge simulation method related to that of [17,18] are used. Charge simulation involves representation of the distribution of physical

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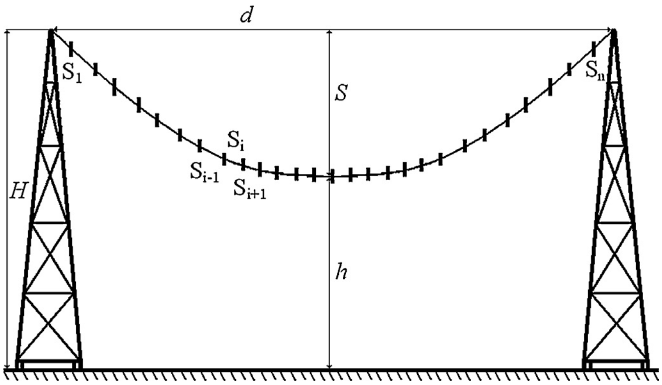

Fig. 1. Line dimensions of the catenary.

charges by a set of discrete charges selected to satisfy boundary conditions at a discrete set of points (contour points).

2. Simulation of the conductors and the tower

2.1. Simulation of electrical charges along the conductors

Conductors of the power transmission lines are nearly erected in periodic catenaries. The sag of each depends on individual characteristics of the line and on terrain topography conditions. Fig. 1 depicts the basic catenary's geometry for a single-conductor line. Whereas H is the maximum height of the line, h is the minimum height at mid-span (hence the sag is: $S = H - h$) and d is the span length.

This geometry can be described by the following equation [17–20]:

$$z' = z(x') = h + 2\alpha \sin h^2 \left(\frac{x'}{2\alpha} \right) \tag{1}$$

where α is the solution of the following transcendental equation:

$$H = h + 2\alpha \ \sinh^2 \left(\frac{d}{4\alpha} \right) \tag{2}$$

The parameter α is also associated with the mechanical parameters of the line: $\alpha = T_h/w$, where T_h is the conductor tension at mid-span and w is the weight per unit length of the conductor.

When the sag of the conductor was taken into account in [17,18], its effect on the conductor charge distribution was neglected. Since the equations that give the relation between the Maxwell's potential coefficients, voltages of the contour points and unknown values of the simulation charges were solved only once at mid-span between the two towers.

That gives the value of the charge density, for each sub-conductor, at the mid-span. Along the length of each sub-conductor, the charge density was assumed to be constant and equal to its value at the mid-span.

However, in this new suggested method, for each sub-conductor, the charge density is calculated at each point along its length. That of course is more complicated than the old method and is considered as a time-consuming, but in other side, it gives accurate values of the charge density along the length of each sub-conductor.

In this paper, each conductor between the two suspension points is subdivided into n segment of the same length (S_1, S_2, . . ., S_n), as shown in Fig. 1. Each segment is described by (1). It is assumed that the distributed charges on the surface of each segment are simulated by a finite line charge of a constant charge density (C/m). This finite line charge is located at the center of each segment. Also, it is assumed that there is a contour point on the surface of each segment. Hence, the equations that give the relation between the three dimensional potential functions (Maxwell's potential coefficients), voltages of the contour points and unknown values of the simulated finite line charges will be solved at each contour point of each segment as follows.

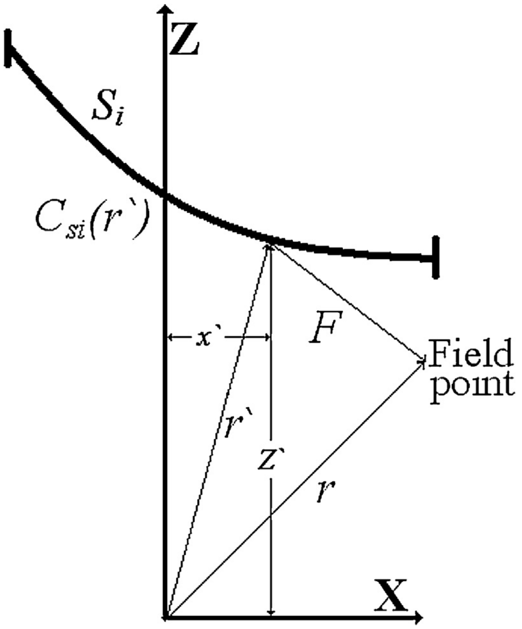

Fig. 2. Presentation of segment S_i and field point.

Assuming, there are no free space charges, the electric potential at any contour point on the surface of any segment S_i, placed in the air far from any other body, can be obtained by

$$V_{si}(r) = \frac{1}{4\pi\varepsilon_0} \int_{C_{si}(r')} \frac{q_{si}(r')}{G} dl_i' \tag{3}$$

where $\varepsilon_0 = 8.85 \times 10^{-12}$ F/m is the free space permittivity, and $q_{si}(r')$ is the finite line charge density (C/m) along the length of the segment S_i, which depends on many parameters such as the electric potential of the conductor, the presence of the ground wires, the line topology and terrain topography (ground surface), nearby conducting objects (towers), and the presence of another OHTL circuit.

The integral in (3) is calculated along the curve $C_{si}(r')$ that defined the segment S_i; $G = |F| = |r - r'|$, where r' is the position of any point on the curve $C_{si}(r')$ (source point) and r is the position of the field point in space, where the field is required to be calculated as shown in Fig. 2; and dl' is a differential element on the curve $C_{si}(r')$. When this single segment S_i is placed over a flat ground of homogeneous properties (i.e. permittivity ε and resistivity ρ) an image line specularly symmetric with respect to the air-ground interface plane has to be introduced to take into account the boundary conditions at the ground surface. Eq. (3) then becomes:

$$V_{si}(r) = \frac{1}{4\pi\varepsilon_0} \left[\int_{C_{si}(r')} \frac{q_{si}(r')}{G_{si}} dl_i' - \int_{C_{si}(r')} \frac{q_{si}(r')}{G_{si1}} dl_i' \right] \tag{4}$$

In this case, the electric-potential at any contour point on the surface of any segment S_i is calculated by the superposition of the electric-potential created by the electric charges induced on the surface of the real curve $C_{si}(r')$ that defined segment S_i minus electric-potential created by the electric charges induced on the surface of the image curve $C_{si1}(r')$ that defined the image of the segment S_i.where;

$$G_{si} = \left| F_{si} \right|, F_{si} = \left(x - x' \right) \vec{a}_x + \left(y - y' \right) \vec{a}_y + \left(z - z' \right) \vec{a}_z \tag{5}$$