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Influence of measurement uncertainty of overhead power line conductor heights on electric and magnetic field calculation results

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ABSTRACT

In this paper, it is analyzed how the measurement uncertainty of the overhead power line conductor heights influences the calculation results of electric field strength and magnetic flux density in the vicinity of the line. It is assumed that the conductor heights have been determined by measurements, by using a laser telemeter which has a certain measurement error. The laser telemeter measures the distance to the target object and inclination, and based on these two quantities and the manually entered data concerning the height on which the telemeter is placed it calculates the height of the target object, as well as the horizontal distance to it. Each of these measured quantities (distance and inclination) is measured with a defined error. The error of the height measurement has to be calculated based on the two defined errors. The procedure for calculating these errors is explained in detail in the paper, and the errors referring to typical heights of the overhead power line conductors are determined. If the calculations of electric field strength and magnetic flux density are made for the conductor heights with the established deviation in relation to the real heights, this will reflect on the calculated field results. The influence of this factor on the results of the electric field strength and magnetic flux density calculations is thoroughly analyzed.

1. Introduction

The assessment of human exposure to power frequency (50 Hz) electric and magnetic fields has become increasingly significant in recent years [1–3]. Overhead power lines are among the most significant sources of power frequency fields, due to their length, proximity to residential areas and field levels they emit. The assessment of human exposure to electric and magnetic fields originating from overhead power lines can be based on measurements or calculations, while the combination of these two methods provides the most reliable results. Measurements are performed in accordance with standards [4–7]. Different methods for calculations of electric and magnetic fields in the vicinity of overhead power lines are presented in [7–15].

The comparison of results of electric field strength and magnetic flux density obtained by measurements and calculations shows that some differences between these results may appear [16]. The main reasons for such differences are measurement and calculation uncertainties. These uncertainties need to be assessed as accurately as possible, taking into account all relevant uncertainty components. The measurement uncertainty comprises the measuring instrument error, applied method of measurement and ambient conditions.

Calculation uncertainty comprises the uncertainty of the calculation method, as well as the uncertainty of input data. The uncertainty of input data is quite often greater than the uncertainty of the calculation method, and therefore must not be neglected. The uncertainties with which power line geometry, voltages and currents are known are the main components of the uncertainty of input data. Geometry of a line includes the heights of the phase conductors and ground wires and their mutual distances. The heights of the phase conductors are the most influencing parameter related to the geometry. During electric and magnetic field testing, phase conductor heights are usually measured by a laser telemeter which has a certain measurement error. When such result is used as an input for calculations, it leads to a certain error, and hence to a deviation from the measurement results. In this paper, the influence of the measurement uncertainty of conductor heights on the values of electric field strength and magnetic flux density is analyzed in detail and is quantified for typical geometries of transmission overhead power lines.

2. Measurements of overhead power line conductor heights

Before measuring overhead power line conductor heights by using a laser telemeter, it is necessary to enter the height above ground on

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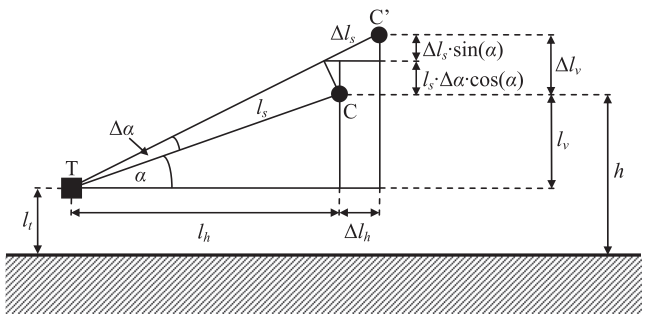

Fig. 1. Measurements of conductor height.

which the telemeter (T) is placed (l_t). In order to obtain accurate results, the telemeter is usually placed on a tripod, but it can also be hand-held. The laser telemeter measures the distance (l_s) from the measuring point to the conductor (C), as well as the angle (α) between the line that connects the measuring point and the conductor, and the horizontal line (Fig. 1). On the basis of the measurements of these two quantities, the distance l_s and the angle α, the telemeter calculates the horizontal distance (l_h) and the vertical distance (l_v). After adding the height above ground on which the telemeter is placed (l_t) to the vertical distance (l_v), the telemeter shows the height of the conductor above ground (h).

Measurement results obtained using high-quality laser telemeters are analyzed in this paper. It is adopted from the manufacturer's datasheet that the telemeter measures distance with an error Δl_s of $\pm$ 0.4 m when measuring distances shorter than 100 m, which is the case when measuring power line conductor heights. The angle measurement range is from $--55^\circ$ to $+85^\circ$, and the error $\Delta\alpha$ amounts to $\pm$ 0.1°. Consequently, the height of the conductor is also measured with an error, which should be quantified. The error in measuring vertical distance is indicated with Δl_v, while the error in measuring horizontal distance is indicated with Δl_h. Due to the error of measuring the distance and the angle, the position of the conductor which deviates from its true position is obtained. In Fig. 1, this position is indicated by C′.

In order to determine Δl_v, the following equation can be written:

$$l_v = l_s\cdot\sin(\alpha) \quad (1)$$

By differentiating Eq. (1), the following equation is obtained:

$$dl_v = dl_s\cdot\sin(\alpha) + l_s\cdot\cos(\alpha)\cdot d\alpha \quad (2)$$

which can also be written in the following way:

$$dl_v = dl_s\cdot\frac{l_v}{l_s} + l_s\cdot\frac{l_h}{l_s}\cdot d\alpha \quad (3)$$

$$dl_v = \frac{dl_s}{l_s}\cdot(h-l_t) + l_h\cdot d\alpha \quad (4)$$

In order to avoid the dl_v, dl_s and $d\alpha$ infinitesimals, the differential Eq. (4) is converted to an equivalent finite differences equation:

$$\Delta l_v = \frac{\Delta l_s}{l_s}\cdot(h-l_t) + l_h\cdot\Delta\alpha \quad (5)$$

The Δl_v, Δl_s and $\Delta\alpha$ finite differences are also shown in Fig. 1.

From the Eq. (5) it can be noticed that the error Δl_v is not constant because it depends on the distance to the object l_s and the angle α. Therefore, this error should be calculated for each particular case.

The calculations of Δl_v are performed for values of conductor heights ranging from 2 m to 60 m, and for distances from the conductor ranging from 1 m to 80 m, in order to encompass as many realistic situations as possible. In this way, cases of measuring conductor heights of overhead power lines of different voltage levels, ranging from LV to EHV, are encompassed, as well as cases of measuring conductor heights of multiple parallel lines measured from the same point. Conductor heights less than 6 m refer to situations when height measurements are not performed from the ground but from terraces and balconies of residential structures located in the vicinity of overhead power lines. It is adopted that the laser telemeter is located at the height of 1.7 m above ground, which represents the eye height.

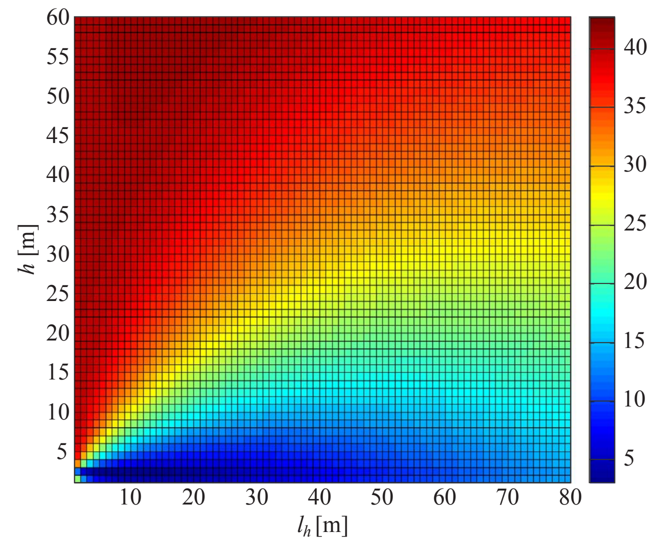

Fig. 2. Error of height measurement, Δl_v [cm].

The errors are calculated for the following four boundary cases:

(1) $\Delta l_s = +40$ cm, $\Delta\alpha = +0.1^\circ$;
(2) $\Delta l_s = -40$ cm, $\Delta\alpha = +0.1^\circ$;
(3) $\Delta l_s = +40$ cm, $\Delta\alpha = -0.1^\circ$ and
(4) $\Delta l_s = -40$ cm, $\Delta\alpha = -0.1^\circ$.

On the basis of the calculations for these four cases, the maximum error range is determined by determining its lower and upper limit. Since the difference between the absolute values of the lower and upper limit is equal to 1 mm or even lower, only the upper limit it presented in Fig. 2, for all analyzed values of conductor height and distance to it. The selected values of the upper limit of the maximum error range corresponding to the most common situations are presented in Table 1. The dashes in Table 1 signify values outside the measuring range.

On the basis of the presented results, it can be concluded that the highest value of Δl_v amounts to 0.414 m. As can be seen in Fig. 2, higher error values appear when measuring higher conductors located at a smaller horizontal distance. This conclusion pertains exclusively to measurements made by the telemeter of the specified ranges of distance and angle measurement error.

3. Method for determining influence of conductor height measurement error on electric and magnetic field calculation results

Influence of conductor height measurement error is determined by calculations of electric field strength and magnetic flux density for typical power line geometries.

The calculations were performed along the lateral profile (perpendicular to the power line axis), located at the height of 1 m above ground.

3.1. Calculation method

The calculations are based on a two-dimensional analysis using the method of image charges. The overhead power line is simulated by a set of infinitely long, straight-line phase conductors and ground wires. The conductors are parallel to each other and to the ground surface. It is assumed that the conductor is located at a height corresponding to the point of maximum sag. For electric field calculations, the ground is