APPLICATION OF ANTENNAE THEORY TO THE DEFINITION OF ELECTROMAGNETIC FIELDS RADIATED BY THE LIGHTNING "CLOUD-EARTH"

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The problem of estimation of electromagnetic fields responces radiated by the lightning is considered to be well - known. In particular, this is refered to the investigation of lightning electromagnetic situation which destabilizes the normal functioning of radioelectronic, electronic and electrotechnical equipment leading even to its failure [1].

The analysis of results of numerous theoretical Investigations in this field [2-9] shows their contradictive character resulting from the neglecting of many factors during formulation and solution of problems which produce a great influence on the shaping of lightning electromagnetic situation. These factors are the following; spreading of lightning currents in the ground; nonuniformity of current wave propagation in the lightning channel produced by the reverse discharge,reflection and refraction of the elektromagnetic fields, radiated by the lightning channel on the conductive ground surface.

So, during theoretical investigations concerned with the formation processes of lightning electromagnetic situation the models that present the channel of lightning discharge in the form of one electric Herz dipole [2] or monopole [3] specular reflected relatively the earth are widely used. The conducting leader lightning channel is often presented in the form of transmitting long line with the propagating current wave of the reverse discharge in it [4].

Many authors analyse the formation processes of lightning electromagnetic situation replacing the lightning discharge channel by the system of infinitesimal dipoles [5,6].

Thereat, it was assumed in all cases that the ground conductivity is infinite, that didn't allow to take into consideration the earth influence on the formation processes of lightning electromagnetic situation and to estimate the horisontal component of electric field intensity at the ground surface, especially in the area nearest to the discharge channel.

An attempt was made [7] to take into consideration the influence of the finite ground conductivity on the formation of the lightning electromagnetic situation where the horisontal component of the electric field intensity has been determined through the vertical component using Leontovich boundary conditions for plane electromagnetic wave propagating along conducting surface. But this method doesn't allow to obtain reliable information about responces of lightning electromagnetic situation, in particular, that is formed by the lightning in the area nearest to its channel, when the distance from the discharge place is equal or smaller than the lightning channel length and the electromagnetic wave can not be interpreted in this case as a plane wave.

To investigate the formation processes of lightning electromagnetic situation we use in this work the method that is widely used in antennas theory during the analysis of radiation processes by the electrically long systems [8]. It follows from the calculative modal shown in fig.1 that the lightning discharge channel is presented in the form of infinitely large number of infinitesimal electric dipoles, whose scalar and vector potential satisfies the Lorenz law. It was assumed that infinitesimal dipoles do not influence on each other and the discharge channel represents infinitely thin straightforward line normal to the earth surface. To present the solution of a problem in a closed form we used the method of sections thet presupposes the subdivision of lightning channel and lightning current curve, fig.2 into functionally inter-dependent sections. The lightning discharge channel was subdivided into sections uniting in themselves the groups of infinitesimal dipoles and the current curve was subdivided into time intervals with the step Δt_k.

The size of the sections subdividing the discharge channel corresponds to the distance covered by the wave of the reverse discharge of the lightning (fig.3) during the time interval equal to the subdivision step of lightning current. The length of sections subdividing the channel, and the time step subdividing the lightning current curve were chosen proceeding from the condition of uniform distribution of current density within the section and under assumption that magnetic wave radiated by the section of a channel for given distances is considered to be a flat one. The analysis of the calculation results shows that for the satisfaction of adopted conditions and assumptions the number of subdivisions equal to k=200 will be sufficient.

Electromagnetic field shaped by the lightning channel is presented in the form of space-time superposition of fields radiated by the single dipoles. As a function of frequency the Cartesian components of these fields will have the form

$$E_y^{rad}(j\omega) = \sum_{k=0}^{200} \int_{h(k\Delta jw)}^{h((k+1)\Delta jw} \left\{ \frac{I(j\omega)}{2\pi} \left[1 - \frac{r}{y}\sqrt{\frac{j\omega\varepsilon_o}{\sigma_g}}\right] * \right.$$
$$\left. * \left[\frac{(2y^2-x^2)}{j\omega\varepsilon_o r^5} + \frac{120\pi(2y^2-x^2)}{r^4} - \frac{j\omega\mu_o x}{r^3} \right] \right\} dy \quad (1)$$

$$E_x^{rad}(j\omega) = \sum_{k=0}^{200} \int_{h(k\Delta jw)}^{h((k+1)\Delta jw} \left\{ \frac{I(j\omega)xy}{2\pi} \sqrt{\frac{j\omega\varepsilon_o}{\sigma_g}} * \right.$$
$$\left. *3\left[\frac{1}{j\omega\varepsilon_o r^5} + \frac{120\pi}{r^4} - \frac{j\omega\mu_o}{3r^3} \right] \right\} dy \quad (2)$$

$$H_z^{rad}(j\omega) = \sum_{k=0}^{200} \int_{h(k\Delta jw)}^{h((k+1)\Delta jw} \left\{ \frac{I(j\omega)x}{2\pi} \left[1 - \frac{r}{y}\sqrt{\frac{j\omega\varepsilon_o}{\sigma_g}}\right] * \right.$$
$$\left. * \left[\frac{j\omega}{cr^2} + \frac{1}{r^3} \right] \right\} dy \quad (3)$$

We determine the electromagnetic fields created in the ground by the lightning current through the solution of the problem

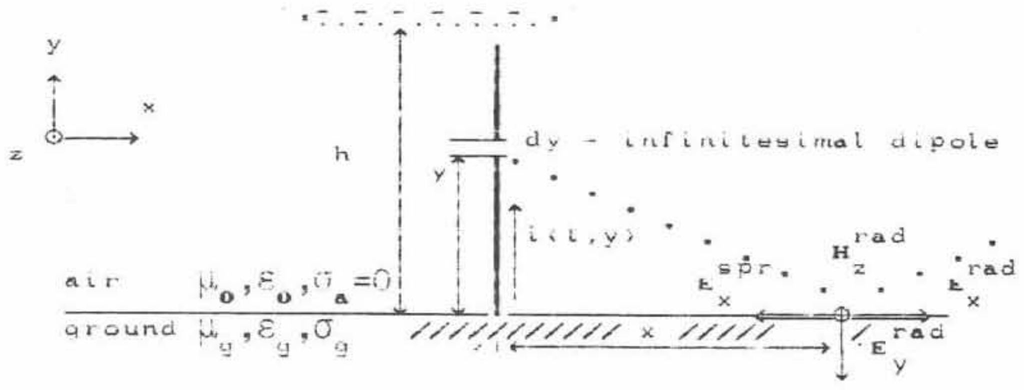

Fig. 1. Disign model

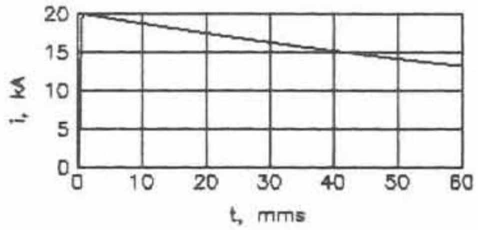

Fig. 2. The shape of the lightning current pulse

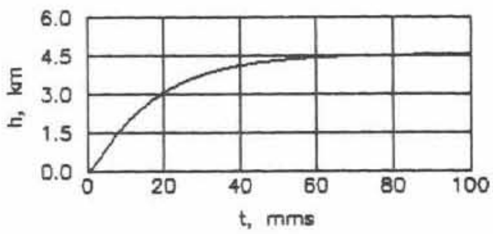

Fig. 3. The change of altitude of reverse discharge as a function of time

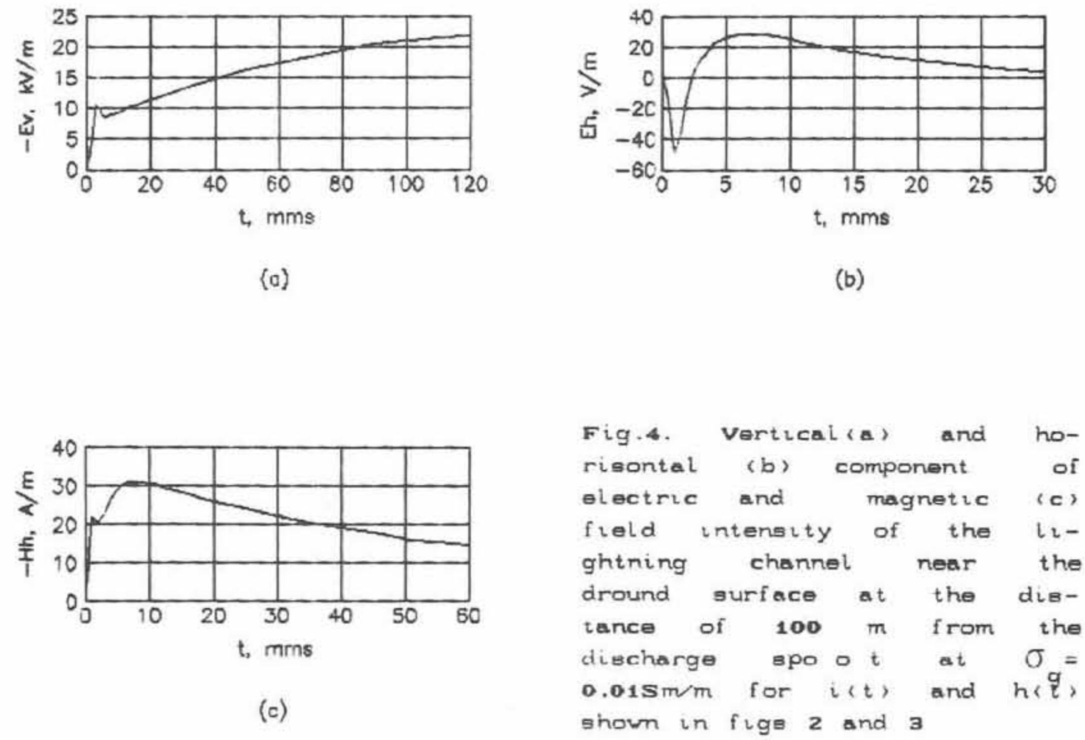

Fig.4. Vertical (a) and horisontal (b) component of electric and magnetic (c) field intensity of the lightning channel near the dround surface at the distance of 100 m from the discharge spo o t at σ_g = 0.01Sm/m for i(t) and h(t) shown in figs 2 and 3

on the current inflow from the point source into conducting half-space possesing uniform and isotropic properties with the further spreading of these currents in different directions. Thereat, we assumed that electromagnetic energy was not radiated into airspace.

The intensity of electric field on the ground surface, created by the lightning spreading currents under condition of relatively good surface conductivity when $\sigma_g \gg j\omega\varepsilon_g$ is determined as

$$E_x^{spr}(j\omega) = \frac{I(j\omega)}{2\pi x^2 \sigma_g} - \left[x\sqrt{j\omega\mu_g\sigma_g} + e^{-x\sqrt{j\omega\mu_0\sigma_g}} \right] \qquad (4)$$

The resulting intensity of electric and magnetic fields created by the lightning channel on the ground surface taking into consideration the spreading of lightning currents in the earth as well as reflection and refraction processes of field radiated by the lightning channel on the conducting ground surface is determined through the "connection" of solutions for two media-air and ground - at the interface of these media

$$E_v(j\omega)=E_y^{rad}(j\omega);\; E_h(j\omega)=E_x^{rad}(j\omega)-E_x^{spr}(j\omega);\; H_h(j\omega)=H_z^{rad}(j\omega) \qquad (5)$$

If the intensity of electric and magnetic fields on the ground surface is known then we can easily determine their value at any altitude above the ground or below its surface [9].

To determine the lightning electromagnetic pulse generated by the lightning discharge channel "cloud-earth" as a function of time itis sufficient to apply to the expressions the formulae of harmonic analysis using Laplace and Furie transformations.

The method discribed in the work allows to determine the lightning electromagnetic situation created by the lightning "cloud-earth" at any distances from the discharge channel taking into account the influence of conductive ground properties and allows to estimate the responces of lightning electromagnetic pulse above the ground or below its surface.

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