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Investigation of peculiarities of discharge formation from the system of artificial charged aerosol clouds of negative polarity

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ABSTRACT

Using artificial clouds of strongly charged water aerosol gives new possibilities for physical simulation of the possible processes corresponding to lightning formation and lightning attachment to object. Paper presents the results of experimental investigation of the peculiarities of the discharge formation from a system of artificial charged aerosol clouds of negative polarity. It has been found that there is a significant influence of upper cloud on the discharge development from the lower cloud and on its parameters. Presence of the upper charge aerosol cloud can increase the probability of the preliminary discharge initiation near the lower cloud boundaries as well as the subsequent stroke from the non-discharged parts of the lower cloud and change its parameters. It was established that with a system of two vertically separated artificial charged aerosol clouds of negative polarity the current amplitude, the charge and the maximal current steepness of final stage of discharge between artificial cloud and a grounded rod electrode increase significantly. Probably, local regions with a higher volume charge density in thundercloud influence the lightning initiation, the formation of the first and subsequent strokes and their parameters.

1. Introduction

Experimental methods are necessary to advance our understanding of the physics of the lightning because without them it is difficult to develop or improve the physical and the mathematical models of lightning initiation, propagation, and attachment to both the grounded and ungrounded objects [1–4].

For instance, some problems require closer consideration. It is important to understand better the processes of discharge development inside thunderclouds, in particular participation of adjacent parts of thundercloud with the higher volume charge density (small cloud regions of the order of a few hundred meters [2,5]) of negative polarity of the main negative charge region of thundercloud on discharge propagation inside it [6]. Such data could help a better understanding of the processes of the negative downward leader development, the formation of first and subsequent return strokes, and clarification its parameters that are interesting to an engineering application.

One of the possible methods to investigate the lightning and lightning protection physics is an application of the artificial charged aerosol clouds for a physical simulation of the processes of the lightning initiation, its development and attachment to an object. It permits appreciably to approximate the simulation to the natural thunderstorm situation [7,8]. Nowadays, artificial clouds of charged water aerosol allow to form and to investigate all range of the discharge phenomena that could occur in natural thunderclouds including the leader and return stroke stages. It permits as well as the modeling of the presence of local small regions with high volume charge density in thundercloud.

2. Experimental setup

Experimental research apparatus consists of an aerosol chamber, a generator of charged aerosol, an electrode system, and a measurement complex. Experimental setup allows to receive artificial clouds of charged water aerosol of the same or of different polarity with volume charge density of 10^{-4} to 10^{-2} C/m^3 and average potential of 1.0–2.0 MV [9,10]. During experimental investigation two variants of artificial charged aerosol cloud location in aerosol chamber which height is 3.7 m could be realized: one cloud of negative or positive polarity, and two cloud structure consisting of two vertically separated artificial charged clouds of the same or different polarity (Fig. 1). Characteristic distribution of electric field strength for the system of two clouds of negative polarity is

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Fig. 1. Picture of disposition of artificial charged clouds in aerosol chamber: outlet current of charged aerosol generator for upper cloud – 100 μA, for lower cloud – 110 μA.

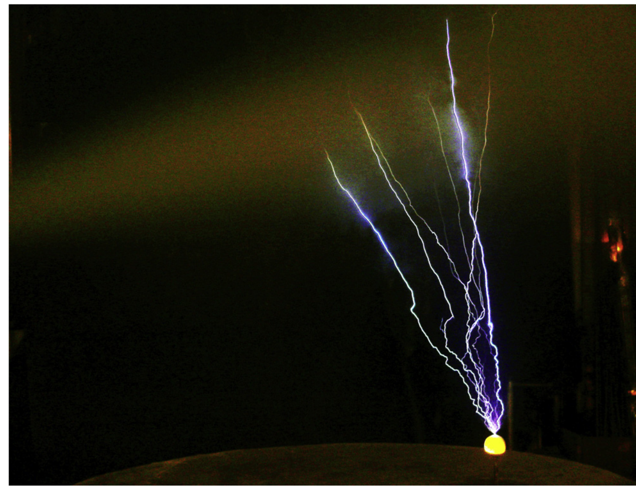

Fig. 3. Discharge development in a cloud of charged water aerosol and in the gap between lower artificial charged cloud and ground.

shown in Fig. 2. The electric field strength increased from 6×10^5 to 9×10^5 V/m near the grounded plate up to 14×10^5 to 20×10^5 V/m near the boundaries of the lower artificial charged cloud. As a result, a development of all forms of the discharge between a lower artificial charged aerosol cloud and a grounded electrode on the plate occurs in the gap (Fig. 3).

The measurement complex of the experimental apparatus included a low inductance shunt resistor for current measurements for all phases of the electrical discharge from the grounded rod electrode. Two digital oscilloscopes Tektronix DPO 7254 and Tektronix TDS 3054 were used for the current measurements. Miniature programmable nine-frame CCD camera K011 with a spectral range 400–800 nm and a system of three photomultipliers directed on the different parts of the gap have been used for registering of optical picture of the discharge formation on the rod tip and its propagation. Whole optical picture of the discharge processes that have occurred in the gap "artificial charged aerosol clouds – grounded rod on the grounded plate" has been formed with a digital camera Panasonic DMC-50.

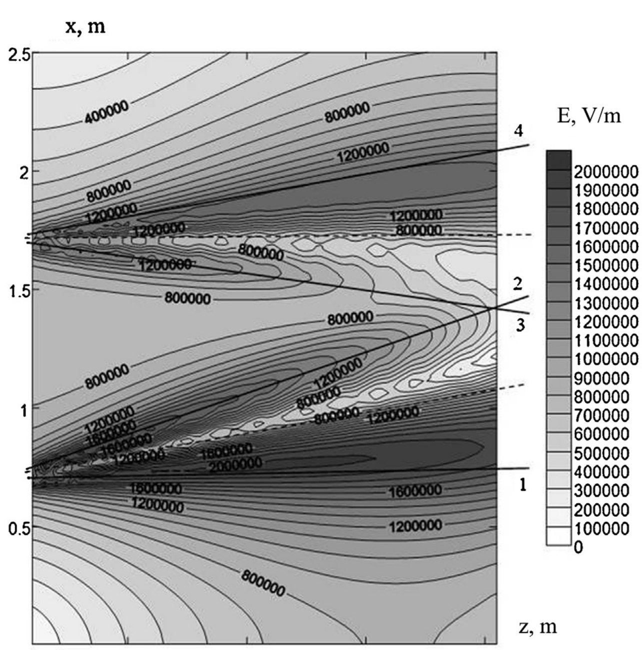

Fig. 2. Distribution of electric field strength in a vertical section of the gap "two vertically separated clouds – grounded plate": 1 and 2 – boundaries of the lower artificial charged aerosol cloud; 3 and 4 – boundaries of the upper artificial charged cloud.

During experiments outlet current of the charged aerosol generator forming lower charged cloud was 110 μA. The outlet current of charged aerosol generator forming upper cloud was changed in the range from 0 μA to 100 μA.

3. Experimental results

Experimental investigations of processes of discharge formation in the gap "two vertically separated artificial charged aerosol clouds of negative polarity – grounded electrode beneath them" have shown significant influence of upper cloud on the discharge development from lower cloud and its parameters.

First of all, presence of upper charged cloud could increase the chance of discharge initiation near cloud boundaries in comparison with the single artificial charged aerosol cloud situation. Probability of primary discharge initiation in the gap "system of two artificial charged aerosol clouds – ground" near lower cloud boundaries as a function of the charge of upper artificial charged cloud are shown in Table 1 (more than one hundred experimental starts for every value of the outlet current of charged aerosol generator that forms the upper cloud).

It is shown in [7,8] that there are the following possible variants of discharge development between artificial charged aerosol cloud and ground: 1 – upward positive leader does not reach the artificial cloud boundaries and stops in the gap; 2 – upward positive leader develops up to the artificial charged cloud boundaries and interacts with the charged cloud; 3 – negative descending leader develops from the artificial charged aerosol cloud and a reciprocal upward positive leader develops from the grounded object which is followed by their interaction (Fig. 4); 4 – negative downward leader develops from the artificial charged cloud without any clearly observed upward positive leader appearance (case of primary discharge initiation near the cloud boundaries). For the last case, characteristic pictures of time dynamics of the discharge development from two artificial charged aerosol clouds to ground including final stage registered by the programmable nine-frame CCD camera and system of photomultipliers are given in Figs. 5 and 6, correspondingly. With an increase of the charge of the upper artificial charged cloud, the probability of discharge formation according