Influence of Hydrometeors on Formation of Discharge between Artificial Thunderstorm Cell and Ground

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Abstract—Application of the artificial thunderstorm cell of negative or positive polarity with the model hydrometeor array could help on clarifying of problem of the lightning initiation in thunderclouds. Results of experimental investigation of the influence of the hydrometeor array disposed inside the artificial thunderstorm cell and near its boundary on the discharge initiation and propagation between the cloud and the ground have presented. Peculiarities of the discharge formation on the hydrometeor array in the negatively and positively charged aerosol clouds have analyzed. Application of the received results to the natural thunderstorm situation has discussed.

Keywords—artificial thunderstorm cell; hydrometeor array; lightning initiation; discharge; experimental investigation; negatively and positively charged cloud; characteristics

I. INTRODUCTION

Problem of the determination of conditions of the discharge phenomena (lightning) initiation in natural electrically active clouds is the less investigated in the lightning physics. Nowadays, there are two main hypothesis of the lightning initiation in thunderclouds: initiation by the runaway breakdown [1], and initiation on hydrometeors [2, 3]. First hypothesis predominated last decades. However, it did not receive the clear natural and experimental evidence, and its authors have become to propose the hybrid hypothesis appending the hydrometeors [4, 5]. Thus, hydrometeor hypothesis of the lightning initiation has received a new impulse and become the field of current interest again [6, 7].

As it has been mentioned in [7-9], the hydrometeor array characteristics (size, kind, quantity, mutual disposition, and location in thundercloud) probably could influence on the lightning initiation and propagation. Another aspect that could be useful for the clarifying of the hydrometeor hypothesis of the lightning initiation and propagation to understand the influence of the polarity of the thunderstorm cell on the discharge phenomena that could form on the hydrometeors in the negatively and positively charged clouds. Application of the artificial thunderstorm cells of the different polarity could help to receive new data about possible peculiarities of the discharge initiation and propagation in the differently charged thundercloud regions at presence of the array of hydrometeors. First results of the experimental investigation of the influence of the model hydrometeor array on the discharge formation between the artificial thunderstorm cell of the negative or positive polarity and the ground have presented in paper.

II. EXPERIMENTAL COMPLEX AND RESULTS

A. Experimental setup

Investigations of the influence of the model hydrometeors on a discharge formation from an artificial thunderstorm cell of negative or positive polarity have been carried out on the experimental complex described in [9, 10]. During experiments outlet current of the charged aerosol generator forming artificial thunderstorm cell was 100 µA. Volume charge density of the charged cloud changed from the 10^-3-10^-4 C/m^3 in the central parts of cloud to the 10^-6-10^-8 C/m^3 in its peripheral parts. In that case, discharges between the artificial thunderstorm cell and the ground are practically absent (for positively charged cloud) or have enough low probability of occurrence (for negatively charged cloud).

Special designed particles have been used for simulation of the array of large hail. Model hydrometeors of two characteristic forms (cylinder and ellipsoid of revolution) have been used. Size of the model hydrometeors was in the range of 1.0 cm to 2.5 cm. Model hydrometeors have been manufactured from the conducted materials. Group of the model hydrometeors has been formed in the gap using independent thing dielectric strings when the neighbor hydrometeors were isolated from each other by the air gap. Portion of experiments has been fulfilled for the case when the model hydrometeors in the group were connected by the dielectric string covered with the hydrophobic material. Distance between the neighboring model hydrometeors was in the range of 1.0 cm to 3.0 cm. The number of hydrometeors in array was 4-7 particles. Common length of a hydrometeor array was 25-35 cm. Group of the model hydrometeors has been disposed inside the artificial thunderstorm cell (in its peripheral parts) or near its lower boundary.
Common optical picture of the discharge processes that have occurred in the hydrometeor array and in the gap “artificial thunderstorm cell – ground” has been registered with a digital camera Panasonic DMC-50. Programmable nine-frame CCD camera K011 with a spectral range 400-800 nm has been used for registering of the dynamical optical picture of the discharge formation on the hydrometeor array and its propagation in the gap.

Experiments partly have carried out with using a rod electrode on the grounded plate in order to analyze the discharge characteristics of spark discharge between the artificial thunderstorm cell and the ground. The system of the plate antennas situated on the different distance and height from the place of model hydrometeor array has used for the registering of the electromagnetic radiation. Current of discharge between the artificial thunderstorm cell and the grounded rod electrode has registered simultaneously with its electromagnetic radiation using Digital Storage Oscilloscope Tektronix DPO 7254.

B. Influence of hydrometeor array on formation of discharge between negative artificial thunderstorm cell and ground

Experiments with the negatively charged artificial thunderstorm cell for both variants of the model hydrometeor array suspension have shown the following three variants of the discharge development between the charged cloud and the ground when the hydrometeor array disposes inside charged cloud and near its boundary. They are: formation of the cloud discharges on the hydrometeor array (variant GMN1, Fig. 1), formation of the channel discharges between the cloud and the ground using wholly or partly the hydrometeor array (variant GMN2, Fig. 2), and formation of the channel discharges between the cloud and the ground past the hydrometeor array (variant GMN3, Fig. 3).

Variant GMN1 is characterized by the development of the spark discharges between the model hydrometeors. Besides, formation of the positive streamer corona from some upper hydrometeors in array has been observed. Such streamers could penetrate into the boundary regions of the charged aerosol cloud. Sometimes, development of the short negative streamers from the lower hydrometeor to the ground direction has been observed.

Formation of the channel discharges between the artificial thunderstorm cell of negative polarity and the ground with using of the hydrometeor array (variant GMN2) is characterized by the development of spark discharges as downward to the ground as upward into the charged cloud direction.
The priority direction of the discharge development from the hydrometeor array is practically simultaneous appearance of the negative streamer corona from the lower hydrometeors and positive streamers from the upper ones. Switching of the charged cloud part intensifies the main stage of discharge and leads to the high impulse current and powerful optical radiation. It is interesting to note that the discharge processes could pass on the hydrometeors during some microseconds after the return stroke ending (Fig. 4). Impulse current amplitude does not obviously exceed some tens of amperes. Velocity of the current rise rarely exceeds 5 kA/μs. In average such parameters are in some times less than for the cases of the powerful discharges between the artificial thunderstorm cell and the ground in the absence of the hydrometeor array in the gap or in the case when spark discharge passes past hydrometeor array (variant GMN3).

In the absence of the hydrometeor array in the gap, discharge initiation from the artificial thunderstorm cell of negative polarity was the very rare event. Upward streamers and leaders as the beginning stage of the discharge development were strongly dominated [9]. Application of the powerful upper charged aerosol cloud of negative polarity has weakly increased the probability of the discharge initiation near bottom boundary of lower artificial charged aerosol cloud (up to 8-9 %) [11]. In the presence of the model hydrometeor array in the artificial thunderstorm cell of negative polarity, cloud discharges initiated by the hydrometeors were in 25 % cases of the experimental events. Probability of the occurrence of the subsequent negative downward leader earlier than upward leader appearance increased significantly. So, the height of the meeting of the downward and upward discharges became in average closely to the ground (Fig. 5).

It is also necessary to note that in 70 % of the experimental cases of the variant GMN2 all hydrometeors in the model array participated in the discharge channel development. Otherwise, from one to three model hydrometeors in array did not participate in the discharge formation. At the same time, it is necessary to note that in a third of the experimental cases the hydrometeor array did not immediately participate in the discharge initiation and propagation between the artificial thunderstorm cell of negative polarity and the ground. However, in such cases, length of sections of the final stage channel with the powerful radial streamer corona has increased in two times (Fig. 3).

C. Influence of hydrometeor array on formation of discharge between positive artificial thunderstorm cell and ground

Experiments with the positively charged artificial thunderstorm cell have shown the following three variants of the discharge development between the cloud and the ground when the hydrometeor array disposes inside charged cloud and near its boundary. They are: formation of the cloud discharges on the hydrometeor array (variant GMP1, Fig. 6), formation of the channel discharges between the cloud and the ground using the hydrometeor array (variant GMP2, Fig. 7), and formation of the diffuse discharges between the cloud and the ground using the hydrometeor array (variant GMP3, Fig. 8).

Variant GMP1 characterized by the development of the spark discharges between the model hydrometeors too. Such discharges trigger practically simultaneous formation of the negative and positive streamers from the upper and bottom hydrometeors in array, correspondingly. Sometimes, discharge phenomena on the model hydrometeor array begin from the appearance of the positive streamers from the bottom hydrometeor in array. Length of the negative streamers could reach 5-10 cm. Positive streamers from the bottom hydrometeor in array could be in 1.5-2.0 times long. As well for the negatively charged artificial thunderstorm cell,
discharge phenomena in the model hydrometeor array disposed near the positively charged cloud have the impulsive flare character that has registered by the plate antennas as the impulse signal pockets.

In difference with the case of the negatively charged artificial thunderstorm cell, formation of the channel discharges between the artificial thunderstorm cell of positive polarity and the ground with using of the model hydrometeor array (variant GMP2) practically always occurs with the participation of all hydrometeors belonging to the array. Development of the channel discharges occurs as into the ground direction as into the charged water aerosol cloud direction. The priority direction of the discharge development from the hydrometeor array was close to vertical for the cases when the model hydrometeors in group have been connected by the dielectric string.

As a whole, impulse current of final stage of discharge between the positively charged artificial thunderstorm cell and the ground was comparable with the case of the negative cloud. However, optical radiation of final stage of discharge between the positively charged artificial thunderstorm cell and the ground was less intensive (Fig. 9). Reason of such difference probably has connected with less velocity of the current rise that in average does not exceed 2.5 kA/µs.
Another distinctive feature of the positively charged artificial thunderstorm cell is the formation of the diffuse discharges between the bottom hydrometeor in array and the ground (variant GMP3). In this case, the negative streamers develop from the upper hydrometeor in array in direction of the charged water aerosol cloud. Impulse signals registered by the antennas before and after the impulse current in the ground are the characteristic feature of such type of discharge.

According to the processing of more than three hundred experimental events, in the presence of the model hydrometeor array in the artificial thunderstorm cell of positive polarity, probability of the occurrence of the cloud discharges, the channel discharges, and the diffuse discharges is approximately equal for the case when the model hydrometeors in group have been connected by the dielectric string. For the array of the independently suspended hydrometeors, the cloud discharges have registered several more than other two types of discharge.

III. DISCUSSION AND CONCLUSIONS

Thus, first series of the experimental investigations using of the model hydrometeors array has shown the significant influence of the hydrometeors on the processes of the discharge initiation and propagation in the artificial thunderstorm cell of the negative or positive polarity. In both cases, presence of the model hydrometeor array increased the probability of the discharge initiation in the gap “artificial thunderstorm cell - ground”. It has connected with spark discharge formation between the neighboring model large hydrometeors in array. These discharge phenomena have registered by the antennas during some microseconds before the spark channel appearance between the artificial thunderstorm cell and the ground. Development of such discharges between the hydrometeors lunches the appearance of discharges from the upper hydrometeor in array directed into the region of charged cloud, and the bottom hydrometeor in array directed to the ground and stimulates the spark channel formation in the gap.

This experimental result could show the possible key role for the lightning initiation of the large hydrometeor arrays in the bottom part of thundercloud where the local excess positive cloud charge is situated [12]. Large hail arrays falling down into region between the main negative charge of thundercloud and the local bottom positive charge trigger the discharge phenomena development that could lead to the volume leader formation and the following downward leader. Presence of the intensive discharge activity in the bottom region of thundercloud before the stage of the preliminary breakdown could point to such possible role of the large hails in the discharge formation in thunderclouds [13].

At the same time, the significant peculiarities of the discharge formation on the hydrometeor array in the negatively and positively charged artificial thunderstorm cell have found correspondingly. It has found that for the same artificial thunderstorm cell conditions (charge, size, electric field distribution) and model hydrometeor array parameters the hydrometeors play more significant role in the processes of the discharge initiation and propagation for charged aerosol cloud of positive polarity. First, model hydrometeor array posed near the boundary of the artificial thunderstorm cell of positive polarity better initiates the discharge phenomena in this region in comparison with the case of the negatively charged artificial thunderstorm cell. Second, for the positive polarity of charged aerosol cloud all hydrometeors in array participate in the spark discharge formation. Probably this is one of the reason of the successful discharging of the natural positive thunderstorm cell containing a big quantity of large hydrometeors. Besides, presence of the hydrometeor array differently modifies the impulse current of the final stage of discharge between the artificial thunderstorm cell of negative or positive polarity and the ground (Fig. 10).

Presence of the hydrometeor array near the negatively charged cloud boundary relatively weakly influences on the form of the final stage current impulse (upper curve in Fig. 10). In average, impulse current amplitude and maximal current steepness become less in comparison with the case of discharge formation without hydrometeors.

![Figure 10. Oscillograms of impulse current of the final stage of discharge from the negatively charged artificial thunderstorm cell (upper) and the positively charged artificial thunderstorm cell (channel form – middle, diffuse form – bottom)](image-url)
For the positively charged cloud, presence of the hydrometeor array could lead to the final stage in two types: diffuse (bottom curve in Fig. 10) and channel (middle curve in Fig. 10). In average, similar current amplitude, slow current rise and more long duration of the current impulse is characteristic for channel type positive discharges in comparison with negative discharges when the hydrometeor array presents in the gap.

Thus, first experimental results have shown significant influence of the model hydrometeor array on the discharge initiation and propagation in the gap “artificial thunderstorm cell of negative or positive polarity – ground”.

Next investigations should be directed on the detail analysis of influence of the hydrometeor array parameters (form and quantity of particles in array, distance between hydrometeors, conductivity of hydrometeors, and disposition of the array relatively the charged cloud) [7, 14] on the discharge phenomena initiation and development taking into account peculiarities of the negatively and positively charged thunderstorm cells.

REFERENCES