International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:11, No:3, 2017

Influence of Model Hydrometeor Form on Probability of Discharge Initiation from Artificial Charged Water Aerosol Cloud

A. G. Temnikov, O. S. Belova, L. L. Chernensky, T. K. Gerastenok, N. Y. Lysov, A. V. Orlov, D. S. Zhuravkova

Abstract**—**Hypothesis of the lightning initiation on the arrays of large hydrometeors are in the consideration. There is no agreement about the form the hydrometeors that could be the best for the lightning initiation from the thundercloud. Artificial charged water aerosol clouds of the positive or negative polarity could help investigate the possible influence of the hydrometeor form on the peculiarities and the probability of the lightning discharge initiation between the thundercloud and the ground. Artificial charged aerosol clouds that could create the electric field strength in the range of 5-6 kV/cm to 16-18 kV/cm have been used in experiments. The array of the model hydrometeors of the volume and plate form has been disposed near the bottom cloud boundary. It was established that the different kinds of the discharge could be initiated in the presence of the model hydrometeors array – from the cloud discharges up to the diffuse and channel discharges between the charged cloud and the ground. It was found that the form of the model hydrometeors could significantly influence the channel discharge initiation from the artificial charged aerosol cloud of the negative or positive polarity correspondingly. Analysis and generalization of the experimental results have shown that the maximal probability of the channel discharge initiation and propagation stimulation has been observed for the artificial charged cloud of the positive polarity when the arrays of the model hydrometeors of the cylinder revolution form have been used. At the same time, for the artificial charged clouds of the negative polarity, application of the model hydrometeor array of the plate rhombus form has provided the maximal probability of the channel discharge formation between the charged cloud and the ground. The established influence of the form of the model hydrometeors on the channel discharge initiation and from the artificial charged water aerosol cloud and its following successful propagation has been related with the different character of the positive and negative streamer and volume leader development on the model hydrometeors array being near the bottom boundary of the charged cloud. The received experimental results have shown the possibly important role of the form of the large hail particles precipitated in thundercloud on the discharge initiation.

Keywords**—**Cloud and channel discharges, hydrometeor form, lightning initiation, negative and positive artificial charged aerosol cloud.

The reported research has fulfilled due to the grant of the Russian Science Foundation (project No. 16-19-00160).

A.G. Temnikov, O.S. Belova, L.L. Chernensky, T.K. Gerastenok, N.Y. Lysov, A.V. Orlov, D.S. Zhuravkova are with the Department of Electrophysics and High Voltage Technique, National Research University “Moscow Power Engineering Institute”, Moscow, Russia (e-mail: TemnikovAG@mpei.ru, a_g_temnikov@mail.ru).

I. Introduction

The physical mechanisms of a lightning initiation between a thundercloud and a ground are the less investigated nowadays in the lightning physics [1], [2]. Hypothesis of the cloud-to-ground lightning initiation due to the runaway breakdown [3], the arrays of the large precipitated hydrometeors [4]-[6] and their combination [7], [8] are in the consideration. Moreover, nowadays proposition that lightning has been initiated by the cloud hydrometeors has the priority under the theoretical simulation and experimental investigations using the high voltage installation [9], [10]. Hydrometeors of the different forms and sizes are considered under these investigations from the small sharp ice crystals [6], [8], [9] to the large volume hailstone arrays [10]-[12]. At the same time, all such simulations and experiments practically did not consider the probability and the peculiarities of the discharge initiation on such model hydrometeors when they are situated inside the negatively or positively charged thunderstorm cells or near its boundaries.

Using the artificial charged water aerosol clouds (artificial thunderstorm cells) opens the possibilities in the investigations of the possible key mechanisms of the lightning initiation between the thundercloud and the ground. For example, the influence of the form of the large model hydrometeors on the discharge initiation and propagation from the negatively and positively charged aerosol clouds could be checked.

II. Experimental Complex

Investigation of the influence of the model hydrometeor forms on the probability of the discharge initiation between the charged water aerosol clouds of the negative or positive polarity and the ground have been fulfilled on the experimental complex described in [13], [14]. It allows to create the single artificial charged aerosol cell or the vertically disposed system of two charged aerosol cells of the same or the different polarity. Single charged water aerosol cloud of the negative or positive polarity has been used in the presented investigation. Cloud had a volume of some cubic meters and has been situated at the height of the meter above the ground. During the experiments, potential of the charged cloud has been varied (changing the outlet current of a charged aerosol generator) from some hundreds of kilovolts to one million volts. The maximal electric field strength near the bottom cloud boundary could achieve of the values of 16-18 kV/cm.

Model hydrometeors simulating the large hail particle have been produced from the conducted materials. Three forms of the model hydrometeors have been used in the experimental investigation: volume ellipsoid of revolution, volume cylinder, and plate rhombus. The longitudinal size of the model hydrometeors was in the range of 3.0-4.0 cm. Each model hydrometeor has been independently suspended in the gap using the dielectric strings. Group from four model hydrometeors has been used in experiments. Distance of the air gap between the neighboring model hydrometeors was approximately 2.5-3.0 cm. Common length of the hydrometeor array was 22-27 cm. Location of the model hydrometeor array in the gap “artificial charged water aerosol cloud of the negative or positive polarity - ground” is shown in Fig. 1.

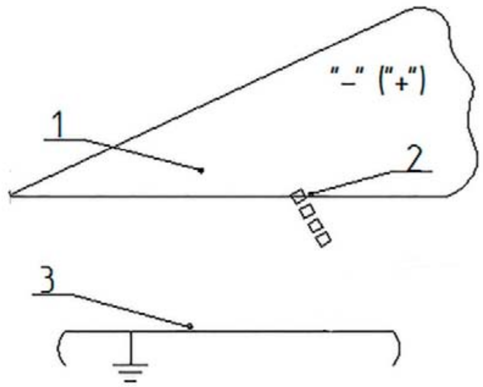

Fig. 1 Disposition of hydrometeor array 2 in the gap “artificial charged aerosol cloud 1 – ground 3”

Group of the model hydrometeors has been situated near the bottom boundary of the artificial charged aerosol cloud when the upper hydrometeor of the array could partly be inside the charged aerosol cloud.

Probability of the initiation on the hydrometeor array of the different forms of discharges in the gap “artificial charged water aerosol cloud – ground” and the peculiarities of their following propagation have been registered using fast frame CCD camera K011 and digital camera DMC-50 with open shutter during some seconds.

III. Experimental Results and Discussion

Experimental investigations of the probability of the discharge initiation and propagation on the model hydrometeor array have shown the significant influence of the model hydrometeor form on the discharge initiation in the gap “artificial charged water aerosol cloud – ground”. Such influence has been established for both polarities of the charged aerosol cloud.

The series of the experimental investigations has been carried out for the different variants of the model hydrometeor array, the polarity of the artificial charged water aerosol cloud, and the value of the outlet current of the charged aerosol generator. Each such series consisted of more than thirty experimental approaches. Outlet current has been varied from 60 μA to 120 μA with the lag of 10 μA (that corresponds to the electric field strength changing of 1.3-1.5 kV/cm near the bottom cloud boundary).

Five possible variants of the discharge initiation and propagation in the gap “artificial charged water aerosol cloud of the negative or positive polarity - ground” at the presence of the model hydrometeor array have been established:

(1) no discharges in the gap,
(2) cloud discharges initiated on the model hydrometeors array,
(3) channel discharges between the cloud and the ground using the hydrometeors array,
(4) diffuse discharges between the hydrometeors array and the ground,
(5) channel discharges between the cloud and the ground past the hydrometeors array.

For both polarities of the artificial charged water aerosol clouds, cloud discharges initiated on the model hydrometeor array consisted of the corona discharges occurring on the single hydrometeors and the spark discharges between the neighboring hydrometeors in group. Characteristic picture of the channel discharges that has been initiated by the model hydrometeors from the charged aerosol cloud of the positive polarity is shown in Fig. 2. Channel discharges formed in the gap “negatively charged aerosol cloud – ground” could be initiated by the hydrometeor group or developed in the gap past the hydrometeors array (Fig. 3). For positively charged aerosol cloud, diffuse discharges between the hydrometeors array and the ground could be observed (Fig. 4). They present multiple weak streamer discharges between the hydrometeor and the ground.

Results of the experimental investigations of the influence of the model hydrometeor form on the probability of the initiation and propagation of the discharge in the gap “artificial charged aerosol cloud – ground” have been generalized. Tables I-III present the results received for the negatively charged water aerosol cloud. Tables IV-VI present the results received for the positively charged water aerosol cloud.

Analysis of Tables I-III has shown that the array of hydrometeors of the ellipsoid revolution form has the lowest probability of the channel discharge initiation between the artificial negatively charged aerosol cloud and the ground (less than 20%) in comparison with the array of the model hydrometeors of the cylinder revolution form or the plate rhombus form. However, the increased probability of the case when the channel discharge between the negatively charged aerosol cloud and the ground passed the hydrometeors array of the ellipsoid revolution form has been observed for the values of the outlet currents more than 100 μA (the large artificial cloud charge).

The biggest probability of the channel discharge initiation between the artificial negatively charged aerosol cloud and the ground has been found for the case when the array of the model hydrometeors of the plate rhombus form has been used. It was approximately in the range from 50% to 60% when the outlet current of the charged aerosol generator exceeded the values of 90-100 μA.

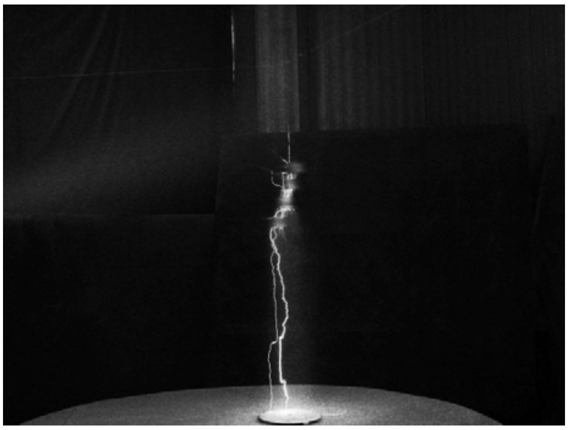

Fig. 2 Channel discharges initiated by the array of cylinder hydrometeors between the positively charged water aerosol cloud and the ground

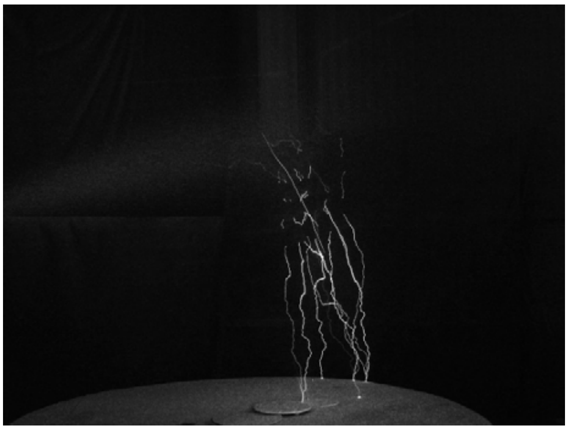

Fig. 3 Channel discharges developing the in the gap "negatively charged aerosol cloud – ground" in the presence of the array of the rhombus hydrometeors

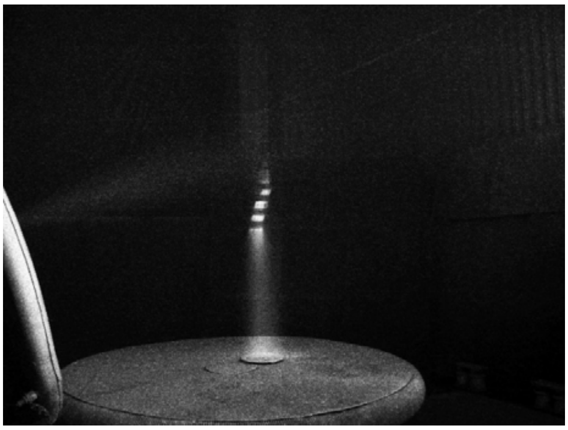

Fig. 4 Formation of the diffuse discharges between the array of cylinder hydrometeors and the ground for positively charged water aerosol cloud

For the array of the hydrometeors of the cylinder revolution form, the highest probability of the channel discharge initiation between the artificial negatively charged aerosol cloud and the ground (30-40%) has been observed when the outlet current of the charged aerosol generator exceeded the values of 110 μA.

Such influence of the form of hydrometeors on the probability of the discharge initiation between the negatively charged water aerosol cloud and the ground could be perhaps explained by two following factors. First, positive streamer corona appearance and its transition to the volume leader require the less values of the external electric field than for the negative discharges. Second, interaction of the streamer and leader discharges on the hydrometeors and the charged aerosol cloud could lead to the local discharging of the cloud.

Appearance of the volume leader on the hydrometeor array is the necessary stage of the discharge formation between the charged aerosol cloud and the ground using the model hydrometeor group. For charged aerosol cloud of negative polarity, two volume leaders could start from the hydrometeor array: (1) positive upward leader from the upper hydrometeor of the group propagated into the direction of the artificial charged aerosol cloud, (2) negative downward leader from the bottom hydrometeor of the group propagated to the ground direction.

As it is known [15], the values of the electric field strength required for the positive leader appearance and propagation are much less than for the negative leader. Moreover, the upper part of the hydrometeor array is situated immediately on the bottom boundary of the artificial charged aerosol cloud where the cloud electric field has the maximal values [16]. So, the array of the model hydrometeors of the plate rhombus form would better initiate the volume leader from the upper part of the hydrometeor array because it has the highest field amplification coefficient among the considered forms of the model hydrometeors. Besides, such form of hydrometeor helps earlier formation of the spark discharges between the neighboring hydrometeors in group. As a result, the elongated conducted object forms in the gap between the charged cloud and the ground and increases the probability of the initiation and propagation from such object not only the upward positive volume leader but the downward negative volume leader.

Appearance of the corona discharge from the upper hydrometeors in the array could significantly influence on the probability of the discharge initiation and propagation too. Such corona could discharge the space aerosol charge of the nearest parts of the charged cloud and lead to the electric field decreasing in the place where the array of the model hydrometeors is disposed.

As result, the probability of the streamer to leader transition decreases too. Such effect explained the decreasing of the channel discharge initiation on the array of the model hydrometeors of the plate rhombus form when the outlet current of the charged aerosol generator exceeded the values of 100-110 μA. At the same time, the array of the hydrometeors of the cylinder revolution form has the lower coefficient of the electric field amplification and the close values of the electric field strength for the positive streamer appearance and for the streamer to leader transition. So, the highest probability of the channel discharge initiation between the cloud and the ground has been achieved for the big outlet currents of the charged aerosol generator.

TABLE I
PROBABILITY (IN %) OF DISCHARGE INITIATION FROM ARTIFICIAL CHARGED WATER AEROSOL CLOUD OF NEGATIVE POLARITY BY ARRAY OF HYDROMETEORS OF ELLIPSOID REVOLUTION FORM

Discharge Phenomenon	Outlet Current (in μA) of Charged Aerosol Generator (Value of Cloud Charge)						
	60	70	80	90	100	110	120
No discharges	50.11	18.82	17.30	10.02	0.0	0.0	0.0
Cloud discharges on hydrometeors array	49.89	81.18	76,84	61.90	24.85	14.70	7.60
Channel discharge between cloud and ground using hydrometeors array	0.0	0.0	0.0	0.0	27.95	8.90	18.70
Diffuse discharges between hydrometeors array and ground	-	-	-	-	-	-	-
Channel discharges between cloud and ground past hydrometeors array	0.0	0.0	5.86	28.08	47.20	76.40	73.70

TABLE II
PROBABILITY (IN %) OF DISCHARGE INITIATION FROM ARTIFICIAL CHARGED WATER AEROSOL CLOUD OF NEGATIVE POLARITY BY ARRAY OF HYDROMETEORS OF CYLINDER REVOLUTION FORM

Discharge Phenomenon	Outlet Current (in μA) of Charged Aerosol Generator (Value of Cloud Charge)						
	60	70	80	90	100	110	120
No discharges	19.95	2.16	0.0	0.0	0.0	0.0	0.0
Cloud discharges on hydrometeors array	80.05	97.84	82.60	67.90	14.80	3.75	3.60
Channel discharge between cloud and ground using hydrometeors array	0.0	0.0	9.08	1.94	23.10	33.10	42.20
Diffuse discharges between hydrometeors array and ground	-	-	-	-	-	-	-
Channel discharges between cloud and ground past hydrometeors array	0.0	0.0	8.32	30.16	62.10	63.15	54.20

TABLE III
PROBABILITY (IN %) OF DISCHARGE INITIATION FROM ARTIFICIAL CHARGED WATER AEROSOL CLOUD OF NEGATIVE POLARITY BY ARRAY OF HYDROMETEORS OF PLATE RHOMBUS FORM

Discharge Phenomenon	Outlet Current (in μA) of Charged Aerosol Generator (Value of Cloud Charge)						
	60	70	80	90	100	110	120
No discharges	4.05	1.20	0.0	0.0	0.0	0.0	0.0
Cloud discharges on hydrometeors array	95.95	98.80	81,80	19.85	20.60	12.80	1.10
Channel discharge between cloud and ground using hydrometeors array	0.0	0.0	9.80	50.80	57.30	58.80	48.70
Diffuse discharges between hydrometeors array and ground	-	-	-	-	-	-	-
Channel discharges between cloud and ground past hydrometeors array	0.0	0.0	9.40	29.35	22.10	29.40	50.20

TABLE IV
PROBABILITY (IN %) OF DISCHARGE INITIATION FROM ARTIFICIAL CHARGED WATER AEROSOL CLOUD OF POSITIVE POLARITY BY ARRAY OF HYDROMETEORS OF ELLIPSOID REVOLUTION FORM

Discharge Phenomenon	Outlet Current (in μA) of Charged Aerosol Generator (Value of Cloud Charge)						
	60	70	80	90	100	110	120
No discharges	44.10	10.85	0.30	0.0	0.0	0.0	0.0
Cloud discharges on hydrometeors array	55.90	89.15	99,70	79.90	50.80	49.20	21.30
Channel discharge between cloud and ground using hydrometeors array	0.0	0.0	0.0	0.0	3.95	7.90	10.60
Diffuse discharges between hydrometeors array and ground	0.0	0.0	0.0	20.10	45.25	42.90	68.10
Channel discharges between cloud and ground past hydrometeors array	-	-	-	-	-	-	-

TABLE V
PROBABILITY (IN %) OF DISCHARGE INITIATION FROM ARTIFICIAL CHARGED WATER AEROSOL CLOUD OF POSITIVE POLARITY BY ARRAY OF HYDROMETEORS OF CYLINDER REVOLUTION FORM

Discharge Phenomenon	Outlet Current (in μA) of Charged Aerosol Generator (Value of Cloud Charge)						
	60	70	80	90	100	110	120
No discharges	25.90	0.85	0.0	0.0	0.0	0.0	0.0
Cloud discharges on hydrometeors array	74.10	99.15	25.10	6.90	0.0	0.0	0.0
Channel discharge between cloud and ground using hydrometeors array	0.0	0.0	0.0	0.0	0.0	39.10	55.10
Diffuse discharges between hydrometeors array and ground	0.0	0.0	74.90	93.10	100.0	60.90	44.90
Channel discharges between cloud and ground past hydrometeors array	-	-	-	-	-	-	-

TABLE VI
PROBABILITY (IN %) OF DISCHARGE INITIATION FROM ARTIFICIAL CHARGED WATER AEROSOL CLOUD OF POSITIVE POLARITY BY ARRAY OF HYDROMETEORS OF PLATE RHOMBUS FORM

Discharge Phenomenon	Outlet Current (in μA) of Charged Aerosol Generator (Value of Cloud Charge)						
	60	70	80	90	100	110	120
No discharges	87.50	23.80	3.10	0.0	0.0	0.0	0.0
Cloud discharges on hydrometeors array	12.50	76.20	96,90	50.80	39.80	22.20	13.90
Channel discharge between cloud and ground using hydrometeors array	0.0	0.0	0.0	0.0	0.0	1.80	3.95
Diffuse discharges between hydrometeors array and ground	0.0	0.0	0.0	49.20	60.20	76.0	82.15
Channel discharges between cloud and ground past hydrometeors array	-	-	-	-	-	-	-

Analysis of Tables IV-VI has shown that the array of hydrometeors of the plate rhombus form has the lowest probability of the channel discharge initiation between the artificial positively charged aerosol cloud and the ground (less than 4%) in comparison with the array of the model hydrometeors of the cylinder and ellipsoid revolution form. It is mainly connected with the peculiarities of interaction between the streamer and leader discharges occurred on the hydrometeors array and the charged aerosol cloud. For positively charged aerosol cloud, two volume leaders could start from the hydrometeor array: (1) negative upward leader from the upper hydrometeor of the group propagated into the direction of the artificial charged aerosol cloud, (2) positive downward leader from the bottom hydrometeor of the group propagated to the ground direction. Very high electric field strengths have required to the negative leader appearance and propagation [15]. So, the prior path of the discharge development in the gap is the formation of the positive downward leader from the bottom hydrometeor of the array. Discharge formation from the upper hydrometeors in the array becomes less preferred (Fig. 2).

Appearance of the corona discharge from the upper hydrometeors in the array could often play the main role in the channel discharge initiation and propagation from the artificial charged aerosol clouds of the positive polarity. When the array of hydrometeors of the plate rhombus form has disposed near the bottom boundary of the positively charged aerosol cloud the powerful corona discharge has formed from the upper hydrometeors and discharged the significant part of the charged cloud led to the sufficient decreasing of the electric field strength in the place where the model hydrometeor array has disposed. That has had more worst the conditions of the upward negative and downward positive volume leader appearance. As result, the probability of the channel discharge formation between the charged cloud and the ground on the hydrometeors array has become much less. And, the biggest probability of the channel discharge initiation between the artificial positively charged aerosol cloud and the ground will be for the case of the array of the model hydrometeor of the cylinder revolution form (approximately in the range from 40% to 50% when the outlet current of the charged aerosol generator exceeded the values of 110-120 μA). Thus, the arrays of the large hydrometeors could significantly influence on the discharge initiation and propagation in thunderclouds. Role of such large hydrometeor would play the hail. Influence of the large hail arrays on the discharge initiation and propagation has been found especially for the positively charged parts of thunderclouds and for the powerful positive lightning [17]. Arrays of hails precipitating in the small positive charge in the bottom part of thundercloud could lunch the downward lightning discharge [18], [19].

Besides, peculiarities of the interaction of the array of the model hydrometeors of the different forms with the charged aerosol clouds should be considered under the theoretical simulations and experimental investigations of the influence of different hydrometeors on the lightning initiation in thunderclouds [6], [8]-[10].

IV. CONCLUSION

Experimental investigation of the influence of the model hydrometeor form on the probability of the discharge initiation from the artificial positively and negatively charged water aerosol clouds has shown the significant effect of the hydrometeor form. Three different forms of the model hydrometeors (ellipsoid and cylinder of revolution, plate rhombus) have been investigated and shown the opposite results as for the channel discharge initiation from the charged aerosol clouds of the negative and positive polarity, correspondingly. It has been found that the array of the model hydrometeors of the plate rhombus form gives the maximal probability of the channel discharge initiation and propagation between the negatively charged cloud and the ground. It was established that the array of the model hydrometeors of the cylinder form gives the maximal probability of the channel discharge initiation and propagation between the positively charged cloud and the ground. Such result has connected with the peculiarities of interaction of the streamer and leader discharges formed on the hydrometeor array with the charged water aerosol cloud. Received results could be used as for the better understanding of the physics of the lightning initiation in thunderclouds as for the development of the means of the artificial lightning initiation between the thundercloud and the ground.

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