DISCUSSIONS ON A LONG GAP DISCHARGE TO AN EHV TRANSMISSION TOWER BY A ROCKET TRIGGERED LIGHTNING EXPERIMENT

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ABSTRACT

The triggered lightning experiments using a rocket have been carried out on a winter mountain in Japan since 1986. The lightning stuck, nineteen times, the EHV test transmission line and tower. This paper emphasizes the methodology for triggering lightning to the transmission system and presents the record of experiments carried out. Based on the results of these experiments, the failure of lightning protection and the striking distance of lightning have been discussed.

INTRODUCTION

The rocket triggered lightning experiments have been carried out in the several countries [1,2,3,4]. In Japan such experiments have been performed in the northern region for the winter thunderclouds since 1977 [5,6,7]. From 1986, the experiment site was shifted to mountainous range of about 1000 m altitude [8]. The lightning struck, nineteen times, the EHV test transmission line and tower. The artificial method for triggering lightning involves a rocket and a bobbin fixed together. The bottom of the rocket system is connected to a 200 m long steel wire which in turn is connected to a 70 - 120 m long nylon line. Both steel wire and nylon line are wounded on a bobbin. The free end on the nylon line is held to the ground and thus acts as a insulator for a rocket steel wire. During the shooting operation of the rocket, the nylon line gets unwound first, followed by unwinding of the steel wire.

Most of the lightning strokes occurred on the ground wire and the peak or the arm end of tower. However, a few lightning strokes occurred on the phase conductors. This indicates the inadequate lightning protection for the transmission line.

The current was measured by a Rogowski coil unit placed on the tower. The sampling time and memory capacity of the unit were one micro-seconds and 256 kilo-words respectively. The peak current was measured by a magnetic tape placed on the top of rocket.

In order to obtain the triggered lightning discharge on a

high tower artificially but similar to the natural one, a two-stage rocket was used to initiate lightning as well as to carry the current measuring system (Rogowski coil - for the measurement of lightning discharge in the air).

The striking distance was estimated from the photograph or the reconstructed channel by an acoustic analysis method. In the measurement of the acoustic analysis, three microphones were used, each separated by a 10 m distance amongst them. This analysis was quite useful to estimate the discharge channel within the cloud or under the invisible condition such as snowfall, etc. This analysis method and its accuracy have been discussed in the literature [9,10]. The striking distance versus the peak current characteristics were thus obtained. The results were comparatively close to the characteristics reported by Golde and Chan [11,12].

This paper primarily emphasizes the methodology for triggering lightning to the transmission system and presents the record of experiments carried out in the four years. Finally, based on the results of these experiments, the failure of lightning protection and the striking distance of lightning have been discussed.

TRIGGERING METHOD

The experiment site was chosen on the peak of the Okushishiku mountain with the altitude of 930 m above sea level and IKL(Iso Keraunics Level) of about forty. A test transmission line of 275 kV of about 2 km length running over seven transmission towers is located near the site. Fig. 1 indicates

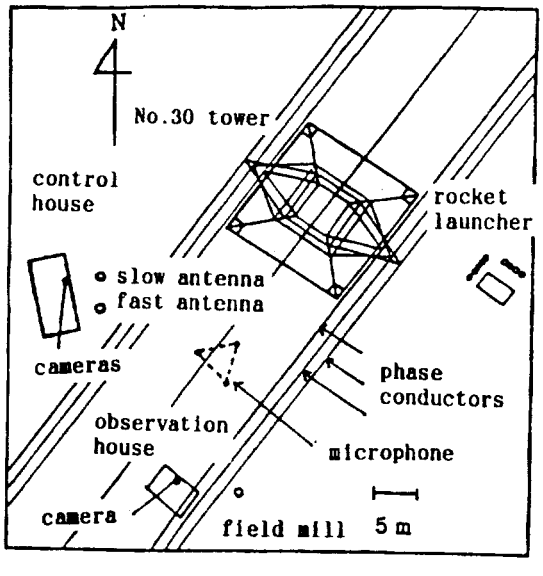

Fig. 1 Experiment site

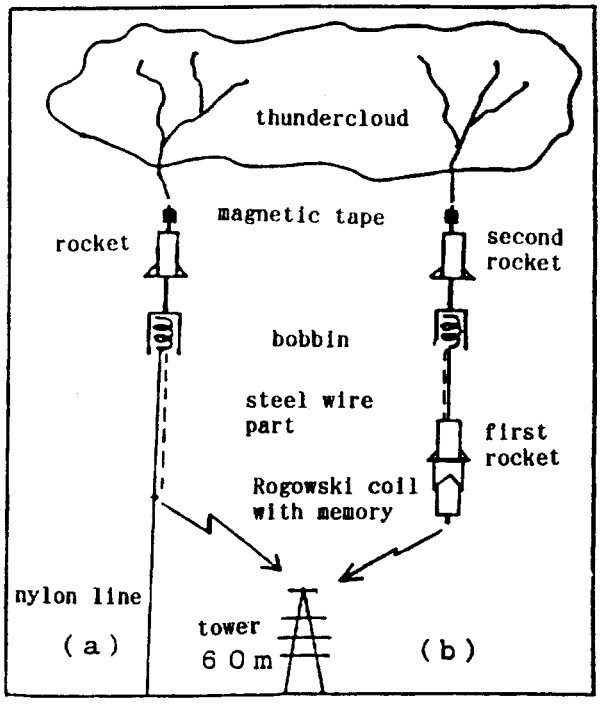

Fig. 2 Rocket triggering methods

the arrangement of the site. The height of one of the towers, tower No. 30, is about 60 m. The rocket launchers were placed at a distance of 10 - 15 m from the tower. In order to get the lightning on the towers one-stage and two-stage rocket methods were applied.

One-stage rocket system

This method has been applied since 1986. One of the rockets launched employing this method is shown in Fig. 2(a). The length, the diameter and the weight of rocket were 170 mm, 40 mm and 0.5 kg respectively. During launching of rocket, initially the nylon line was pulled out by about 70 to 120 m from the ground followed by unwinding of the steel wire of 0.2 mm diameter. With such a long nylon line, the steel wire gets well insulated from the ground. This paves the way for triggering of the lightning discharge to the nearest transmission line and tower making a long gap discharge of length 10 - 60 m. Hence the change in the starting point of the downward leader, (i.e. the distance from the ground), can be achieved simply by selecting the different lengths of nylon line. Fig. 3 shows one example of the triggered lightning to the top of tower.

Two-stage rocket system

In the one-stage rocket system the comparatively long partial discharges were often observed along the surface of the nylon line in the beginning of triggering of the lighting discharge [8]; To eliminate these discharges, the two-stage rocket system was then developed completely dispensing with the nylon line.

As shown in Fig. 2(b), the two-stage rocket was launched by firing the first rocket and within two seconds the second rocket got automatically fired to separate each other in the air and then the steel wire was unreeled connecting them. On the top of the second rocket a magnetic tape and on the bottom side of the first rocket a compact Rogowski coil with a memory unit were equipped to measure the lightning current peak and waveform respectively. The diameter of Rogowski coil was 70 mm. The current signal was directly written into a compact memory card with memory of 256 kilo-words. As the magnetic tape used was pre-magnetized with 1 kHz signal and so the peak current was estimated from the demagnetized distance on the tape. The triggered lightning by the two-stage rocket system was obtained two times in 1989, but unfortunately the current measurement could not be successfully recorded.

EXPERIMENTED RESULTS

General

The table 1 depicts the results of the triggered lightning strokes occurred on the ground wire, phase conductors and tower. In the table, the nylon length indicated is that of the nylon

line wound on the bobbin for the one-stage rocket system. The results shown against the experiment No.89-16 and No.89-21 have been evaluated using the two-stage rocket system. The striking points were estimated either using the camera photograph or the lightning channel reconstruction by an acoustic analyzing method. Several points were identified and confirmed through the visual inspection after the end of experiment as well as other measurements such as the induced voltage on the insulator strings. The peak currents were obtained by Rogowski coil measurement except in case of experiment No.89-16 and 89-21 in which relevant observation were taken by the magnetic tape measurement. The triggering time means the time lapse after the rocket launching till the occurrence of lightning.

Striking distance here is defined as the distance between the striking point on the transmission system and the nearest bending point of the channel. According to the streak photograph, the downward leader began from the tip of the partial discharge appeared along the surface of the nylon line, and propagated towards the transmission system. The local return stroke run up from the transmission system to meet the leader within several hundred microseconds before the vaporization of wire. The main discharge occurred after the upward leader reached the nearest cloud [8].

Table 1 Experimental Results

No.	nylon length	striking points	current peak(kA)	remarks (protection)
86-11	70 m	upper arm end of tower	>+50	
86-13	70	ground		
87-05	100	peak of tower	+23.0	
87-07	100	upper arm end of tower	-8.5	
87-08	100	ground wire	-11.0	
87-10	100	rocket launcher	negative	
87-18	100	upper arm end of tower	+14.0	
87-21	100	middle phase conductor	negative	failure
87-22	100	upper arm end of tower	(-5.5)	
88-12	100	ground wire	-	
88-04	120	upper phase conductor	-	failure
88-16	120	ground wire	-	
89-04	120	peak of tower	+25.6	
89-05	120	upper phase conductor	positive	failure
89-07	120	upper phase conductor	positive	failure
89-09	120	peak of tower	-18.1	
89-10	120	ground wire	-4.3	
89-16	•	ground wire	+13.0	(two-stage)
89-21	•	middle arm end of towe	+5.0	(two-stage)

Lightning Discharges

The length of nylon line applied in the 1986 was 70 m. The

experiment No. 86-11 in Fig. 3 shows the sketch of the triggered lightning to the tower, obtained by the three dimensional analysis of photograph. In this case, the lightning discharge propagated 23 m from the junction point of the steel wire and the nylon line to strike the upper arm end of tower with the angle of 50 degrees. According to the current measurement, the peak value was estimated to be +50 kA [8].

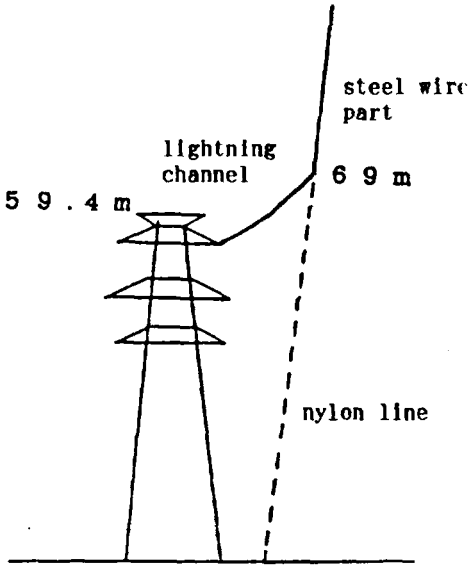

Fig. 3 Lightning flash 86-11(sketch)

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Fig. 4 Lightning flash 87-10

The length of nylon line used in this experiments conducted during 1987 was 100 m. Rocket launcher was placed 12 m distant from the tower with an elevation of 87 degrees. As described in Table 1, six lightning occurred on the transmission tower, the ground wire and directly on the ground. One of the lightning struck the phase conductor which indicates the inadequacy of lightning protection.

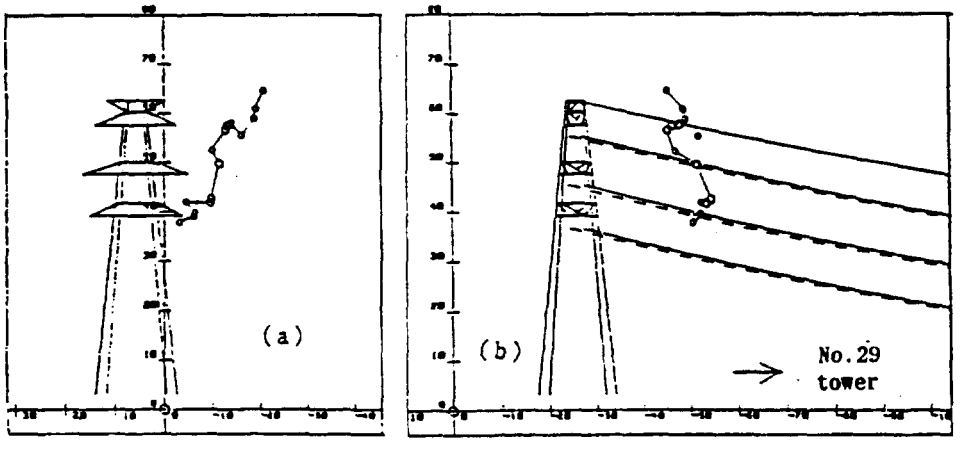
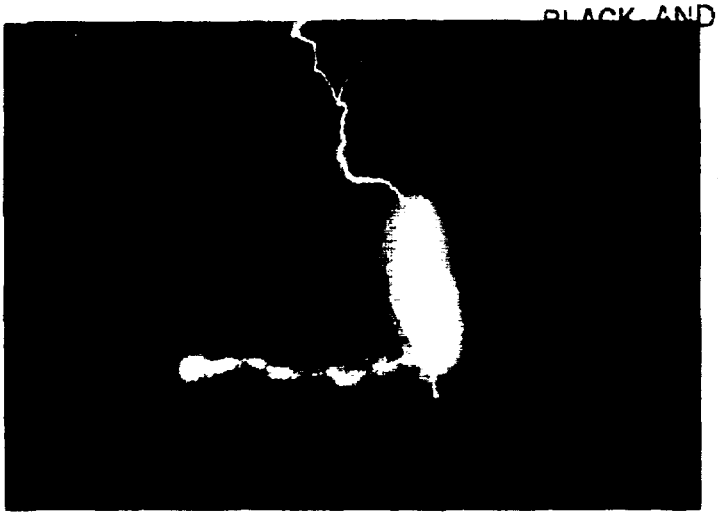


Fig. 5 Reconstruction of lightning flash 87-21 (middle phase)

Fig. 4 shows the lightning flash of experiment No.87-10 on the launcher. The lightning discharge came down straight from the air, and jumped to one of the six launchers on the ground after flashing over along the nylon surface for about 20 m length. Fig. 5 shows the reconstruction of the lightning experiment No.87-21. The striking point was estimated to be on the middle phase conductor 20 m at a distance from the tower.

Fig. 6 shows a photograph and a current through the ground wire measured by a Rogowski coil unit in the lightning experiment No.87-08. The lightning experiments viz, No.87-21 and No.87-10 was the negatively charged clouds.



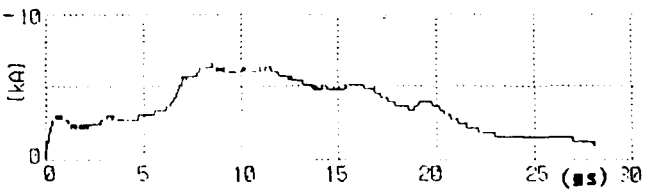


Fig.11 Current through the ground wire

Fig. 6 Lightning flash and current through the ground wire 87-08

In case of experiments conducted during 1988, two nylon lines of 100 m and 120 m length were applied. Two lightning occurred on the ground wire and one occurred on the upper phase conductor. Fig. 7 shows the reconstruction of the lightning flash of 88-04. Fig. 7-a , 7-b and 7-c are the front, the side and the plane views, respectively. The striking point were estimated to be 60 m away from the tower.

In the year 1989, such experiments were conducted using nylon line of length 120 m. Seven triggered lightning including the two initiated by the two-stage rocket system were obtained. The triggering lightning strokes as recorded in the experiments No.89-05 and No.89-07 occurred directly on the upper phase conductor which indicates the insufficient shielding against lightning. Clear photographs could not be obtained for any of lightning discharges because of the heavy snowfall. Fig. 8

indicates the seven striking points of the lightning estimated by the reconstruction method. The locations of these points were evaluated by another methods and found to be in good agreement.

DISCUSSIONS

As shown in Table 1, two lightning strokes occurred separately on the tower or the ground without the failure of shielding against lightning in the case of 70 m nylon line. However, out of seven lightning strokes triggered using nylon line of 100 m length, only one struck the middle phases conductor, whereas one of same number of strokes triggered using nylon line of 120 m length, three struck the upper phase conductor. On evaluating of this date, it was observed that the failure rate of the lightning protection was 14 % in the case of 100 m nylon line and 43 % in the case of 120 m nylon line.

These results suggest that the longer the nylon line, the higher is the failure rate of the protection as well as the striking point of the lightning. It was also observed that in the event of triggered lightning striking the tower, the downward leader began near the junction of the nylon line and the steel wire [8]. Thus the starting location of the leader may depend on the length of nylon line. If the length of the nylon line is small so as to make the starting point of the leader within the attracting

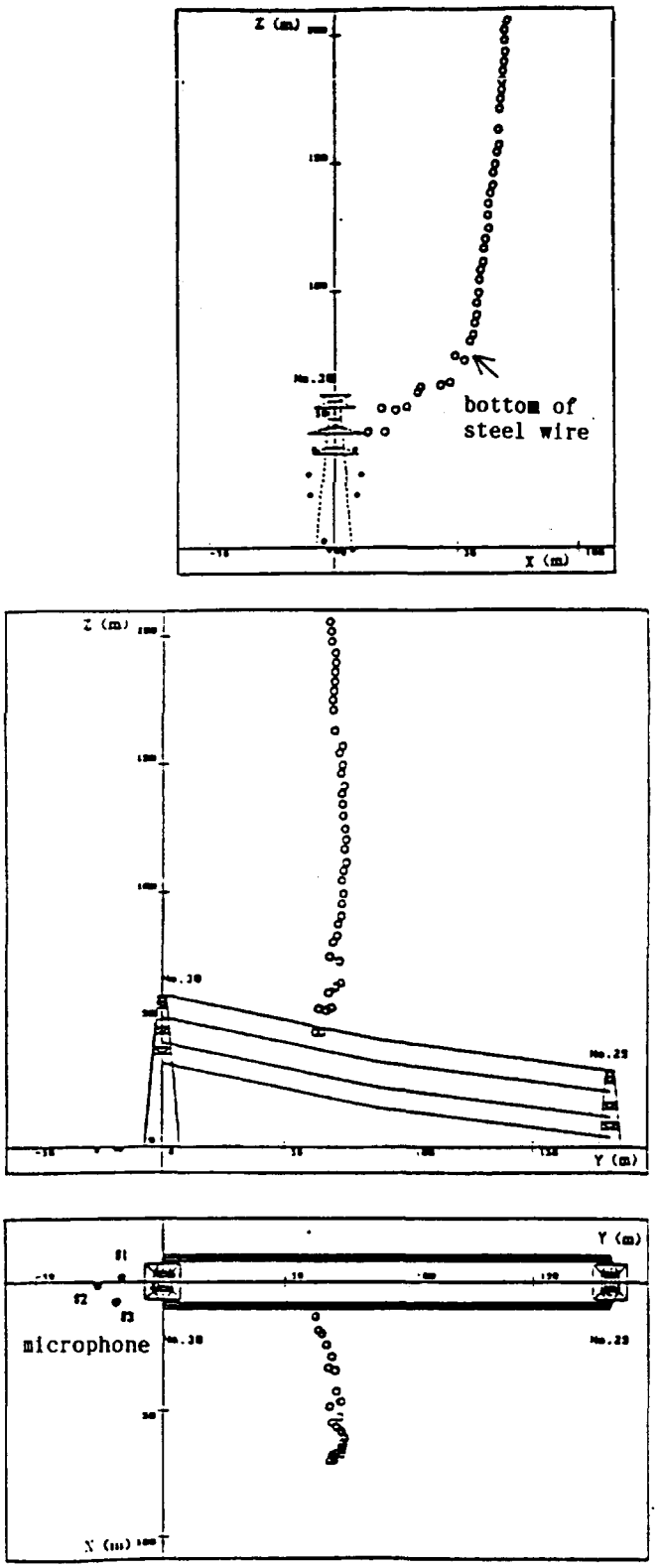


Fig. 7 Lightning reconstruction (88-04)

area of the tower, the lightning can occur on the tower. If the length of the nylon line is comparatively long, the leader can begin outside from the attracting area and then the lightning can take place on somewhere the nearest point from thc leader.

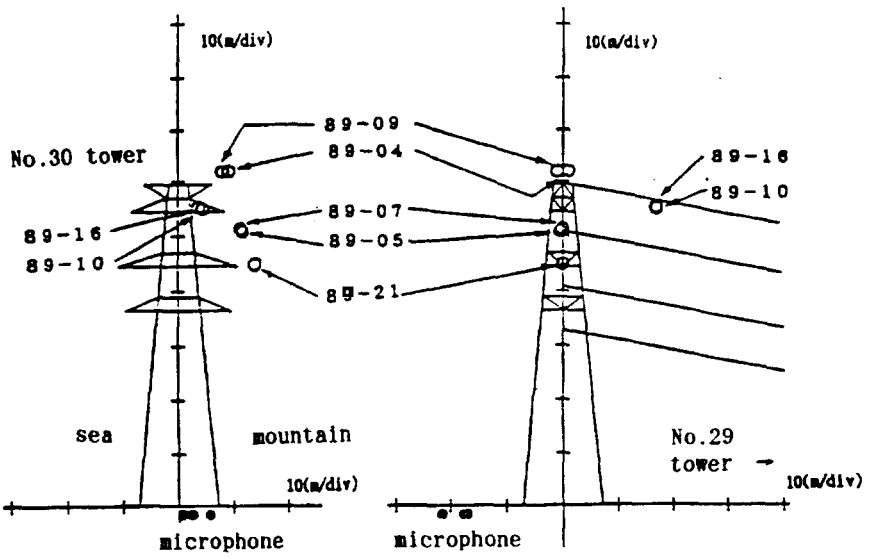


Fig.8 Striking points identified by the reconstruction

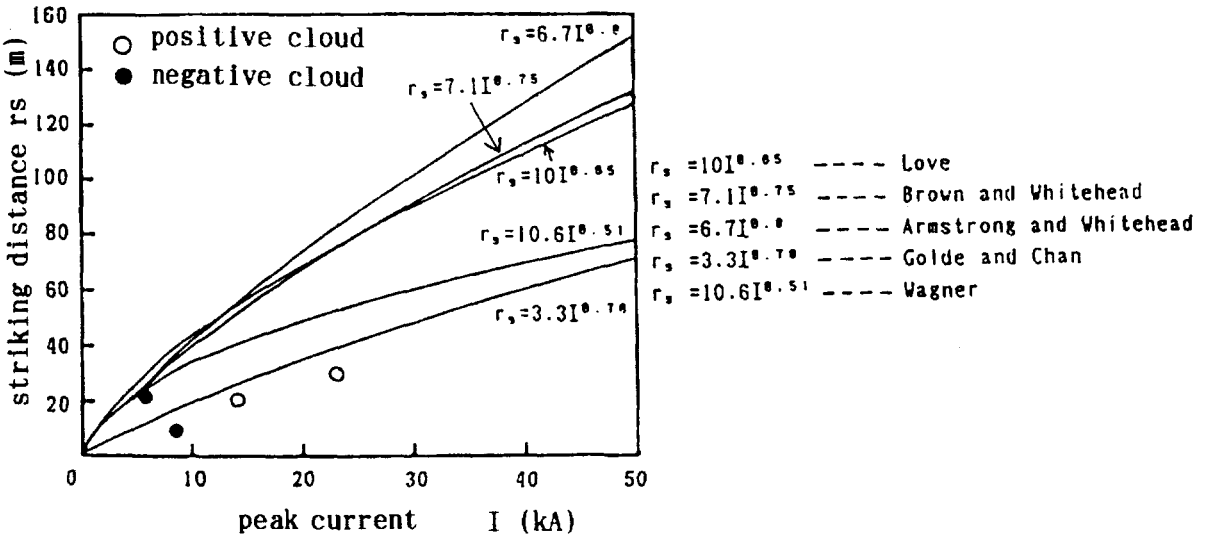


Fig. 9 Striking distance and peak current

Fig. 9 shows the characteristics of thestriking distance versus the current peak. Several theoretical curves are documented together. The characteristics curve of the triggered lightning becomes close to or comparatively below the curve reported by Golde and Chan. According to the theory, the larger the total charge of the downward leader, the longer is the striking distance or the final jump because of the higher potential of the leader. And the return stroke current must be larger enough to cancel the corresponding charge the leader left

behind.

On the other hand, the downward leader was forced to start from the bottom of wire and propagated only several tens meters towards the transmission system in the triggered lightning. Then the return stroke did not reach the cloud at a dash, but ceased in the way. For this reason we named it as a partial return stroke. Within a few hundred microseconds the upward leader subsequently began to move towards the cloud to initiate the main lightning discharge. The peak current in Fig. 9 is not corresponding to the partial return stroke current, but the main discharge current. Therefore, the comparatively large currents were obtained corresponding to the same striking distance. If the current during the partial return stroke can be measured by using the two-stage rocket, the more reasonable characteristics may be obtained.

CONCLUSIONS

The results and the discussions on the triggered lightning experiments to the transmission line for four years from 1986 to 1989 are summarized as follows.

(1) Thirty nine rockets were launched and nineteen triggered lightning strokes were obtained on the transmission line and tower, and on the ground. The rate of success was 50 %. Four times lightning strokes occurred on the phase conductor which meant the failure of lightning protection, and the twice struck the ground.

(2) The nylon lines of 70 - 120 m length were used for the insulation of the steel wire. The longer the nylon line, the higher was the failure rate of the protection.

(3) The characteristics of the striking distance was close to or comparatively below the curve reported by Golde and Chan.

(4) The lightning using the two-stage rocket was successfully triggered. Unfortunately, the measurement of the discharge current could not be done successfully.

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