A Positive Lightning Discharge that Caused Severe Damage to the Blade of a Windmill

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***Abstract*— The optical progression characteristics of an upward connecting negative leader and a downward positive dart leader contained in a positive lightning discharge that hit on the blade tip of a windmill have been reported. The pulse discharges in the negative leader are found to propagate backward usually with a distance of a few tens of meters. Their propagation speeds tend to be around 1.0×10^{8} m/s initially and soon drop to a stable value of about 2.0×10^{7} m/s. The downward positive dart leader also exhibited a speed of about 2.0×10^{7} m/s. The plasma formed on the windmill blade tip by the lightning tends to be much brighter than the free space lightning channel.**

Keywords-positive lightning; stepped leader;dart leader;positive return stroke

I. INTRODUCTION

We have been observing the lightning discharges to a windmill and its lightning protection tower which locate on the coast of the Sea of Japan for consecutive 11 winter seasons [1-5]. During each of the winter seasons we have observed a dozen lightning discharges hitting either the tower or the windmill or both. At 05:33:02, December 31, 2014, we recorded a positive lightning discharge that hit on the blade of the windmill and caused severe damage to the blade. With the data, we have been able to study the optical progression characteristics of the observed upward negative leader, the downward positive dart leader as well as the luminosity characteristics of the lightning-caused plasma on the blade. This paper is to report the results.

II. OBSERVATION AND DATA

As described previously [5], the windmill and its lightning protection tower, with their respective heights of 100 m and 105 m separated at a distance of 45 m, located on a small hill at Uchinada-chou, Ishikawa prefecture of Japan. The hill is next to a sea inlet and has a height of about 40 m above the sea level. Figure 1 shows the picture of the lightning and the lightning caused damage on the windmill blade. For this lightning, we have documented its data primarily with the following equipment.

(1) Two high speed video camera. One is Photron SA 5.1 operated at a frame rate of 330000 frames per second and the other is NAC MEMRECAM GX-8 operated at a frame rate of 40000 frames per second.

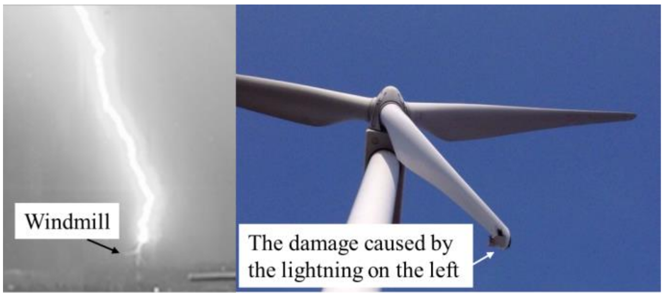

Figure 1. The picture of the lightning and the damage caused by this lightning.

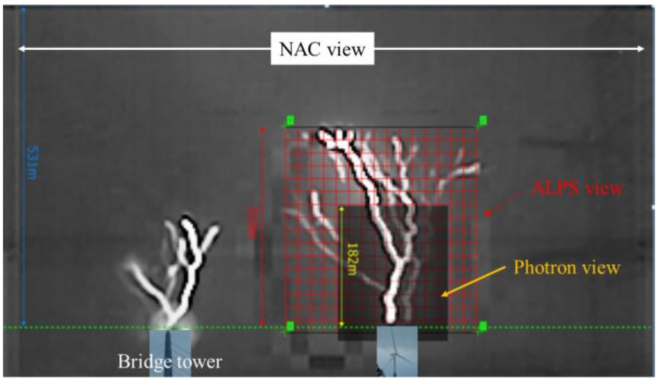

Figure 2. Views of the three high speed optical observation systems used in this study.

(2) One ALPS (Automatic Lightning Progressing Feature Observation System). ALPS is the same one used in [6] and was operated at a sampling rate of 0.1 µs. The overlapped view of ALPS and the two high speed camera with the upward leader of the lightning in Figure 1 is shown in Figure 2.

(3) 3 field mills and 2 slow and fast capacitive antenna.

III. RESULTS

A. Overall characteristics

Figure 3 shows the relative light intensity of the lightning discharge recorded by Photron camera and ALPS. ALPS has a recording length of only 1.6 ms, but its sensitivity is much less than Photron camera. As seen in this figure, the discharge

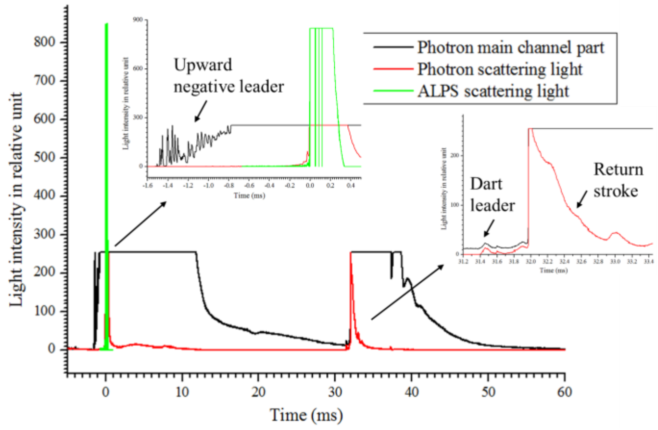

Figure 3. Luminosity waveforms of recorded by Photron camera and ALPS.

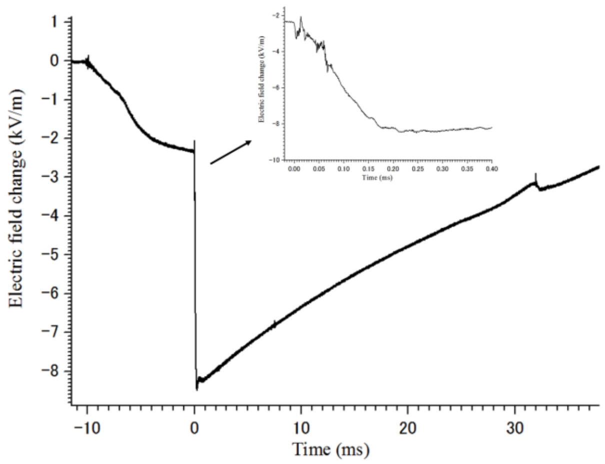

Figure 4. The electric field change produced by the lightning shown in figure 1.

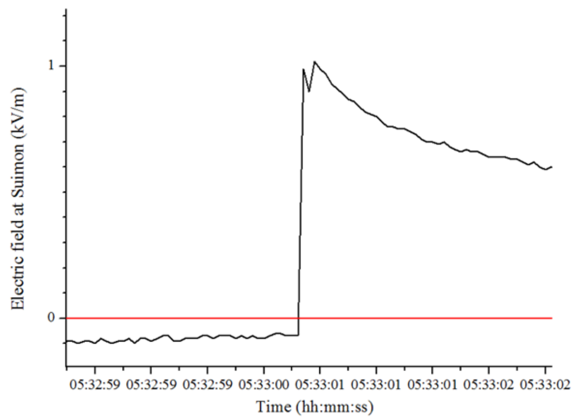

Figure 5.The electric field measured by a field mill at ground at a distance of about 400 m from the windmill.

contained two sequences totally lasting about 50 ms. The first

Figure 6. Photo of the upward negative connecting leader immediately prior to the return stroke type of discharge.

sequence was preceded with an upward negative leader with several branches. Prior to the upward negative leader, light could be seen coming from sky. This upward leader was clearly triggered by other discharge event. Figure 4 shows the electric field change recorded at about 4 km away from the windmill. From this waveform, both sequences apparently transferred positive charge to ground, in agreement with the upward negative leader judged from the high speed camera. Figure 5 shows the electric mill recording of the lightning discharge. The overall discharge started at negative electric field, very usual for a normal downward positive lightning flash. Some discharge occurred at other places and made the electric field positive and then triggered one negative upward leader from the windmill and another one from a nearby bridge tower as shown in Figure 2. The inset of Figure 4 shows the expanded version of the initial dominant electric field change. A few rapid large field changes at a time scale of tens of microseconds can be seen immediate after time 0. These rapid changes and the subsequent large electric field drop indicate that the upward negative leaders have connected to some positive leaders above and produced some return-stroke-type discharges. According to our estimation from the light intensity shown in Figure 3, the peak return stroke current reached a much as about 140 kA. Figure 6 shows the upward leader picture recorded by NAC camera immediately prior to the rapid electric field change in the inset of Figure 4. The total distance covered by the upward connecting leader is about 500 m during 1.5 ms, resulting in an average speed of 3.3×10^5 m/s, similar to that of an upward negative connecting leader reported in [7].

B. Progression characteristics of the upward negative leader of the first sequence

Figure 7 shows the height of the main leader tip versus time obtained from the Photron camera recording. From this figure,

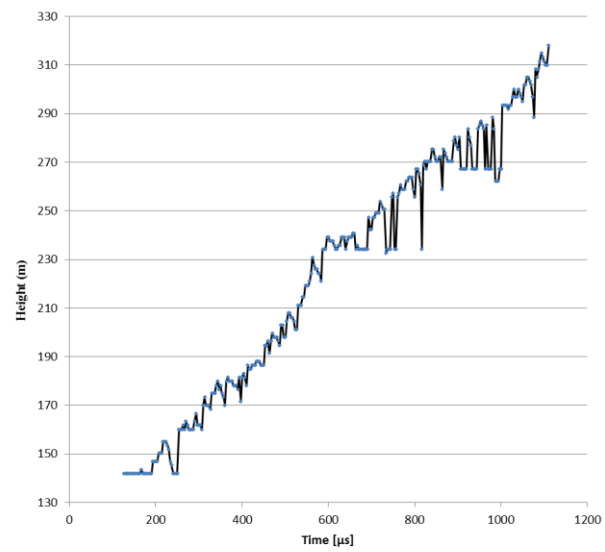

Figure 7. Height of the upward negative leader tip versus time.

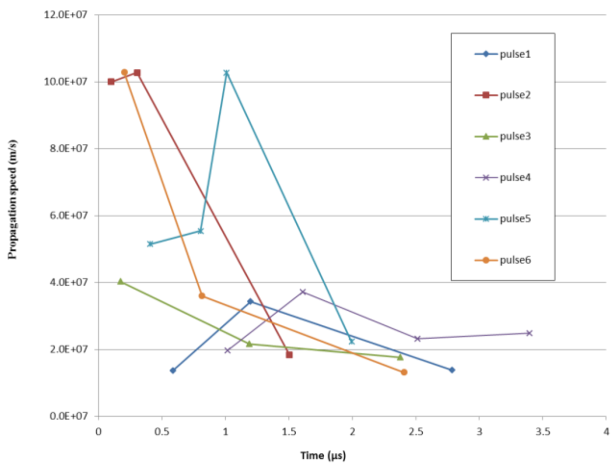

Figure 8. Leader pulse discharge propagation speed versus time.

the average initial leader speed is estimated to be about 1.8×10^5 m/s, smaller than the speed obtained from NAC recording. This simply indicates that the upward negative leader has accelerated significantly during the later stage. Also as seen in this figure, the leader is accompanied by many backward pulse discharge processes. Figure 8 presents the propagation speed of 6 typical pulse discharges versus time. It is interesting to note that although the pulse discharges may have an initial propagation speed of 1.0×10^8 m/s, their speeds eventually drop to around 2.0×10^7 m/s. The pulse discharge speeds are similar to those reported for dart stepped leaders [8].

C. Progression characteristics of the downward positive dart leader of the second sequence

Figure 9 shows the consecutive frames of the downward positive dart leader of the second sequence with a frame rate of

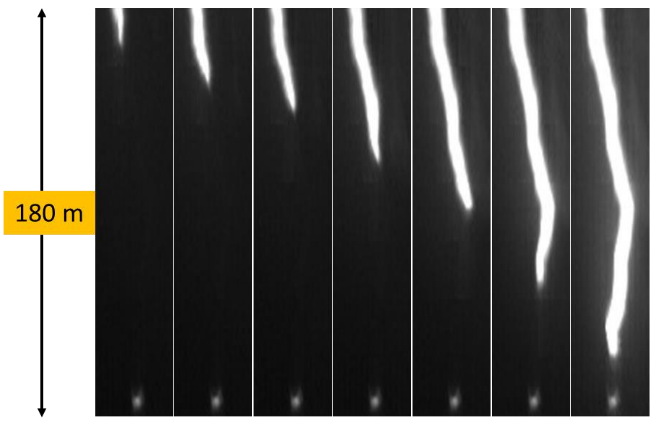

Figure 9. Seven consecutive frames of the downward positive dart leader in the second sequence shown in Figure 3.

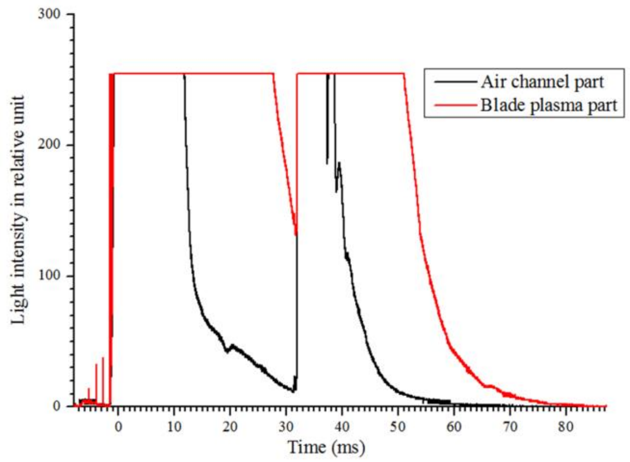

Figure 10. Luminosity waveforms of air channel part and the blade plasma part.

3.3 μs. From this figure, the average propagation speed of the positive dart leader is about 6.1×10^6 m/s. Positive dart leader appears to have a similar speed to its negative counterpart.

D. Luminosity characteristics of the lightning-caused plasma on the blade

Figure 10 compares the light intensity of the air channel and the blade plasma part. It appears that the light intensity from the blade plasma is about 20 times brighter than that from the air part of the lightning channel.

IV. CONCLUSIONS

The characteristics of a positive lightning discharge that hit on the blade tip of a windmill have been reported. The pulse discharges in the upward negative connecting leader are found to propagate backward usually at a distance of a few tens of meters. Their propagation speeds tend to be around 1.0×10^8 m/s initially and soon drop to a stable value of about 2.0×10^7 m/s. The downward positive dart leader also exhibited a speed of about 2.0×10^7 m/s. The plasma formed on the windmill blade tip by the lightning tends to much brighter than the free space plasmas.

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