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Characteristic of Upward Lightning Currents from a Wind Turbine and its Lightning Protection Tower

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Abstract

We have measured the electric currents of the upward lightning that hit on a wind turbine and its lightning protection tower during Japanese winter seasons using Rogowski coils from 2006 to 2009. With the recorded data, we have performed a study of the total charge transfer, peak current, duration, and rise time for winter upward lightning. It was found that mean value of the upward lighting can be characterized with a total charge transfer of 113.3 C, a peak current of 5.3 kA, a duration of 200.1 ms, and a rise time of 7.7 ms, respectively.

***Keywords** : Upward lightning, Wind turbine, Lightning protection tower*

1. INTRODUCTION

Many wind turbines have been built along the coast of the Sea of Japan because strong wind could be expected there. It is well known that during Japanese winter thunderstorms, these wind turbines could be hit frequently by lightning. A number of researchers have reported that compared to more common lightning during summer thunderstorms winter lightning discharges have very different features and have caused a lot of damages to high grounded structures, such as wind turbines (Asakawa et. al, 1997; Wada et. Al, 1996). Thus, there is an increasing need to find a better lightning protection method for wind turbines that are located along the coast of the Sea of Japan (Sekioka et. Al, 2007). For this reason, in this paper we have performed a statistical study on the electric current of the upward lightning that hit on a wind turbine and its lightning protection tower.

2. DATA

The wind turbine and its lightning protection tower chosen as observation target were located at Uchinada City, Ishikawa Prefecture of Japan, with their heights being 100 m and 105 m, respectively. The wind turbine and the tower are separated at a distance of about 45 m, and are built on a small hill just adjoining the sea, the height of the hill being 40 m above sea level. The electric currents were measured with Rogowski coils installed at bottom of the wind turbine and the tower with their length being 4 m and 1 m, respectively which has a frequency bandwidth from 1 Hz to around 100 kHz. The outputs of all Rogowski coils are recorded with digital mobile recorders which are operated at a sampling rate 1 MS/s, 16 bit digitizer, 40 GB HD capacity. All the recording systems are GPS synchronized with a time accuracy of about 100 ns.

During our observation period from 2006 to 2009, we recorded a total of 32 lightning flashes which stuck on the wind turbine or/and its lightning protection tower as shown in Table 1. All the data are recorded from December to February in winter season. The winter lightning currents show a variety of waveshapes in terms of polarity, duration, and pulses. As examples, Figure 1 shows the current waveshape of a normal upward lightning, while Figure 2 shows the current waveshape of an abnormal upward lightning that has bipolar pulses. Upward lightning always contains an initial continuing current (ICC) usually lasting for several hundred milliseconds with the current amplitudes in the range from some ten to some hundred Amperes. Some of our results have been reported previously (Wang et. Al, 2008; D. Wang et.al, 2010).

TABLE 1 SUMMARY OF THE UPWARD LIGHTNING DURING THE WINTER SEASONS FROM 2006 TO 2009 AT UCHINADA, JAPAN

	2006	2007	2008	2009	Total
Pos. Upward Flashes	-	1	-	1	2
Neg. Upward Flashes	-	7	3	11	21
Bi. Upward Flashes	2	1	1	5	9

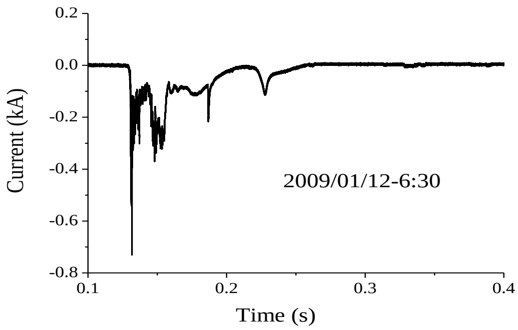

Fig. 1. Current waveshape of a normal upward lightning

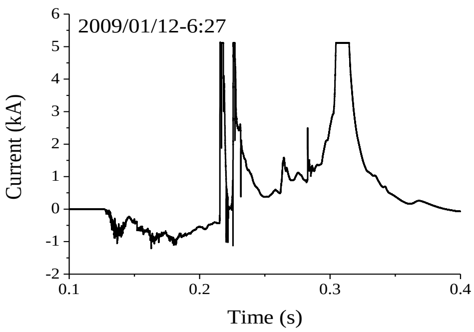

Fig. 2. Current waveshape of an abnormal upward lightning

3. DISCUSION AND CONCLUDING REMARK

The terms used in this paper to describe the electric currents are defined as follows. The current duration is the time interval from the initial deflection of the varying current from zero to the time at which the measured current become distinguishable from noise level. The total charge transfer is the integral of the current over the entire duration. The peak current is the maximum value of a varying current. The rise time is the time required for a current to change from a specified low value to a specified high value (10-90%). Figure 3 shows the cumulative frequency of total charge transfer. The mean value of charge transfer is 113.3 C and its standard deviation is 105.5 C. With these parameters only 6% of upward flashes have a total charge transfer more than 300 C.

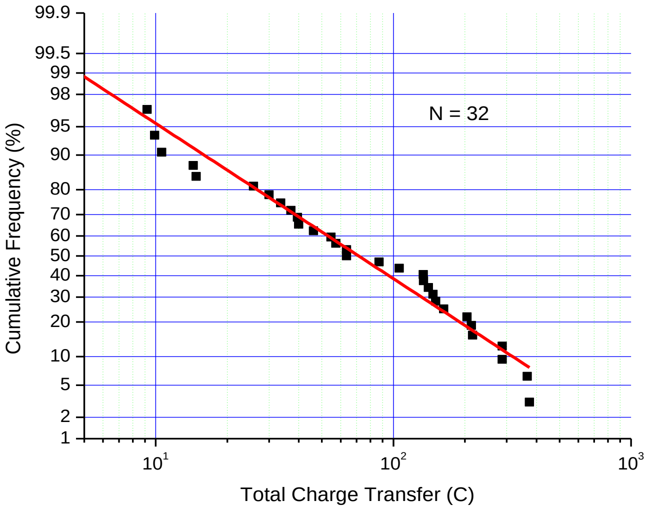

Fig. 3. Cumulative frequency distribution of total charge transfer

Characteristic of peak current of upward lightning statistically showed in Figure 4. The mean value of current is 5.3 kA and its standard deviation is 4.7 kA. Figure 5 shows the cumulative frequency of the flash duration which has a mean value of 200.1 ms and a standard deviation of 130.9 ms. As seen in Figure 5.3% of the upward lightning flashes have the duration more than 700 ms.

Cumulative frequency of rise time of upward lightning can be seen in Figure 6. The mean value of the rise time is 7.7 ms and its standard deviation is 10.8 ms.

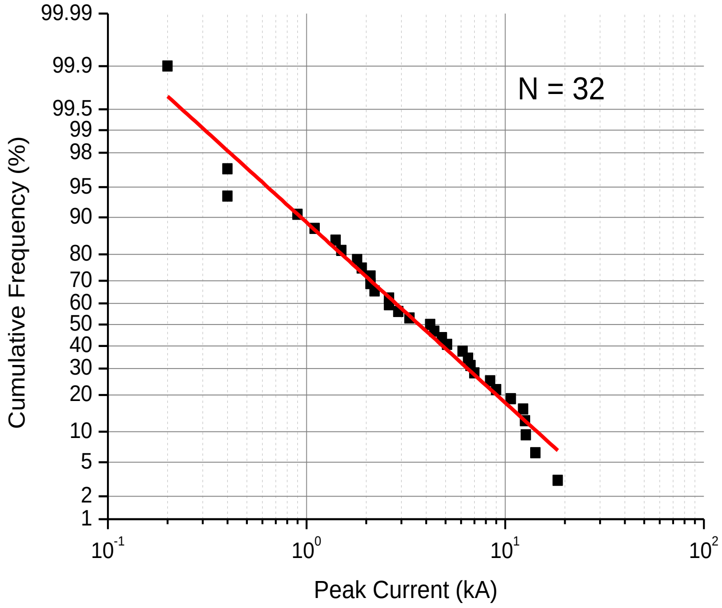

Fig. 4. Cumulative frequency distribution of peak current

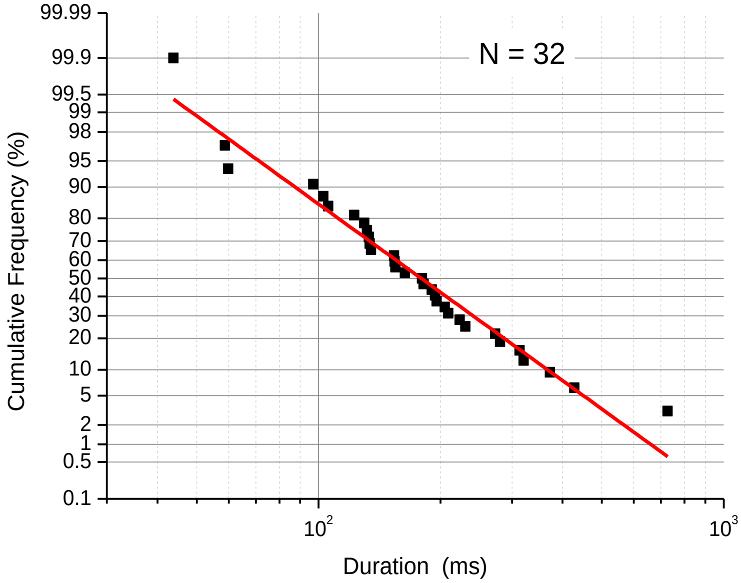

Fig. 5. Cumulative frequency distribution of flash duration

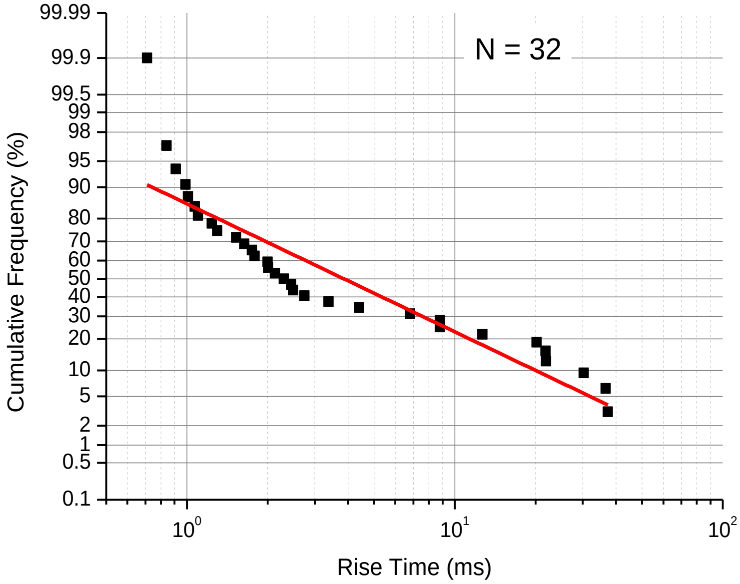

Fig. 6. Cumulative frequency distribution of rise time

A comparison between the lightning that occurred at different sites along the coast of the Sea of Japan has been made as shown in Table 2. It appears that duration of upward lightning flashes at Uchinada site are more energetic.

TABLE 2 MEDIAN OF THE UPWARD LIGHTNING CURRENT CHARACTERISTICS ALONG THE COAST OF THE SEA OF JAPAN

Experimental Site	Charge Transfer (C)	Peak Current (A)	Duration (ms)	Rise Time (ms)
Uchinada (2006-2009)	63.5 (N=32)	3.75 (N=32)	171.7 (N=32)	2.2 (N=32)
Nikaho Kougen (2005-2008) [10]	27.7 (N=205)	3.71 (N=278)	156 (N=205)	-
Fukui (1989-2002) [11]	64.3 (N=149)	7.71 (N=171)	101.2 (N=178)	-

4. RESULTS

Upward lightning discharge is characterized by continuous current with long duration of some hundred milliseconds and peak current of some tens to some thousand Amperes. The maximum value of the total charge transfer and the duration of upward flashes have more than 350 C and 700 ms, respectively. The lightning protection level recommended by the IEC standard is 300 C (IEC TR, 2002). Thus, the IEC standard is not sufficient for Japanese wind turbine generator lightning protection level.

5. ACKNOWLEGDEMENTS

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