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Study of Wind Turbine Generation System Shutdown Using Atmospheric Electric Field Potential

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***Abstract*—Recently, lightning damage causing distress to wind turbine generation systems have been frequently reported. If these systems can be shut down before lightning strikes, potential secondary damage due to rotation can be prevented and damage can be mitigated. In shutting down systems in advance, it is necessary to know the probability of a lightning strike. We consider that potential differences in atmospheric electric fields are suitable for forecasting lighting strikes. In December 2014, we measured potential differences and lightning strikes on a wind turbine system using a Rogowski coil at one of the coasts of the Sea of Japan. In this paper, recommended potential differences are reported for shutting down wind turbine systems by comparing the loss of generated power incurred by shutting down and success in preventing damage based on the relation between the potential difference and actual lighting strikes.**

Keywords: Lightning; Wind turbine generation; Winter lightning; atmospheric electrostatic field

I. INTRODUCTION

There exists a method for measuring atmospheric electrostatic fields to assess the degree of risk of lightning [1]. On a clear day, the relevant atmospheric electrostatic field value is 100 V/m [2].

On the one hand, we perform a measurement of the atmospheric electrostatic field near wind turbine generator systems in a Sea of Japan coast area [3]–[6]. In the results, we obtained data by measuring atmospheric electric fields and lightning strikes at the Hachiryu wind turbine generator in Mitane City, Yamamoto-gun Akita, during January 1–28, 2014.

In this report, we investigated how to shut down wind turbines before lightning strikes by measuring the atmospheric electrostatic field and comparing it with two types of data [7].

II. MEASUREMENT SYSTEM

A. *Measurement system*

Fig. 1 shows the lightning warning measurement system ‘Kaminari Watcher’ that we developed to maintain construction safety. It is comprised of two sensor elements and a personal computer. One is called a ‘lightning sensor,’ which measures electromagnetic waves in lightning. The other is called a ‘field mill sensor,’ and measures the atmospheric electric field.

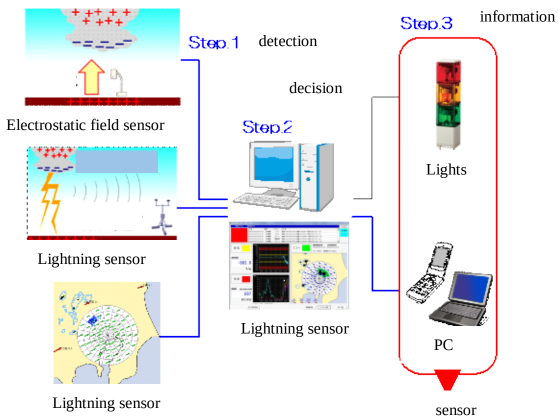

Fig. 1. System configuration diagram.

B. *Observation panel*

Fig. 2 shows an observation panel as an example, displaying the level of danger in color and numeric data for a field mill, along with a trend graph, lightning frequency detection data, a map of the rainy area, etc. This system can detect the approach of a thundercloud according to electrical signals and displays a warning in real time.

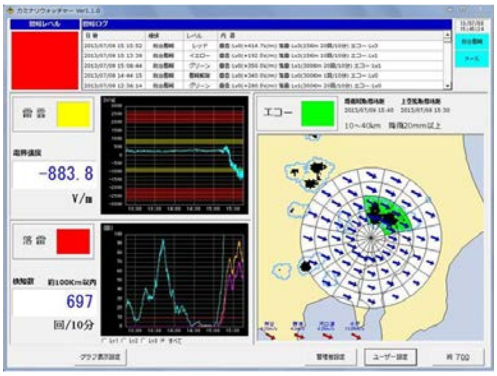

Fig.2 Display screen image. (in Japanese)

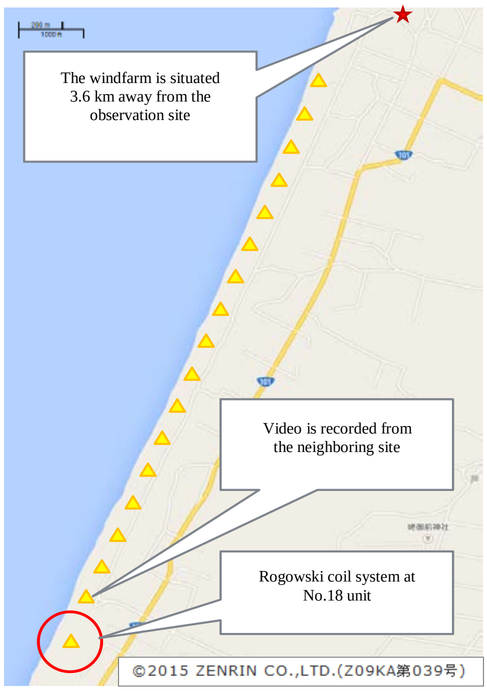

Fig.3 Windmill position and observation point.

Fig.4 Sensor situation at in event 1.

III. MEASUREMENT OUTLINE

We installed 'Kaminari Watcher' three systems measuring the atmospheric electric field continuously in the Japan coastal area during winter 2014. Table 1 shows the characteristics of the monitoring sites.

These monitoring sites were at distances of between several hundred and several thousand meters away from wind turbines, measuring the atmospheric electric field successfully as lightning struck.

Table 1 Characteristics of monitoring sites.

Site No.	Installation zone	Windmill	Situation
A	Mitane town Akita Pref.	1,500 kW×17 2,500 kW×1	300 m from coastline
B	Awara city Fukui Pref.	1,500 kW×17	On a hill
C	Nikaho city Akita Pref.	1,500 kW×17	On a mountain

A. *The monitoring site*

In this paper, we report measurement results for site A only.

Fig. 3 shows the locations of wind turbine generators and the monitoring site used to measure the atmospheric electric field (red star mark) and the position of the 18th wind turbine generator (triangle mark). The Rogowski coil system was installed at the south end of the 18th unit.

Fig. 4 shows the settings for the field mill sensor on the outside wall. At this setting site, the distance between the wind turbines and the 18th unit was about 3,600 meters because the latter requires a power supply along with space for a personal computer and connection to a network.

IV. RESULTS OF MEASUREMENT

During January 1 to February 28, 2014 at the A site, the 18th unit equipped with the Rogowski coil system was able to measure the atmospheric electric field and lightning strikes.

A. Measurement period and results of lightning strike measurements

It was the period around two months, during 1st January 2015 to 28th February 2015.

Table 2 shows lightning strike detection times according to measurements using the Rogowski coil system during the same period. There were fourteen lightning strikes at the 18th unit. It was revealed that multiple lightning strikes occurred per day on January 1st and 3rd and on February 9th. In three days of nine times was struck by lightning.

Table 2 Lightning strike detection times.

	date (2015)	time	charge(C)
①	Jan. 1st	4:50:09	1.52
②	Jan. 1st	9:38:33	78.66
③	Jan. 1st	10:07:39	
④	Jan. 2nd	14:44:26	
⑤	Jan. 3rd	6:53:31	
⑥	Jan. 3rd	7:59:02	
⑦	Jan. 3rd	7:59:59	
⑧	Jan. 20th	3:13:02	10.7
⑨	Jan. 23th	15:22:44	
⑩	Feb. 9th	14:58:29	
⑪	Feb. 9th	18:34:41	0.561
⑫	Feb. 9th	19:16:22	
⑬	Feb. 12nd	23:01:34	
⑭	Feb. 27th	6:08:53	15.7

B. Results of measuring the atmospheric electric field

Figs. 5 and 6 show the results of measuring the atmospheric electric field at site A (the red star mark in Fig. 3) on January 1st, 2015. Fig. 5 shows events ①–③ in Table 2 with the times of lightning strikes.

Fig. 6 shows the graph expanded during the period from 9:30 to 10:00 for lightning strike detection event ②.

As for the atmospheric electric field, the downward direction is defined as positive. Therefore, the graph shows a positive direction when a positive charge is distributed over the bottom end of the cloud.

V. SETTING THE THRESHOLD AND OPERATION

A. Setting the threshold

We can set the threshold from data accumulated by measuring the atmospheric electric field and lightning strikes simultaneously.

The approach assumes wind turbine shutdown if the atmospheric electric field threshold is exceeded and wind turbine restart if the atmospheric electric field is below the threshold.

The dashed line in Figs. 5 and 6 shows the threshold value of ±4,000 V/m. In this case, periods when the atmospheric electric field values exceed the threshold correspond to shutdown times for wind turbines.

If a lightning strike occurs during a time when a wind turbine is shut down, the prediction of lightning strikes can be considered to have succeeded.

The probability of predicting lightning activity rises if the threshold is lowered, but this results in longer shutdown time for the wind turbines.

B. Prediction of lightning strikes

Fig. 7 shows the lightning strike prediction success rate when we changed the threshold. Fig. 8 shows the shut down time per day for the wind power generators, and Fig. 9 shows the number of shut down periods per day.

Table 3 shows summarized results.

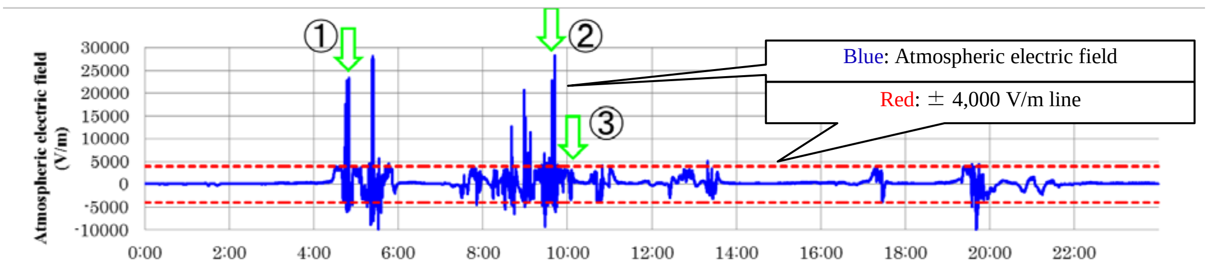

Fig. 5 Atmospheric electric field observation result (January 1st, 2015).

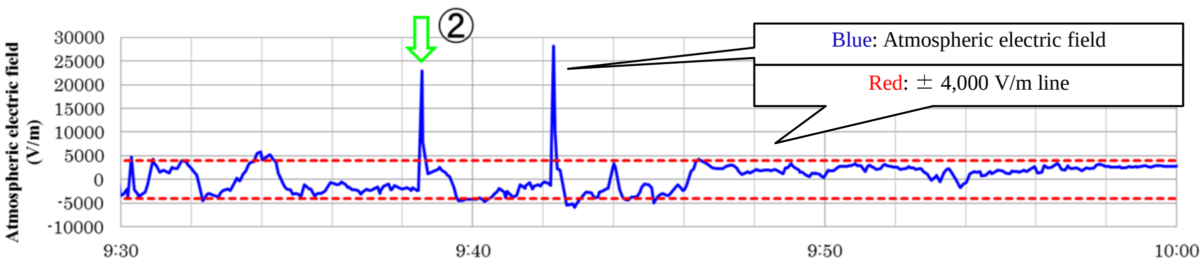

Fig.6 Atmospheric electric field enlarged view (09:30 – 10:00, January 1st, 2015).

The above mentioned result, it is necessary to lower the threshold to ±2,000 V/m if we want to make the success rate around 80%, and it is then 65.1 minutes per day at mean average shutdown time.

To the contrary, it is necessary to raise the threshold to ±8,000 V/m if we wish to reduce the number of shutdown periods to below five per day, and the mean success rate is then 21.4%.

As a result, we understood that, in this example, the success rate is 42.8% with an average shutdown time of 14.6 minutes per day if we assumed a threshold ±4,000 V/m.

As observed above, we can operate wind turbines reasonably by setting an appropriate threshold.

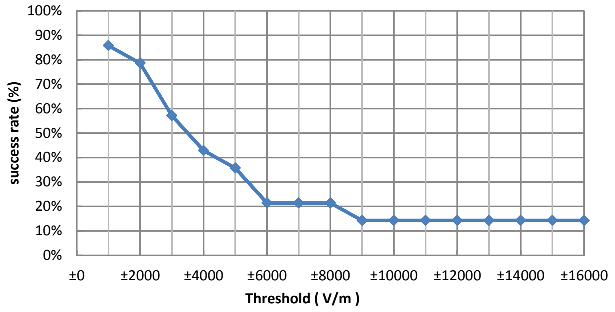

Fig. 7 Threshold – success rate characteristics.

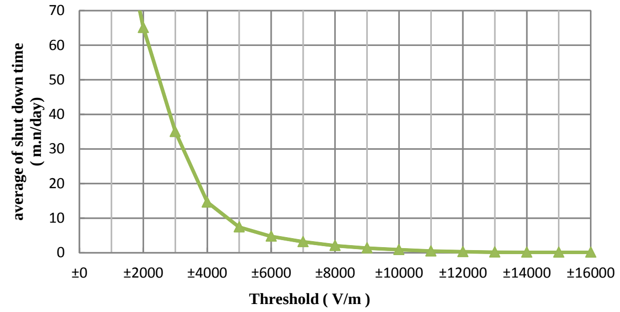

Fig. 8 Threshold – average shutdown time characteristics.

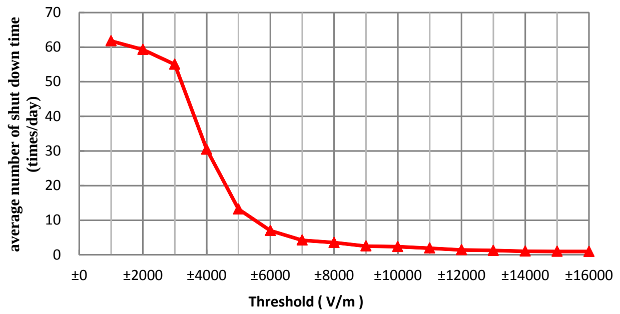

Fig. 9 Threshold – average number of shutdown time characteristics.

Table 3. Threshold, shutdown time, and number of shutdown periods.

Threshold (V/m)	Success rate (%)	Shutdown time (min/day)	Number of shutdowns (instances/day)
±1,000	85.7	109.1	61.8
±2,000	78.5	65.1	59.3
±3,000	57.1	35	55
±4,000	42.8	14.6	30.5
±5,000	35.7	7.4	13.2
±8,000	21.4	2	3.5
±10,000	14.2	0.9	2.4

VI. CONCLUSIONS

This paper presented assessment results of a control approach including the shut down of wind turbine generators by observing the local atmospheric electric field relative to a threshold value. The contributions of this study are as follows.

- It is possible to narrow the threshold by comparing the generator running time with the prediction success rate.
- It is very important to compare the prediction success rate and the shutdown time of wind turbine generators.
- In this case, the success rate was 42.8% and the average stop time was 14.6 m/day when the threshold was ±4000 V/m.
- It is very important that several personal computers used for recording data use synchronized times.
- It is essential to record the time of lightning strikes for all wind turbine generators and to compare them.
- Recording relevant visual information is effective.

We believe that the long measurement of the atmospheric electric field at many sites relative to a threshold value is necessary for wind turbine generators at risk from lightning strikes.

ACKNOWLEDGMENT

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