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OBSERVATION OF WINTER LIGHTNING FLASHES TO NADACHI WIND POWER STATION ON THE COAST OF THE JAPAN SEA

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Abstract - This paper presents the observation results of lightning flashes to Nadachi Wind Power Station for about four months in winter season from December, 1999 to March, 2002. The flashes more than 50 were observed for three seasons. The flashes with large current over 200kA were measured two times. In a case of VTR system records, lightning flashes struck the protection tower with INDELEC Prevectron lightning conductor. Also it was found that several lightning flashes struck the lightning protection system within a few minutes.

1 - INTRODUCTION

A number of wind power stations have been projected and planted to use natural energy for environmental protection. Wind turbines are steadily growing in height and the risk that wind turbines are struck with lightning flash increases. During the last few years, lightning damage to wind turbines has been an increasing problem [1].

The area along the Japan Sea coast has experienced a lot of lightning in winter [2]. The winter lightning caused many damages on power systems, telecommunication systems and tall structures [3]-[5].

Nadachi Wind Power Station was inaugurated in December 1996. The Station is on the hill closing to the Japan Sea. The site is located in a region with isokeraunic level between 35 and 40. Most of lightning flashes have occurred in winter.

In January 1997, the Wind Power Station has been considerably damaged with winter lightning. A blade was broken and electrical and control systems were damaged. In autumn 1997, a protection tower was constructed between the two turbines. INDELEC Early Streamer Emission (ESE) system was installed on top of the tower. Next year (1998), ring earth electrodes were sunk around the protection tower and the Power Station.

The protection tower and ring earth electrodes reduced the big damages and numbers of damage with lightning flashes to the Power Station. However, some damages and troubles have been induced, so that lightning observations were carried out in the site with some improvements of INDELEC lightning protection system. In 1999, the measurements of current waveforms at legs of the protection tower were started. No more damage occurred on the turbines. In 2001 winter season, observation of VTR system was carried out.

In this paper, it was indicated the observation results of lightning flashes to Nadachi Wind Power Station for about four months in winter season from December, 1999 to March, 2002.

2 - OBSERVATION PROCEDURE

2.1 - OBSERVATION SITE

As shown in figure 1, Nadachi locates the coast of the Japan Sea. As shown in figure 2, Nadachi Power Station is on the hill of about 280m in altitude and closes to the Japan Sea. As shown in figure 3, the Power Station has two wind turbines and one protection tower. The protection tower with a height of 60m was constructed between the two turbines, 25m from one and 100m from the other along a roughly straight for line of north and south. The wind turbine height was 51.5m.

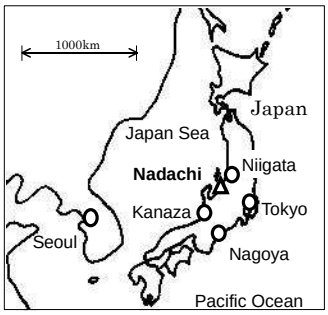


Figure 1 - Location of Nadachi

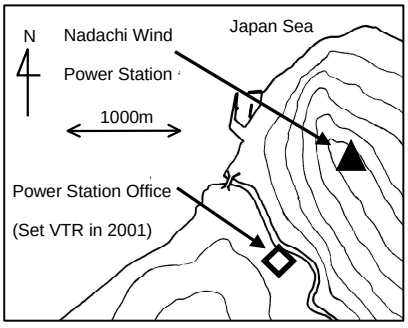


Figure 2 - Site of Nadachi

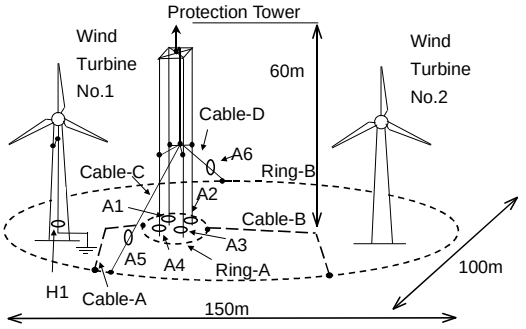


Figure 3 – Sketch of Nadachi Wind Power Station

2.2 - OBSERVATION SYSTEMS

In 1999, the cable-D shown in figure 3 has not set. Five measurement systems of the current were installed protection tower legs and cable-C. The points of A1, A2, A3, A4, and A5 were observation points. The observation was carried out from December 10, 1999 to March 10, 2000.

In 2000, the cable-D was set. The current observation points were pulsed two points, A6 and H1. As shown in figure 3, point A6 was on the cable-D and point H1 was on the down-conductor in the wind turbine No.1. The down-conductor has connected the steel tower at upside of the wind turbine tower. The Lightning currents have diverged into the down-conductor and the steel tower at striking to wind turbine No.1. The current measurement system on H1 has recorded currents through the down-conductor. The observation was carried out from December 2, 2000 to March 15, 2001.

In 2001, only one current measurement system was installed at the point A3, one of the legs of the protection tower. The Power Station office was located 1km away from the wind turbines (figure 2). A VTR system was installed the office. The clock in the VTR system had been correcting with GPS satellite signal during observation. The VTR system had pre-trigger function and recordings were started with photo-sensor signal. Image data were recorded from 3 second before photo-trigger signal to 27 second after the trigger signal for 30 second.

Observation year	**1999**	**2000**	**2001**
Sensor	Rogowski coil		
Observation range*[1]	±30kA	±15kA	±50kA
Triggered level	5% of range		3% of range
Sampling speed	4MS/sec		
Recording time	1ms(4MS/sec) + 30ms(666kS/sec)		2ms (4MS/sec) + 80ms (666kS/sec)
Number of recording data	10		40
Power	lithium battery		

*[1] : The capable recording range is 1.28 times observation range.

Table1 - Specifications of current measurement systems

The current observations were started December 2, 2001 and stopped March 17, 2002. The observation with VTR system was started December 20, 2001 and stopped March 18, 2002. Table 1 indicates specification of current measurement systems.

3 - RESULTS AND DISCUSSIONS

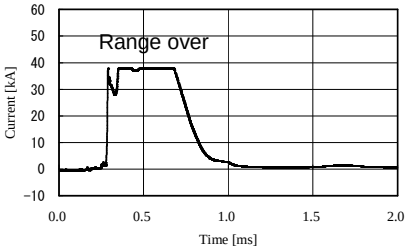
Table 2 indicates the data of observation results in 1999 winter season. That shows the observation number, the date and time, the peak lightning current through the each tower legs and cable-C, respectively.

Figure 4 shows current waveforms observed for No.C9901, during 2ms from the beginning. I_{A1}, I_{A2} and I_{A5} were over the range. The estimated peak current of I_{A1} was about at +150kA. I_{A2} and I_{A5} were estimated at about +155kA each. I_{A3} was +37.2kA and I_{A4} was +38.4kA. They were not the range over. The current waveforms were similar to each other. The polarities of observation currents of No.C9901 were all positive, so it was inferred that striking point was the protection tower. In this time, other team photographed lightning flash to the top of the protection tower on INDELEC unit. Lightning current was estimated about at +240kA. This lightning current was very large. The lightning flash struck INDELEC lightning arrester located on the protection tower, avoiding important damage on the wind turbine No.1.

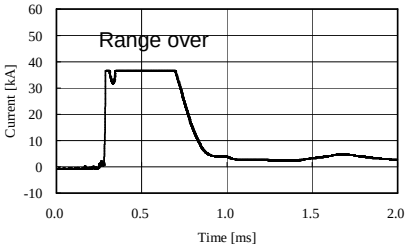
No.	Date	Time	I_{A1}(kA)	I_{A2}(kA)	I_{A3}(kA)	I_{A4}(kA)	I_{A5}(kA)
C9901	1999/12/17	09:34	>+38.4 (+50) *[2]	>+37.5 (+55) *[2]	+37.2	+38.4	>36.9 (+55) *[2]
C9902	1999/12/21	13:21					-5.1
C9903	1999/12/26	12:37		-2.7			
C9904	1999/12/26	16:16	-2.1	-2.7	-1.8	-2.4	
C9905	2000/01/31	02:13	+3.0			+2.7	-4.8
C9906	2000/02/27	05:06	+9.0		+2.1	+7.5	-15.3

SP: Striking Point, T:Protection Tower, W1:Wind Turbine No.1, *[1] : inference , *[2] :calculation value

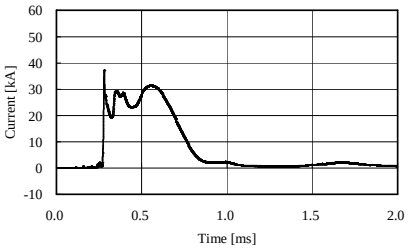
Table 2 - Results of observation in 1999 winter season



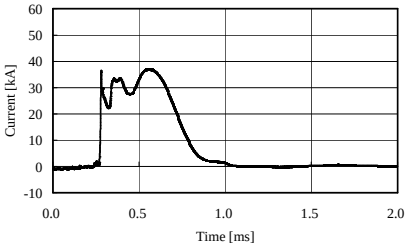
(a) Current waveform of A1



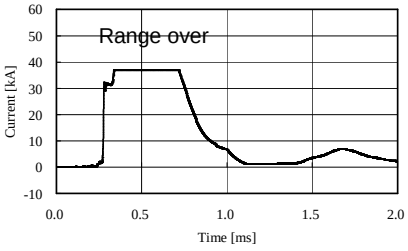
(b) Current waveform of A2



(c) Current waveform of A3



(d) Current waveform of A4



(e) Current waveform of A5

Figure 4 - Current waveforms of No.C9901

Table 3 indicates the observation results in 2000 winter season. The table 3 shows the observation number, the date and time, the peak lightning current through the each tower leg, cable-C, cable-D, and the down-conductor in the wind turbine No.1, respectively. It was presumed that two lightning flashes, No.C0006 and No.C0010 were struck the protection tower and the other struck the wind turbine.

Lightning currents of No.C0004 and No.C0010 were estimated about at –7.8kA and at –8.25kA, respectively. Lightning currents diverged each tower legs, cable-C, and cable-D. It was estimated that lightning current was more than six times the I_{A3}.

Table 4 indicates the data of observation results in 2001 winter season. In this season, Lightning flashes of 39 were observed with current measurement system and VTR system. Sometimes the VTR system could record only flash because thick with snowfall.

In No.V0111, lightning flashes struck simultaneously three points, the protection tower and two wind turbines. A few minutes late, wind turbine No.2 was struck (No.V0112). It was observed that several lightning flashes to the Power Station occurred within a few minutes. No.C0117 and No.C0118 lightning flashes struck the protection tower during one minute.

Figure 5 shows current waveforms observed for No.CV0125. The peak current through the tower leg (A3) was –40kA. Therefore this lightning current was estimated over –240kA. It was large current.

Figure 6 shows current waveforms observed for No.CV0129. The current through the tower leg (A3) had flowed for 30ms. The stroke duration was long and peak current was +12kA. This lightning peak current was estimated over +72kA.

No.CV0125 and No.CV0129 were observed January 29, 2002. Next day, It was found that the control systems inter wind turbine No.1 was damaged and the turbine was stopped. It was infer that No.CV0125 or No.CV0129 lightning flash damaged the control systems.

The observation systems could not acquire all lightning flashes struck the Power Station. It was speculated that there were 50 more lightning flashes in 2001 winter season and 30 more lightning flashes every year.

ESE system was damaged and changed a few times every year. It was uncertain when the ESE system was damaged. It was inferred that the damages were caused with large lightning currents, frequent lightning flashes and rigorous climate in winter. Also, blade tips of wind turbine was damaged and mended at spring every year.

Table 5 shows the lightning parameters, current I, stroke charge Q and specific energy W/R (prospective energy integral $\int i^2 dt$), estimated value for No.C9901, No.CV0125 and No.CV0129.

No.	Date	Time	I_{A1}(kA)	I_{A2}(kA)	I_{A3}(kA)	I_{A4}(kA)	I_{A5}(kA)	I_{A6}(kA)	I_{H1}(kA)	SP*[1]
C0001	2000/12/12	07:44					-1.05		-4.50	(W1)
C0002	2000/12/12	07:51					-1.05		-4.00	(W1)
C0003	2001/01/03	15:45							-4.00	(W1)
C0004	2001/01/12	05:05	-1.35	-1.35	-0.90	-1.35	-1.50	-1.35		(T)
C0005	2001/01/12	09:54							-3.00	(W1)
C0006	2001/02/10	14:59	+0.9				-1.05		-4.00	(W1)
C0007	2001/03/05	03:05					-1.05		-5.00	(W1)
C0008	2001/03/05	03:06							-3.00	(W1)
C0009	2001/03/05	03:07	+0.9						-3.00	(W1)
C0010	2001/03/12	20:38	-1.80	-1.50	-1.35	-1.35	-1.05	-1.20		(T)

SP: Striking Point, T:Protection Tower, W1:Wind Turbine No.1, *[1] : inference

Table 3 - Results of observation in 2000 winter season

No.	**Date**	**Time**	**I_{A3}(kA)**	**SP**
C0101	2001/12/14	10:43	-2.0	
C0102	2001/12/14	18:03	-7.5	T*[1]
C0103	2001/12/15	00:09	-2.5	T*[1]
C0104	2001/12/17	16:17	-4.5	T*[1]
CV0105	2001/12/22	21:59	-3.5	T
C0106	2001/12/30	09:52	-1.0	T*[1]
V0107	2001/12/30	14:36		T
C0108	2001/12/30	14:47	-1.5	F
C0109	2002/01/02	15:07	-0.5	F,W1*[1]
C0110	2002/01/02	15:09	-3.0	F,W1*[1]
V0111	2002/01/05	00:33		T, W1,W2
V0112	2002/01/05	00:36		W2
V0113	2002/01/05	00:59		T
V0114	2002/01/05	01:03		T
C0115	2002/01/05	06:35	-1.0	F
C0116	2002/01/05	13:41	-4.5	F
C0117	2002/01/05	13:42:14	-1.0	F,T*[1]
C0118	2002/01/05	13:42:55	-1.0	F,T*[1]
C0119	2002/01/05	13:47	-2.0	F
C0120	2002/01/05	13:48	-1.5	F
C0122	2002/01/05	13:49	-2.5	F,W1*[1]
V0123	2002/01/24	01:29		T
C0124	2002/01/28	22:39	+1.0	F
CV0125	2002/01/29	00:43	-40.0	T
CV0126	2002/01/29	01:16	-1.5	T
V0127	2002/01/29	02:02		T
V0128	2002/01/29	02:03		T
CV0129	2002/01/29	02:17	+12.0	T
V0130	2002/01/29	02:32		T
V0131	2002/01/29	02:36		T
V0132	2002/01/29	02:37		T
V0133	2002/01/29	02:45		T
C0134	2002/01/30	18:14	-2.5	F
V0135	2002/01/30	18:45		T
V0136	2002/02/07	16:50		T
V0137	2002/02/07	16:52		T
V0138	2002/02/07	16.54		T
C0139	2002/02/12	15:07	-1.0	

SP:Striking Point, T:Protection Tower,
W1:Wind Turbine No.1, W2:Wind turbine No.2,
F:Flash recorded with VTR
*[1] :Result of observation with other team

Table 4 - Results of observation in 2001 winter season

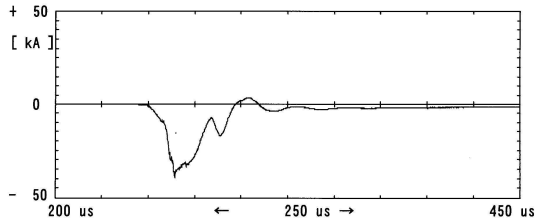


Figure 5 - Current waveforms of A3 of No.CV0125

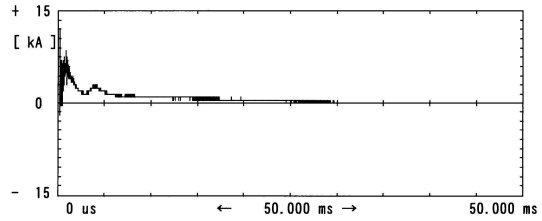


Figure 6 - Current waveforms of A3 of No.CV0128

No.	**I (kA)**	**Q (c)**	**W/R (kJ/Ω)**
C9901	+240	+100	17,000
CV0125	-240	-14	810
CV0129	+72	+180	2300

Table 5 - Lightning parameter estimated value of No.C9901, No.CV0125, and No. CV0129

In No.C9901 and CV0125, current peak was estimated more than 200kA, respectively. In No.C9901 and CV0129, each stroke charge was estimated more than 100c. The specific energy (prospective energy) of No.C9901 was estimated about at 17,000kJ/Ω and this was very large lightning. Three large lightning flashes had been observed for three winter seasons. It was considered that lightning protection system for the Nadachi Power Station was needed performance which withstood 50 more lightning flashes including large lightning (250kA, 200c, 20,000 kJ/Ω) every year.

4 - CONCLUSIONS

(1) The observation of lightning flashes to Nadachi wind power station had carried out for about four months in winter season from December, 1999 to March, 2002.
(2) The flashes more than 50 were observed for three seasons. The flashes with large current over 200kA were measured two times. One of them has 100c and 17,000 kJ/Ω.
(3) A long duration stroke with 30ms was measured. The peak current, charge, and specific energy were estimated about at +72kA, +180c, 2300 kJ/Ω, respectively.
(4) In a case of VTR camera records, lightning flashes struck simultaneously the two wind turbines and the protection tower. Also it was found that several lightning flashes to the power station occurred within a few minutes.
(5) Nadachi Wind Power Station needs effective lightning protection system which withstand more than 50 lightning flashes including large lightning (250kA, 200c, 20,000 kJ/Ω) every year. INDELEC Prevectron is able to serve this purpose.

Several measurements and experiments were made in this site. They were measurements of ground potential difference, experiments of protection effect with ring earth electrode, and spectral analysis at lightning. We would notify results next time.

5 - REFERENCES

[1] Cotton, I., McNiff, B., Zischank, W., Christiansen, P., Hoppe-Kilpper, M., Ramakers, S., Pettersson, P., Muljadi, E., "Lightning Protection for Wind Turbines", *24th ICPL Proceedings,* pp. 848-853, Rhodes, Greece, September 2000

[2] Miyake, K,, Takahashi, M., Takuma, M., Tada, T., "Winter Lightning on Japan Sea Coast - Lightning Striking Frequency to Tall Structures - ", *IEEE Trans. Power Delivery,* vol5, No.3, pp.1370-1376, 1990

[3] Nakada, K., "Lightning Protection Methods for Customer's Facilities Located in Mountainous Areas Facing The Sea of Japan", *IWHV'00 Proceedings,* vol2, pp. 1-6, Tottori, Japan, November 2000

[4] Wada, A., Asakawa, A., Shindo, T., "Characteristics of Lightning Strokes to A 200m-High Stack in Winter ", *10th ICAE Proceedings,* pp. 464-467, Osaka, Japan, June 1996

[5] Nagai, T., Matsui, T., Sonoi, Y., Adachi, M., "Observation on Winter Lightning at A Toll Transmission Line Tower in Hokuriku District ", *10th ICAE Proceedings,* pp. 476-479, Osaka, Japan, June 1996

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