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Lightning Detection Systems Mentioned in Upcoming Japanese Industrial Standard about Lightning Protection for Wind Turbines

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***Abstract*— In 2013, there were many instances of severe damage caused by lightning in Japan. In some of those incidents, blade rotation (after lightning damage to the blade) might result in further severe damage. Hence, it is recognized that the accurate detection of lightning strikes to a blade is important to prevent damage expansion. According to an amendment of a ministerial notification in 2015, a lightning detection system should be implemented at all wind turbines constructed in winter lightning areas in Japan. With the release of the Final Draft International Standards version of the IEC 61400-24:2019, the revision of the JIS C 1400-24 relating to IEC 61400-24:2019 has begun in Japan. In the upcoming JIS C 1400-24, the requirement for lightning detection systems for wind turbines is planned as a new content. Herein, the content relating to lightning detection systems in the ongoing discussion for the upcoming JIS C 1400-24 are introduced.**

Keywords*— *Lightning detection system, Japanese Industrial Standard, Lightning protection, Winter lightning

I. INTRODUCTION

Global warming has become a worldwide problem owing to the effects of greenhouse gases. The ability of these gases to trap heat causes the greenhouse effect. Subsequently, the more greenhouse gases are in the atmosphere, the more heat remains on Earth. Hence, demand for renewable energies such as wind power, hydropower, solar heat and sunlight has increased, as their carbon dioxide production is minimal and their burden on the environment is low.

Among them, wind power generation has spread widely across the world, because it is comparatively easy to commercialize on a large scale. It has been forecast that the established capacity of wind turbines will exceed 700 GW by year 2020. To obtain high-performance power from wind, wind turbines are being designed with longer blades and higher towers [1]. Although a larger wind power generator presents the advantages described previously, its tall structure poses a risk of being damaged owing to natural phenomena such as lightning. It is well known that tall objects are often struck by lightning. From 2004 to 2012, the average amount of lightning failures and incidents in Japan was 17.6% (The total number of failures and incidents was 1,492) [2].

For reducing the risk of lightning damage to wind turbines, IEC 61400-24:2019 has been revised and released in July, 2019. In Japan, the Japanese Industrial Standards (JIS) is used. As the Japanese standard related to the IEC 61400-24:2010 [3], JIS C 1400-24:2014 was published [4]. The JIS C 1400-24:2014 includes most of the contents in the IEC 61400-24:2010. However, Appendix JA (normative) "Lightning with large amount of charge" was added. Furthermore, it is mentioned that wind turbines should be able to withstand lightning currents with 600 C and 20 MJ/Ω.

In 2013, many cases of severe damage caused by lightning occurred in Japan. In some of those incidents, blade rotation after lightning damage (on a blade) might result in further severe damage [5]. Hence, it is important to detect lightning strikes to a blade to prevent damage expansion. According to an amendment of a ministerial notification in 2015, a lightning detection system should be implemented at all wind turbines constructed in winter lightning areas in Japan. However, false detections by some lightning detection systems have been reported, causing serious consequences such as unnecessary stoppages and a decrease in power generation. Therefore, the development of accurate lightning detection systems with the required performance, and the establishment of their evaluation methods, are fundamental requirements [6-8].

The new international standards of the IEC 61400-24:2019 has been released [9]. With the release of the Final Draft International Standard (FDIS) version of the IEC 61400-24:2019, that of the JIS C 1400-24 has begun in Japan. In the upcoming JIS C 1400-24, the requirement for lightning detection systems for wind turbines is planned as a new content. Herein, the content relating to lightning detection systems in the ongoing discussion for the upcoming JIS C 1400-24 are introduced.

II. Lightning Detection Systems for Wind Turbine Lightning Detection

A. Requirements of Lightning Detection Systems

As detailed in annex JA and the commentary to the current JIS C 1400-24:2014, winter lightning on the Japan Sea coast is long-duration lightning, and high-electric-charge lightning is concentrated on tall structures including wind turbines. Many wind turbine blades have been damaged severely by such winter lightning.

It is known that energy damage to blades and other components of wind turbines is related to the electric charge of lightning, and adding a test to confirm the durability of wind turbine blades or gears under high energy lightning that stipulates electric charge to the IEC 61400-24:2019 has been discussed. Hence, lightning detection systems shall now, in addition to clarifying the accurate current peak value of lightning, detect electric charges accurately.

To detect electric charges of long-duration lightning currents accurately, lightning detection systems should expand the frequency range of lightning current that they can capture to a lower range. In winter lightning regions, in particular, lightning detection systems that can observe current waveforms at a duration from a few tens of milliseconds to 200 ms (see Figure 1 for example), and can accurately record electric charges of winter lighting of this type are required.

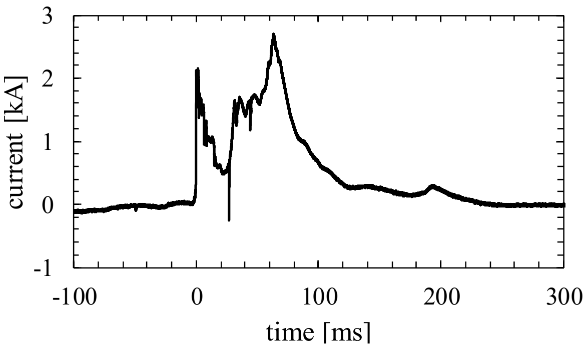


Fig. 1. Example of winter lightning current waveforms

B. Current-Sensing Lightning Detection Systems

Lightning detection systems are pieces of equipment that detect various factors (lightning flash, thunder, and transient magnetic fields caused by lightning current flowing through down-conductors including the tower) caused by a lightning striking a wind turbine, to detect that lightning has struck. However, many existing types of lightning detection systems detect lightning current using various current sensors, as explained in section 2.1. Deliberations concerning the upcoming JIS C 1400-24 have included discussions regarding the required performance of a current-sensing lightning detection system that will detect the electric current that flows through items (such as receptors, down-conductors, and ground wires) when lightning strikes a wind turbine. This is accomplished with various types of current sensors (such as Rogowskii coils, CT, hall effect sensor and solenoid coils).

III. Install Locations and Classification

A. Winter and Summer Lightning Regions

To prepare for the upcoming JIS C1400-24, the required performance of current-sensing lightning detection systems has been discussed by dividing Japan into a region where lightning is frequent during the winter. This is a range of approximately 30 km inland from the coast of the Japan Sea where long-duration lightning occurs frequently (see Part 2.1) (winter lightning region: area enclosed by solid line on Figure 2), and other regions (summer lightning regions).

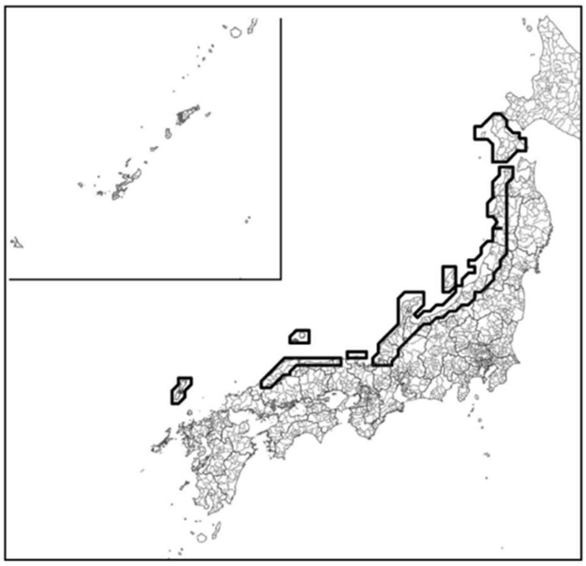


Fig. 2. Winter lightning area

Hitherto, winter lightning regions have been considered as land areas; however, it is predicted that if high structures such as wind turbines are constructed at sea, lightning will strike these structures as frequently as (or more than) it strikes wind turbines on dry land. Hence, in the upcoming JIS C 1400-24, the surrounding normal sea areas are regarded as winter lightning areas in addition to the winter lightning areas defined in Figure 2.

B. Classification

Through past deliberations concerning the upcoming JIS C 1400-24, current-sensing lightning detection systems are categorized into the three classifications shown in Table 1 according to the region where they can be installed. Briefly, current-sensing lightning detection systems that satisfy the conditions for Class I can be installed anywhere in Japan.

However, those that satisfy only Class II conditions shall not be installed on wind turbines constructed in the winter lightning regions shown in Figure 2, and can only be installed on wind turbines in summer lightning regions.

TABLEI. CLASS OF LIGHTNING CURRENT DETECTION SYSTEMS

Class	Installed Region	Charge Calculation Function
I	All regions in Japan	Yes
II-1	Summer lightning regions	Yes
II-2		No
Note: Class I systems can also be used In Class II area.		

Current-sensing lightning detection systems include a type that captures shunt lightning currents to a ground wire with various types of current sensors. However, because it is difficult to clarify the frequency characteristics of lightning current and the shunting ratio of the shunt current to the ground wires of a wind turbine, in the proposed upcoming JIS C 1400-24, using this type as a Class-I current-sensing lightning detection system is not recommended. However, it may be used if the characteristics of the shunt ratio can be understood accurately and its performance can be guaranteed as equal to that of a current-sensing lightning detection system that captures wind turbine lightning currents that satisfies the required performance stipulated in Chapter V with each type of sensor. However, it is difficult to guarantee such an equal performance. Furthermore, considering the costs, it is more rational to use a detection system that captures actual lightning currents flowing through a tower with a current sensor.

IV. CONDITIONS FOR USE

For the upcoming JIS C 1400-24, the following proposal has been considered. Conditions for use of current-sensing lightning detection systems shall be decided and clearly specified with reference to the provisions of JIS C 1400-1:2017 "Wind power generation systems – Part 1: Design requirements" and JIS C 60721-3-3:1997 "Classification of environmental conditions, environmental parameters and classification by group of their strictness, conditions for individual indoor use". Further, all current-sensing lightning detection systems shall at least clearly exhibit the following specifications, and the conditions shown under each item shall be satisfied.

1) *Power-supply voltage:* DC (Direct Current) and AC (Alternating Current) power-supply types can be used, and the operating voltage, "AC100V ± 10% or AC200V ± 10%" shall be clearly specified.

2) Power-supply frequency: In the case of an AC power source, the operation frequency range, such as "50 Hz ± 2% or 60 Hz ± 2%" shall be clearly specified.

3) Peripheral temperature: An equipment that can withstand a temperature of at least –10 to +40 °C.

4) Relative humidity: An equipment that can withstand a relative humidity of at least 5% RH to 95% RH.

V. REQUIRED PERFORMANCE

To propose the upcoming JIS C 1400-24, which is being discussed currently, specifying the following items as the required performance (not recommended, but mandatory) is being considered.

A. Identification and Indications

Manufacturers are required to display the following information clearly concerning current-sensing lightning detection systems

1) Manufacturer's name or brand and model name
2) Current detection
  a) Detection method
  b) Current detection frequency bandwidth
  c) Observation period
  d) Minimum detected current value
  e) Maximum measurable current value
  f) Minimum detected electric charge value (only Class I and II-1)
  g) Maximum measurable electric charge value (only Class I and II-1)
  h) Trigger current value
  i) Alarm current value
  j) Alarm electric charge value
  k) Polarity (when necessary)
  l) Measurement precision
3) Contact relay output for alarm
4) Withstanding voltage
5) Recording of lightning information
  a) Detection time
  b) Maximum current value
  c) Electric charge value (only Class I and II-1)
  d) Integration of electric charge (when necessary)
  e) Current waveform (when necessary)
  f) Recording method
6) Peripheral temperature and relative humidity
7) Environmental resistant
  a) Salt damage (when necessary)
  b) Ultraviolet damage
8) Electromagnetic compatibility
  a) Electromagnetic susceptibility
  b) Electromagnetic interference (when necessary)
9) Maintenance
10) Installation

B. Electrical Performance

Among the items listed in Section 5.1, manufacturers shall manufacture current-sensing lightning detection systems that satisfy the electrical performances described below.

1) Current detection

a) Detection method: The detection method shall be one of the following methods

- Detection when the current value is equal to or higher than the trigger current value

b) Current detection frequency bandwidth: It shall be a detection device with the following current detection frequency bandwidth at the least

- Class I: frequency bandwidth of 0.1 to 100 kHz
- Class II-1: frequency bandwidth of 10 Hz to 100 kHz
- Class II-2: frequency bandwidth of 1 kHz to 100 kHz

c) Observation period: The observation period shall satisfy the following conditions according to class

- Class I and II-1: shall be at least 0.5 s and specified by the manufacturer
- Class II-2: shall be specified by the manufacturer

d) Minimum detected current value: The minimum detected current value shall be the smaller of the following two values: 1% of the maximum measurable current value or 2 kA.

e) Minimum detected electric charge value: The minimum detected electric charge value shall be 1 C or higher and shall be specified by the manufacturer.

f) Maximum measurable current value: The maximum measurable current value that is the maximum value of the current that can be detected during the observation time, shall be at least 100 kA and shall be specified by the manufacturer.

g) Maximum measurable electric charge value: The maximum measurable electric charge value, which is the calculated current during the observation period of one lightning strike, shall be at least 1,000 C, and shall be specified by the manufacturer.

h) Trigger current value: The trigger current value, which can be set based on the minimum detected current value, can be set variably according to a value equal to or higher than the minimum detected current value.

i) Polarity: Positive polarity (Example: +10 kA) or negative polarity (Example: –10 kA) shall be recorded.

j) Measurement precision: The measurement precision shall be specified by the manufacturer.

2) Contact relay output for alarm: When the current or electric charge values equal to or higher than the alarm current or electric charge values has been detected, an alarm contact shall be output. The rating and type of alarm contact output shall be specified by the manufacturer.

The alarm output condition shall be one of the following methods:

- Output when the current value is equal to or higher than the alarm current value
- Output when the electric charge value is equal to or higher than the alarm electric charge value
- Output when the electric current value is equal to or higher than the alarm current value, or when the electric charge value is equal to or higher than the alarm electric charge value
- Output when the electric current value is equal to or higher than the alarm current value, and when the electric charge value is equal to or higher than the alarm electric charge

3) Withstanding voltage: The withstanding voltage shall be specified by the manufacturer (see JIS C 60664-1).

C. *Recording the Lightning Information*

The lightning data are, for the operator, important for the maintenance of wind turbines. Accordingly, current-sensing lightning detection systems shall record the items in Section (a)-5) Recording of lightning information in Chapter V and clearly indicate the recording method.

D. *Environmental resistant*

For the outdoor portions of current-sensing lightning detection system, the salt and ultraviolet damage tests shall be conducted

E. *Electromagnetic compatibility*

The countermeasures for electromagnetic susceptibility shall be conducted. If the lightning detection systems has high frequency switching equipment, the countermeasures for electromagnetic interference also shall be conducted.

F. *Maintenance*

Operation shall be confirmed regularly, and the method and frequency of operation confirmation shall be clearly displayed. However, operation confirmation may be performed either automatically or manually.

G. *Installation*

The system shall be installed such that it cannot fall off. The installation method shall be clearly indicated.

H. *Operation flowchart*

The operation flowchart shall be specified by the manufacturer.

VI. Testing Method

Stipulating or recommending the testing method used to confirm that a current-sensing lightning detection system satisfies the required performance shown in Section 5 under the Japan Electric Manufacturers Association (JEM) standards instead of the JIS is being discussed. The JIS present essential conditions that a current-sensing lightning detection system should satisfy, and the JEM is expected to form a committee to deliberate the testing method used to confirm these essential conditions; additionally, the JEM standards are currently being prepared.

The following is a testing method used to obtain the frequency characteristics of current-sensing lightning detection systems that is being discussed in preparation for stipulation in the JEM standards.

A. *Test to Obtain Frequency Characteristics*

Figure 3 shows an example of a test circuit. A power amplifier is connected to the function generator to amplify the current output and input the signal to the sensor. In the case where a Rogowskii coil or CT is used as a sensor, the current is linked to the sensor. In the case where a magnetic field sensor using a solenoid coil is used, the current is passed around it and a sinusoidal wave magnetic flux is linked to the magnetic field sensor. The input current is measured by the shunt resistance method or using a measuring device with adequate precision in this frequency bandwidth. Along with the input current, the sensor output signal that the lightning detection system uses to judge whether lightning has struck is measured, and the frequency characteristics shown in Figure 4 are obtained from the results of the input.

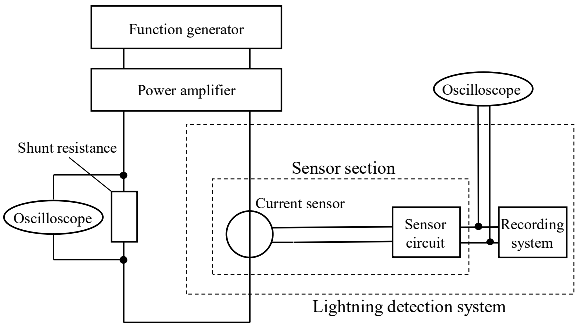
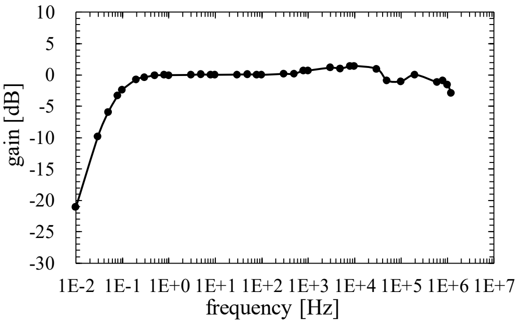
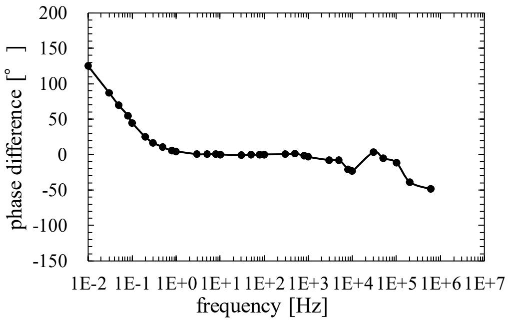


Fig. 3. Test setup for frequency characteristic measurements



(a) Gain



(b) Phase

Fig. 4. Measured result of frequency characteristic

VII. Conclusions

Parts of JIS C 1400-24:2014 that are presently being revised and are related to lightning detection systems were introduced herein. Discussions of its content have been conducted as part of the studies contracted by the Ministry of Economy, Trade, and Industry, and was conducted by the Wind Power Generation Protection Subcommittee (supervisor: Yoh Yasuda, Special Professor of Kyoto University) and Standardization Management Committee (Group leader: Kazuo Yamamoto: Professor at Chubu University) under the Wind Power Generation System Lightning Protection International Standardization Committee (Administrative Office: Japan Electrical Manufacturers Association). JIS C 1400-24 is currently being revised; therefore, partial changes of its content can still be reflected.

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