2

Considering of Lightning Damage Protection and Risk Reduction for a Safe and Secure Society

KUNIKO URASHIMA
Environment and Energy Research Unit

1 Introduction

Since ancient times, Japanese culture has considered thunder to be the second most frightening thing (after earthquakes). It does not occur that often in Japan, it is not something the Japanese experience every day. When thunder and lightning do occur, however, lightning strikes can cause major damage such as blackouts, as well as serious injuries to people. For example, in September 2003, lightning struck the National Diet Building. The lightning rods did not function properly, and lightning struck the outer walls and other areas it should not have been able to strike. It also struck the area around the lightning rods on the building's iconic 65m tall central tower, knocking off pieces of granite that fell to the ground.

Of course, various fields to date have addressed lightning countermeasures. Damage to home appliances powered by electricity has decreased. Furthermore, lightning countermeasures both by manufacturers, on the device side, and by power companies, on the supply side, are evolving. The number of power outages due to lightning strikes is decreasing[1]. However, because computer systems are particularly vulnerable to lightning surges*1, lightning damage to data networks is actually increasing. For example, if lightning causes a mere 20-msec., 30-percent voltage fluctuation, the shock may cause a system to malfunction or lose data. If this happens to a company's or public institution's core computer, it may negatively impact not just a single computer system, but society as a whole[2,3]. With the spread of IT environments, the risk of lightning damage to networks increases every year. The creation of a society with ubiquitous connections may further exacerbate this risk in the future.

Furthermore, there are also recent reports of damage to wind power generation, which is a desirable renewable energy source for the building of a sustainable society[4,5]. Adoption of renewable energy sources is advancing in Europe in particular as a measure against problems such as global warming and petroleum depletion. Because wind and solar power generation rely on nature, there are many issues. Lightning damage countermeasures are therefore essential for the adoption of wind power generation.

This article discusses lightning damage risk, which must not be neglected in the building of a safe and secure society. Narrowing its focus to information technology and wind power generation, the article discusses current conditions and future measures.

2 Lightning occurrence and observation

2-1 Lightning occurrence

As depicted in Figure 1, solar heat can warm the ground so that rising air currents form cumulonimbus clouds, so-called thunderclouds. Rising air currents can sometimes grow into tornadoes[6]. At altitudes above 5 km, the air temperature is below freezing, so atmospheric moisture turns into tiny particles of ice. Collisions between these particles generate friction charges, so the upper part of the cloud has a positive charge and the lower part has a negative charge, eventually resulting in an electrical discharge. When the discharge occurs within a cloud or

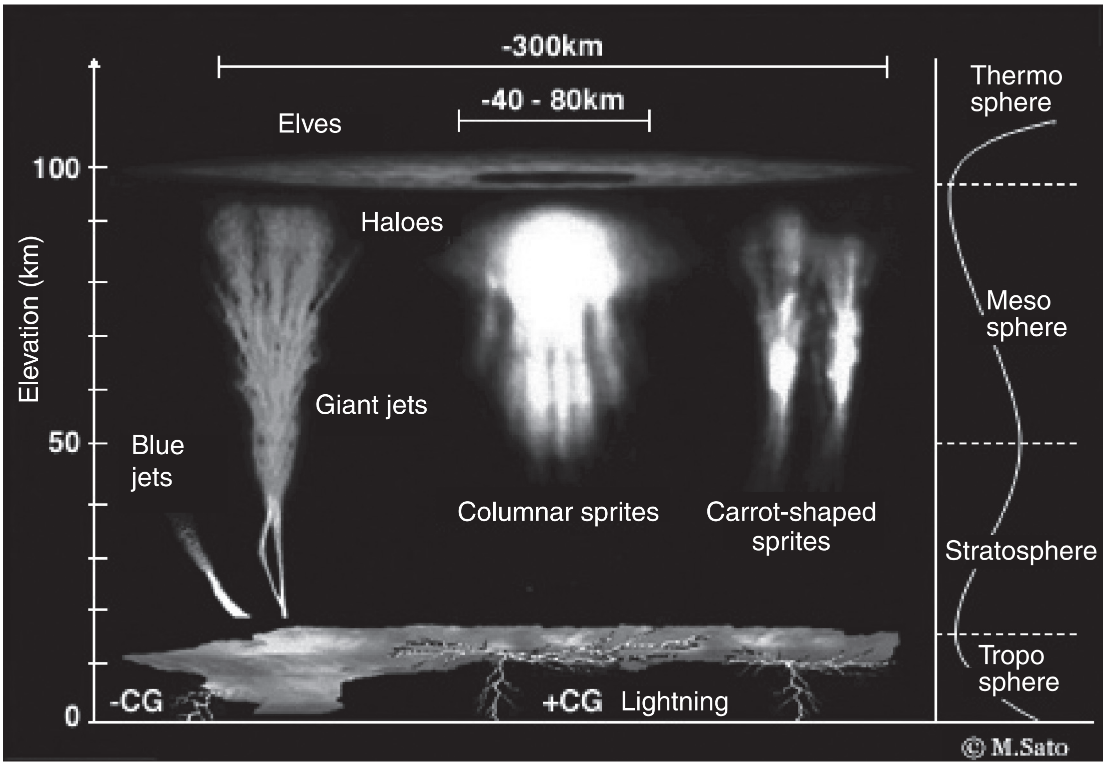


Figure 1 : Luminescent phenomena high above thundercloud activity (see color chart on cover)

Reproduced from JAXA website

clouds, it is called cloud-to-cloud lightning. The phenomenon of a discharge powerfully striking the ground is a lightning strike. Lightning can strike anywhere there are thunderclouds, whether they be over oceans, plains, or mountains. Discharges within clouds are called cloud-to-cloud lightning, while discharges from thunderclouds to the ground are called cloud-to-ground lightning (CG). There are four kinds of cloud-to-ground lightning, in combinations of upwards and downwards and positive (+CG) and negative (-CG) polarities. A single lightning strike discharges tens of thousands to hundreds of thousands of amperes and has a voltage of 100 million to 1 billion volts. Converted to electric power, the average is about 900,000 megawatts. Although a lightning strike lasts only about 1/1,000 of a second, research to utilize it as electric power is underway.

In addition to cloud-to-ground lightning generated between thunderclouds and the ground and cloud-to-cloud lightning generated within thunderclouds, lightning can also accompany volcanic eruptions and tornadoes. The length of the discharge path when lightning strikes the ground is several kilometers. Recent research has observed luminescence accompanying discharges that attains an altitude 100 kilometers above the top of thunderclouds[7]. As depicted in Figure 1, ground-based observation and observation using aircraft and Space Shuttles have confirmed three types of discharges (blue jets, sprites*2, and elves) above thunderclouds in the stratosphere, the mesosphere, and the lower thermosphere during cloud-to-ground lightning strikes, mainly those delivering strong positive charges. Discharges occurring above thunderclouds have also been observed to generate NO_X that can cause of acid rain[8], electromagnetic waves, x-rays, and gamma rays. Research into their influence on environmental problems and communications failures is underway. Some theorize that lightning generates 20-30 percent of the world's NO_X. Elucidation of lightning and the aurora phenomenon is essential to research on human-induced atmospheric environmental change[9].

Lightning occurs during all seasons, but its nature varies by season. In winter, lightning is common along the Sea of Japan coast and rare more than 35 km inland. It strikes the ground relatively less often than summer lightning, but may occur throughout the day. It is characteristically preceded by snow or hail[10]. The winter lightning that occurs frequently in

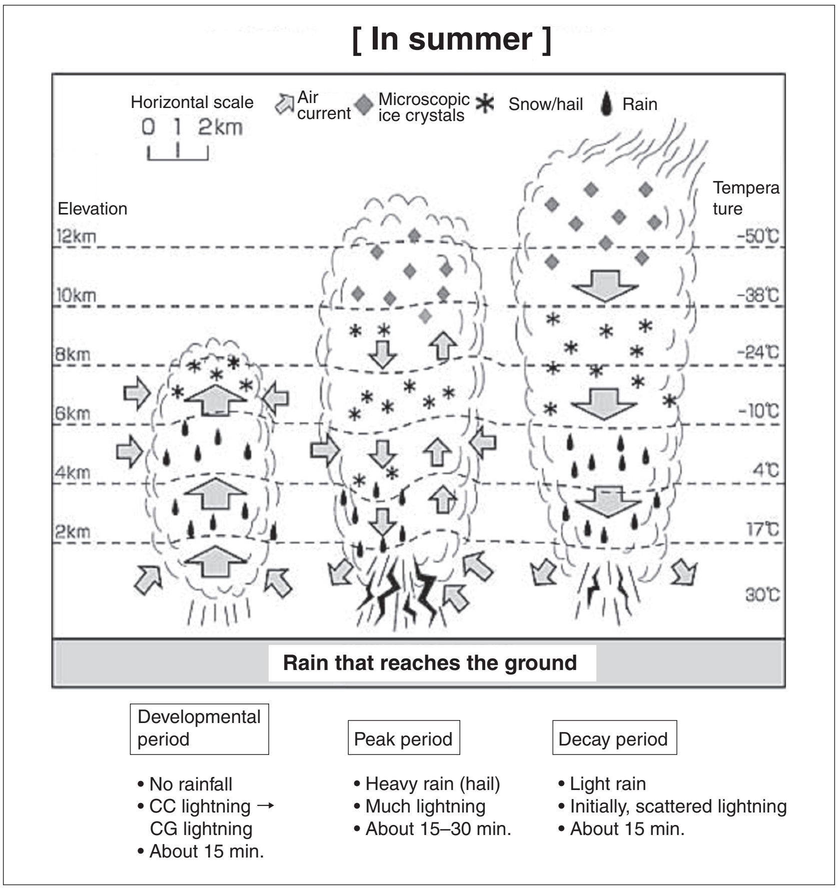


Figure 2 : Model of the life of a thundercloud[11]

the Hokuriku area is rare in the rest of the world, and it often has a hundred to several hundred times the energy of summer lightning. Figure 2 is a model of thunderclouds, while Figure 3 depicts differences between summer and winter thunderclouds[11].

2-2 Lightning observation

Although the basic mechanisms of lightning generation are understood, there is much that is unclear about the actual behavior of lightning inside clouds. In the future, observation of all lightning by lightning observation sensors located in space is desirable. Observation from space offers the advantages of accurate detection of the altitudes and forms even of lightning inside clouds, as well as a rapid identification of location and direction of movement.

According to statistics collected over the past 10 years, about 500,000 lightning strikes are observed annually in Japan. Currently, power companies and private-sector weather information companies observe the electromagnetic waves generated when lightning strikes and use “lightning location systems” that estimate the location and size of

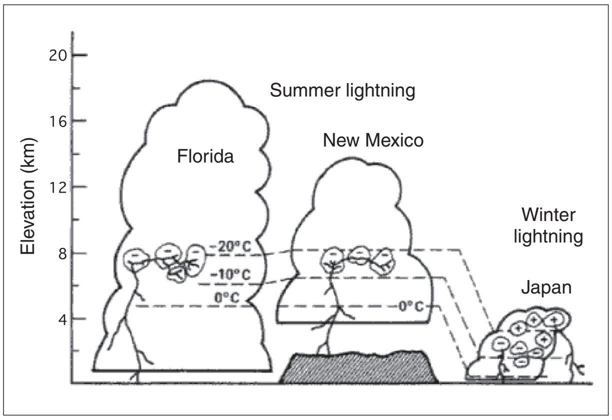
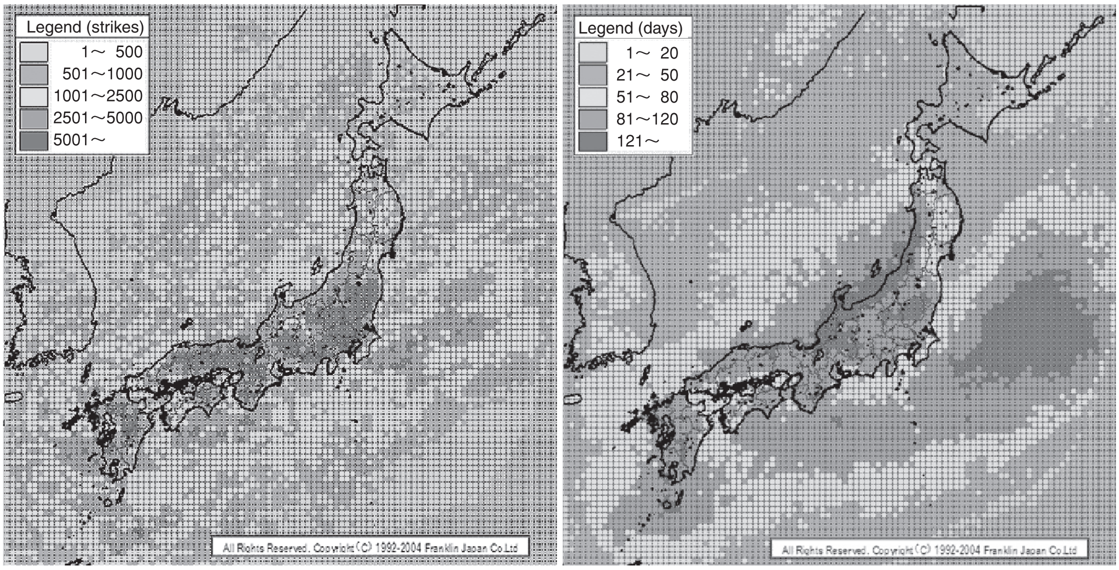


Figure 3 : Thunderclouds at summer and winter in North America and Japan[12]

lightning strikes to ascertain lightning conditions. They provide information to mitigate or prevent lightning damage. According to these observation data, almost all strikes occur during the summer season (April through October). The above-mentioned winter (November through March) lightning that occurs along the Sea of Japan coast is quite unusual, having been observed only in Japan and Norway where set up measurement equipment.

Figure 4 shows the Japanese archipelago covered with a mesh of 20-km by 20-km squares



(a) Number of lightning strikes (b) Number of days with lightning strikes

Figure 4 : Map of lightning density and lightning days in Japan (see color chart on cover)

and tabulates lightning strikes within the mesh for the four years from 2000 through 2003. In (a), the frequency of lightning strikes in the major cities Tokyo and Osaka and the surrounding densely populated areas is distinctive. In (b), there is a high number of days on which lightning strikes occur on the Sea of Japan side from Tohoku into Hokuriku. This is because lightning strikes are common during the summer season in the Kanto, Chubu, and Kyushu areas, while during the winter season they are common along the Sea of Japan coast[13]. On the Sea of Japan coast, frequency climbs because of the addition of winter lightning to summer lightning. The area is notable for often suffering lightning damage during the winter as well as the summer[14].

Founded in 1991, the Franklin Japan Corp. has a weather forecast business permit from the Japan Meteorological Agency. It independently gathers information on lightning and weather and provides it to businesses that operate semiconductor factories and golf courses, theme parks, and other recreational facilities. In October 1998, Franklin Japan began operating Japan's first nationwide lightning observation network, the Japan Lightning Detection Network (JLDN). The JLDN networks data obtained from two types of sensors placed in 29 locations around Japan. Based on accurate time data sent by global positioning systems (GPS), it observes lightning strike locations, times, current values, and so on and makes such data available. Power companies have their own similar systems, using the Internet and PHS to provide information on lightning strikes within the areas where they supply electricity.

The Maido 1 satellite scheduled for launch by Osaka Prefecture's Astro Technology SOHLA will use multiple broadband antennas to receive electromagnetic waves from lightning. The plan is to use an instrument called a "broadband interferometer sensor" to determine location, and to predict from space where lightning will occur. This will be the first attempt to use a broadband interferometer in space. If this kind of observation becomes practical, it may enable lightning prediction in obstacle-ridden mountainous areas and over oceans unreachable by terrestrial observation networks. It may also aid in understanding the relationship between torrential rain and global warming[15].

Lightning observation has been underway since 1976 at the CN Tower, the world's tallest tower (553 m), in Toronto, Canada[16,17]. An ordinary power line that is 100 meters tall is struck by lightning about once a year, and the Tokyo Tower (333 m) is struck a few times, while the CN Tower is struck about 60 times every year. With skyscrapers being built in Japan and around the world, lightning countermeasures for tall buildings have become important[18].

2-3 Induction of lightning

It has been about 250 years since Benjamin Franklin experimented with a kite and proved that lightning is an electrical discharge. Based on Franklin's observation, "rocket-induced lightning," where small rockets equipped with wires are launched into thunderclouds to draw lightning to the earth, began in France in the 1970s. Experiments around the world have successfully induced lightning. Research replacing the rocket wires with lasers to draw "laser-induced lightning" to the ground and with water jets for "water-induced lightning" is currently underway. In order to reliably draw lightning to the ground, the ability to discover the location of thunderclouds accurately and the proper timing of rocket launches and so on are important. Accordingly, weather data are essential to this research.

3 The state of lightning damage

3-1 Damage from direct lightning strikes

Lightning strikes cause various kinds of damage. In general, there are two types, damage from direct lightning strikes, and induced damage from lightning-generated electromagnetic waves. Table 1 shows types, phenomena, and mortality rates for lightning strikes.

3-2 Human injuries

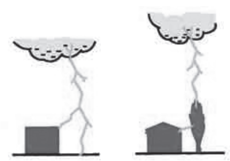
According to data for 1996-2005 in the White Paper on Police, the number of people killed or missing due to lightning strikes per year is 1 to 6 (3.5 annual average). In light of the fact that during the 1960s there was one year in which over 50 people were killed, defensive measures against lightning appear to have become generally disseminated. The primary causes of death from lightning strikes are lightning-induced respiratory arrest and cardiac arrest.

In a recent catastrophe involving lightning, 19 people were killed and 13 injured on April 21, 2005, in Chongqing, China. When lightning strikes a person, the current may travel through the human body (with a high mortality rate), or it may travel mostly along the body's surface before reaching the ground. (The majority of survivors of lightning strikes are the latter type.) Loss of consciousness or paralysis due to lightning strikes often causes death by falls or drowning. When lightning strikes the surface of a sea, people within approximately 20 meters of the strike may be killed or seriously injured. Table 2 shows some examples of damage occurring in Japan and China[19].

3-3 Damage to data networks

Although the more widespread and efficient data network environment of an advanced information society using IT increases convenience and productivity, it is more vulnerable to lightning damage. In recent years, lower voltages are being used in the integrated circuits and other electronic circuits in home appliances and computers. Therefore, damage to

Table 1 : Lightning strike types and phenomena

Type	% of strikes	Strike phenomena	Mortality rate if struck
Direct strike	57%	Most of the current passes through the object struck, so it receives the most damage. • Human/livestock deaths • Destruction of machinery by momentary high-temperature electromagnetic force • A cause of fires • Dielectric breakdown of electrical work	74% 
Non-direct strike	30%	A discharge path branches off the main lightning discharge path and passes through the object struck, or lightning strikes a tall tree, etc., and separates from the trunk, passing through a person located within a few meters and reaching the ground. Damage is less than with direct strikes.	90% 
Multi-point strike	13%	Lightning strikes multiple points almost simultaneously, causing multiple injuries and/or deaths.	Averages 1 death per incident

network devices, shutdowns, malfunctions, and other damage from momentary voltage drops due to lightning strikes and lightning surges that penetrate networks are increasing. Even when lightning does not strike to the somewhere, the electromagnetic waves it generates can cause of electromagnetic compatibility (EMC) in communication lines and electronic circuits.

Figure 5 shows the types of voltage surges and noise that affect electrical devices. Voltage surges exceed the ordinary voltage in electrical circuits or systems. The excess voltage may be momentary or continuous. Voltage surges in electrical devices can cause dielectric breakdown, shutdowns, degradation, and so on. As illustrated in Figure 5, surges are high voltage and low frequency. They may be lightning surges (direct and induced lightning surges) caused by natural phenomena, switching surges caused by transient phenomena in electrical circuit systems, excess

Table 2 : Examples of locations and situations of damaging lightning strikes in Japan and China

Date	Location	Site of strike	Damage
1975/8/5	Kagawa Pref.	Helicopter	A Self-Defense Forces helicopter crashed after being struck by lightning, killing 4.
1989/8/12	Shandong, China	Petroleum tank	A storage tank at a petroleum storage facility in Huangdao exploded after being struck by lightning. Several other tanks subsequently exploded. Five dead, 12 missing, 86 injured.
1990/12/11	Osaka International Airport	Parked aircraft	Lightning struck the ground near the nose of a B-747 parked in parkway spot at Airport. One person working nearby was injured.
1994/8/31	Gunma Pref.	Train	LightnA storage tank at a petroleum storage facility in Huangdao exploded after being struck by lightning. Several other tanks subsequently exploded. Five dead, 12 missing, 86 injured.ing struck the cockpit at the rear of a parked local train. A conductor was injured.
2000/8/7	Yamanashi Pref.	Rugby field	Before rain began falling, lightning struck a tree near a rugby field being used by a junior high school team for its training camp. Two players practicing 5–10 meters away from the tree were injured.
2001/7/17	Shiga Pref.	Biking home from school	A 5th grade student was seriously injured when struck by lightning while biking home from school.
2002/5/24	Hokkaido	School	Lightning struck near an elementary school's boiler room. A manhole cover in the adjacent kitchen was blown into the air, injuring one food delivery worker.
2003/9/3	Saga Pref.	On the way home from school	A 4th grader was stuck by lightning on the way home from school and killed. (This was the same day that lightning damaged the National Diet Building.)
2004/7/5	Okinawa Pref.	Telephone line worksite	Lightning struck the construction site (pedestrian path) of a bridge to an island. A worker installing telephone lines was killed.
2004/7/27	Nara Pref.	Construction worksite	Lightning struck the worksite for the dismantling of a steel transmission tower, which had been halted because of rain, injuring two people.
2005/4/21	Chongqing, China	Explosives factory	During a heavy thunderstorm, the emulsification worksite of a civilian-use explosives factory exploded immediately after a lightning strike. The 3-story factory was completely destroyed, with 19 workers killed and 10 injured.
2005/8/23	Tokyo	Riverbed baseball field	During a rubber-ball baseball game at a riverside ball field, lightning struck the grass about 10 meters behind second base. Two high school students were injured and began hyperventilating for a short time due to shock. There was some blue sky, but distant thunder was heard.
2005/9/10	Fukuoka Pref.	School grounds	A thunderstorm began during a sports day, so those present took shelter in a gymnasium. When the rain grew light, the festival began again. During a cheering contest, lightning struck the woods next to the sports field. Eight students sitting in the front row of temporary bleachers were injured.
2006/7/14	Chiba Pref.	Construction area	A thunderstorm became increasingly violent during pipe-laying work in a housing development. Lightning struck just when work was about to be suspended. One foreperson was rendered unconscious and seriously injured, and one worker was injured.
2006/8/8	Tokyo	Pedestrian	A downpour began one morning, so a person parked his/her motorbike near a 30-meter tree and walked a few meters towards a public restroom when lightning struck the tree. The side strike killed the person.

Quoted in part from the Aobaya website

voltage caused by malfunctions, and so on. In recent years, there have been reports of people being burned by electromagnetic wave induction generated by lightning. Ordinarily, noise causes electromagnetic compatibility that is lower in voltage and higher in frequency than voltage surges. While it does not destroy light electrical devices such as semiconductors, it can generate enough abnormal voltage to cause fire alarms to malfunction or lose memory, for example[20].

Electric home appliances are not the only items subject to damage. For example, momentary voltage drops at semiconductor manufacturing works and so on that interrupt manufacturing, decreasing manufacturing yield and increasing initial costs, are increasing. Table 3 shows devices frequently damaged by lightning, while Table 4 shows examples of lightning damage in different industries.

Lightning arresters and lightning protection elements for industrial and home use have been developed and are sold, but there are no complete technologies that avoid from lightning. Although improvements to communications devices such as fax machines have made them less susceptible

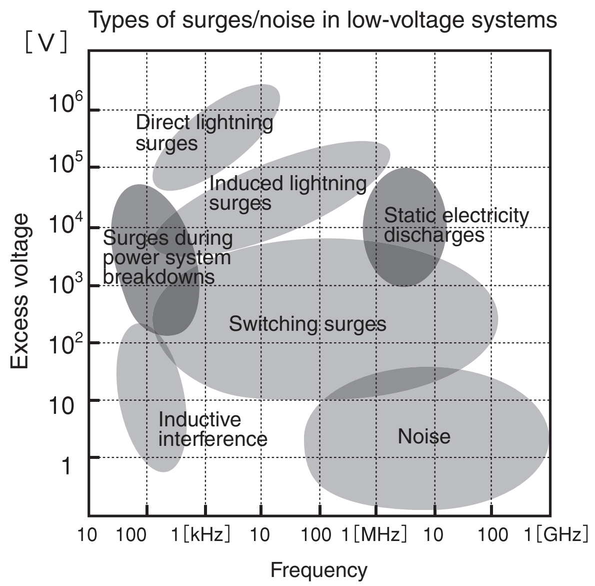


Figure 5 : Types of voltage surges and noise

Provided by Otowa Electric Company, Ltd.

Table 3 : Devices frequently damaged by lightning

Devices frequently damaged by lightning	Subject equipment
Devices with separate bodies and terminals	Surveillance cameras, disaster prevention equipment, entry/exit gates, factory control equipment, hot water heaters, air conditioners, etc.
Communications devices and network equipment	Office buildings: not only transponders and switching equipment, but also many network terminal devices, etc., connected to power and communications lines Homes: multifunction telephones, fax machines, modems, PCs, cable TV terminals, etc.
Communications equipment with antennas	Wireless relay stations, broadcast equipment, wind power generation control equipment, etc.

Table 4 : Examples of lightning damage in different industries[21]

Cost per strike	Industry	Type of damage
Human life	Petrochemical plants, explosives industry	Human lives are endangered because they frequently deal with dangerous explosives.
10s of millions of yen to 100s of millions	Steel	Problems can occur across a wide range of processes, mainly from control systems to rolling. Diverse processes mean losses are high.
Millions of yen to 10s of millions	Semiconductor industry	Because there are many processes that are extremely sensitive to voltage changes, momentary drops can cause damage.
100s of thousands of yen to millions	Fiber, chemical film, printing, machining, surface processing, software development, waste incineration	Momentary voltage drops cause variations in the quality of manufacturing materials. If not detected before final processing, major losses can result, which is the same as for film application in the micron order processes. In software development, momentary voltage drops can destroy data, causing serious damage. Processes using blast furnaces for high-voltage processing can be seriously damaged by power outages.
10s of thousands of yen to 100s of thousands	Food, unmanned communications bases, water and sewage monitoring sheds, hospitals	Electronically controlled processing, especially rice cooking and baking, which use many electronic devices, suffer losses (defective products) due to voltage drops. Unmanned communications bases are equipped with backup systems such as emergency power, but they often suffer damage to communications and control systems.

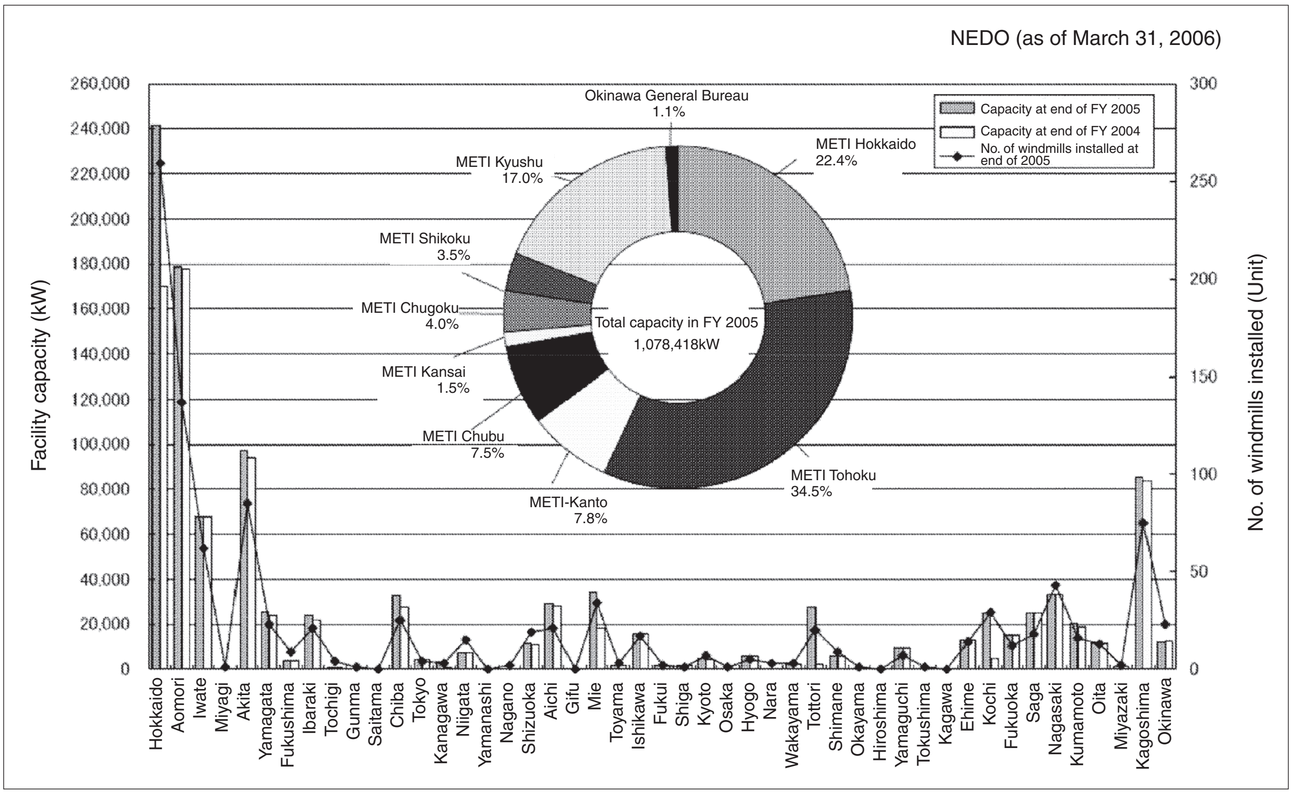


Figure 6 : Adoption of wind-generated power by prefecture[24]

to lightning damage, because lightning surges are current-carrying, lightning surge current flows to the protective devices on the telephone line side, which can destroy terminal adapters and routers. Furthermore, if devices such as outlets where ground terminals for surge protection are bare happen to be touched when lightning strikes, there is danger of electric shock[22]. The cost of adopting lightning damage countermeasures should be determined in light not only of repair and replacement costs, but of lost profits as well[23].

3-4 Damage to wind power generation systems

Conventionally, lightning damage has mainly been to home appliances and telephones, and power transmission and generation equipment malfunctions and damage due to strikes on power lines. With the adoption of wind power generation equipment, however, lightning damage is also increasing in this area. The construction of tall structures for wind power generation or other purposes changes the surrounding environment and can increase the number of lightning strikes. In the case of Canada's CN Tower, damaged number by lightning increased doubled than before. In this way, the increasing installation of wind power generation equipment is causing problems not found in other countries due to Japan's particular weather conditions. Damage to wind farms from winter lightning on the Sea of Japan side is one example. Figure 6 breaks down by prefecture the adoption of wind power generation. Hokkaido and the Tohoku area have the most wind power generation sites.

The winter lightning on the Sea of Japan side occurs along the coastline all the way from western Hokkaido to the Sanin region. There is lightning on 30 to 40 days per year. This area currently has 46 wind power generation sites, of which 23 have received lightning damage at some time. Of these, 8 have steel towers for lightning protection. Although steel towers can be effective in the event of a lightning strike, lightning rods are not 100-percent effective. Depending on the magnitude of the lightning current, mechanical effects in addition to heat effects such as temperature increases in electrical circuits and melting from arcs have been observed. Simulations indicate that the mechanism in such cases is expansion and contraction from sudden overheating on the discharge path, which

Table 5 : Damaged windmills by component (unit: %)

Damaged component	Denmark	Germany (450 kW and up)	Sweden (450 kW and up)
Blade	10	35	43
Power system	20	20	22
Control system	51	36	18
Mechanism	7	4	4
Other	12	5	13

causes supersonic pressure waves to spread to the surroundings, generating impact pressure. Furthermore, unlike summer lightning, winter lightning is not necessarily a momentary current, but instead is sometimes a large current flowing for a certain amount of time with a very large amount of energy. Therefore, the energy from lightning strikes apparently can react with steam on windmill blades to cause explosions that damage the equipment. One windmill blade was struck more than 100 times in a single year by winter lightning in Japan. In addition, repair costs over five years for lightning strikes on some windmills equaled the original construction costs.

In recent years, windmills have become markedly larger. The height of the blade tips on many of these large windmills is over 100 meters, which increases the frequency of damage from lightning strikes. Damage to the blades of large windmills have higher repair costs and require more time for replacement (including transport and installation). The increase in windmill downtime has brought about a decrease in the operation rate and utilized capacity of windmill equipment[24].

In Europe, where wind power generation is being aggressively adopted, the effects of lightning on wind power generation equipment have been monitored since 1990 in Germany, Denmark[25], and Sweden. On flatlands over the past 10 years, lightning strikes have damaged 8 percent, 3.9 percent, and 8.5 percent of the respective countries' turbines. In hilly country, lightning has damaged about 15 percent of turbines. The cost of the damage reportedly averages about 300,000 yen per strike[26]. Table 5 shows statistics for lightning damage to windmills by component for Denmark, Germany, and Sweden[27].

4 Lightning damage ountermeasures

4-1 Measures for indoor and outdoor wiring

Lightning surge currents enter homes and buildings via the routes shown in Figure 7. Measures to protect those routes are therefore necessary[23]. In light of the characteristics of lightning, the important functions of surge protection equipment are the ability to tolerate large surge currents, with construction that will not allow fires to start, and the ability to withstand induced lightning several times. There are numerous products on the market for lightning protection. The main types are called varistors and arresters. They cause lightning surges to flow into external grounds to protect connected devices.

4-2 Prediction from weather data

The Japan Meteorological Agency's daily weather forecasts predict lightning with the expression "accompanied by lightning in some places." Furthermore, it only issues "lightning advisories" rather than "lightning warnings." This is because it is difficult to predict the occurrence of lightning with a high degree of accuracy. Current forecasting technology can predict the potential formation of the cumulonimbus clouds that generate lightning, but cannot predict locations or times with high accuracy. Moreover, even when cumulonimbus clouds form, it is very difficult to tell in advance whether they will be the type of cumulonimbus clouds that generate lightning or those that do not. Under these circumstances, forecast periods can be divided into three types depending on the targeted time period, "nowcasts," "short-time forecasts," and "short-range forecasts," with appropriate methods for each. Table 6 shows the forecast periods and methods for each type. In addition to these methods, research to predict lightning with greater accuracy is also underway. One new method being researched is numerical forecast models on a short-range scale. In order to raise the accuracy of lightning

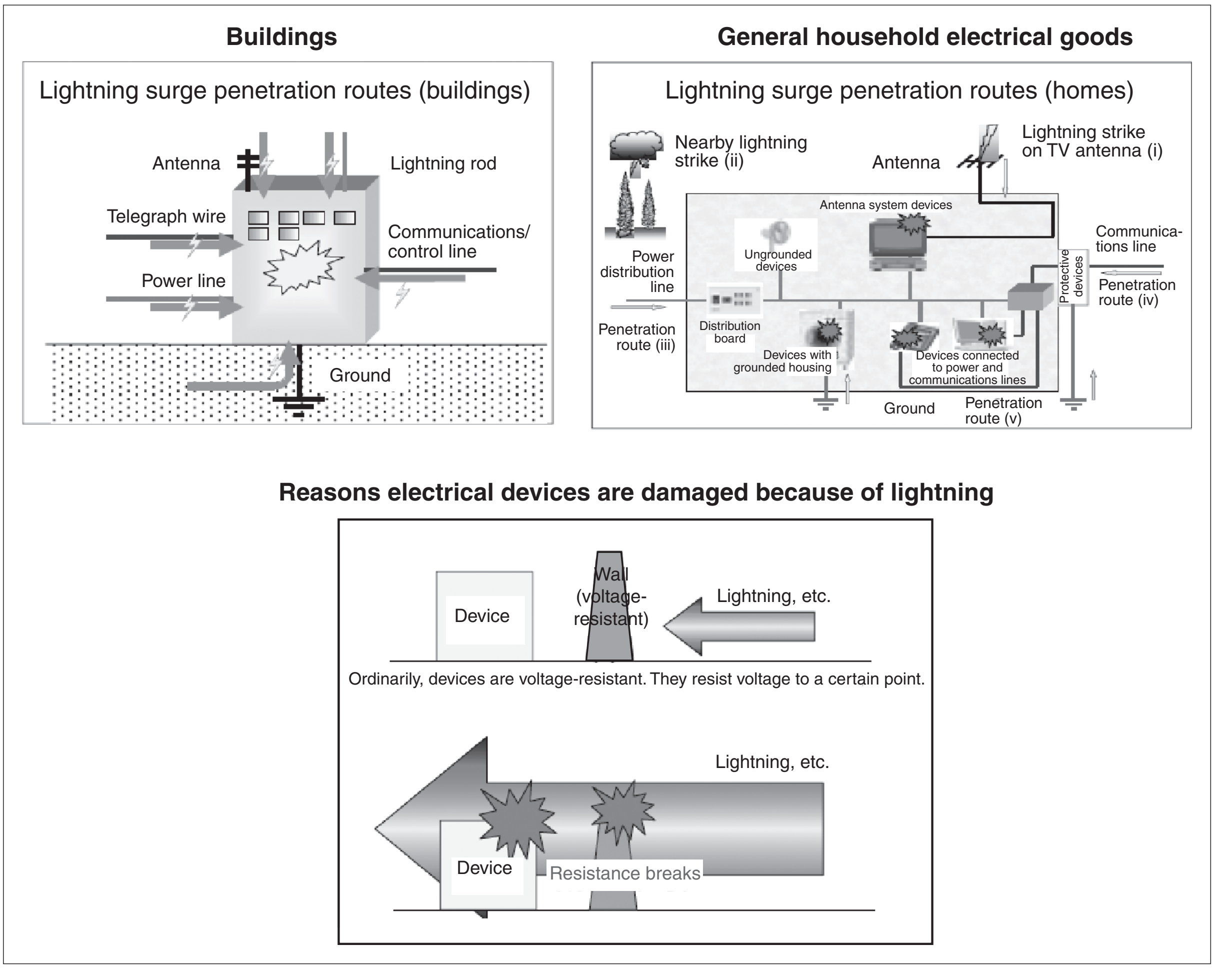


Figure 7 : Lightning surge penetration routes

Quoted from Tokio Marine and Nichido Risk Consulting Co., Ltd. RISK RADAR No. 2004-4

Table 6 : Lightning forecasting targets and goals

Type	Target time period	Goal
Nowcast	Forecast a few minutes to 10 minutes ahead	After cumulonimbus clouds form, assesses the signs of lightning generation and forecasts lightning. Requires frequent observations and a swift transmission system.
Short-time forecast	Forecast a few 10s of minutes ahead	Regarding thunderclouds with observed lightning, forecasts their movement and approach. Forecasting quickly forming or transient thunderclouds is difficult.
Short-range forecast	Forecast several hours to 2 days ahead	Based on results of numerical forecasts, produces indices such as air stability with possible relationships to lightning generation and forecasts the potential of lightning generation.

prediction using numerical forecasting models, the development of various technologies and knowledge, such as accumulation of lightning observation data, understanding of lightning-generating mechanisms from those data, and greater precision in the models and in surface imagery, is essential. Furthermore, not only the Japan Meteorological Agency, but also local power companies and weather-related businesses also actively issue information and forecasts related to lightning[28].

4-3 Measures for wind power generation equipment

Lightning-strike damage to the blades of wind power generation site consists of delamination or burning of surface composite materials and heating or melting of metal components (receptors and conductors) at the point of the strike. Blade damage occurs when a lightning current is conducted through composite materials or between their layers, and the shockwaves thus generated follow the blade's edges, tearing or bursting the blade's surface from the inside. The greatest damage occurs when lightning causes an arc discharge inside a blade. Blade damage follows many patterns, ranging from surface cracks to complete destruction. Improving materials is an effective countermeasure against this phenomenon. When lightning damage occurs, the destruction behavior of the materials is complex and the mechanism is difficult to ascertain. However, improved plastics reinforced with fiberglass or carbon fiber have a number of outstanding characteristics that cannot be obtained from a single material, so their use in blades is common.

Of course, surveys of the locations of wind power generation machinery are also important. The New Energy and Industrial Technology Development Organization (NEDO) is constructing a database on wind conditions[29].

5 Lightning countermeasures that should be considered

5-1 Database construction and accurate forecasting

The ability to forecast lightning strike locations in advance would simplify the prevention of lightning damage. This requires an understanding of the dynamics inside thunderclouds to clarify the distribution of charges. Furthermore, it is necessary to measure the progress of discharges using systems that combine radar and interferometers and to pursue research on lightning discharges. Regarding observation, observing lightning from space will enable scientific elucidation of the correlation between lightning activity and global warming. This will require cross-sectoral research spanning electrical engineering, meteorological engineering, and space engineering.

Because the occurrence of lightning varies by season and location, countermeasures specific to local characteristics are necessary. For example, the difference in current between weak lightning and strong lightning is a factor of 100. Countermeasures that address intermediate lightning will not work against strong lightning. Currently, users must estimate what countermeasures they require when selecting equipment, so in many cases lightning countermeasures are incomplete.

The Japan Meteorological Agency does not make public data on the number of times lightning occurs. With the current observation system and technology, lightning occurrence, which is a local weather phenomenon, is observed relatively accurately. Yet because prediction is difficult, the Agency does not issue the above-mentioned “lightning warnings.” More accurate forecasting and the dissemination of information transfer are necessary for the prevention of lightning damage.

Power companies are aware of how many power outages are caused by lightning, but they are not aware of all lightning damage. It is therefore necessary to collect the data that are presently scattered and create an environment that makes it easy for users to select lightning damage countermeasures. Furthermore, because prompt transmission of lightning information is essential in order to prevent damage to ordinary people, the construction of networks is also an issue. In order to combine the data held by individual companies and build conditions for easier forecasting, private-sector technical development and further promotion of forecasting services are necessary.

5-2 Interagency cooperation and legal development

Lightning current penetrates facilities and homes by various routes, and different government agencies have jurisdiction over the different routes. The Ministry of Internal Affairs and Communications oversees communications, while the Ministry of Economy, Trade and Industry handles electric supply equipment, and the Ministry of Land, Infrastructure and Transport is in charge of lightning rods. This makes it difficult to create comprehensive standards for countermeasures. The creation of measures that span agency boundaries is necessary.

The JIS standards for prevention of lightning damage in Japan are based on standards created during the 1940s. Although they have been steadily upgraded recently, they are not adequate for high-rise buildings or for networks. As the information society advances, the standards must be revisited.

5-3 Initiatives at the design stage of structures

Recently, construction of high-rise buildings is advancing in the Tokyo metropolitan area in particular. An increase in damage to buildings from direct lightning strikes has accompanied this. For example, on July 22, 1999, lightning struck an exterior wall of the Tokyo Metropolitan Government building. An approximately 20 cm × 20 cm, 10-cm deep piece of the exterior wall on the northwest corner of the 41st floor (about 180m above the ground) broke off. The roughly 400g chunk of rock was found on the pedestrian walkway on the north side of the building. Measures against this kind of accident are also necessary.

With favorable wind conditions common in areas along the Sea of Japan coast, introduction of wind power generation site is being encouraged. For the purpose of risk avoidance as well, a survey of nationwide windmill damage from lightning strikes, measurement of winter lightning and collection of data on its characteristics, creation of a comprehensive lightning strike map based on these efforts, and compilation of guidelines for lightning protection measures are necessary. NEDO is currently working on a project that began in 2005 to "survey lightning countermeasures for wind power generation site". NEDO is engaged in another project that "aims to set guidelines for Japanese-type airflow power generation" since this project began in 2006. However, despite these initiatives, lightning-strike damage is still occurring. Into the future, creation of detailed diagrams of the relationship between lightning-prone areas and structures, reexamination of the economics of wind power generation site, and research on technology resistant to lightning damage are necessary. Furthermore, the New Tokyo Tower will building in Japan that will stand 610m tall, so it will likely be struck by lightning about as often as Canada's CN Tower is now. If broadcast equipment is damaged by lightning, it could cause long-term problems for information transmission in the Kanto region. Elucidation of the phenomenon of lightning strikes on high-rise structures and the devising of countermeasures are urgent tasks.

Wind power generation turbines stand about 100m height, yet there are data that indicate they are struck by lightning more frequently than power transmission towers of the same height. To resolve this matter, about 220 scientists from 18 countries, mainly in the EU, involved and began working on the five-year COST Program at the end of 2005. The program aims to investigate how the amount of NO_X generated by lightning, electromagnetic damage, natural disasters, and so on are changed by wind power generation equipment. Since the project is related to understanding where to locate wind power generation sites, which are flourishing in Japan, and mechanisms for mitigating natural disasters, Japan's active participation is desirable.

5-4 Response to overseas standards

Standards for lightning damage countermeasures in the International Electrotechnical Commission (IEC) 61400-24 international standards for windmills are based on damage to conventional American and European wind power generation equipment (i.e., windmills with blades of 20m or less) and set forth cross sections for areas prone to lightning and for conductors. Data collection and evaluation of actual cases are therefore necessary for large-scale wind power generation equipment and lightning with greater energy (e.g., winter lightning).

Overseas, many buildings are connected to grounded communications and power lines, so lightning surges do not cause potential differences between them. Under the IEC standards, malfunction tests are performed at several kV. When foreign products that meet this standard are used overseas, there is no problem, but in Japan, where separate grounding is common, a lightning surge of about 20 kV will easily destroy them. In Japan as well, the method of grounding individual buildings to make them equipotential was adopted in the 2003 revision of the Japanese Industrial Standards (JIS) as "lightning protection for structures." However, it is feared it will take years before that grounding method is widely disseminated.

In Japan as well, wind power generation equipment is spreading as a form of renewable

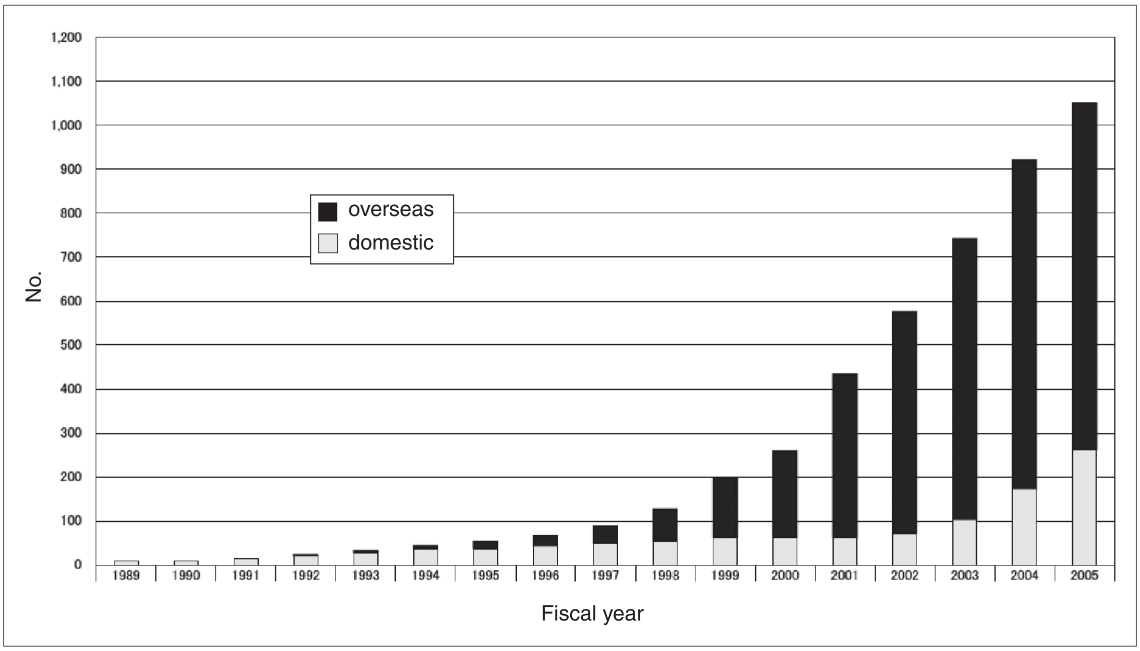


Figure 8 : Number of foreign and Japanese windmills installed at wind power generation sites

energy, but there is concern in this sector as well regarding the issue of separate grounding. As can be seen in the graph showing the rate of adoption for foreign and Japanese equipment in Figure 8, use of foreign equipment is growing. Equipotential grounding should be required when foreign equipment is adopted[30].

5-5 Development of personnel involved with high voltage

The fostering of human resources related to high voltage is another important issue. This is a shared issue among developed nations. Lightning is taught almost entirely in electrical engineering, especially in high-voltage engineering. Even though the electrical engineering sector has a good employment rate, in recent years it has been unpopular with students, who show little interest in the field. Furthermore, the criteria for establishing a university department of electrical engineering no longer include the obtaining of certification as an electrical chief engineer. Most universities therefore have decreased their courses for this form of certification. There is a danger of not being able to train sufficient personnel at universities to work in the high-voltage field. At the pre-university level as well, there are already problems with elimination of university courses on high voltage and with developing successors to the present generation of engineers.

It is necessary first to highlight the importance and fascinating aspects of energy and to generate interest among students. Energy education is important not just for high school students, but for elementary school students as well. It is necessary to build frameworks to enable the Japanese people to appreciate the importance of energy. Relevant academic societies such as the Institute of Electrical Engineers of Japan must take the lead on efforts spanning industry, academia, and government.

Acknowledgements

The author wishes to thank Drs. Shigeru Yokoyama, Takatoshi Shindo, and Mr. Hideki Motoyama of the Central Research Institute of Electric Power Industry; Professor Emeritus Jen-Shih Chang of McMaster University; Professor Zenichiro Kawasaki of Osaka University; Mr. Osamu Yoshida and Mr. Junichi Kimura of Otowa Electric Co., Ltd.; Professor Kenichiro Senoh of the University of Tokyo Research Center for Advanced Science and Technology; Mr. Masahiko Ebata, office manager of the Lightning Damage Risk Reduction Consortium; and Mr. Yuji Hara of Franklin Japan Corp. for providing much valuable advice and information, as well as everyone else whose assistance made this article possible.

Glossary

*1 Surges in current generated by lightning;

called "induced lightning."

*2 A luminous phenomenon that occurs in the mesosphere above thunderclouds. It is a completely different phenomenon from lightning, but is believed to be associated with lightning (lightning discharge). In recent years, it has been observed by satellites (such as the ROCSAT-2 equipped with an ISUAL imager).

References

[1] Easy-to-Understand Fundamentals and Technologies of Lightning Countermeasures, Kensetsutsushin Shimbun Corp., 2006, ISBN 4-902611-14-7 (Japanese)

[2] Lightning and the Advanced Information Society, Institute of Electrical Installation Engineers of Japan, 1999 (Japanese)

[3] Protecting the IT Society from Lightning Damage, OHM, July 2004, p.54-76 (Japanese)

[4] Measures against Rapidly-increasing New Types of Damage: Lightning Damage Risk, ed. by Kenichiro Senoh, Diamond, Inc. (Japanese)

[5] "Electromagnetic Transients on Electric Power Systems including New Electric Power Equipments and Its Analysis Method," Technical Report of the Institute of Electrical Engineers of Japan, no. 1027, June 2005 (Japanese)

[6] Ando, A., and Inutake, M., High-voltage Engineering, Asakura Publishing Co. Ltd. (Japanese)

[7] ILPC 2006 (International Conference on Lightning Protection), Proceedings, 2006

[8] Price, C., Penner, J., and Prather, M., "NOX from lightning. 1. Global distribution based on lightning physics," Journal of Geophysical Research Atmospheres 102 (D5): p.5929-5941, Mar. 20, 1997

[9] "Development of Lightning Discharge Observation," JAXA Institute of Space and Astronautical Science: http://www.isas.jaxa.jp/j/forefront/2006/takahashi/index.shtml

[10] Hokuriku Electric Power Co. website: http://www.rikuden.co.jp/kaminari/tokucho.html

[11] "Lightning Countermeasures Manual, 2001 Revision," supervised by Shigeru Yokoyama, GTPA Report (Japanese)

[12] Rakov, V. A. and Uman, M. A., "Review and evaluation of lightning return stroke models including some aspects of their application," IEEE Trans. on Electromagnetic Compatibility 40(4): 403-426, Part 2, Nov. 1998

[13] "The Wonders of Lightning," Central Research Institute of Electric Power Industry website: http://criepi.denken.or.jp/jp/pub/pamphlet/light.pdf#page=3

[14] Franklin Japan Corp. website: http://www.fjc.co.jp/jldn/data.html

[15] Personal communication with Mr. Kawasaki

[16] Motoyama, H., Janischewskyj, W., Hussein, A.M., Rusan, R, Chisholm, W. A., and Chang, J. S., "Electromagnetic field radiation model for lightning strokes to tall structures": IEEE Trans. on Power Delivery 11(3): p. 1624-1632, Jul. 1996

[17] Chang, J., Beuthe, T., Seto, L., Duft, A., Hayashi, N., Chisholm, W., and Janischewskyj, W., "An investigation of the possible relationships between thundercloud electric-fields and the lightning parameters for tall structures," Journal of Geophysical Research-Atmospheres 94 (d11), p. 13197-13205, Sep. 30, 1989

[18] Yokoyama, S., Lightning Damage Countermeasures for Power Lines, Ohmsha, Ltd. 2005, ISBN4-274-50043-8 (Japanese)

[19] Aobaya website: http://www.aobaya.jp/chishiki.html

[20] "Recent Development and Future Prospects of Technologies on Lightning Surge Analysis," Journal of the Institute of Electrical Engineers of Japan, p.654-673, Vol. 126, 2006

[21] JFE Systems, Inc. website: http://www.jfe-systems.com/products/thundersafety/higairei.html

[22] Technical data from Otowa Electric Company, Ltd.: http://www.otowadenki.co.jp/technical/04surgenoise.php

[23] "Lightning Surge Status and Countermeasures," Tokio Marine and Nichido Risk Consulting

Co. Ltd.:
http://www.tokiorisk.co.jp/risk_info/up_file/200404232.pdf

[24] NEDO Energy and Environment Policy Department, "The adoption of wind power generation equipment in Japan":
http://www.nedo.go.jp/enetai/other/fuuryoku/index.html

[25] "Type Approval Scheme for Wind turbines Recommendation for Design Documentation and Test of Wind Turbine Blades," by Danish Energy Agency, Nov. 2002:
http://www.wt-certification.dk/

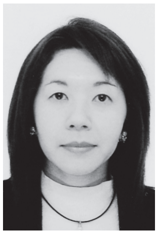
[26] International Electrotechnical Commission IEC 61400-24

[27] Izuno et al., "Research on lightning damage to wind power generation systems," 27th Symposium on Utilization of Wind Energy (Japanese)

[28] Hayashi, S., "Current Status and Future Development of Weather Forecasting," materials from 3rd Seminar on Lightning Damage Risk Reduction Dissemination (Japanese)

[29] Guidebook on Adoption of Wind Power Generation:
http://www.nedo.go.jp/kankobutsu/pamphlets/dounyuu/fuuryoku.pdf

[30] NEDO report:
http://www.nedo.go.jp/enetai/other/fuuryoku/kaigaikokusan_graph.pdf



Kuniko URASHIMA, PhD
Head of Environment and Energy Research Unit, Science and Technology Foresight Centre

Doctor of Engineering. Before joining the STFC in 2003,she worked on the use of plasma technology for the development of disposal and detoxification technologies for environmentally hazardous materials at a Japanese electric machinery manufacturer, and universities, national research institutes, and corporations in Canada, USA, and France. Her current research primarily addresses the entirety of the world's environment and energy issues.

(Original Japanese version: published in April 2007)