4.10 Alternative Power Supply and Lightning Protection

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1. Introduction

1-1 Feasibility study on micro-grid system

The establishment of a NOx-free alternative power supply is a long-term goal of the Mt. Fuji Research Station, and therefore we conducted a feasibility study on a micro-grid system. The most promising NOx-free alternatives are solar batteries and wind generators. Recent development in these fields has enabled domestic use of a micro-grid system—a combination of rechargeable batteries and solar and wind generators—at a reasonable price. Mountain huts can provide a good test environment for investigating the feasibility of solar and wind power utilization in mountainous conditions at 2000-3000 m a.s.l. and on steep slopes. From the investigation, it was found that the micro-grid system at mountain huts was feasible, although it was a small-scale system.

As a next step, power generation was simulated using 30 years of meteorological data at Mt. Fuji to investigate the benefits of a micro-grid system. The results were very promising. As shown in Fig. 4.10-1, wind and solar generation were complementary. At high altitude such as atop Mt. Fuji, UV intensity from May to August is 20-30% higher than at low altitude. Conversely, wind strength is lowest in August, meaning we can now utilize mainly solar power in summer and mainly wind power in winter, allowing for constant power generation. When the simulation was extended to see the number of generators needed for 24 h, we found that 5-10 solar generators, 4-8 wind generators, or 3-6 solar + wind generators would be sufficient to generate 12-24 kWh/day, enough to operate the instruments alone. When manual operation is assumed, the numbers increase to 13-18 solar, 10-14 wind, or 7-10 solar + wind generators in order to generate the higher expected amount of 32-44 kWh/day.

We next tried to operate an actual micro-grid system at the summit of Mt. Fuji in 2009.

1-2 Unique characteristics of Mt. Fuji: Why we had to give up wind generation

A simple micro-grid system was purchased in 2009. The electricity generated by the wind generators was designed to be stored in the system's lead-acid batteries. We started testing the system at Tarobo, located at 1300 m a.s.l. on the southeast slope and found that the power generated was equivalent to that estimated by the initial simulation. Given our expectations for wind power, these results were very encouraging. We then consulted with the relevant authorities and administrative officials for Mt. Fuji, the Ministry of the Environment, and the local government regarding the safe installation of the micro-grid system. We were warned about operating the system during the high visitor season, especially on narrow trails and in steep areas, which we complied with to the greatest extent possible. The wind power generator was improved to the "Mt. Fuji model"; the high supporting post of the original system was converted to a shorter one for safety and the propellers were painted brown for landscape preservation.

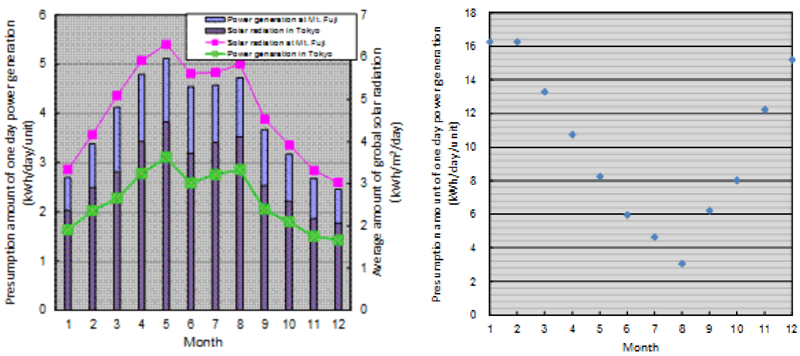

Fig. 4.10-1: Simulated monthly power generation by wind and solar power
Left: Simulated daily wind power generation. Right: Simulated daily solar power generation and global solar radiation at Mt. Fuji and in Tokyo.

Fig. 4.10-2: Views of the micro-grid system at the Mt. Fuji Weather Station (2009)

However, during the week of the experiment in summer 2009, wind conditions were very calm, which may have been favorable for climbers and other researchers but the winds were too weak to generate a sufficient amount of electricity for the collection of useful data. There were also several problems with the wind system. Maximum wind speed at the summit has been recorded at over 60 m/s, which we must prepare for to avoid accidents involving the crowds of climbers. It was also difficult to find a suitable installation site at the summit, which has loose gravel and permafrost rather than the strong rock floor needed to anchor the system. Lastly, the issue of icing on the propellers in winter needed to be considered. Given our results and the scope of these issues, we ultimately concluded that it would be better to avoid wind power generators for now and wait for a more suitable Mt. Fuji model to be developed.

1-3 Solar panels show promise

In the 2009 summer research campaign, we also tested solar panels on top of the water tank near Building 3 of the weather station (Fig. 4.10-3). The results of a 25-day power generation experiment (June 24-August 17) indicated that these panels are a promising alternative power supply at the summit. Power generation took place from 06:00 to 18:00, yielding daily average maximum power generation of 40 W and daily average electricity

Fig. 4.10-3: Four solar panels and an ozone monitor installed on the water tank (2010)

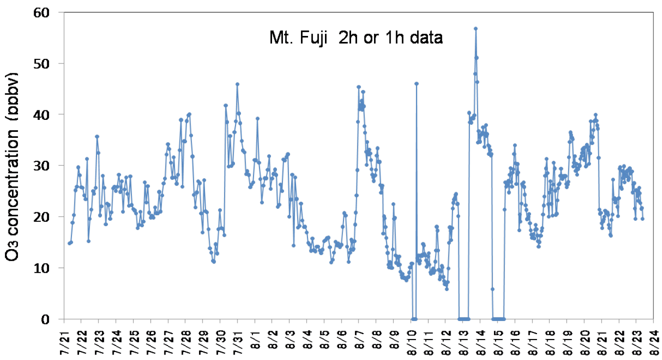

Fig. 4.10-4: Ozone concentration measured by an ozone meter connected to solar panels (July 21-August 23, 2010)

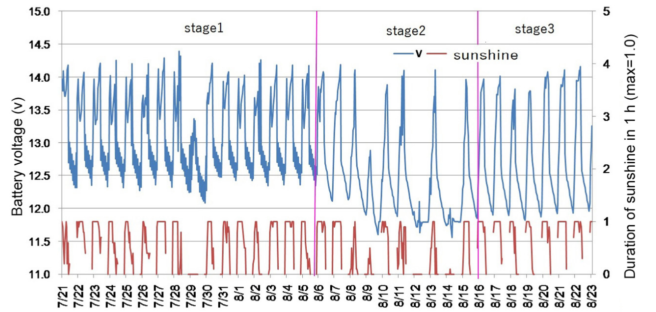

Fig. 4.10-5: Battery voltage and duration of solar radiation (July 21-August 23, 2010)

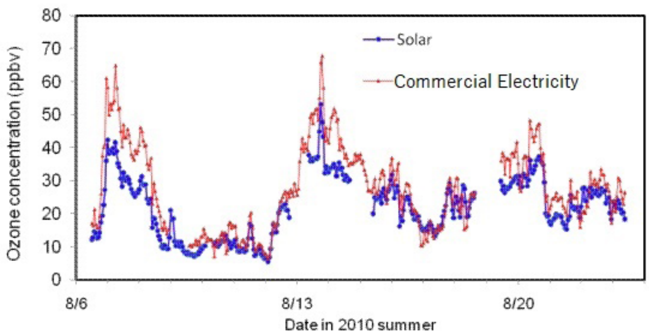

Fig. 4.10-6: Comparison of two ozone monitors: one connected to solar panels and one to commercial electricity

generation of 228 Wh. This is roughly enough power to operate a notebook laptop for 4-5 h or a 20-W LED light for 20 h, and is more power than we expected to generate given the system specifications. A remarkable finding was that the change in power generation due to the change of sunshine hours was small. This was because of the large contribution of ultraviolet rays to power generation at the summit of Mt. Fuji. Solar panel power generation is generally reduced by environmental conditions such as geographical effects, but there is no geographical shading at the summit of Mt. Fuji, so yields were high. Also, during the experimental period, the average temperature at the summit was stable at about 9.5°C, which might have been favorable for stable power generation.

1-4 Long-term operation of an ozone monitor using solar batteries

Based on the success of the experiments conducted in 2009, in 2010 a simple ozone monitor was connected to a micro-grid system of 4 solar panels and a cold-proof battery, installed on the same water tank outside Building 3 of the weather station. Measurement was successfully performed for 34 days (July 21-August 23, 2010) (Figs. 4.10-4 and 4.10-5).

The experiment was planned to include three stages to maximize the data obtained on energy saving operations (Fig. 4.10-5). In stage 1 (July 21-August 6), intermittent on/off switching was tested every hour, to shorten the operation time to half. Another ozone measurement was performed inside the weather station building by Dr. Shungo Kato, to provide a comparison with the ozone meter's measurement and check the accuracy of the meter's data (Fig. 4.10-6).

The ozone monitor was calibrated later when the instruments were carried off the mountain to the Global Environmental Center at NIES. The experiment showed that intermittent measurement every hour yielded similar results to continuous measurement; intermittent measurement is thus very promising in the extreme environment at the summit.

Stage 2 (August 7-16) involved continuous ozone monitoring, with the addition of an additional safety system that would shut off the monitor when there was not enough solar radiation to produce the necessary electricity. Within the experimental period, on August 13-15, the safety system worked well, showing an ozone concentration of zero for these days. This experiment also provided fundamental information on the amount of electricity needed for measurement.

In stage 3 (August 16-23), the safety system was removed to see whether ozone values would be irregular when solar radiation was insufficient, Unfortunately, however, solar emission was high enough during this period to cause no irregular ozone values. We may repeat this test when we expect bad weather conditions.

The many valuable research results of this experiment showed that ozone determination at the summit of Mt. Fuji could be performed with an independent electric power supply. However, this still left one major problem to overcome: how to avoid lightning damage.

2. Lightning protection

2-1 Lightning at the Mt. Fuji Weather Station

The weather station is constructed at the highest peak in Japan (3776 m above sea level) and consists of 5 buildings built on bedrock. Building 1 is a steel-framed two-story structure which had housed the former radar dome until 2001. Buildings 2 and 3 are two-story aluminum monocoques. Building 4 is a one-story steel frame attached to Building 1, serving as the power supply section, and Building 5 is a one-story temporary steel frame construction. Altogether, the structures occupy a 27 m × 60 m area. After consulting an old and rather inaccurate wiring diagram, we investigated the electrical resistance between metal components, the condition of the grounding wiring system, and the gauge of the grounding wires at the weather station. This was not easy to do because atmospheric pressure is only 650 hPa at the summit, making it physically difficult to move quickly or carry many instruments. It took two summer seasons to complete the wiring map, carrying back the sketches and climbing the mountain multiple times to confirm the measured data. The results showed that the grounding system at the Mt. Fuji Weather Station consists of three parts: the building foundation, the ground conducting wires running down the slope of the rock base, and the grounding wire conductor connected to the foot of the mountain. Even though the buildings are built on bedrock, there is permafrost in the rock and the ground resistance was read as 300 Ω, which was the upper limit of measurement. However, the resistance at the foot of the mountain was very small. The results showed that when lightning strikes a building, the electric current flows through the foot of the mountain. The design was intended to protect the buildings from lightning, but in reality, this setup causes the buildings to act as a lightning "collector". As in Benjamin Franklin's famous 1752 kite experiment involving a metal key bound to a kite via a long string attached to a Leyden jar, the Mt. Fuji Weather Station, located high on the summit and connected to the foot of the mountain by a long wire, serves as a "kite" that gathers lightning.

This helps explain the large number of lightning strikes. When the Japan Meteorological Agency maintained the station, many researchers felt their hair stand on end or saw sparks between the distribution switchbox and metal part of the adjacent washing vessels when a thundercloud was over the building, even when they were indoors. These phenomena can be explained as the effects of the lightning entering the weather station through a gap in the Faraday cage (Faraday hole). There are three problems in establishing good lightning protection at the Mt. Fuji Weather Station. First, the ground connection is easy for lightning to strike; because the electrical grounded system is not a Faraday cage, its wires provide an easy "way in" for the lighting (Fig. 4.10-7). Second, when lightning current flows to the grounding conductor and a voltage drop occurs, a potential difference will develop between the ground terminals of measuring equipment connected to the grounding conductor. Third, there is contact failure between components, such as that caused by the heat insulation between the metal roof and metal structure, and these contact failures impede electrical conduction.

2-2 Establishment of ideal lightning protection system

The ideal way to protect the weather station from lightning is to make the building into a perfect Faraday cage. For the observation equipment outside the station, it is necessary to place it in the area covered by the rolling sphere method by using a lightning rod or Faraday cage-structured building that functions as a lightning rod. The lightning current should flow to the ground via the grounding wire. However, the Faraday cage structure fails because many observation instruments are used outside the building and the building interiors are connected by cables. Thus, in order to realize ideal protection, we devised a new method based on mutual inductance and a new cable and connection terminal.

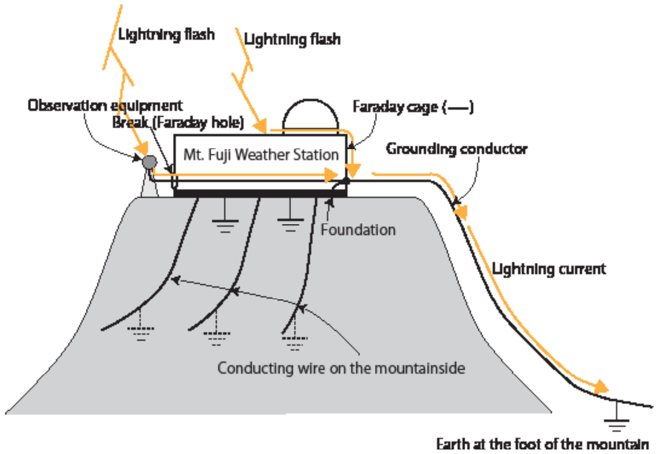

Fig. 4.10-7: Ground system at Mt. Fuji Weather Station

Because normal houses will likely have small-scale solar systems installed in the near future, lightning protection will become an urgent issue to be solved and our research can likely contribute in this regard. Our findings could also be applied to other common lightning-related inconveniences, such as train stoppages due to lightning-related blackouts. To this end, we would like to start collaborating with researchers in related fields. We started measuring the electric current of lightning strikes at the summit of Mt. Fuji from 2012, with the aim of determining the actual current of lightning strikes on the mountain.