Expectations for Large-scale Solar Power Generators

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Abstract

Although expectations for solar power generation have increased in recent years, along with the rising importance of preserving the global environment, its introduction has been mostly limited to small-scale residential facilities. To prevent further global warming in the future, large-scale solar power generation systems must be introduced. This article describes the effects of introducing large-scale systems and the accompanying problems.

1. Need for solar power generation

The situation surrounding solar power generation has changed greatly in the 50 years since silicon solar cells were invented in the United States in 1954. Initially, the mounting of solar panels on artificial satellites caught the public's eye. In the days when it was still the Nippon Telegraph and Telephone Public Corporation, NTT began using solar generation systems to provide power at unmanned microwave relay stations on isolated islands and for remote telecommunication systems where commercial electric power was not available. The introduction of solar generation systems was promoted from the viewpoint of energy security as part of Project Sunshine following the first oil shock. After the 1980s, an aggressive policy for preventing global warming by establishing an outline for introducing new energy sources was put into effect in 1994.

Thus, the purpose of solar power generation has changed greatly over the mere 50 years since its invention. As a result of the new energy industry vision put forth by the Agency for Natural Resources and Energy of the Ministry of Economy, Trade and Industry in June 2004 [1], the expectations for solar power as a new energy source that will allow continued energy self-sufficiency have been steadily increasing.

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The worldwide production of solar cells amounted to a generating capacity of about 744 MW in 2003. Of that, about 364 MW, or close to 50% of the world total, was produced in Japan, making Japan the world's largest solar cell producer. Furthermore, Japan also has the world's largest installed solar power generating capacity, which totaled 637 MW in 2003 [2]. That is twice the amount installed in Germany, which ranks second. Nevertheless, more than 80% of the facilities in Japan are small-scale residential systems. To contribute even more to the prevention of global warming in the future, the introduction of large-scale power generation systems that can produce a megawatt or more is an urgent task.

2. Trend of large-scale solar power generation

In many countries, solar power generation has been developed up to the level of residential systems, but the introduction of large-scale systems is progressing and more than 30 facilities with a power generation scale of 1 MW or more have been introduced, mainly in the United States and Germany. The largest one operating in the world is the giant 5-MW system in Germany. This trend toward larger systems is steadily accelerating, and in the near future, the world share of working solar power generation systems will be dominated by Europe and the United States because Japan differs greatly from those countries in terms of policies and organization that provide substantial support and legislation for solar power generation.

The fact that solar power generation systems in

Japan have developed mainly around residential systems can be attributed to Japan being a small country, with more than 70% of its land being mountainous, and to the late establishment of an organization responsible for the adoption of solar power generation. The introduction of large-scale systems has been promoted mainly by field tests conducted by NEDO (New Energy and Industrial Technology Development Organization), and about 30 economically feasible systems with outputs of 100 kW or more have been established over the last ten years [3]. Nevertheless, Japan also recognizes the expectation that the introduction of large-scale generating systems will play a major role in preserving the global environment. With the increasing environmental consciousness of various local governments in recent years, systems of 1 MW or more are gradually being introduced at water treatment facilities and so on. In addition, a 555-kW power generation system was introduced at the NTT Central Training Institute (now NTT East Training Center) in 1997 [4],[5].

We have been commissioned by the Ministry of the Environment to research the feasibility of large-scale solar power generation systems. Furthermore, with the Russian ratification of the Kyoto Protocol, a climate change framework treaty that strongly influences the future of global environment preservation, that Protocol became effective on February 16, 2005. The significance of that event is that expectations for solar power generation will increase even more in the future.

3. Overview of large-scale solar power generation systems

Our investigation of large-scale solar power generation systems does not stop at the simple construction of the system, but includes determining the economic feasibility of power generation as well. The power generation scale of 1 MW or higher provides the basis for this study. The basic system configuration is shown in **Fig. 1**. The area required for megawatt-scale facilities is 15,000 m^2 of level ground. The system also has multiple inverters for converting the direct current output of the solar cell to alternating current for connection to the commercial power grid. The stabilization unit protects the grid from excessive fluctuation in the output from the solar power generation system caused by sudden changes in sunshine. It consists primarily of storage batteries and related equipment. We are also studying using it for output control to provide power at times when the load requires maximum power.

4. Toward solving the problems

Conventionally, the electricity produced by solar generation systems is used locally, mainly for private consumption, and any excess is sold to the power company.

In the approach studied here, all of the generated electricity is sold. We investigated the feasibility of power generation based on this premise. The specific

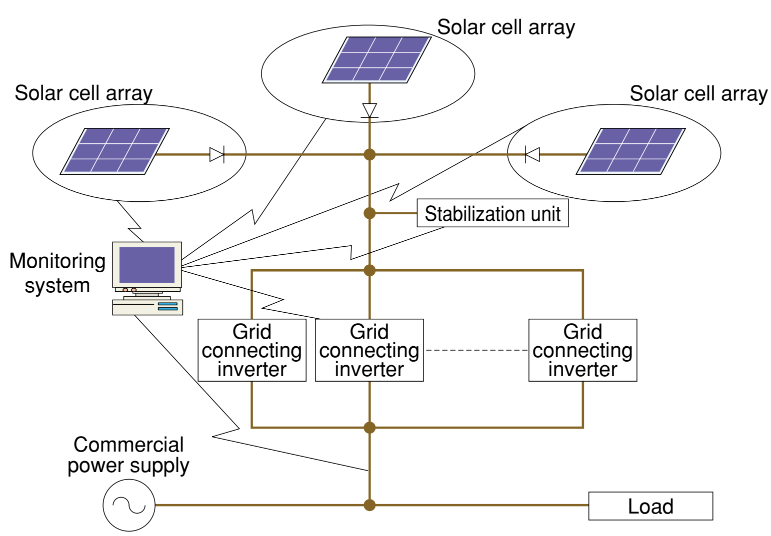

Fig. 1. Basic system.

Table 1. Specific evaluation tasks.

Commercial feasibility	Technological development
• Study enterprise forms • Study government support schemes • Calculate trial investment results • Study relevant laws and organizations • Hold overseas surveys and conferences • Investigate candidate sites • Consult with electric power companies	• Study stability relative to the commercial grid and analyze protection collaboration for facilities distributed to maintain the system • Analyze the degree of distribution of facilities, stability, and economic cost • Analyze high-frequency wave factors • Analyze optimum operation at times of sudden weather changes • Analyze optimum control of distributed power sources and predict power generation for the next day and for the next several hours using weather forecasts • Study countermeasures against lightning damage and analyze the effects of electromagnetic waves • Analyze the degree of environmental contribution taking into account LCA elements • Analyze the system lifetime

LCA: life cycle assessment

evaluation tasks are listed in **Table 1**. Because the greatest problems for solar power generation are achieving economic feasibility by lowering the cost of power generation and system reliability in power generation, our evaluation focused on operations and technology. The individual tasks, however, are not independent, but are intimately related, so we performed a comprehensive analysis and evaluation in the final step.

One factor in the practicality of wind power generation, which also uses natural energy, is the selection of a location where wind conditions are suitable and a large-scale power generation facility can be constructed to gain the merits of scale. For solar power generation, however, power can be generated anywhere as long as sunshine is available. The Japanese archipelago ranges from Hokkaido in the north to Okinawa in the south, and the solar energy averages 1 kW/m^2. The amount of time for which power generation is possible also varies, ranging from about 1000 to about 1400 hours per year [6]. The efficiency of solar cell power generation is, at best, 18% per cell. The cells are made into modules (panels) and the modules are combined into arrays (i.e., installed on a rack that accommodates the modules). When those are combined with conversion equipment in a system, the output efficiency is still at least 10%, taking into account wiring loss and other factors.

From the above information, we can compute the amount of power generated per unit area. Assuming the overall cost of current systems, the economic feasibility faces severe challenges. Accordingly, government support is an important factor in commercial feasibility. There are also legislative constraints on commercial power generation, such as the Electric Power Industry Act. Further progress in commercialization requires a new legislative support scheme for solar power generation enterprises. To evaluate technological feasibility, on the other hand, we considered technological development together with improvements in economic feasibility, such as improving the power generation efficiency of the solar cells and raising the system operation ratio to the level of a reliable commercial system.

5. Requirements for large-scale power generation

A power generation enterprise requires a large site. Acquiring the use of such sites requires tremendous cooperation from local governments. We therefore investigated a regional new energy vision centering on local governments. Candidates for sites include leasing the rooftops of public buildings or unused fields belonging to local governments and corporations, as illustrated in **Figs. 2** and **3**.

For economic feasibility, centralized systems are generally beneficial, but an increase in cost is assumed for large-scale systems. From the viewpoint of reliability, a distributed system configuration is employed to maintain the level of power generation when a system fails. When the installation space is limited, such as on public building rooftops, a large-scale system is configured of distributed installations of solar cells on multiple buildings. When there are few constraints on installation space, such as on an unused field, an array of solar cells with a total capacity of a megawatt or more can be installed in one

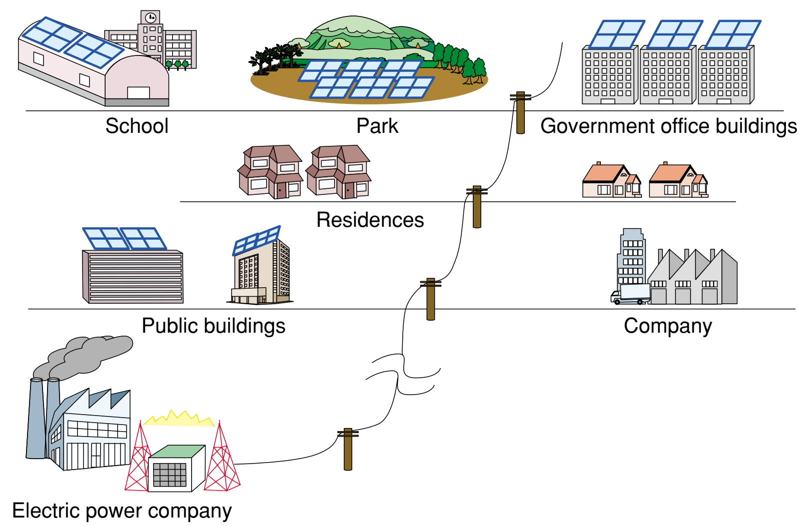

Fig. 2. Installation on public buildings.

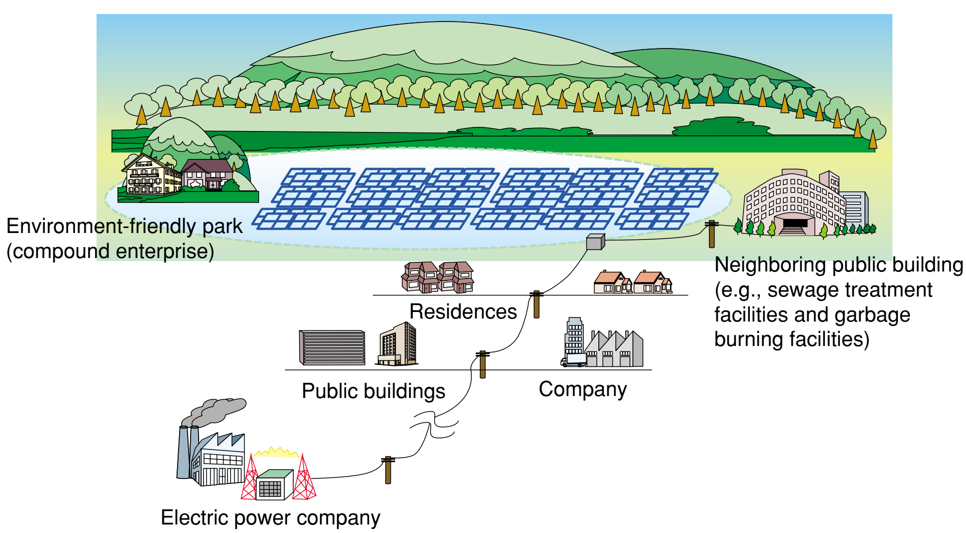

Fig. 3. Installation on unused field.

place. At some scale, however, distributed installation of solar cells will become necessary. Therefore, we are investigating large-scale systems in which the relationships between the degree of distribution and economic feasibility and reliability are clear. Furthermore, although we are basically investigating only the solar power generation industry, we are also looking into compound enterprises, such as solar power generation combined with environmental education and sightseeing.

6. Making the most of technology

An overview of solar power generation facilities introduced by the NTT Group is shown in **Fig. 4**. In the NTT Group alone, there are 112 systems totaling 1.7 MW. Combined with orders from customers, the total is 4.7 MW. The system output ranges from as little as about 100 W to the 555-kW system at the NTT East Training Center. We also have considerable experience in system design, such as the 844-kW system for the National Institute of Advanced Industrial

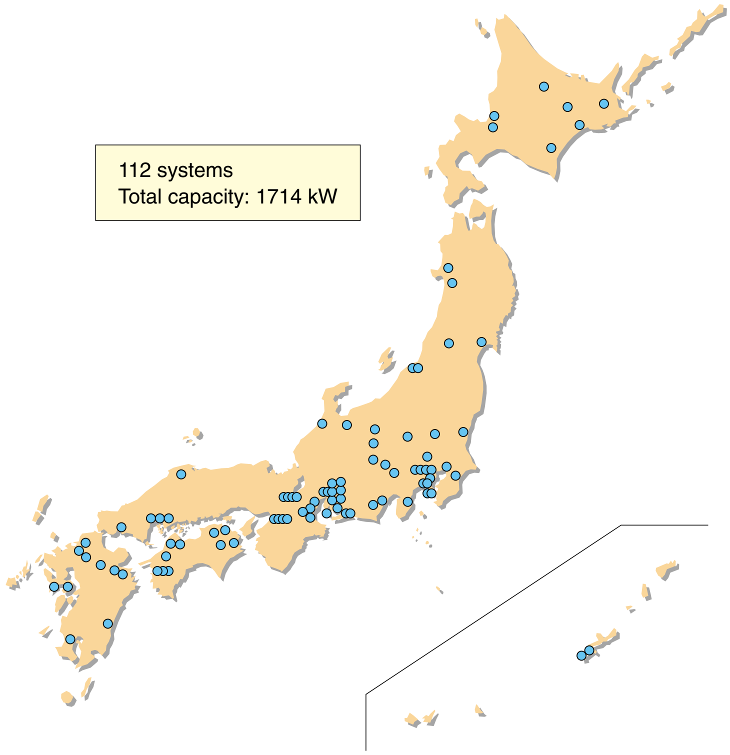

Fig. 4. Overview of solar power generation systems in the NTT Group (end of 2003).

Science and Technology. Our expertise will be useful in creating large-scale power generation enterprises.

7. Expected benefits

A 1-MW solar power generation facility can be expected to generate 1.10 million kilowatt-hours (kWh) per year, which is equivalent to the annual electricity usage of 320 ordinary households. (The actual output varies from about 1.0 to about 1.40 million kWh, depending on the region. Moreover, current solar panels are installed at a fixed tilt angle, so if the angle is adjusted to the optimum each month, an increase in power generation of 15% or more can be expected.) If this replaces electricity produced by conventional power plants, the expected reduction in CO_2 emissions is approximately 420 tons for electricity produced by all sources and 760 tons for thermal power generation. If we estimate the area of forests required to absorb that much carbonic acid from all electric power sources, it is equivalent to 102 hectares of forest according to an investigation conducted by the Ministry of the Environment.

In conclusion, solar power generation can be expected to have an important effect in preserving the environment. It is an excellent power generation system that is not impeded by the problems associated with wind power, such as constraints on installation sites, generation of noise, and danger to wildlife (birds).

8. In the 21st century

The 21st century is being called the era of the environment. Japan's outline for introducing new energy sources calls for the introduction of solar power generation systems producing a total of 4820 MW by the year 2010. Therefore, it will be necessary to introduce 7.5 times the current installed capacity (637 MW as of 2003) over six years to achieve this goal. This might be seen as a bold plan, but energy consumption is increasing along with economic development, while the exhaustion of fossil-fuel energy sources is becoming a reality. In addition, this policy is necessary considering the need to preserve the global environment. It is not excessive to say that the future of the earth depends on effective use of solar energy, which is uniquely inexhaustible.

Although the current status of solar power generation is characterized by many problems, including economic feasibility, we take a forward-looking perspective in continuing our research toward achieving commercial solar power generation.

References

[1] Energy Conservation and Renewable Energy Department, Agency for Natural Resources and Energy (ANRE), "The New energy industry vision," 2004 (in Japanese).

[2] Japan Photovoltaic Energy Association, http://www.jpea.gr.jp/ (in Japanese).

[3] NEDO (New Energy and Industrial Technology Development Organization), http://www.nedo.go.jp/index.html

[4] R. Tanaka, Y. Kohama, J. Kato, and Y. Sajika, "Solar Power Systems," NTT REVIEW, Vol. 9, No. 4, pp. 38-43, 1997.

[5] R. Tanaka, "Spread of Multimedia and solar system," SOLAR ENERGY, Vol. 22, No. 6, pp. 2-8, 1996 (in Japanese).

[6] NEDO (New Energy and Industrial Technology Development Organization), "The introduction guide book for photovoltaic generation," 2000 revised edition, pp. 7-10, NEDO, Japan, 2000.

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