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Creation of Power Supply Systems Incorporating Distributed Power Sources

— A Quest to Construct Systems Meeting Regional Demands in Japan —

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5.1 Introduction

Supported by the ever-increasing demand for electricity, large-scale centralized power supply systems have been enhancing power generation efficiency by expanding their operations, which in turn has improved their cost effectiveness, eco-friendliness and credibility. On the other hand, there is a growing movement to make use of distributed energy supply systems such as fuel cells and biomass as a means to curb global warming[1].

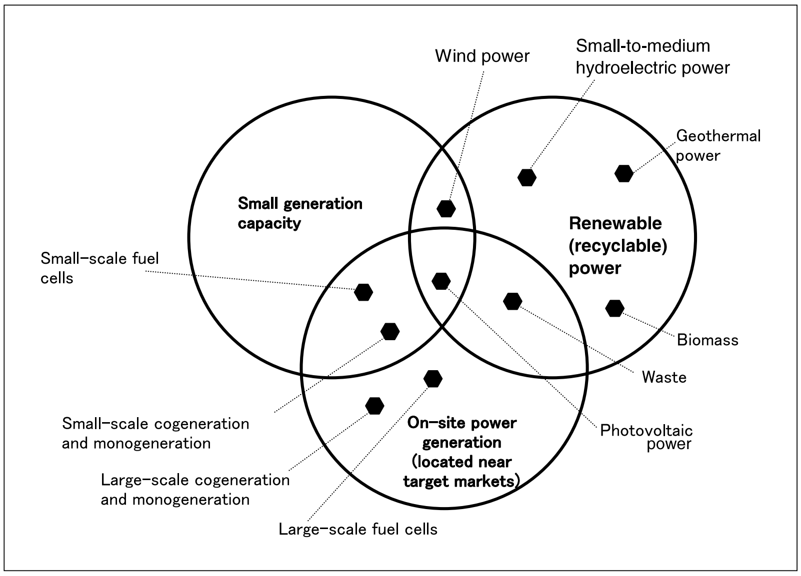
"New-energy Measures in the Future," a report prepared in June 2001 by the New Energy Subcommittee under the Advisory Committee for Natural Resources and Energy, established an innovation: it incorporated hydroelectric power generation (excluding pumping-up power generation) and geothermal power generation into the "supply-side new energy*1" to establish a category termed "renewable energy" with an aim to increase its share of the total supply of primary energy from 4.9% in 1999 (29 million kl out of 593 million kl) to about 7% in 2010 (about 1.4 times the amount in 1999, or 40 million kl out of 602 million kl) on a crude-oil basis. With regard to the "demand-side new energy,*2" namely natural-gas cogeneration and fuel cells, the plan is to increase their share by 3.1 times (4.64 million kW) and 183 times (2.2 million kW), respectively, compared with the 1999 levels. In the meantime, the RPS (Renewable Portfolio Standard) system*3 came into full operation on April 1, 2003. This system mandates power suppliers to use a certain amount of new energy in proportion to the amount of power they sell - they are obliged to use new energy equivalent to 1.35% (or 12.2 billion kWh) of the total amount of power they will sell in 2010.

The market for distributed power sources centered on cogeneration systems using generating machinery (gas engines and turbines, etc.) is expected to grow in the future.

In response to the recent deregulation in the electric industry*4 and the introduction of the RPS system, the circumstances surrounding Japan's power supply system is changing. While the conventional power supply system is relatively simple in its structure (i.e., a one-way flow, from supply to conversion and utilization of power), a system incorporating distributed power sources involves backflow of power - distributed power sources supply power to the electricity grid (i.e., energy flows back and forth through the system). In this case, however, power fluctuations of distributed power sources may have an impact on the grid to which they are connected[2]. It is thus necessary to create a power supply system that harmonizes distributed power sources with the power of grids.

This report, therefore, takes a broad view of the characteristics of distributed power sources in the framework of Japan's current power supply system, and points out what is needed for the future power supply system that is expected to incorporate an increasing number of distributed power sources. Furthermore, it provides an overview of the recent trends in the development of power supply systems incorporating distributed power sources in Japan, Europe and the U.S., and explores possibilities for constructing power supply systems responding to regional demands.

Figure 1: Classification of distributed power sources



Source: Author's compilation based on a reference[3]

Table 1: Characteristics of large-scale power sources and distributed power sources

	Power sources	① Power quality (frequency) characteristics	② Cost effectiveness	③ Eco-friendliness (CO_2 emissions)
Large-scale power sources	Nuclear power	— (see Note 1)	○	○
	Thermal power	○		×
	Hydroelectric power			○
Distributed power sources	New energy	×	△	
	Cogeneration system	△	○	△

Note 1: Base supply capacity

5.2 The Characteristics of distributed power sources in power supply systems

While large-scale power sources generally refer to nuclear and thermal power generation, distributed power sources include small-to-medium on-site power generation (located near target markets) that is renewable (recyclable) and limited in output power, as shown in Figure 1 (there is no clear definition at home and abroad of "distributed power sources" in terms of generation method and capacity).

Table 1 shows the power quality (frequency) characteristics, cost effectiveness and eco-friendliness of both large-scale power sources and distributed power sources. Of distributed power sources, photovoltaic and wind power generation is subsidized by the government and their surplus power is purchased by electric power companies because of their eco-friendliness. In particular, Japan leads the world in the introduction and total output of photovoltaic power generation. With respect to cogeneration systems, the ESCO (Energy Service Company) project is expanding, offering energy-saving services to the business sector including office buildings -e.g., improving energy-use systems by installing cogeneration systems, quantifying energy-saving effects after installation, and controlling the operations of the systems. This project enjoys part of the profits generated by energy-saving measures as a reward, which indicates that the running costs of cogeneration systems are approaching those of large-scale power sources.

With an increasing number of distributed power sources connected to the grid, the power quality of the entire power supply system may fluctuate, as mentioned earlier.

"Power quality" usually refers to the quality of voltage or frequency. An increase in power supply from distributed power sources to the grid (back flow of power) raises the voltage of the grid. There is thus a need to regulate the voltage (low voltage: 101V±6V) through regulators installed in the distribution lines or by the distributed power sources themselves.

With regard to frequency, a major problem involves frequency fluctuations caused by the connection of unstable power sources to the grid. Power demand fluctuates daily and seasonally[4], and hence the output of thermal power generation (oil, LNG, etc.) and hydroelectric power generation (pumping-up type or pondage type) is controlled in response to load fluctuations in order to strike a balance between supply and demand, maintaining a frequency of 50Hz or 60Hz. Distributed power sources, on a relatively limited scale of introduction, need not to contribute to maintaining frequency (which is not the case when they are introduced on a large-scale basis).

Of distributed power sources, those using generating machinery such as gas turbines and engines are highly controllable and can contribute to maintaining frequency technically. These power sources, however, are not used for this particular purpose due in part to their relatively limited number. With regard to new energy sources such as photovoltaic and wind power generation, their stability needs to be secured if they are to contribute to maintaining frequency, because their output fluctuates in response to weather conditions.

5.3 Requirements for the future power supply system

Japan's power supply system is expected to evolve in the future, from the existing, relatively simple system into a complex system comprising of various factors -i.e., a shift to create a new system incorporating distributed power sources into centralized ones.

This chapter addresses requirements for the future power supply system, which is expected to become complicated in response to the introduction of distributed power sources.

5.3.1 The viewpoint of cost minimum

In introducing various types of distributed power sources in the future, there is a need to create a mechanism that minimizes incremental costs.

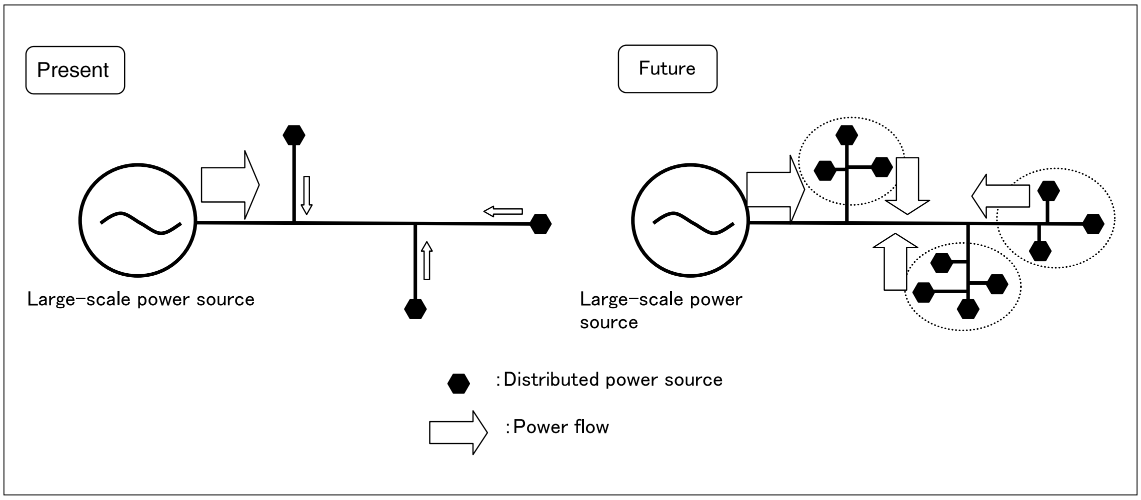
"The Framework for an Ideal System of the Future Electric Industry," a report prepared in February 2003 by the Power Industry Subcommittee under the Advisory Committee for Natural Resources and Energy, argues that it is appropriate to facilitate power supply by making use of distributed power sources and that measures should be taken to prevent detrimental effects to society associated with dual investment in distribution facilities. "Dual investment" in this particular case refers to capital investment by electric power companies (i.e., existing suppliers) and by new comers planning to install distributed power sources, whose payout period is relatively short.

In the meantime, the RPS system enforced in April 2003 regulates the use of power generated by new energy (over the next three years or so) to the extent that it does not require specific measures for the grid. Underlying this policy is that specific measures required for the grid as well as the distribution of their costs have yet to determined. Thus, incremental costs associated with the increasing introduction of distributed power sources remain an issue in constructing a system that is required.

In consideration of these circumstances, there is a need to pursue regional economic benefits (i.e., energy conservation and cost reductions through the installation of distributed power sources within the precincts of users taking a cue from the ESCO project) and to minimize an increase in costs for the entire power supply system.

As shown in Figure 2, the existing grid system is designed to supply power from upstream (large-scale power sources) to downstream. However, the introduction of distributed power sources will result in a multi-directional power flow. For this reason, it becomes necessary to: consider multiple distributed power sources as one unit; conduct evaluations and analyses based on simulations; and assess the impact of the introduction on cost efficiency and power quality.

Figure 2: Example of increased introduction of distributed power sources



5.3.2 The viewpoint of users

Since power failures happen infrequently in Japan, the need for low-quality, low-cost power may arise in the future. In other words, demand for low-cost power with sporadic failures may outpace demand for high-quality power with enhanced credibility in supply. For that matter, it should be necessary to develop technologies for supplying power in accordance with the need of each user (in terms of cost, credibility and quality), rather than pursuing standardized credibility and quality.

5.4 R&D efforts to construct power supply systems incorporating distributed powersources

5.4.1 Power storage technology

Methods using power storage equipment are being studied in order to level off the load and stabilize the power generated by new energy power sources (photovoltaic and wind power generation). Power in its nature should be generated and consumed simultaneously, a characteristic often described as “the same amount at the same time” or just “power cannot be stored.” The utilization rates of power facilities, however, can be raised by storing surplus power (during night hours) in power storage equipment, which is released during daytime peak hours to level off the load.

From the viewpoint of environmental conservation, new energy power generation such as photovoltaic and wind power generation should be promoted. But this particular type of power generation usually involves an imbalance between supply and demand because it cannot generate power in accordance with fluctuations in demand. Power storage equipment is one of the means to reduce the instability in such power sources.

Table 2 shows power storage technologies currently under study at home and abroad, each of which is designed to store “otherwise unstorable power” by converting it into other energy such as kinetic energy, potential energy and chemical energy.

In addition to already commercialized centralized power storage equipment such as pumped hydropower, there are growing expectations for distributed power storage that aims to reduce the instability of distributed power sources (photovoltaic power generation, etc.) located near the market. Whatever the case may be, the effective utilization of power storage equipment in the power supply system requires considerable cost incentives that would encourage capital investment in this technology.

5.4.2 R&D trends in energy network systems

In connecting distributed power sources to the grid in Japan, measures are taken not for the gird but for distributed power sources in compliance with the technical guidelines for the connection to the grid - an arrangement to maintain supply credibility and safety of power. These measures, however, are unique to each distributed power source; the increased introduction of distributed power sources would result in connection

Table 2: Power storage technologies under study

<table>
<tr><th colspan="3">Energy storage mode</th><th>Power storage method</th><th>Issues, etc.</th><th>Scale</th></tr>
<tr><td rowspan="5">Mechanical energy</td><td>Dynamic</td><td>Kinetic energy</td><td>1) Fly-Wheel Energy Storage : FWES</td><td>• Vibration and noise</td><td>Distributed</td></tr>
<tr><td rowspan="4">Static</td><td>Potential energy</td><td>2) Pumped hydropower</td><td>• Limited location
• Harmonization with surrounding environment</td><td rowspan="3">Centralized</td></tr>
<tr><td>Pressure energy</td><td>3) Compressed Air Energy Storage : CAES</td><td>• Ground ssubsidence
• Conservation of groundwater</td></tr>
<tr><td rowspan="2">Electromagnetic energy</td><td rowspan="2">4) Superconducting Magnetic Energy Storage : SMES</td><td rowspan="2">• Magnetic leakage
• High-temperature superconduction</td></tr>
<tr><td rowspan="2">Distributed</td></tr>
<tr><td colspan="3">Chemical energy</td><td>5) Battery Energy Storage: BES</td><td>• Measures to prevent the leakage of active substances
• Fire defense law</td></tr>
</table>

Source: Author's compilation based on a reference[5]

difficulties due to constraints on the part of the grid. Hokkaido Electric Power Co., Inc. (HEPCO), for instance, announced the upper limit of power supply from wind power generation in order to maintain its power quality: 250,000kW, up 100,000kW from the current level[6]. This in turn raises an awareness of the need for systems free of constraints from the connection to the grid. With the recent progress in power storage technologies as a backdrop, new systems such as the "Demand Area Power System" and the "Flexible, Reliable and Intelligent Energy Delivery System" (FRIENDS) have been proposed in Japan[7,8].

(1) Demand Area Power System

In order to solve the problems related to power quality and other issues associated with the increased introduction of distributed power sources, the Central Research Institute of Electric Power Industry (CRIEPI) proposed the "Demand Area Power System" (see Figure 3) as a new power supply system that makes use of distributed power sources and power storage equipment[7].

This system flexibly accommodates power flow fluctuations caused by an increase in power demand (primarily in cities) and distributed power sources, without complicated control settings.

To control voltage and equalize power flow, the system is primarily composed of a loop grid. Each loop point has a loop controller that controls voltage and power flow. In addition, supply-demand interfaces are installed in the loop grid for each group of users (including distributed power sources) to control distributed power sources, based on the information provided by suppliers and users - an arrangement to pursue cost efficiency.

The Central Research Institute of Electric Power Industry will set up demonstration facilities to materialize this system; the immediate plan is to demonstrate and evaluate the system and to develop the necessary technologies.

(2) Flexible, Reliable and Intelligent Energy Delivery System (FRIENDS)

A research group led by Hokkaido University has proposed the "Flexible, Reliable and Intelligent Energy Delivery System[8]." This system accommodates control, protection and operations appropriate for future power supply systems that are expected to incorporate a large number of distributed power sources, while supplying multi-quality power according to users' needs.

The existing power distribution systems are generally designed to supply standardized power through pole-mounted transformers installed along distribution lines radiating in all directions.

FRIENDS, on the other hand, sets up a "Quality Control Center" (QCC) between a distributing substation and users; it incorporates distributed power sources and power storage equipment to supply various types of power to users -i.e., a service to supply multi-quality power. Each QCC is set up near the users to which it supplies power, and the entire electric energy delivery network is composed of QCCs connected with one another through high-tension distribution lines (see Figure 4).

5.5 Trends in Europe and the U.S.

5.5.1 The U.S.

The Department of Energy (DOE) announced the "Strategic Plan for Distributed Energy Resources" in September 2000[11]. The essence of this plan is to make full use of low-cost distributed energy resources and to construct clean, efficient and reliable energy systems. It also sets out federal and national objectives in developing distributed power sources and their related technologies.

Technological development themes involved are: (1) basic research on combustion systems, etc.; (2) development of technologies for utilizing distributed energy resources (natural gas, renewable energy, etc.); and (3) energy storage and transportation technologies. In addition, relevant systems will be improved to solve institutional problems.

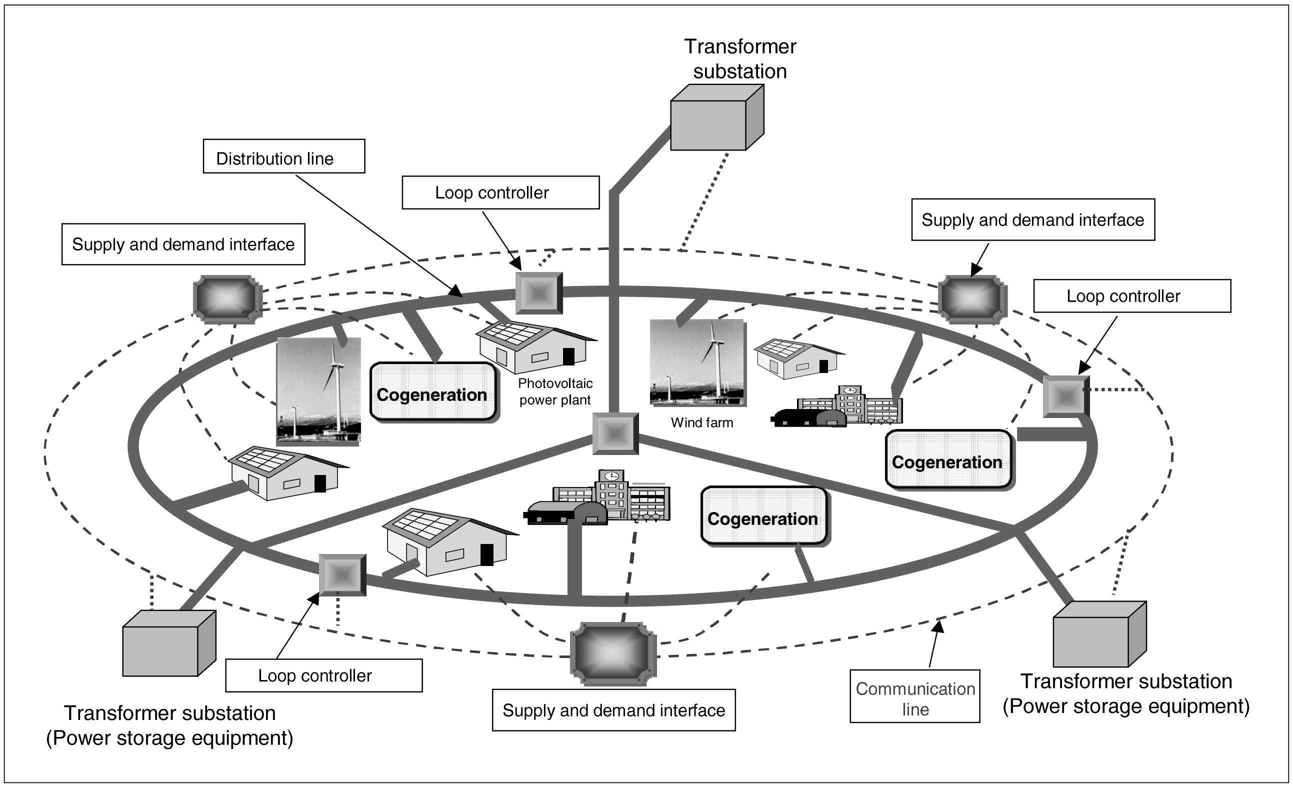
In the U.S., competition has been brought to the power-generation and power-retailing markets, while new billing systems are becoming widespread to encourage competition among power suppliers. On the other hand, there have been restrictions in capital investment in power distribution facilities, which in turn is bringing about unstable power supply and lower power quality (as is evident from the recent serious power failure in California). To address power shortages and surges in power rates, therefore, applications of distributed power sources are being expanded in line with the conventional themes comprising: (1) accommodation of dispersed demand; (2) co-existence with cogeneration systems; (3) maintenance of credibility; (4) maintenance of power quality; (5) management of energy and sales of power; (6) establishment of ancillary services in which distributed power sources and power distribution facilities cooperate with each other to maintain power quality; and (7) sales of power to the domestic power market.

5.5.2 Europe

As an EU Directive was announced in September 2001 concerning the introduction of renewable energy[12], a series of measures to promote distributed power sources are being discussed. Promotional programs for distributed power sources in Europe include the "Target Action Integration Program (2001-2002)," which facilitates the access of distributed power sources to energy network systems, and the "Cluster Integration Program (2002-2006)," which ensures stable supply and credibility through the integration of distributed power sources into the EU and regional distribution networks. The latter program aims to develop next-generation technological programs to create new power supply systems incorporating distributed power sources; it also sets out major technological development themes -i.e., (1) innovative control of stand-alone power generation systems in the case of increased renewable energy and its storage, (2) development of distributed power sources primarily using renewable energy resources, and (3) promotion of a European network project for renewable energy resources and the integration of distributed power sources.

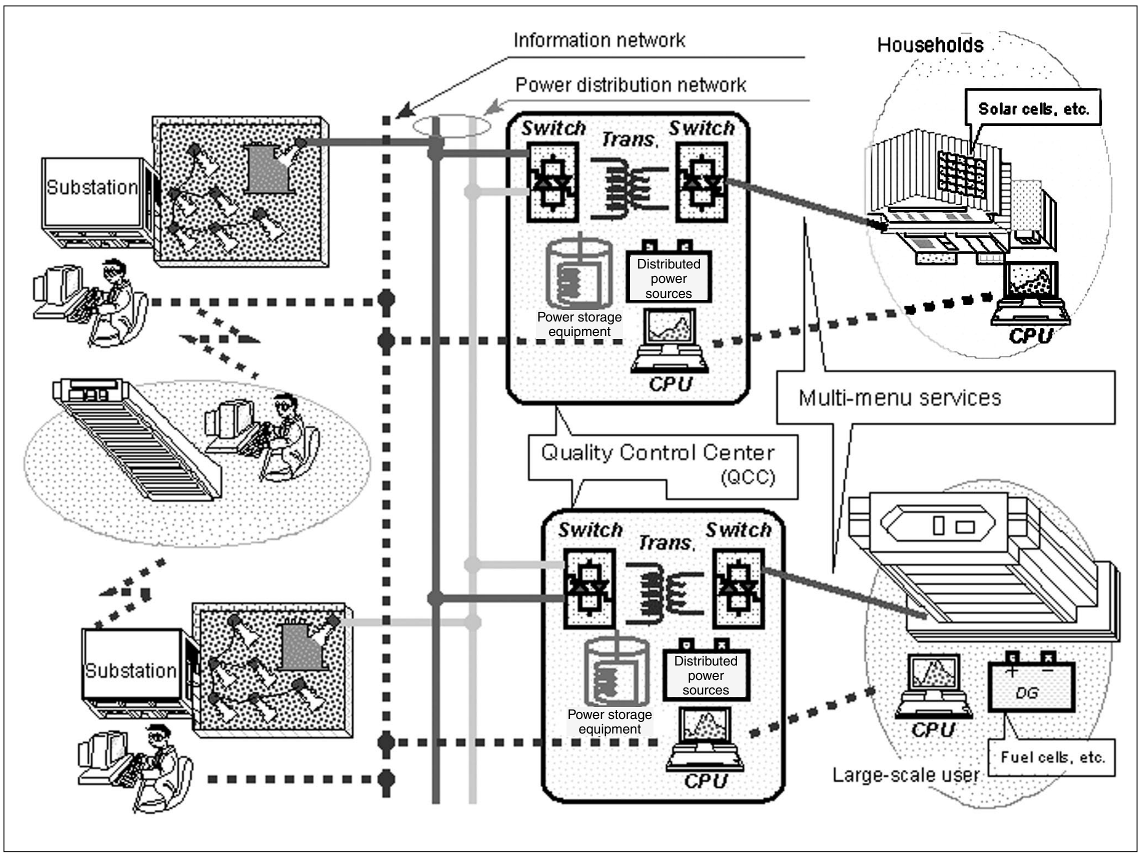
As discussed above, backgrounds in introducing distributed power sources differ between the U.S. and Europe. In the U.S., the recent trend has been to restrict construction of new power plants and to use distributed power sources as a means to ensure stable power supply, which situation can be attributed to the problems such as power shortages and surges in power rates. In Europe, on the other hand, distributed power sources (with particular emphasis on renewable energy) are being promoted from the viewpoint of environmental conservation, an effort to create sustainable energy systems.

Figure 3: Example of Demand Area Power System



Source: Author's compilation based on a reference[9]

Figure 4: Flexible, Reliable and Intelligent Energy Delivery System (FRIENDS)



Source: Author's compilation based on a reference[10]

5.6 Conclusion

Japan's energy policy aims to "ensure stable supply of energy and accommodate the need for environmental conservation and efficiency," which seems difficult to achieve under the current circumstances[13]. The energy suppliers in Japan are increasingly diversified in response to the liberalization of the domestic electricity market; in addition to the existing large-scale power supply system, new comers are branching out into the market and distributed power sources are becoming widespread, which situation is expected to continue into the future, and thus should be taken into account in creating a system for society.

Since Japan shares little in common with other countries in terms of electric power infrastructures, geographical conditions and the availability of energy resources, Japan's power supply system should be tailor-made, paying particular attention to the recent trends in energy policies and technological developments in Europe and the U.S.

In the meantime, relevant factors such as energy demand, wind conditions and the amount of biomass resources differ from region to region in Japan. As mentioned in Section 5.4.2, power supply systems incorporating distributed power sources are designed for specific regions (town/ward/city) or areas (designated areas such as industrial parks). However, it has yet to be determined how additional costs associated with these system will be shared among the parties concerned.

For these reasons, the construction of power supply systems incorporating distributed power sources inevitably involves region-specific approaches, and the cooperation of the municipalities is essential to materializing these systems.

There has been some progress in the system designating special zones for structural reform, in which each party concerned such as a municipality voluntarily implements structural reform in specific areas through the introduction of special regulations in accordance with the regional demand and characteristics. The authority started accepting applications for the plans for these special zones on April 1, 2003. In the energy-related fields, the "Special Model Zone for the Promotion of New Energy" has been applied for the system.

As distributed power sources are usually set up near the market to which the power is supplied, municipalities are expected to play a leading role in sponsoring debates between energy suppliers (electric power companies, constructors and owners of distributed power sources, etc.) and local residents in each region, shedding light on issues and needs unique to each region, and keeping track of the characteristics of the energy resources available in each region - which together will contribute to constructing power supply systems incorporating distributed power sources (through concerted efforts of the municipalities and local residents concerned).

Notes

*1: "Supply-side new energy" refers to power-generation including those using photovoltaic cells, wind power, waste and biomass as well as heat utilization based on heat sources such as solar, untapped energy (snow and ice energy, etc.), waste, biomass, black liquor and waste materials.

*2: "Demand-side new energy" refers to automobiles using clean energy, natural gas cogeneration and fuel cells.

*3: Energy sources to be covered by the RPS system are wind power generation, photovoltaic power generation, geothermal power generation, hydroelectric power generation (limited to conduit type power plants with less than 1,000kW output) and biomass power generation.

*4: Deregulation in the electric industry :
The retailing of electricity was liberalized in March 2000, exclusively for users of special high voltage power (with a receiving voltage of more than 20kV and a usage of more than 2,000kW). In order to provide users with more options, further liberalization is expected to take effect by April 2005, targeting all areas whose demand exceeds 50kW (or by April 2004 for areas whose demand exceeds 500kW). In view of

diversifying power sources, it is considered appropriate to facilitate power supply by making use of distributed power sources.

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