Key Issues: **11- Benefits due to Power Generation**

Upper and Lower Adjustment Reservoirs of the Shin-Takasegawa Power Plant

Climatic Zone:
Cf : Temperate Humid Climate

Subjects:
- Benefits of Large-scale Pumped Storage Power Plants in relation to the Networks

Effects:
- Peak load power source, storage of electricity, instantly usable reserve capacity, phase modification function, test transmission power source

Project Name: Large Scale Pumped Storage Power Plants in Tokyo Electric Power Company
Country: Kanto District, Japan (Asia)

Implementing Party & Period
- Project: Tokyo Electric Power Co., Inc
1960(Commencement of construction) -
- Good Practices: Tokyo Electric Power Co., Inc
1965(Commencement of operation) -

Key Words:
Pumped storage power plant, Power network operation

Abstract:
Pumped storage type power plants have been developed in Japan since 1930. Tokyo Electric Power Co., Inc. (TEPCO) has 9 pumped storage power plants with approximately 10,000 MW in total, including one under construction. They have contributed to stable operation of a huge power network in Kanto distinct including Tokyo metropolitan area, functioning as peak load power sources, storage of electric power, spinning reserve, voltage support ability to control reactive power and black start capability for power network recovery.

1. Outline of the Project

Pumped storage power generation uses two adjustment reservoirs that are located at different elevations and are connected together by conduits together with reversible pump-turbines, to utilize surplus electricity generated during the low-demand small hours and weekends to pump water from the lower adjustment reservoir up to the upper adjustment reservoir so that the water can be used to generate electricity during the daytime peak demand hours and/or in the event of an emergency. Tokyo Electric Power Company (TEPCO) currently owns a total of 9 pumped storage power plants (including one under construction), which are being operated by TEPCO to meet the daytime peak electricity demand.

Table-1 and Fig.-1 show a list of TEPCO's pumped storage power plants and their locations, respectively.

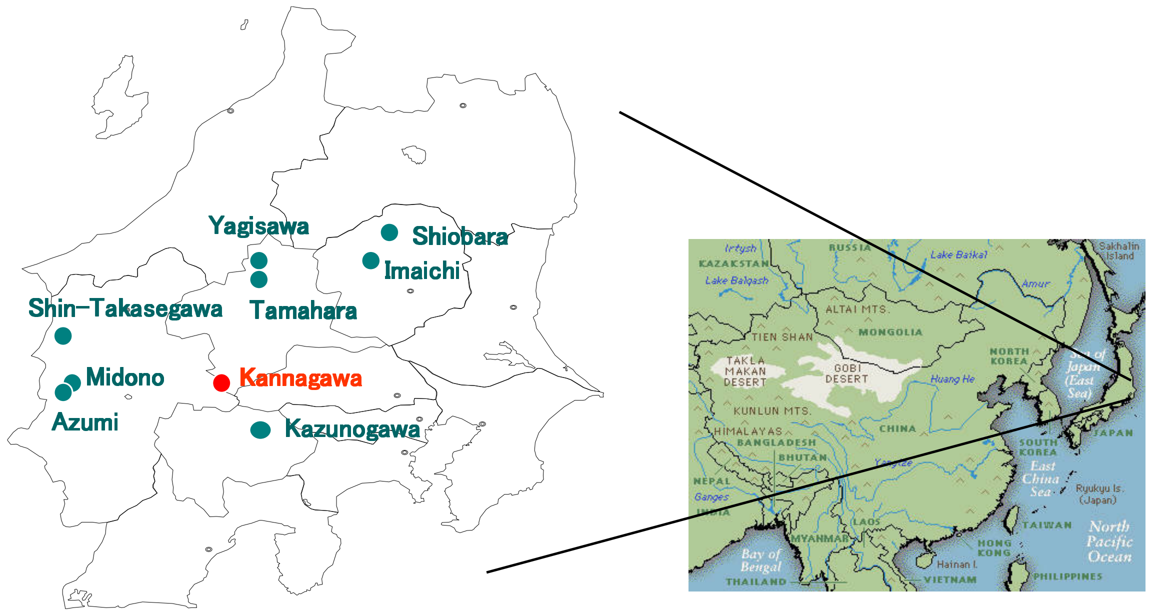


Fig.-1 Locations of TEPCO's Pumped Storage Power Plants

Table-1 TEPCO's Pumped Storage Power Plants

Name	Output（MW）	Operational since	Type
Yagisawa	240	1965	Mixed
Azumi	623	1969	Mixed
Midono	245	1969	Mixed
Shin-Takasegawa	1,280	1981	Mixed
Tamahara	1,200	1982	Pure
Imaichi	1,050	1988	Pure
Shiobara	900	1994	Pure
Kazunogawa	1,600	1999 partially commissioned	Pure
Kannagawa	2,700	Under construction	Pure

Table-2 Main Facilities of Tokyo Electric Power Company's Pumped Storage Power Plants

Name of Power Plant	Upper Dam and Adjustment Reservoir				Lower Dam and Adjustment Reservoir			
	Type	Dam Height (m)	Dam Volume (10,000 m^3)	Total Storage Capacity (10,000 m^3)	Type	Dam Height (m)	Dam Volume (10,000 m^3)	Total Storage Capacity (10,000 m^3)
Yagisawa	Concrete arch	131	57	204	---	---	---	---
Azumi	Concrete arch	155.5	66	12,300	---	---	---	---
Midono	Concrete arch	95.5	30	1,510	Concrete arch	60	7	1,070

Name of Power Plant	Upper Dam and Adjustment Reservoir				Lower Dam and Adjustment Reservoir			
	Type	Dam Height (m)	Dam Volume (10,000 m^3)	Total Storage Capacity (10,000 m^3)	Type	Dam Height (m)	Dam Volume (10,000 m^3)	Total Storage Capacity (10,000 m^3)
Shin-Takasegawa	Rock-fill	176	1,159	7,620	Rock-fill	125	738	3,250
Tamahara	Rock-fill	116	544	1,480	---	---	---	---
Imaichi	Rock-fill	97.5	252	707	Concrete gravity	75.5	19	910
Shiobara	Rock-fill	90.5	211	1,190	Concrete gravity	104	59	1,050
Kazunogawa	Rock-fill	87	406	1,120	Concrete gravity	105.2	62	1,150
Kannagawa	Rock-fill	136	722	1,836	Concrete gravity	120	73	1,910

2. Features of the Project Area

2.1 Supply and Demand in TEPCO's Service Area

TEPCO is supplying electricity to approximately 42.8 million people in its service area that covers most of the Kanto region including the Tokyo metropolitan area. The total area of the service area is approximately 39,500km^2. The total amount of electricity sales and the peak demand in fiscal year 2001 were 275.5 billion kWh and 64.3 million kW, respectively. The annual total amount of electricity sales in TEPCO has increased by approximately 50% in the last 10 years and is currently larger than the annual total amount of electricity sales in Italy.

Japan is the third largest energy consumer in the world that consumes approximately 6% of the total primary energy generated in the world, but depends on imports for about 80% of the energy resources it needs to meet its energy demand. To ensure that TEPCO will be able to supply electricity in a stable, uninterrupted manner for the years to come, TEPCO is striving to achieve, taking into consideration the anticipated global energy demand trends, the most efficient mix of energy resources which best accommodates the hourly, daily and seasonal fluctuations of electricity demand and is best from the standpoints of economics, environmental protection and securing stable sources of fuel procurement.

The pattern of daily electricity usage in the summertime in TEPCO's service area is as follows (Fig.-2): The demand starts increasing sharply at around 6 a.m. and continues to increase up until the lunch hour when it dips slightly. It starts increasing again at 1 p.m. and continues to increase up until around 2 p.m. when it peaks. It then decreases gradually up until around 6 p.m. when it starts to decrease sharply. The demand continues to decrease until it reaches the bottom at around 4 a.m. when it starts increasing again. To accommodate this variation in an economical and efficient manner, it is necessary to develop dedicated power sources for each of the peak, middle and base demand portions explained in Table-2 and use them in combination.

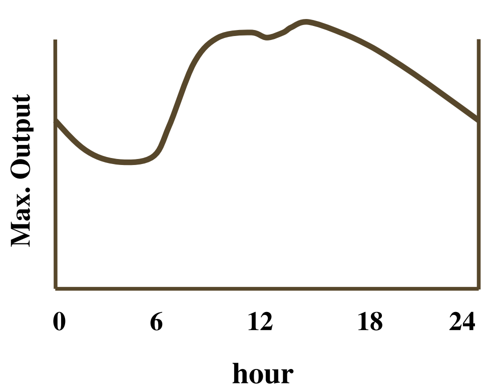


Fig.-2 Pattern of Daily Electricity Usage in TEPCO's Service Area

Table-2 Characteristics of the Individual Components of Electricity Demand and the Requirements for Suitable Power Sources

<table>
<tr><th rowspan="2">Demand component</th><th rowspan="2">Characteristics of demand component</th><th colspan="2">Power source requirements</th><th rowspan="2">Suitable power sources</th></tr>
<tr><th>Operational requirements</th><th>Economic requirements</th></tr>
<tr><td rowspan="2">Peak</td><td rowspan="2">○ Sharp fluctuations
○ The duration of power generation operation is short</td><td rowspan="2">○ Load adjustment capability
○ Hot reserve and frequent start/stop capability</td><td rowspan="2">○ Low fixed costs. Relatively high variable costs can be tolerated as long as this requirement is satisfied. (Note 1)</td><td>Pumped storage and pondage type hydropower , gas turbine</td></tr>
<tr><td rowspan="2">Oil and LNG-fired thermal power</td></tr>
<tr><td rowspan="2">Middle</td><td rowspan="2">○ Large daily fluctuations
○ The duration of power generation operation is relatively long</td><td rowspan="2">○ Capable of being activated and deactivated at a relatively high frequency during the day or of otherwise being adjusted so that similar effects can be achieved</td><td rowspan="2">○ Both variable and fixed costs are relatively low</td></tr>
<tr><td rowspan="2">Coal-fired thermal power</td></tr>
<tr><td rowspan="3">Base</td><td rowspan="3">○ Negligible fluctuations
○ Power is generated all day</td><td rowspan="3">○ Capable of continuous 24-hour operation</td><td rowspan="3">○ Low variable costs. Relatively high fixed costs can be tolerated as long as this requirement is satisfied.</td></tr>
<tr><td>Run-of –river type hydropower</td></tr>
<tr><td>Nuclear power</td></tr>
</table>

(Note 1) “Variable costs” mainly refers to fuel costs.
“Fixed costs” mainly refers to depreciations and interests on the construction cost.

2.2 History of Pumped Storage Power Plant Development in TEPCO

After World War II, Japan’s electricity demand increased sharply as the Japanese economy developed rapidly into an autonomous economy, but thermal power plants were used as the primary means to accommodate the sharp increases in electricity demand, with pondage and reservoir type hydroelectric power plants (which have high adjustment capabilities) developed as peak load power sources. At the time, thermal power plants were improving their thermal efficiencies thanks to the development of high-temperature, high-pressure equipment and were considered to be optimal power sources to meet the electricity demand which was increasing at a rate of more than 10% per year, because of their large capacities and short construction periods. As a result of the accelerated development of thermal power plants, the share of thermal power relative to the total amount of electricity generated surpassed the share of hydropower by the early 1960s, signaling the advent of the so-called “era of thermal electricity.”

Hydroelectric power plants continued to be developed and used as important peak load power sources, but as the number of sites suitable for hydroelectric power plant development decreased as a result of progressive exploitation of economical sites, mixed pumped storage hydroelectric power stations started to be developed. Mixed pumped storage hydroelectric power plants are pondage type hydroelectric power plants added with pumped storage power generation systems to enable them to make large-scale daily adjustments to meet peak demand. Examples include the Yagisawa Power Plant (Tone River, 240MW, operational since 1967) in Gunma Prefecture, the Azumi Power Plant (Shinano River, 623MW, operational since 1970) in Nagano Prefecture and the Shin Takasegawa Power Plant (Shinano River, 1,280MW, operational since 1969) in Nagano Prefecture.

From around the second half of the 1970s, the need for mixed pumped storage hydroelectric power plants started to increase as the summertime peak electricity demand increased sharply due to sharp increases in the cooling- and air conditioning-related consumption of electricity. However, because the number of suitable sites for mixed pumped storage power plant development had decreased as a result of progressive exploitation of sites where natural river flows can be utilized effectively, pure pumped storage hydroelectric power plants started to be developed. Because pure pumped storage hydroelectric power plants essentially have no river water inflow into their upper adjustment reservoirs and generate

power using water pumped up from their lower adjustment reservoirs only, they can be sited without the need to consider river system conditions as long as the heads are sufficiently large.
The scales of pumped storage power plant development projects and the proportion of the pumped storage capacity as a percentage of the total capacity of the entire power network are determined based on the results of a power network system analysis that aims to minimize the power generation cost of the entire power network taking into consideration the above-mentioned pattern of daily electricity usage in TEPCO's service area. The current optimal proportion of the pumped storage capacity as a percentage of the total capacity of the entire power network in TEPCO's service area is estimated to be about 10 to 15% (Fig.-3). In line with the increases in electricity demand in recent years, the Tamahara Power Plant in Gunma Prefecture (1,200MW, head = 518m, operational since 1982), the Imaichi Power Station in Tochigi Prefecture (1,050MW, head = 524m), the Shiobara Power Station in Tochigi Prefecture (900MW, head = 338m), the Kazunogawa Power Station in Yamanashi Prefecture (1,600MW, head = 714m) and then the Kannagawa Power Station in Gunma Prefecture (2,700MW, head = 653m, currently under construction) were planned and constructed sequentially, to maintain the proportion at the optimal level.

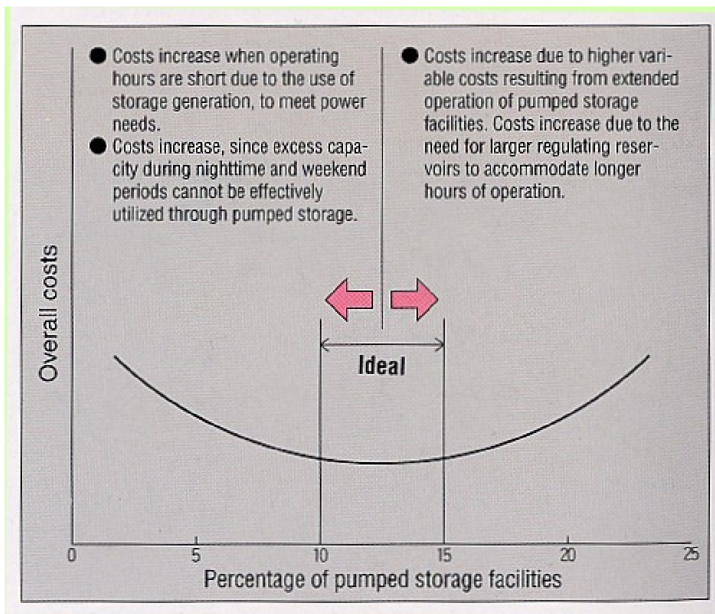


Fig.-3 Optimal Proportion of the Pumped Storage Capacity as a Percentage of the Total Capacity of the Entire Power Network

3. Benefits

3.1 Functions of Pumped Storage Power Plants

Pumped storage power plants play a wide range of roles in power network system, including such functions as peak supply source, storage of electricity, hotreserve capacity, phase modification function and power source for black start for power network system recovery.

(1) Peak Load Power Source

For the peak portion of the demand, it is desirable to use a power source whose fixed costs are low even if it means relatively high variable costs, because the duration of power generation operation is short. Pumped storage power plants are lowest-cost power plants in terms of fixed costs because they can be constructed at a low unit construction cost per kW and comprise long-life structures such as dams and conduits. In terms of fuel costs, which make up the bulk of the total variable costs of a power plant, approximately 30% of the fuel consumed to run a pumped storage power plant is wasted in the form of losses due to the upward and downward transport of water in the waterway and losses of reversible pump-turbines and generator-motors, but the pumped storage power plant can be run at a

lower total fuel cost by using low-cost electricity generated by nuclear power as a power for pumping water than that for a coal-fired thermal power plant. Fig.-4 shows the relationship between the annual operating hours and energy costs (i.e. fixed costs plus variable costs) by power plant type. As is clear from the figure, the economical approach is to use nuclear power and thermal power for the base and middle demand portions, respectively, because the annual operating hours for these portions are long. For the peak demand portion, however, pumped storage hydropower generation is the lowest-cost, because the annual operating hours is short.
In addition, the peak portion of the electricity demand is characterized by sharp load fluctuations and thus requires a power source that has an excellent load adjustment capability and is also capable of frequent start/stop. These operational requirements can only be met by pumped storage hydroelectric power plants, which can adjust their outputs quickly and can start/stop in a matter of minutes.

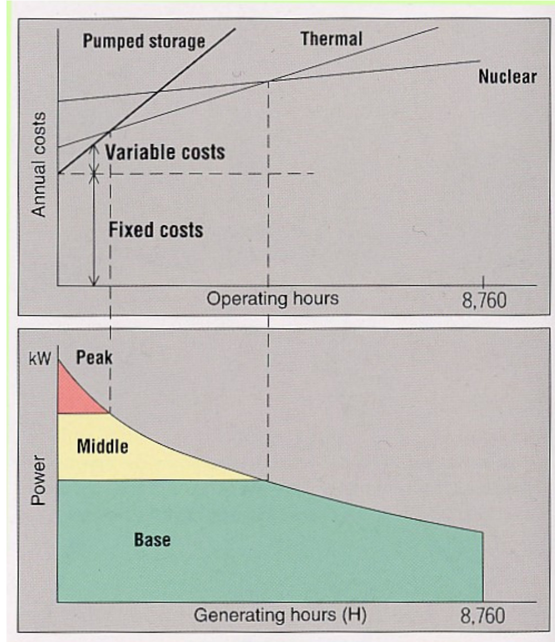


Fig.-4 Relationship between the Annual Operating Hours and the Annual Costs

Because of these economic and operational characteristics, pumped storage hydroelectric power plants have been developed and used as peak load power sources.

(2) Storage of Electricity

Because electricity demand changes daily, weekly and seasonally, it is convenient to utilize the cheaply available electricity generated by nuclear and coal-fired thermal power plants (whose variable costs are low) during the low-demand hours such as midnights and weekends to operate pumped storage power plants, so that low-cost electricity can be stored in the form of water in upper adjustment reservoirs, and it can be used as a generator during peak-load hours of weekdays to reduce the overall electricity supply cost, saving the use of power sources that are higher-cost in terms of fuel costs (such as oil-fired thermal power plants).

(3) Hot Reserve Capacity

To ensure stable, uninterrupted supply of electricity, it is necessary to provide for unexpected demand increases and unscheduled power source outages, as well as output reductions by having sufficient reserve capacities in place.
In general, it is desirable to achieve this with power sources whose fixed costs are low even if it means relatively higher variable costs, because the operating hours is much less than that in the case of ordinary power generation. In addition, a reserve capacity should be capable of being activated instantly in the event of a power source failure or other emergency to make up for the lost capacity to ensure that the supply of electricity is not disrupted or reduced.
Because these requirements, which are similar to those for peak load power sources, are best satisfied by pumped storage power plants, it is best to use pumped storage power plants as hot reserve capacities.

(4) Phase Modification and Frequency Control Functions

Because of parallel capacitance increases in power networks due to the increase of long overhead and underground transmission lines, voltage rises and drops occur at receiving ends when the load is low and high, respectively. These phenomena are usually controlled by means of shunt reactors and power condensers installed in substations, but electricity utilities can also use pumped storage power plants as synchronous phase modifiers that adjust power network voltages by operating generator-motors without load and adjusting magnetic field currents to provide or absorb reactive power.

In addition, the recent development of variable-speed pumps has enabled pumped storage power plants to be used as a means of power network frequency control (AFC; automatic frequency control) during nighttime hours. AFC is usually achieved by means of extra burning at thermal power plants, but it is becoming increasingly difficult to do this with operating thermal power plants alone, because the number of thermal power plants that have to shut down during the low-demand nighttime hours and weekends is increasing as a result of the increasing use of nuclear power stations as power sources for weekends and nighttime hours. Because pumped storage power plants pump up water during the night and weekends, they can also be used as a means to meet the nighttime AFC requirement which also reduces the thermal power generation fuel consumption and hence the overall cost.

(5) Power Source for Black Start

In the event of an emergency such as a total outage of an entire power system due to a major accident, etc., it becomes necessary for some power plants to generate electricity with black start, and charge the transmission lines and restore the power network system in order.

Pumped storage power plants are very suitable to be used as such emergency power sources because they operate on power from a nearby run-of-river hydropower plant, they can be activated in 3 to 5 minutes and their rates of output increase are high.

3.2 Planning and Development of Pumped Storage Power Plants that is in Line with Increases in Electricity Demand

The scales of pumped storage power plant development projects and the proportion of the pumped storage capacity as a percentage of the total capacity of the entire power network are determined based on the results of a power network system analysis that aims to minimize the power generation cost of the entire power network taking into consideration the pattern of daily electricity usage in TEPCO's service area. The current optimal proportion of the pumped storage capacity as a percentage of the total capacity of the entire power network in TEPCO's service area is estimated to be about 10 to 15%.

In line with the increases in electricity demand in recent years, the Tamahara Power Plant in Gunma Prefecture (1,200MW, head = 518m, operational since 1982), the Imaichi Power Plant in Tochigi Prefecture (1,050MW, head = 524m), the Shiobara Power Station in Tochigi Prefecture (900MW, head = 338m), the Kazunogawa Power Plant in Yamanashi Prefecture (1,600MW, head = 714m) and then the Kannagawa Power Plant in Gunma Prefecture (2,700MW, head = 653m, currently under construction) were planned and constructed sequentially , to maintain the proportion at the optimal level.

In locating and constructing these power plants as well as in developing associated technologies and techniques, TEPCO has used the following four (4) criteria to ensure that the power plants are constructed in a most economical and efficient manner.

(1) High Storage Capacity

Pumped storage power plants require upper and lower dams. Sitting requirements for the dams include a topography that will enable large reservoirs to be created behind small dams, as well as a geological structure strong enough to hold the weight of the dams and the pressure of the water.

(2) Good Access to Power Supply Network

Power plants must be built as close as possible to demand areas in order to minimize power loss and transmission costs, such as the cost of building transmission lines and substations. In addition, they must be built in locations that provide good access to electric power from thermal and nuclear power plants, since power is required for pumping operations.

(3) Suitability for Excavation of Large-scale Underground Caverns

Since it is most economical to link the upper and lower dams by the shortest route, most powerhouses are built underground. The powerhouse can not be constructed economically unless the subterranean rock mass is hard and extensive enough to allow the excavation of a large cavern. In recent years, however, it has become possible to reduce the size of caverns thanks to improvements in output capacity per generator. Fig.-5 shows the chronological changes in the maximum output capacity per pump turbine.

(4) High Head with Sort Waterway

The output capacity of a pumped storage power plant is determined by the volume of water used and its effective head. Efficiency can therefore be optimized by minimizing the distance between the upper and lower reservoirs and maximizing the head. These requirements are also reflected in efforts to improve the maximum head of pump turbines (Fig.-6).

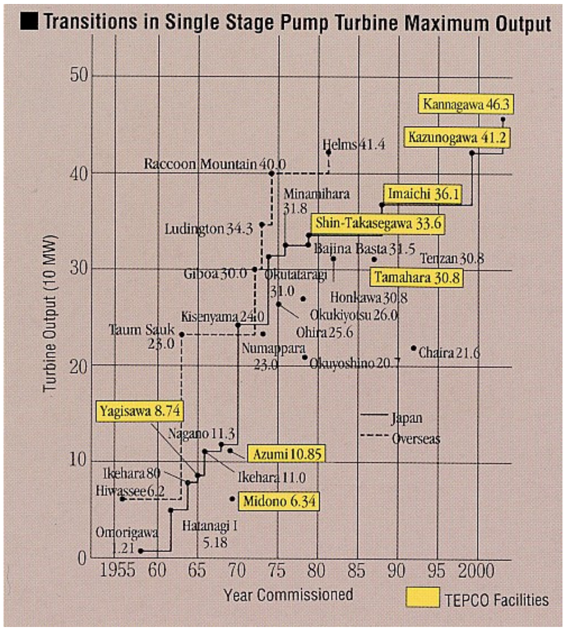


Fig.-5 Chronological Changes in the Maximum Output Capacity per Pump Turbine

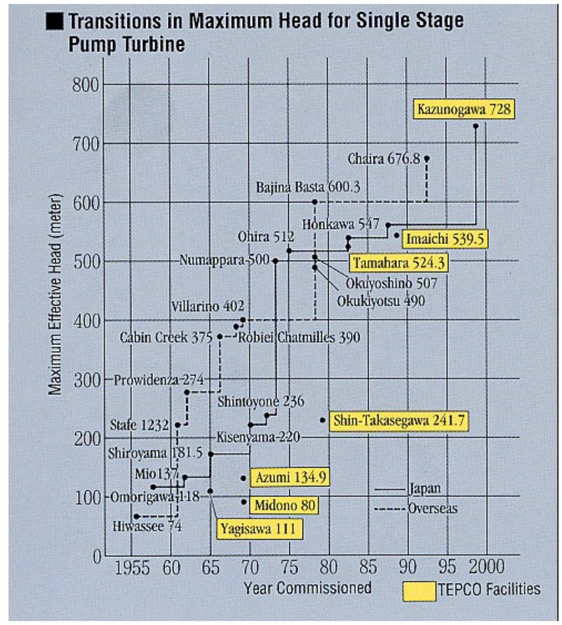


Fig.-6 Chronological Changes in the per-Pump Turbine Maximum Head

4. Effects of the Benefits

Fig.-7 shows the operation record of the pumped storage power plants for July 24, 2001, on which day the highest peak demand was recorded in TEPCO's service area. Fig.-8 shows the combination of energy sources to meet changing demand. As can be seen from these figures, pumped storage power plants are being fully utilized as peak load power sources to help meet the electricity demand during the summer, which is the peak load season in Japan. Table-3 shows the average cost for pumping up water at the pumped storage power plants per unit electricity (kWh) generated versus the average cost of extra burning at the oil-fired thermal power plants per unit electricity (kWh) generated as of 2001. TEPCO is minimizing the overall power generation cost of the power network as a whole by utilizing its pumped storage power plants, whose unit cost of power generation is lower than the unit cost of extra-burning at oil-fired power plants during daytime, and achieving an "electricity storage" effect.

Table-3 Comparison of the Average Unit Cost for Pumping up Water at TEPCO's Pumped Storage Power Plants and the Average Unit Cost of Extra Burning at TEPCO's Oil-based Thermal Power Stations

	Unit power generation cost	Remark
Average unit cost for pumping up water at pumped storage power plants	4 to 5 yen/kWh	Pumping efficiency = 66%
Average cost of extra burning at oil-fired thermal power stations	6 to 7 yen/kWh	Unit fuel cost under operation with a utilization factor of 30%

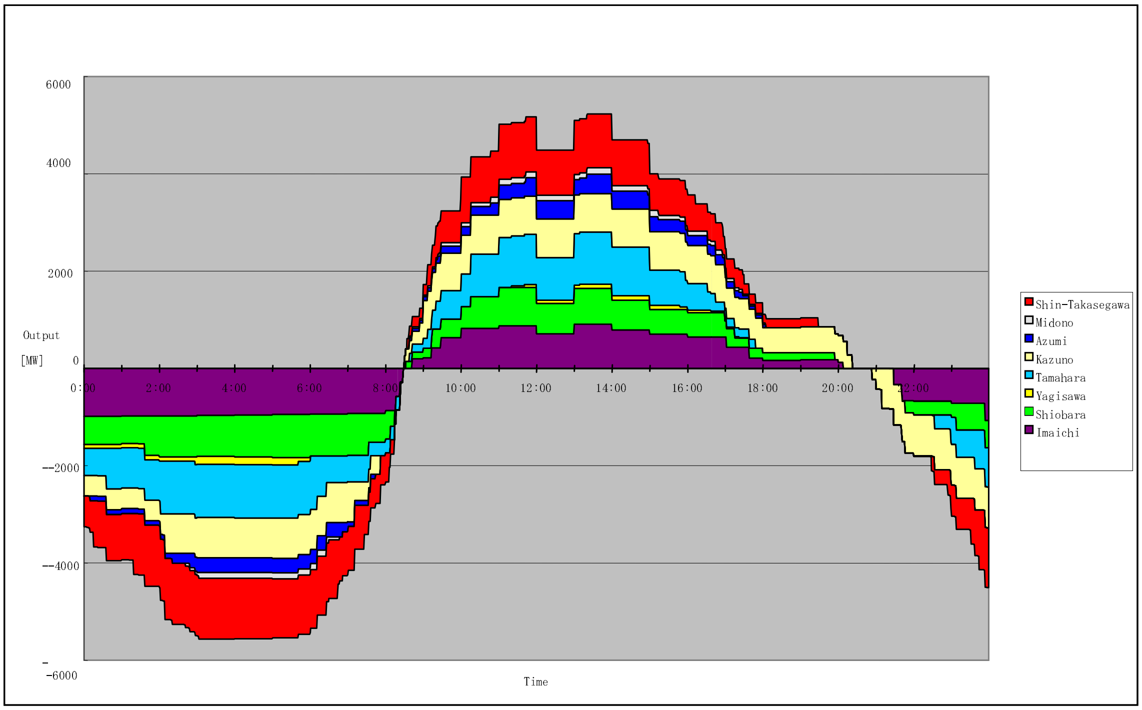


Fig.-7 Operation Record of Pumped Storage Power Plants for July 24, 2001, on Which Day the Highest Electricity Consumption of 64.3 million kW Was Recorded in the Tokyo Electric Power Company's Service Area

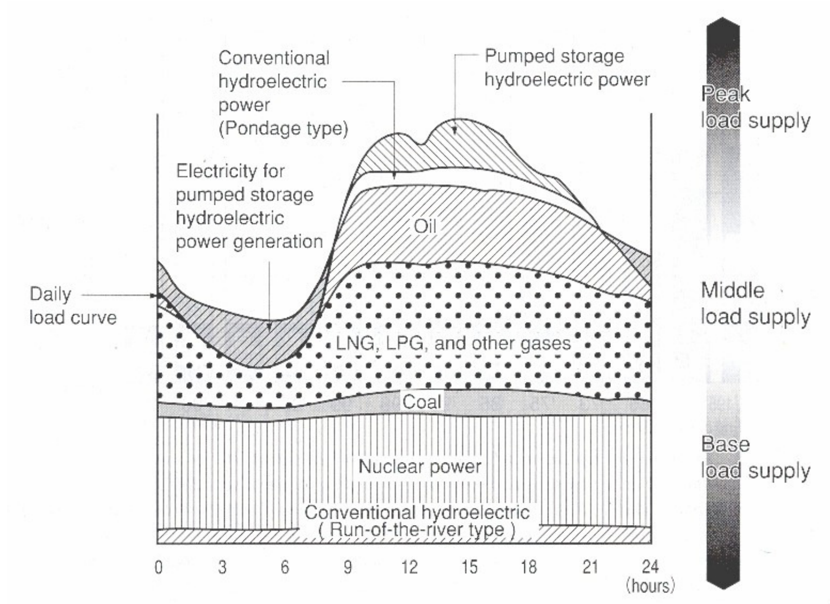
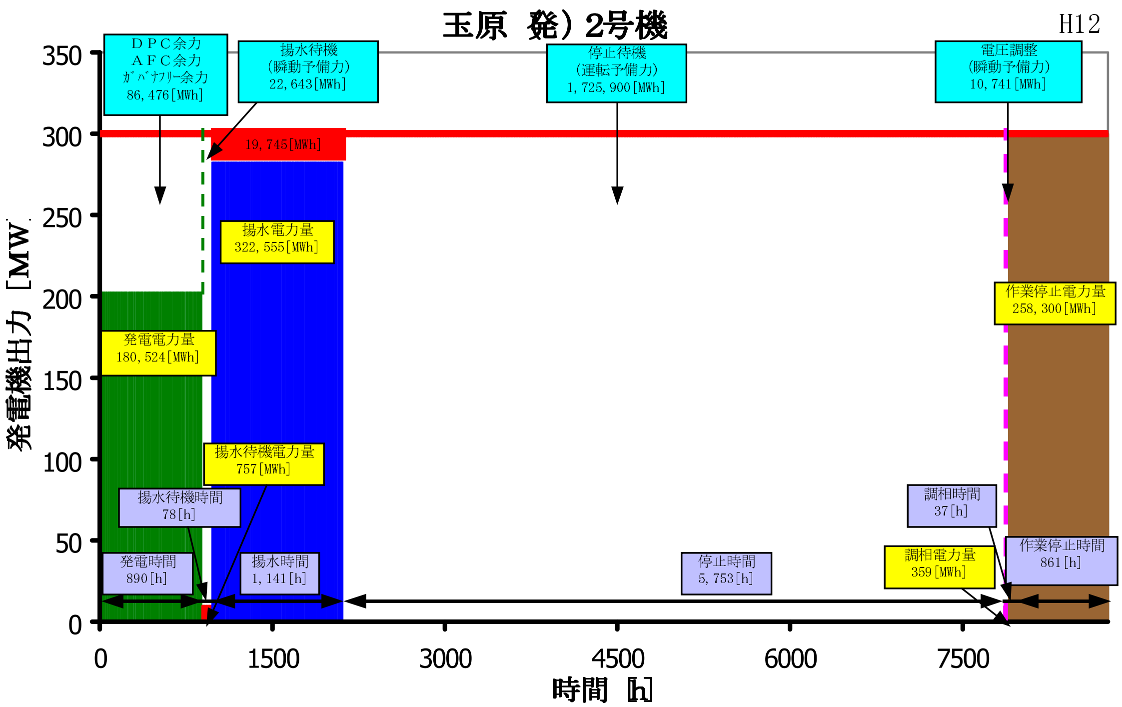


Fig.-8 Combining of Energy Sources to Meet Changing Demand

Fig.-9 shows the operation hours of a unit of a typical pumped storage power plant in TEPCO. As is shown, the unit was operated for 900 to 1,000 hours in the pumped storage mode and 1,000 to 1,100 hours in the power generation mode, of the total 8,760 hours (365 x 24). The figure also shows that there was 37 hours of phase modification operation. During the deactivated standby periods and "200MW operation periods," the capacity of the unit (300MW) and the surplus capacity of 100MW, respectively, contributed to stabilizing the operation of the power network by serving as an instantly usable reserve capacity.



Power generation mode: 1000 to 1100 hours

Pumped storage mode: 900 to 1000 hours

Fig.-9 Operation Hours of a Unit of Typical Power Plant in 2000 by Operation Mode

5. Reasons for Success

As mentioned above, pumped storage power plants have been successfully used in Japan as useful power sources that contribute to stabilizing the operation of power systems. This is partly attributable to the presence of the following conditions in the Tokyo Electric Power Company's service area which includes Tokyo, the center of Japan's economic activities.

(1) Sharp Increases in the Peak Electricity Demand

As mentioned above, the electricity demand in TEPCO's service area starts increasing sharply at around 6 a.m., continues to increase up until the lunch hour when it dips slightly, starts increasing again at 1 p.m. and continues to increase up until around 2 p.m. when it peaks. This peak demand, which is largely due to the consumption of electricity by factories and office buildings as well as the summertime electricity consumption for air conditioning, has been increasing sharply over the years as a result of the growth of the Japanese economy, with the current load factor standing at around 55%. Thus pumped storage power plants in this region are an important means to accommodate the increasingly sharpening peak portion of the daily load curve.

(2) Spatial Expansion of Power Networks

TEPCO's service area includes the Tokyo metropolitan area and the surrounding cities which together comprise one of Japan's heaviest electricity-consuming regions, but these days new power plants tend to be sited in areas remote from this region because of the scarcity of sites suitable for power plant development. With the increaseof longer-distance overhead transmission lines and underground transmission lines, the need for power network voltage control has been increasing.

(3) Improved Economic Efficiencies of Pumped Storage Power Plants
Because the two Oil Crises which Japan experienced in the 1970s revealed the vulnerability of the energy supply system of the nation which was heavily dependent on oil, Japan started an all-out effort to develop new non-oil power sources, which has resulted in a sharp increase in the share of nuclear power relative to the total amount of electricity generated. As a result, Japanese electricity utilities have gradually been increasing the proportions of nuclear power relative to those of thermal power as a source of electricity to run their pumped storage power plants, because nuclear power is less expensive than thermal power in terms of fuel cost. This has significantly improved pumped storage hydroelectric power plants' economic efficiencies.

(4) Social Responsibility as a Public Utility
As a public utility serving a region that includes Tokyo, which is the center of Japan's economic activities, TEPCO must ensure that stable, uninterrupted supply of electricity is maintained 24 hours a day, 7 days a week, including during the peak hours explained above. For this reason, it is vital that TEPCO develop peak load power sources even if they require higher costs than ordinary power sources.

6. Further Information

6.1 Inquiries

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