



# Transmission pricing in Japan\*

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*This paper describes the present status of competition in the electric utility industry in Japan and the present transmission pricing system. Under the amended Electricity Utility Industry Law of 1995, the electric utility industry was categorized into the 3 types: 'general', 'wholesale', and 'special supply' utilities. This paper also summarizes the first competitive bidding from independent power producers (IPPs) and the evaluation of demand site proximity in the bid process. In 1996 the major utilities published wholesale wheeling price lists for IPPs. Although wholesale wheeling prices are similar to the megawatt-mile (MW-mile) approach, the trunk transmission line cost and the average local transmission cost are treated separately. The present study reviews the present wheeling price system in Japan from the principles of transmission pricing established for short-term and long-term efficiency and implementation. Finally, we propose a 2-part tariff on transmission services for IPPs. Capacity cost should be allocated by a modified usage method. Operating cost including line losses should be allocated by a marginal or incremental method. We further propose the application of the cooperative game theory to the cost allocation problem. © 1997 Elsevier Science Ltd. All rights reserved.*

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## Introduction

Before the amendment of the Electric Utility Industry Law, there were no practices of wholesale wheeling and retail wheeling. Transmission systems were to open to only 9 electric power companies (EPCos) and Electric Power Development Co., Ltd. (EPDC). These 10 companies exchanged 40 TWh of electricity in fiscal 1994, with interutility wheeling charges set as low as possible

for mutual benefit.

The Japanese government decided to liberalize the electricity generation market in 1995. On the supply side, by encouraging the entry of independent power producers (IPPs) into the wholesale market, electric power companies should be able to reduce their supply costs. This would be achieved through the introduction of a bidding system. New entrants are not limited to the area of the purchasing electric utility. Wholesale wheeling allows for the development of a wholesale generation market over a wide area. Winners would acquire the right to ask the electric power companies to wheel the power to the purchaser in a fixed price. This made transmission another important issue also in Japan.

## The electric utility industry in Japan

Today the electric utility industry in Japan is mainly operated by 10 regional investor-owned electric power companies. Nine utility companies from Hokkaido to Kyushu EPCos were created in 1951 when the country's electric utility industry was reorganized. The 10th, Okinawa Electric Power Company was created in 1972. They are vertically integrated and have the legal obligation to provide electricity. There are also wholesale power companies which supply electricity to the 10 regional electric power companies. Wholesale electric power companies include EPDC, The Japan Atomic Power Company, 34 public corporations, and 20 investor-owned companies jointly established by the regional electric power companies and major electricity consumers. Besides these utilities, facilities that generate electricity for themselves, termed self-generating facilities are also popular in Japan, generating 115 billion kWh in 1994. Self-generation has been increasing in both installed energy generation capacity and energy production since 1986, making self-generation one of the driving forces for the introduction of competition.

Three background considerations for deregulation in Japan must be discussed. First, 9 of the major Japanese utilities are rather large companies. Five of these have more than a 10 GW peak-load; the smallest one has a 4 GW peak-load. Second, the differences in electricity prices are relatively small; the most expensive average

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price is 27 yen/kWh for residential customers, only 16% higher than the least expensive average price of 23.4 yen/kWh. Third, Japan is a resource poor country that respects energy security and long-term investment plans, and is thus reluctant to depend fully on a market driven system.

*Power-generating facilities*

Utilities have directed efforts toward diversifying their power sources and reducing oil consumption through the development of nuclear, hydroelectric, coal fired, and liquefied natural gas (LNG) fired plants. At the end of September 1996, the total installed generating capacity of the 10 electric power companies and wholesalers was 207,723 MW. Of this generating capacity, nuclear power accounted for 19.8%, hydroelectric power 20.8%, thermal power 59.4% (with oil burning accounting for 28%, LNG burning for 22%, and the rest for coal). In 1995, the 9 utilities generated 845 billion kWh, of which nuclear power accounted for 34%. To secure a stable electricity supply, Japanese utilities have achieved a well balanced mix of power sources. However, public acceptance is waning and new plants tend to be located in remote areas.

*Power demand*

Total power consumption was 859 TWh in fiscal 1994, a 6.7% increase from the previous year. Total power consumption for fiscal 1995 is shown in Table 1.

One of the most pressing issues facing Japan's utilities is the need to decrease the growing consumption differences between times of day as well as between seasons. Spiraling peak demand can be attributed to a growing number of air conditioners in use. The annual load factor of the 9 major utilities fell below 60% in the mid 1980s and remains between 55% and 60% in the 1990s.

*Power transmission*

The electric utility industry has been promoting wide-area operation by reinforcing and expanding interregional transmission facilities. Japan's bulk transmission network consists of 500 kV, 275 kV, 187 kV, and 132 kV lines. These transmission lines are owned and operated by 10 regional power companies and EPDC. Power transmission capacities are shown in Table 2.

**Table 1. Consumption of utilities and wholesalers (excluding self-generation) in fiscal year 1995**

Residential	224 TWh
Commercial	153 TWh
Small industry (<500 kW)	108 TWh
Large industry (over 500 kW)	274 TWh
Other (agricultural, night-only service, etc.)	17 TWh
Total	777 TWh

Source: Japan Electric Power Survey Committee (1996).

**Table 2. Power transmission capacities of the 10 EPCOs**

Route length of transmission line (km)	
Under 110 kV	52,414
More than 110 kV	17,064
More than 187 kV	17,564
Total	87,042

Source: JEPIC (1995), *Electric Power Industry in Japan 1995/96*.

Trunk transmission systems for major load centers, such as the Tokyo and Osaka areas, have been installed on an outer loop of 500 kV transmission lines, with trunk lines from the power sources connected to the outer loop in a radial pattern. Tokyo EPCo is preparing to meet increasing future demand by constructing a 1000 kV line outside the existing 500 kV outer loop transmission line.

**Amendment of the electric utility industry law**

*The amended system (Federation of Electric Power Companies, 1995)*

The amendment of the Electric Utility Industry Law was implemented in December 1995. Five major amendments were made:

- encouragement of new wholesale electricity suppliers;
- introduction of a bidding system;
- establishment of a wholesale wheeling system;
- creation of special supply utilities; and
- implementation of a flexible rate making and contract system.

Under the Amended Electricity Utility Industry Law, the electric power industry is now categorized into the 3 types: 'general', 'wholesale', and 'supply' utilities. Any supplier owning facilities with a capacity of up to 2000 MW is defined as a wholesale supplier and is exempt from the regulations for wholesale electric utilities. Under the Japanese system, special supply utilities are allowed to supply electricity in limited, designated areas. This micro-utility was created to introduce limited competition into the retail market. Cogenerators in redevelopment areas are expected to launch such service. The first micro-utilities, serving hospitals and health care centers for the aged, are anticipated to begin operation in 1998.

Figure 1 shows the revised supply structure in Japan. This reform is based on a model of competitive bidding and wholesale wheeling. Transmission and distribution functions are bundled. Even with new competitors, the existing general utilities will continue to provide the bulk of electricity as the mainstay of the supply system. The roles of new entrants and the existing electric utilities are different. New entrants in electricity generation have a

free choice of power plant type while existing electric utilities must continue to follow the optimum fuel mix

policy. Generally, power sources are selected based on economies, energy security, and environmental concerns.

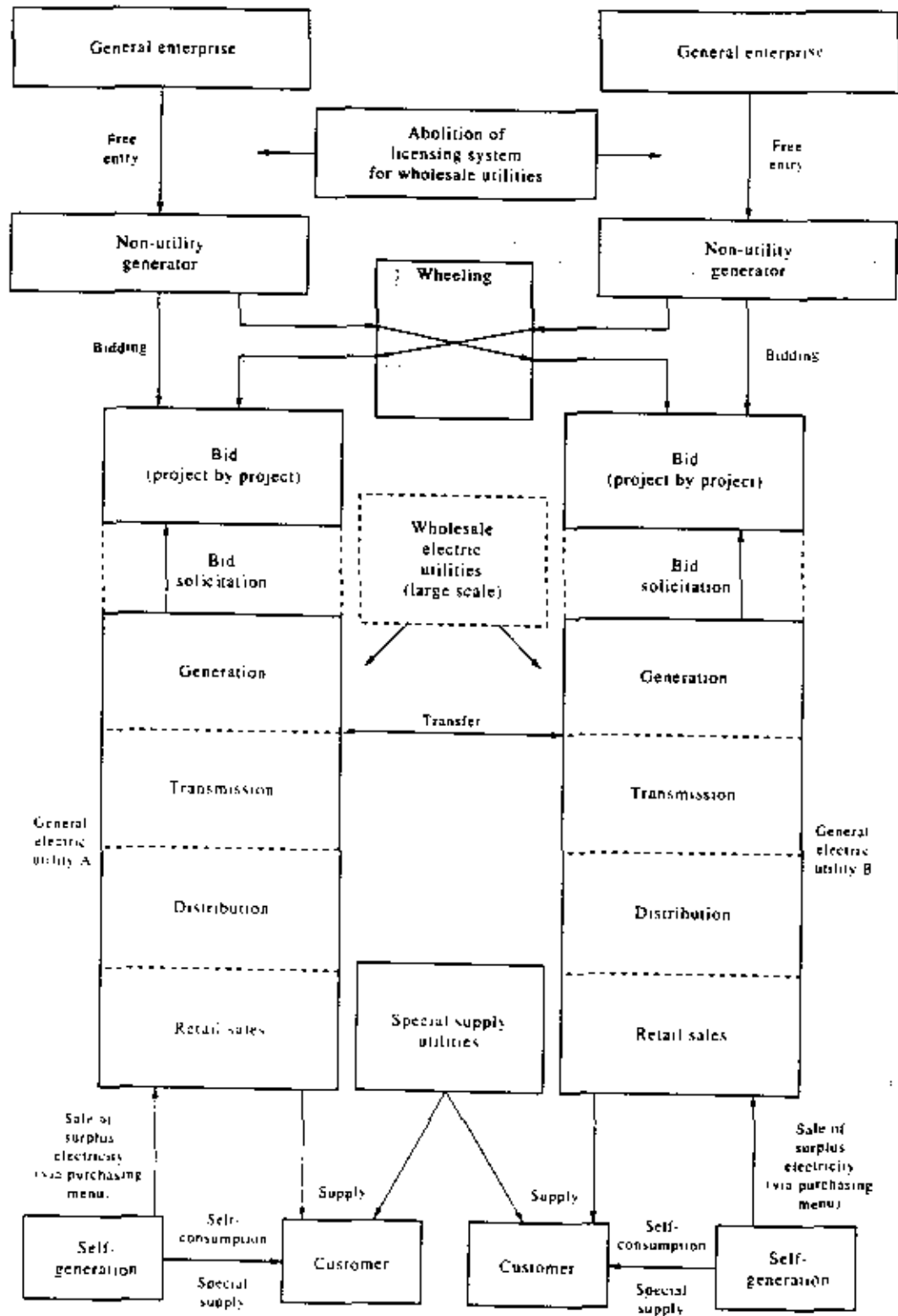


Figure 1. The revised supply structure in Japan

Economy as the primal criterion is respected most not only in Japan but also in other industrialized countries.

Roughly speaking, nuclear and coal fired power are usually chosen as base-load plants in Japan because both technologies are characterized by low expensive operating cost. LNG fired plants are popular as intermediate-load plant, oil fired plants and pumped hydro as peak-load plant. These choices are desirable not only from the economical viewpoint but also from other 3 factors: security, environment, and system operation. Stable electricity supply both in the short run and in the long run against energy supply fluctuations and disruptions requires diversification of generating fuels and fuel suppliers. Japan's electricity and energy supply depends on imports except for hydro power. Therefore, from the energy security aspect, this means Japan had better have a diversified and well balanced fuel mix (that is the optimum fuel mix policy). From the environmental aspect, especially from the global warming problem, non-fossil energy sources are desirable. However, environmental issues are not simple and should be discussed separately). Further, from the operational point of view for power systems, our selection of the generators is suitable to maintain the system reliability.

IPPs as decentralized small or medium sized power plants might demonstrate the advantage of their short lead time if sharp demand fluctuations are observed in the future. The revised system should efficiently combine the merits of these separate roles.

#### *Bidding of IPPS (Matsuo, 1996)*

The first competitive bidding was conducted in 1996. Since general utilities continue to have an obligation to supply electricity, the bidding system applies to small and medium sized thermal power plants that begin operation within 7 years from the time the plans are formulated.

Six utilities (Hokkaido, Tohoku, Tokyo, Chubu, Kansai, and Kyushu) will collectively procure 3 GW by a new bidding system. The total amount of power purchased is equivalent to 11-15% of the additional capacity. Bidders' capacity accounts for 4 times the capacity put up for the bidding. The iron and steel industry has shown a big advantage in plant location and infrastructure for fuel supply. For the IPP supply to

Kansai EPCo, all oil fired plant projects failed to win bids. However, for the IPP supply to Tokyo EPCo, oil fired plant projects won 7 of 8 bids.

A contract term, in principle, is 15 years, thereby securing a long-term plan for both IPPs and utilities. In the market for non-utility power, price is determined by the announced avoided cost of the utility. Avoided cost represents an upper limit on price for bid projects. For Tokyo Electric Power Company, the avoided costs are calculated capacity factors of 10% to 80%.

Table 3 shows the relative scale of IPPs to the generating capacity developed by the utilities. Considering the effects on the environment, IPPs might exacerbate the environmental load. For example, among IPPs decided informally, coal fired plants account for 47% of the total capacity of IPPs. IPP plants also have lower thermal efficiency and a larger coefficient of CO<sub>2</sub> emissions. There is also concern that increasing numbers of IPPs located near urban areas may significantly increase air pollution since power plants of less than 150 MW total capacity are not legally required to submit an environmental impact assessment. In fact, 12 of the 20 successful projects range in total capacity from 100 MW to 150 MW.

#### **Present transmission pricing**

##### *Supply transfer charges (relay charge among utilities)*

Charges for the exchange of electricity among utilities are based on the assumption that supply transfer varies little from predetermined patterns. Supply transfer charges are set for 2 types of contracts as follows:

1. In contracts involving the exchange of surplus electricity among utilities without specified routes, supply transfer charges are determined according to the average transmission costs (book value base) of each utility, to promote mutual aid rather than competition.
2. In contracts involving the exchange of electricity between 2 utilities from specified power plants, when specified routes need reinforcing, supply transfer charges are calculated individually by route. That is based on the incremental capacity cost of the reinforcement.

**Table 3. IPP 1996 and 1997 solicitation**

Start year of operation	10 utilities amount (GW)	IPPs	
		Amount (GW)	Cumulative (GW)
1999-2001	22.50	3.05 <sup>a</sup>	3.05
2002-2004	22.09	2.65+ <sup>b</sup>	5.70+

<sup>a</sup>6 utilities, coal = 47%, oil = 40%, gas = 11%

<sup>b</sup>6 Utilities, Hokkaido will announce. Other 5 utilities fixed the amount of purchased power. Shikoku will start bidding

### Wholesale wheeling charges

In the immediate future, new entrants are likely to be smaller than the present power plants developed by the electric utilities and thus will not require the reinforcement of specified transmission routes. Therefore, the supply transfer charges determined for the exchange of surplus electricity among utilities may also be applied to wholesale wheeling. This will allow electric utilities to publish wheeling price lists. The present Japanese wheeling rate is similar to the MW-mile method. The cost necessary for the connection of successful bid projects to the local utility is calculated individually. A separate method of calculation applies if large scale bids require the reinforcement of specific transmission routes. Figure 2 shows transmission capacity and wheeling rates for wholesale wheeling to Tokyo EPCo. These figures are the amount of capacity which each company can use for that price. And for example, the 400 MW capacity (in Tohoku) means the maximum available transmission capacity for the sum of power from IPPs in the area of Hokkaido EPCo and that from IPPs in the area of Tohoku EPCo. So if wheeling power from Hokkaido is 100 MW, the maximum wheeling power from IPPs in Tohoku is 300 (=400-100) MW.

For the relay from Tohoku EPCo to Chubu EPCo, Tokyo EPCo assumes the trunk transmission route from an interconnecting point (Shin Fukushima) to the frequency conversion station (Sakuma). The relay wheeling charge is the annual capacity cost divided by the power flow of the IPP and the annual operating time. For

an IPP located within a Tokyo EPCo service area, the wheeling charge is the sum of this trunk transmission line cost (0.33 yen/kWh) and the average local transmission cost (0.11 yen/kWh). The method of calculating the compensation for energy losses in wholesale wheeling is that in relay charges among utilities. Transmission losses for wholesale wheeling are based on the average losses of electricity exchange in the previous year. Transmission losses are calculated for several zones (up to 5 zones) in each utility.

### Evaluation of demand site proximity

Bid price should be a major element in the bid evaluation process. However, evaluation also includes operating conditions, proximity to demand, environmental characteristics, and project reliability. The most relevant factor to transmission pricing is proximity to demand. Because power plants have been built in remote areas, consideration needs to be given to demand site proximity. Evaluation should therefore include transmission costs and transmission losses; these reflect demand site proximity and influence transmission pricing. For example, Tokyo EPCo gives a credit of 0.30 yen/kWh for IPPs located in the load center, considering transmission costs. Hokkaido EPCo evaluates the demand proximity of 4 different zones in calculating transmission loss.

### Objectives behind setting transmission charges

Transmission charges should be set to achieve the following objectives:

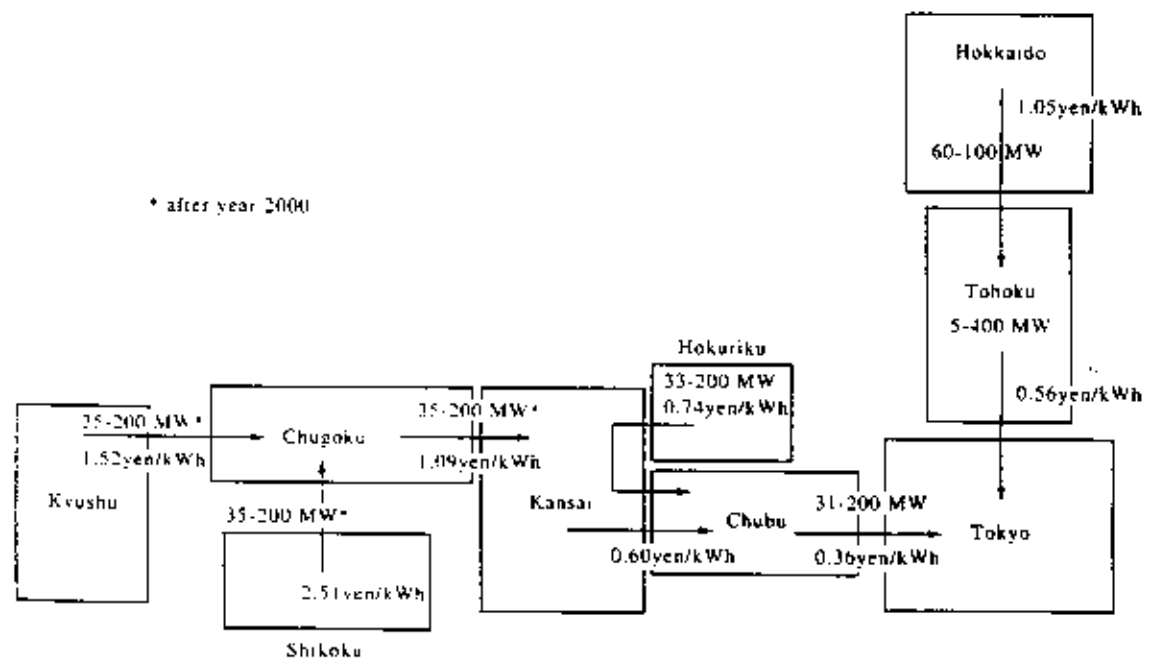


Figure 2. Transmission capacity and wheeling rates for wholesale wheeling to Tokyo EPCo

1. promote the efficient day-to-day operation of the bulk power market;
2. signal locational advantages for investment in generation and demand;
3. signal the need for investment in the transmission system;
4. compensate the owners of existing transmission assets;
5. appear logical, based on obvious calculations; and
6. appear practical and politically feasible to implement.

The present transmission charges are predetermined based on generating capacity and peak demand in Japan. Therefore, they can not promote the efficient day-to-day operation of the bulk power market (Objective 1).

Utilities have set their transmission charges to recover all of the revenue that the government allows (Objective 4). However, they also consider the consistency with interutility charges. Utilities have also been concerned that their charges should be straightforward, and their calculations logical (Objective 5). At present, they consider nodal pricing too complex for transmission users.

Prices currently do not signal the need for investment in the transmission system (Objective 3). Each regional utility holds a licensed monopoly, and has a duty to operate an efficient and economical power system. As such, their transmission planning should be based on captive demand. Investment decisions are internal to the company.

### **Proposed transmission pricing**

In Japan, people expect the electric utilities to continue to be responsible for transmission planning to meet the steadily growing demand, because they are especially interested in long-term stability of energy supply. The Electric Utility Industry Council, therefore, suggests that for full cost recovery, utilities should base the price of wheeling power service on the average costs of transmission facilities. On the other hand, however, short-term operation is also important to achieve an efficient energy supply.

Generally, the provided transmission price should be determined by the following: (1) capacity cost, (2) transmission loss cost, including ancillary services, and (3) congestion management costs. Asano and Okada (1996) evaluated the first 2 factors using a simplified Japanese power system (Asano and Okada, 1996), and Tsukamoto (1996) addressed the allocation of transmission loss costs among line users.

The present study proposes a 2-part tariff for transmission services to realize both the full cost recovery of transmission facilities and the system efficiency of total power supply. The following section deals with capacity

cost allocation and the next section does with operating cost allocation.

At present, the Japanese wheeling system notices only real power (MW transactions), and all regional power companies are given the responsibility of transmission operation and planning. In the future, however, ancillary services for reliable operation should be defined also in Japan, which is discussed in a later section.

Further, although some utilities foresee possible overloading in lower voltage (e.g. 66 kV, 77 kV) transmission lines where IPPs interconnect, congestion management for trunk transmission lines is not a big issue for Japanese utilities owing to the relatively small share of IPPs. We, therefore, do not discuss congestion costs in this paper.

### *Allocation of transmission capacity costs*

The present transmission prices in Japan fail to give appropriate geographical signals for generators' investment decisions (Objective 2). According to load flow calculations, flat transmission charges do not reflect actual load flow. Certainly, most of the IPPs winning contracts from Tokyo EPCo took advantage of demand site proximity (0.3 yen/kWh). However, 2 zones are not enough to reflect locational cost differentials. According to our proposed cost allocation rule, at least 4 zones are necessary to reflect transmission cost differentials and improvement of utilization rate of transmission loading.

We propose a method of calculating regional transmission capacity cost based on the interconnection of IPPs, to reflect the proximity of the demand site and to allocate transmission capacity cost. In our model, economic load dispatching (ELD) and power flow calculation are integrated to evaluate regional transmission cost. First, in the ELD process, the total output of a utility's generators and IPPs are determined by the law of equal incremental fuel cost under the total system load demand. Then, with the allocated demand quantity and the generator output of each node included in the calculation, the power flow (also called the base flow) of each transmission line is obtained by flow calculation (using the direct current method). In this case, the capacity of each transmission line is an optimum value in which the operational control factor is considered and heat capacity is calculated during heavy flow periods such as peak summer months. From this, changes in the annual cost of transmission caused by the incremental flow at IPP interconnection points are calculated. Although the charging system of the Britain National Grid Company uses the incremental capacity averaged across the whole power system, we have improved the method to include both old and new individual transmission lines. Therefore, our pricing method would signal the need for investment in the transmission system (Objective 3). Finally, the transmission capacity cost and price are estimated by the

proposed allocation rule that reflects the proximity of the demand site and the improvement of the reserve margin in the network.

*The proposed allocation rule.* We propose a modified usage method that allocates transmission cost for each facility based on the percent of power flow. We divide cost allocation into 2 components:

$$R = R_B + R_R \quad (1)$$

$$R_B = \sum_{i=1}^n C_i \frac{F_i + f_i}{K_i} \frac{f_i}{f_i + F_i} \text{ for } f_i > 0 \quad (2)$$

$$R_B = 0 \text{ for } f_i \leq 0$$

$$R_R = \sum_{i=1}^n C_i \frac{K_i - (F_i + f_i)}{K_i} \frac{f_i}{f_i + F_i} \quad (3)$$

where  $R$ : allocated cost to IPP,  $C_i$ : annual cost of circuit  $i$ ,  $f_i$ :  $i$ -circuit flow caused by IPP (incremental power flow),  $K_i$ :  $i$ -circuit capacity.

$R_B$  is related to the circuit capacity that is actually being used, called 'base capacity.' The allocation criterion is similar to that for the usage method, changing the circuit cost to the cost of the base capacity.  $R_R$  is related to the difference  $K_i - f_i$ , called 'additional capacity.' The allocation criterion is similar to that for the usage method, changing the circuit cost to the cost of the additional capacity.

The results of case studies show that our proposed method can be applied to the quantification of factors unrelated to cost such as demand side proximity when purchasing from IPPs. Zonal prices for an IPP with a 70% annual utilization rate are - 0.27 yen/kWh for Zone I, 0.07 yen/kWh for Zone II, 0.19 yen/kWh for Zone III, and 0.37 yen/kWh for Zone IV. Zone I is the area in which demand most exceeds service, while Zone IV has many generators. This zoning corresponds to actual load flows at peak times and the age of each transmission line. We confirmed that our proposed method is feasible for actual implementation (Objective 6).

#### Allocation of operating cost

The operating cost for wheeling transactions is composed of the transmission loss recovery and the ancillary services cost. The transmission loss allocation mechanism could be considered as one of the ancillary services for power systems operation, because it is highly related to second-by-second reliable power systems operation. However, we deal with transmission loss allocation as a separate category from ancillary services.

#### Transmission loss allocation

A contract for wholesale wheeling in Japan is an extremely long-term prospect. Therefore, one possible method for transmission loss allocation is based on the

average energy loss of a given year. However, there are problems with the use of the average energy loss method. First, economic efficiency is not guaranteed, because loss responsibility for each transaction is fixed, regardless of the power system condition. Second, this method can not contribute to the frequency regulation for a supply area. Third, there is a cross-subsidy of loss responsibility between economical and uneconomical transactions.

For more efficient dispatch of generation resources including captive generators and IPPs, the short-term operational perspective is desirable. In particular, if point-to-point transactions such as self-wheeling (wheeling services for purpose of self-consumption by a non-utility) were introduced into the electricity supply system, the short-term operation for loss allocation would be indispensable to guarantee the improvement of system efficiency. We propose that the incremental or marginal loss method be applied to allocate a transmission network loss. It should be an optimal signal for the efficient dispatch of several generation resources (Objective 1).

It is, however, very controversial as to whether or not point-to-point transactions such as self-wheeling should be treated as comparable services to the native load. In the case where self-wheeling is treated as a non-discriminatory transmission service against the native load, the marginal loss method is a compromised one. This method allocates hour-by-hour transmission system losses among transmission customers. According to this method, all transmission customers are confronted with the same responsibilities of transmission system loss, irrespective of the transaction characteristics. In addition to the above, the advantage of this method is that the allocated loss is increased in heavy load periods and decreased in light load periods (Objectives 1, 5, and 6). The main disadvantage of a marginal loss method is that an uneconomical transaction which causes a high system loss has the same responsibility as an economical transaction which causes a low system loss. A nodal pricing approach is indispensable in resolving this problem (Objective 2). Utilities in Japan, however, recognize that this approach requires further economical and technical discussion.

On the other hand, there is an alternative that deals with self-wheeling as a discriminatory service against the native load, because utilities have a legal obligation to supply the native load. This view requires that the incremental loss by self-wheeling transactions should be compensated by the self-wheeling users themselves. The incremental loss method is appropriate for this alternative. Under this method, transactions which reduce the system loss are imposed with the negative responsibility; therefore, the advantage of this method is that it is strongly transaction specific, and thus could be an economic signal to improve the total efficiency with

respect to time and location (Objective 1 and 2). The unresolved problem of the incremental loss method is how to allocate the incremental loss caused by self-wheelings to each transaction. Tsukamoto and Iyoda (1996) have applied cooperative game theory to this kind of cost allocation problem.

*Ancillary services.* Generally, utilities in Japan do not develop a set of ancillary services with regard to a power system's reliable operation such as voltage control, frequency regulation, energy imbalance, operational reserve, and so forth. The reason why is that a contract for wholesale wheeling in Japan takes an extremely long-term perspective, as was mentioned before. Utilities, therefore, offer the service cost for reliable power system operation from this long-term perspective. For example, one utility evaluates the function of load frequency control (LFC) of IPPs as a pricing element (0.2 yen/kWh), although it is calculated by just extracting a fixed value from the bid price. It might be possible that it is recognized as a kind of ancillary service.

In the meantime, as the number of market players such as IPPs, special supply and self wheeling entities is going to be increased, the detailed definition of each ancillary service will be required not only to improve the system efficiency but also to elude the price distortion with satisfying a reliability criterion of the entire control area (Objective 1 and 2). Especially, the reliability criterion of the power system in Japan is at extremely high levels, compared to other countries. Therefore, it is important to develop the sophisticated ancillary services mechanism in order to keep the present reliability level without cross subsidy among entities. Firstly, it is desirable that ancillary services should be divided into 2 kinds of

categories, which are provided by generating equipment and transmission system. And then, the cost of ancillary services affiliated with the transmission system should be impartially distributed among transmission customers (Objectives 3 and 4). Further, the dealing mechanism should be introduced with regard to ancillary services provided by generating equipment. We particularly propose that the correct incentives should be built in the price mechanism for ancillary services (Objective 1). This however, depends on further research and analysis of the individual elements of ancillary services.

We propose a 2-part type tariff for transmission services in this paper. It should be noticed, however, that the coexistence of the long-term and short-term perspective could cause economic distortions. Although it is an unresolved problem in our proposal, a possible resolution might be that the allocation of capacity cost is charged on a long-term basis so as not to discourage the economic dispatch of generators. The detailed analysis of this problem is for the further research.

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