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Novel Continuous Auction Algorithm with Congestion Management for the Japanese Electricity Forward Market

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Abstract - In an electricity market, the spot market is normally integrated with a forward or future market. The advantage of the forward market is to allow the market participants to deal in a part or the whole trading portfolio at a fix price in advance and to avoid risk associated to the uncertain price of the spot market. Japan has introduced a continuous auction base forward market from April 2005. This paper analyzes the Japanese forward market rules and operations, and introduces a new algorithm that may improve the efficiency of the market itself. The proposed algorithm enables us to give consideration to the specific characteristics of the power system and to integrate them in the auction mechanism. The benefits of the proposed algorithm are verified on an electronic simulation platform and the results described in this paper.

Keywords: Forward market, power flow, congestion management, bilateral contract, transmission capacity, continues auction

1. Introduction

JEPX (Japan Electric Power Exchange) started the operation in April 2005. JEPX is offering two types of exchange services: a spot market and a forward market. The spot market is a day ahead single price auction market. The forward market is a continuous auction market in which it is possible to trade products such as monthly peak electricity forward or monthly base electricity forward. The transactions of the forward market are all physical and bilateral [1].

Because of the peculiar topology of Japan, the Japanese electric network is composed of series of control areas connected by one or two inter-tie lines. A simplified model of the Japanese transmission network is presented in Fig. 1.

The east part of Japan (Tokyo Electric, Tohoku Electric and Hokkaidou Electric) are operated at a frequency of 50 Hz, the west part at 60 Hz. Between the two parts of Japan there is a frequency converter facility.

The interconnections between control areas are characterized by a relatively small capacity and may easily become congested. For this reason congestion management is very important in Japan.

In the Japanese spot market, transmission congestion is managed with a market split method: in case of congestion on one or more lines, the market is divided in two or more sub-markets cleared independently and with different prices. This method makes it possible to give a strong signal regarding congestion to the market participants: large price difference between two sub- markets means high congestion on the inter-tie line that connects them [2].

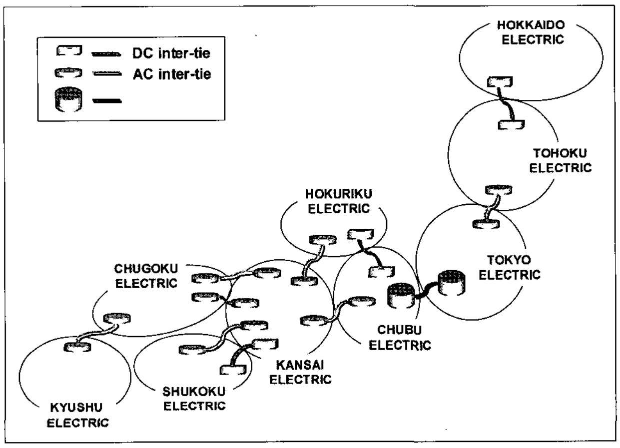

Fig. 1 Structure of interconnected Japanese network

For the forward market, JEPX is adopting an implicit congestion management method. Utilizing a continuous auction algorithm, bids and offers are matched in transactions. Once a transaction between a seller and a buyer is decided JEPX examines whether the transaction is feasible or not from the transmission network point of view along with ESCJ (Electric Power System Council of Japan) In case the transfer capability of the network is sufficient, the transaction is fixed and the price is published. On the contrary, if there is congestion in the network, the transaction is cancelled. In this way, even if the feasibility

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of the transaction is ensured, the price of the forward market is independent from the location of the bid and offer and no congestion signal is available for market participants.

Before to adopt the current congestion management, Japan evaluated several other methodologies.

The first one was the nodal price that gives a right signal about congestion to the market participants. The disadvantages of the nodal price are in the difficulty of modeling of the power system and in the complexity of the calculation. In addition the optimal power flow has to be calculate by an entity that manage at the same time the market and the transmission lines and this was in contrast with the concept of an independent market operator [3], [4].

Another approach for the congestion management is the flow gate. Using the flow gate approach it is possible to have a bilateral distributed market. Unfortunately the flow gate approach implicates a parallel market for transmission rights [5], [6].

In this paper, the authors propose an approach that consents to keep the actual market rules but improve the transmission congestion management. The paper demonstrates how it is possible to obtain results similar to the market split also for continuous auction introducing the concept of hub and integration of power flow calculations in the matching algorithm.

After a description of the current Japanese electricity forward market rules in section 2, a new auction algorithm, based on the concept of hub and power flow calculations is introduced in section 3. Section 4 presents some simulation results using the proposed algorithm and section 5 concludes the paper.

2. The Japanese Electricity Forward Market

The Japanese power exchange opened the forward market in April 2005. At the moment, it is possible to trade 24 products (12 monthly peaks and 12 monthly bases) that cover over one year in the future. All the trades are physical and bilateral and cannot be cleared financially. For this reason it is important that the transmission constraints are respected for all the transactions.

The Japanese power exchange adopted a continuous auction or so called 'Zaraba' method to match each order individually during a trading session [5].

A common order is a bid (buy) or an ask (sell) composed of a price, the correspondent quantity and the location of the order. In addition to the common orders, JEPX is also accepting 'iceberg' orders and 'fill or kill' orders.

Transactions are completed on the principle of auction:

- Price priority: in which the selling (or buying) order with the lowest (or highest) price takes precedence over other orders,
- Time priority: in which an earlier order takes precedence over other orders at the same price.

The continuous auction type of market is a widely adopted mechanism for commodity trading. It has advantages of quick trade matching, the ability to handle a huge volume of trading, a simple mechanism, and further the reduction of transaction costs for market participants.

For these advantages, the continuous auction method is currently adopted not only in the Japanese power exchange but also in several power exchanges such as EEX and Nord Pool [8], [9] worldwide.

In a continuous auction, a market player has the possibility to post an order at the price he wants to trade electricity and wait for an order that match it or to analyze the order already posted and decide to buy or sell at the posted price. The first type of players is called a market maker and is the player that gives liquidity at the market. Table 1 shows an example of order posted in a market for a product. A player that decides to sell electricity for the same product has the possibility to make a match for 100 MW at 20¥/kWh and Table 1 will be modified as in Table 2 or post a order of the desired price. If, for example, he will decide to post an order of 120 MW for 22¥/kWh, Table 1 will be modified in Table 3.

Table 1 Posted Order in a market

Bid (buy) MWh	Price ¥/kWh	Ask (sell) MWh
	30	180
	28	100
	25	155
100	20	
170	18	

Table 2 Posted Order of desired price

Bid (buy) MWh	Price $/MWh	Ask (sell) MWh
	30	180
	28	100
	25	155
170	18	

Table 3 Posted Order after the player action

Bid (buy) MWh	Price ¥/kWh	Ask (sell) MWh
	30	180
	28	100
	25	155
	22	120
100	20	
170	18	

Bid (buy) and ask (sell) are matched in transaction. Before fixing a transaction, JEPX check the deliverability of the transaction along in cooperation with ESCJ.

In the previous example the sell order of 100 MW at 20¥/kWh was matched with the buy order of 100 MW at 20¥/kWh. Each order location is considered as the supply point and the delivery point of the transaction. Locations and quantity are sent to the ESCJ to control the capability of power transfer. If the available transfer capability is sufficient to satisfy the match, the transaction is fixed and table 1 will be changed to table 2, otherwise the match will be cancelled and the order made available for other matching and table 1 will be modified as table 4.

Table 4 Posted Order after the refuse by ESCJ

Bid (buy) MWh	Price ¥/kWh	Ask (sell) MWh
	30	180
	28	100
	25	155
	22	120
100	**20**	***100***
170	18	

While the period of time that a matching is transferring from EPX to ESCJ for transmission availability check, the order table will be frozen and order that will be done during this time will be listed in a query list.

To avoid checking similar unfeasible matches, JEPX does not match orders between two locations that were already rejected by ESCJ within the same trading day.

The method is simple, easy to understand and ensures that the power flowing on each transmission inter-tie will not exceed the transmission capacity. On the contrary, the method presents two main disadvantages. There is no clear congestion price signal to market participants and the check for feasibility between JEPX and ESCJ may be time consuming and may slow down drastically the trading session.

Introducing the concept of hub and integrating the power flow calculation in the matching algorithm, it is possible to keep all the advantage of the current market rules, producing congestion price signal and to avoid the ESCJ check operation.

3. Power flow based continuous auction

In a continuous auction type of market it is impossible to use a pure market split approach for the congestion management because the transactions are sequential in the time and the contracts are bilateral, and further market split evaluation cannot be performed.

3.1 Concept of Hub

The basic concept is the introduction of several exchanges hubs connected by physical transmission lines. The concept fit particularly with the particular Japanese network and with the areas defined in the Japanese spot market. Each control area can be seen as a hub in the forward market and as a zone in the spot market. Any player can sell or buy electricity in each hub subject to the condition of available transfer capability.

The available transfer capability for each inter-tie may be supplied to the power exchange by ESCJ every morning before starting the trading day. After the closing of the trading day, the power exchange may inform ESCJ about the transactions that were fixed during the day.

The available transfer capability can be updated, thought the trading day, by JEPX instantly at the moment that a transaction is finalized.

The method will automatically drive the price of congested hubs at a higher level compared with the price of no-congested hubs.

The market operator may reconFig. the hubs and the interconnection, following the moves in the market. If power system operators individuate new congested areas, new hubs can be created.

Followings are descriptions on the concept of the hub reconfiguration with an example. Fig. 1 is a simple representation of a possible structure:

Firstly, it is assumed that at the current trading time, the orders listed in Table 1 be posted in Hub No. 3 and the location of the order is the same Hub No. 3.

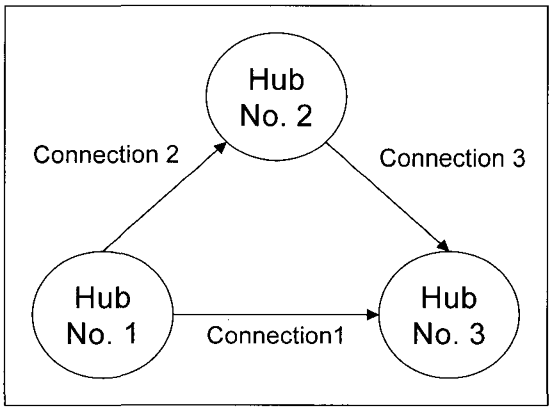


Fig. 1 Hubs and connections

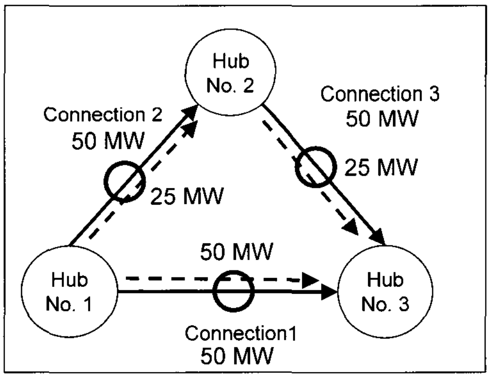
Secondly, it is assumed that the available transfer capability be 50 MW for all the three interconnections and that the impedance for each interconnection is the same, through a simple power flow calculation it can be examined that a player is able to sell from Hub No. 1 a maximum of 75 MWh at 20¥/kWh: 50 MW flow from Hub No. 1 to Hub No. 3 on Connection 1, 25 MW flow from

Hub No.1 to Hub No. 3 through Hub No.2 on Connection 2 and 3 as shown in Fig. 2-a. Once the transaction is fixed, the available transfer capability for each interconnection has to be updated. The available transfer capability has to be set to 0 MW for the connection 1 and to 25 MW for the connection 2 and 3.

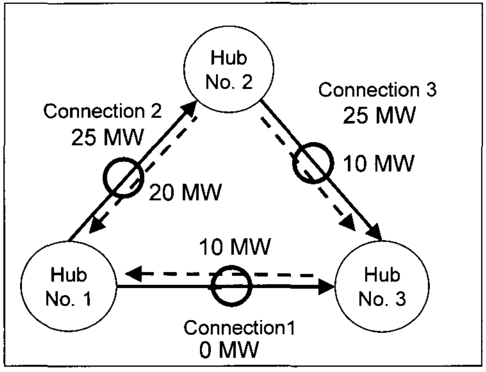
Since the continues auction is a sequential process, it may happen that another transaction of 30 MW is scheduled from Hub 2 to Hub 1 after the previous transaction is processed. Because this transaction is in counter flow on connection 1 with respect to the previous transaction and transfers the same flow of the previous transaction on connection 2, the available transfer capability can be upgraded as: 10 MW from Hub No. 1 to 3 on connection 1, 45 MW from Hub No 2 to 3 on connection 2 and 15 MW from Hub No.2 to 3 on connection 3.

At this time it is possible to trade more 15 MWs from Hub No. 3 to Hub No. 1 for 20¥/kWh (Fig 2-b).

In case the available capacity on the connection 1 persists to be 0 MW, players that try to buy electricity in Hub 3 automatically have to purchase from high price offers (in the example 25¥/kWh or more) and, on the other hand, players who are located in Hub No. 1 and Hub No. 2, that intend to sell electricity are forced to sell it in their own hub.



(a) Transaction for player A



(b) Supplementary transaction

Fig. 2 The available transfer capability before and after the transactions

Since the number of transaction may be very high and for each hub it is possible to have many products (spot market, weekly forward, monthly forward and so on) that all utilize the same connection schema, it is fundamental that the update process of the available capability is fast. For this reason and for keeping the market liquidity higher it is important to have a small number of hubs.

3.2 Match quantity calculation

The fundamental concept in the calculation process is that all the transactions are processed sequentially. This assumption is consistent with the continuous auction rules adopted by JEPX, since, in the continuous auction, each transaction is decided independently and sequentially following the price merit priority and the posting time priority.

Each order is defined by 6 parameters:

1) kind of product (in the same market several product may be traded, in the Japanese forward market monthly peak and base products are available)
2) player name
3) location (it will be considered as source for an ask and as sink for a bid)
4) order type (bid for buying and ask for selling)
5) price for unit (¥/kWh)
6) quantity (MW)

- Determination of the transaction quantity

When two orders can be matched in a transaction a simple power flow calculation is performed for each time period that composes the product.

The ask order location is recognized as the source and the bid order location is recognized as the sink. All the transactions already processed are ignored.

The power flowing on each connection is individuated and compared with the available transfer capability between hubs. The transaction quantity is then fixed at the minimum quantity that satisfies all the transmission constraints and the order quantities. In formula:

$$Q_t = \max\left(Q_{bid}, Q_{ask}, Q^{t_1}_{i\to j}, \ldots\ldots, Q^{t_n}_{i\to j}\right) \qquad (1)$$

where,

Q_{bid} = quantity to purchase by the bid order

Q_{ask} = quantity to sell by the ask order

$Q^{t_i}_{i\to j}$ = maximum quantity that can be transferred from location of the source i to location of the sink at time period t_i

n = total number of time periods

$Q_{i\to j}$ is calculated for each time period using a power flow calculation as follow:

$$\begin{aligned} & Q_{i\to j} \max Q_i \\ & s.t \\ & Q_i = -Q_j \quad , \\ & \underline{H}\cdot\bar{Q} \le \overline{ATC} \end{aligned} \tag{2}$$

where Q_i is the quantity from the source hub i, Q_j is the quantity at the sink hub j, H is the transfer admittance matrix that transforms the power at each hub in the flow on each line, $\bar{Q}$ is the vector of the hubs injection (the only 2 elements are at hub i and hub j), and ATC is the vector of the transfer available capability for each interconnection line.

- *Upgrade of the ATC values*

Once the transaction quantity is decided, the opposite process is performed to find the real flow on each interconnection and to upgrade the ATC values:

$$\overline{ATC}_{new} = \overline{ATC} - \underline{H}\cdot\bar{Q}_t \tag{3}$$

where $\bar{Q}_t$ is the vector of the power injection at each hub ($+Q_t$ at hub i, and $-Q_t$ at hub j)

In case of simple networks, the calculation may be performed in a few milliseconds.

- *Upgrade of the posted order*

Once that the ATC are upgraded, it may happen that some of the posted orders become non-deliverable or non-transmittable. A calculation similar to the one described in the determination of the transaction quantity is then performed on each order to determine the availability of the transmission capacity. In this calculation the counter party location is set as the hub location.

All the ask order that cannot be delivered and all the bid order that cannot be satisfied transmission capacity limitation have to be temporary deleted from the posted information in order to avoid the possibility to give a wrong signal to the participants. The orders may be reposted in case of congestion relief or the players may cancel them.

Speediness in the upgrade of the ATC process and in the upgrade of the posted order process is a fundamental issue. Players may follow inappropriate behaviors if the information about both transfer capabilities and orders are not correct or delay in the time. For this reason, the authors concentrated on a method that can manage the transmission capability and can be performed in a short time span.

3.3 Operation constraints

In the previous session, the base case in which all the inter-ties are in alternating current was described. As showed in Fig. 1, in Japan there are 4 DC interconnections with specific operation constraints.

The Japanese inter-ties have a minimum flow to be respected, and in some case, they can be operated only in a discrete way (for example the FC interconnection between Tokyo Electric and Chubu Electric must be operated as multiple of 20 MW). The DC interconnections can be operated at a fix flow independently from the network configuration. For this reason, the kinds of constraints, previously described, can be easily integrated in the method adding the following constraints:

$$Q_t = \begin{cases} Q_t & if \quad Q_t \ge \bar{\bar{Q}}_k \quad \forall k \\ 0 & otherwise \end{cases} \tag{4}$$

where $\overline{\overline{Q}_k}$ is the minimum flow constraint on each DC connection k.

4. Tests Result

The described model was utilized in a simulation game to testify the efficiency of it. 10 players were involved in the simulation.

To each player, a role was assigned in the market. The players were divided in:

- retailers (6 players)
- generation companies (4 players)

The resources were divided in two hubs linked by an interconnection with a capacity of 100 MW.

The hub 1 was characterized as an area with cheap generation capacity and small demand. On the contrary, hub 2 had large demand and expensive generation capacity. The simulation intent was to verify that after a few transactions the interconnection between hub 1 and hub 2 would be congested and the prices in the 2 hub would diverge.

The players were trading hourly MWs for the following day. Fig. 3 is a simple representation of the simulated market.

The players are informed about the total demand for each hub, the available transfer capability of the

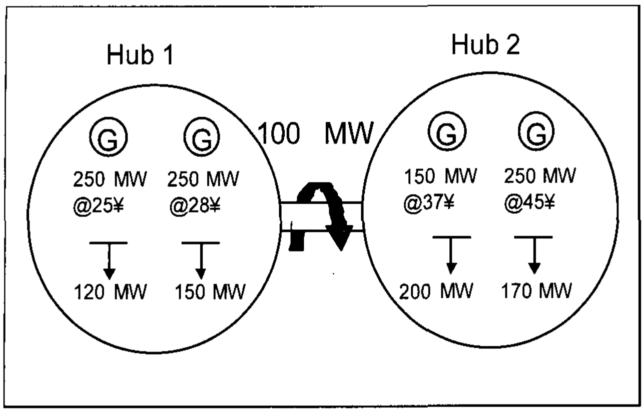


Fig. 3 Market model

interconnection between the two hubs and the range of costs of generation (25-45 ¥/kWh).

The simulation session was ranging over 6 hours. During the session the retailers were asked to buy a quantity of electricity equal to the contracted demand.

Fig. 4 represents the plotting of the price during the simulation.

It is evident from the graph that during the first 2 hours of the simulation the price in the two hubs is almost the same. Basically the electricity is sold from players located in hub 1 in both hubs. Once the interconnection is full the market is suddenly split and the prices in the two hubs change drastically.

In hub 1 the price decreases due to a strong competition of the generation companies; on the contrary, in hub 2 the price increase since the only generation capacity available has high cost.

The market mechanism gives a right signal of the physical situation. Players can easily understand looking at the price trend in each hub that the price difference between the two hubs is caused by congestion.

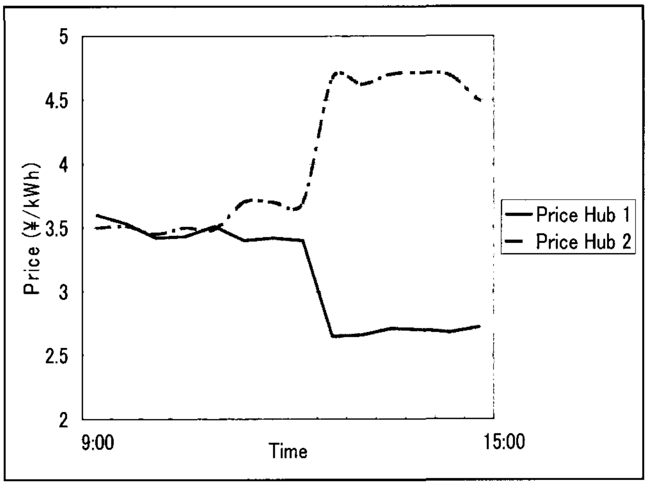


Fig. 4 Comparison of the price trend in the two hubs

5. Conclusion

Congestion management is one of the main aspects that determine the fail or the success of a new electricity market.

After an analysis of the current Japanese forward market the paper proposed a congestion management method that can be utilized in case of a continuous auction market and produce, as a result, a strong signal obtained by the price difference among congested areas. The proposed algorithm is able to treat specific constraints such as minimum operational flow on DC interconnection or digital flow on FC.

Simulation results showed the efficiency of the proposed approach in terms of a market signal and congestion management.

A crucial point in the congestion management is the level of granularity at which the price should be calculated. The authors intend to deepen this problem to find the best number of areas that compromise the power system characteristics and the market liquidity needs.

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