Electric Power Exchanges: A Review

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***Abstract*—In this paper, an overview of electric power exchanges is discussed. Trading mechanism, bid types and execution conditions are explained in brief. Features of various power exchanges world wide are summarized.**

***Index Terms*—Bid types, international experience, trading mechanism.**

I. Introduction

Electricity trading through Power Exchanges (PX) is hitherto introduced in many electricity markets. In India, two power exchanges viz., Indian Energy Exchange (IEX) and Power Exchange of India Ltd. (PXIL) are functioning with guidance from Central Electricity Regulatory Commission (CERC). Exchanges in India have only two years of experience and are continuously evolving. Evolution of power exchange depends on the experiences and lessons from international power exchanges. Nord Pool power exchange (Elspot) is being considered as a standard exchange design. Design and implementation issues of a power exchange or power market, in general, depend on the market supplies and demands, liquidity, economy etc. Philosophy of exchange design may vary from country to country or exchange to exchange (working in the same country). In India, electricity market is supply deficit (in some regions) and has a mix of different generation technologies. PX is a trading center where utilities, power marketers, and other electricity suppliers submit price and quantity bids to sell energy or services, and potential customers submit offers to purchase energy or services. Key points of a power exchange include:

- facility for trading of electricity
- foster the development of competition
- transparency
- liquidity

According to the section 66(178) of the Indian Electricity Act 2003 [1], development of a market for electricity is responsibility of the regulators. In light of the same, CERC took an initiative to develop a common platform for electricity trading with its staff paper on July 20, 2006 [2]. The CERC also suggested function diagram of a power exchange. Indian electric sector is in the process of becoming an industry by opening energy markets, unbundling the electricity services and opening access to electrical networks. It is deemed that more options and freedom to market participants may stimulate competition in power trading, in order to achieve lower power prices, improvement of system efficiency and incentives to innovation.

It is a well known fact that electricity is a commodity much different than other commodities for trading. The distinguishable features of electric power make the trading of electricity more complex and need to consider technical, economical and regulatory aspects while designing the market.

The idea of trading through an exchange enables the traders to discover the best price in the market and to find the optimum buyer or seller for trade. Power exchange introduces transparency in the market clearing and reduces counter-party credit risk. Exchange manages trades, clears market and settles financial transactions. In the electricity market, the exchange is synchronized with Transmission System Operator (TSO) to get technical clearance for transacting power over the grid.

Trading should be done in an efficient manner to provide quality and affordable power to end users. Power exchange formation could prove to be a mile stone in the above mentioned purpose. Power Exchange (PX) directly operates wholesale energy markets, such as day-ahead and hour-ahead markets, while the real-time market for energy balancing and the market for the ancillary services may be operated directly by the TSO or by PX on behalf of TSO and under specific technical requirements. The TSO controls and operates the transmission grid and facilitates transactions and transmission avoiding influence on the generation schedules created by the PX. Success factor of a PX can be measured with the following inputs:

- Number of participants in PX
- Liquidity in the market
- Market growth in terms of traded volume
- Competitiveness of fee structure

For PX, the day-ahead energy market is based on a single or double-side auction scheme. Single side auction allows either buyers or sellers to submit their bids or offers respectively. In double sided auction scheme, both power suppliers and consumers are allowed to submit volume-price offers and bids respectively. Auction process can be open or closed (sealed). In open auction participants repeatedly bid and know about the previous bids. In close or sealed auction, bids or offers are not opened to the market participants. In most of the PX, double sided sealed auction scheme is implemented. Participation in electricity trading through exchange can be mandatory or voluntary. Mandatory participation, though, maximizes the traded volume and better price discovery in the market, it restricts the participants for arranging bilateral contracts. Electricity flows on a transportation network and physical delivery of trades may cause congestion in the network. Issue of congestion should be handled in the market clearing mechanism. Congestion management techniques differ in implicit and explicit auctions. Some PX use market splitting method in case of network congestion [3]. The issue of congestion management is not discussed in this paper.

Most of the exchanges provide hourly and block bid products. Some new bid structures are also proposed in [4] considering generators' start up and shut down cost. In [5], authors present a new concept of coupling of emission trading with the MW trading on the exchange.

In the next section, the components of electricity trading through an exchange are discussed. Section III of the paper discusses the design issues of a power exchange in terms of bid types, execution and validity conditions and bid matching. International experiences on power exchanges are investigated in Section IV. Section V concludes the paper.

II. Electricity Trading

In electricity market, power can be traded either bilaterally or via exchange. Bilateral contracts are negotiated between two parties, one being buyer and other the seller. The contract price information is, therefore, limited to the parties involved. New traders in the market may face difficulty in making a good deal or be unable to explore the market. In this type of contract, traders also have credit risk in case of default by counter party.

On the other hand, exchange trading is a more sophisticated way to make deals and explore the market. Traders can quote their offers and bids a day ahead of physical delivery. The exchange aggregates the offers and bids separately and clears the market on the basis of supply-demand equilibrium [6]. In Fig. 1, the intersection point of supply and demand curve determines the MCP and MCV. This point is called equilibrium point. At the equilibrium point, the offer price equals the bid price for the same volume of electricity. For a bid to be cleared, the bid price should be higher than or equal to the MCP and for an offer to be cleared, the offer price should be lower than or equal to the MCP. The orders can be executed fully or partially as per the trader's instructions.

Exchange, in this way, discovers price in the market and arranges good deals for its members. Exchanges also eliminate the counter party credit risk by having the bank guarantee of its members. All financial transactions and settlements are done via exchange and associated clearing bank(s).

Primary objective of a market clearing exchange is to maximize the social welfare which is the sum of the consumers' surplus and producers' surplus.

1) Consumers' Surplus: Consumers' surplus is product of quantity and the difference between consumers' bid price and market clearing price. This is a surplus to the consumers in the sense that they get the quantity at lesser price than their bids.

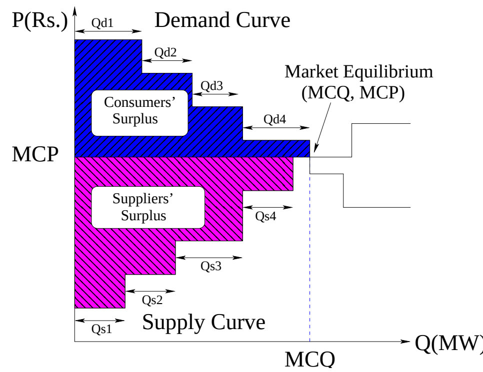

Fig. 1. Market Equilibrium and Social Welfare

2) Producers' Surplus: Producers' surplus is the product of quantity and the difference between the market price and the offer price. In a fully competitive market, the offer price submitted by a supplier is equal to the marginal cost of production. In monopoly or oligopoly market, offer price can be higher than the marginal cost of production.

3) Social Welfare: The sum of the consumers' surplus and the producers' surplus is called total or social welfare (Fig.1). Maximization of social welfare in an uncongested market results in the equilibrium point.

III. Design Issues of Power Exchange

A. Bid Types

Generally, exchanges provide at least a day-ahead market, where the bids are submitted and the market is cleared on the day before the actual dispatch. The day to be scheduled is divided into n periods of m minutes each. Each bidding firm makes a price for for every generation unit for the whole day. In the day-ahead market either hourly contracts (for the 24 hours of the calendar day) or block contracts (i.e. a number of successive hours) are common. Whereas the former allows the market participants to balance their portfolio of physical contracts, the latter allows them to bring complete power plant capacities into the auction process. Block contract bidding may either be organized for a certain number of standardized blocks, or for flexible blocks. Along with day-ahead market, many exchanges also offer intra-day market and other customized products like weekend peak or weekend base load. Exchanges across the world have a wide range of such products due to market responses and innovations. We discuss only hourly and block products.

1) Hourly Products: Hourly bids/offers are the simplest product in most of the power exchanges except UKPX. In UK, a simple product of half hour is provided [7]. Genesis of the hourly product could be on the basis of demand supply balance at each point of time. For practical purposes, the hourly auction is a good choice for the TSO. Auction having only hourly product is easy to implement and involves less computational effort.

In a double side auction with only simple hourly bids, hourly auction problem can be formulated as an optimization problem of maximizing social welfare subject to the constraint that total supply at the optimal point is equal to the total demand at that point. Linear programming problem for 24 decoupled hourly auction can be represented as

$$\max \left(\sum_j P_{dj}^h \times \ Q_{dj}^h - \sum_i P_{si}^h \times \ Q_{si}^h \right)$$

subject to:

$$0 \leq Q_{dj}^h \leq Q_{dj}^{h^{max}} \tag{1}$$

$$0 \leq Q_{sj}^h \leq Q_{sj}^{h^{max}} \tag{2}$$

$$\sum_j Q_{dj}^h = \sum_i Q_{si}^h \tag{3}$$

$$h \in \{1, 2, \cdots, 24\}$$

Where P_{dj}^h and Q_{dj}^h are bid price and bid quantity submitted by customer j in h^{th} hour and P_{si}^h respectively and Q_{si}^h are offer price and offer quantity submitted by supplier i in h^{th} hour respectively. Lagrangian multiplier associated with the constraint (3) gives the market clearing price.

Note that the transportation network is assumed to be uncongested and lossless in the above formulation.

2) Block Products: In electricity market the supplier, having a generator with high start up or shut down cost, may feel the hourly products economically inefficient. Suppose, a supplier submits offers for hourly products for, say, 10 consecutive hours and cleared only in alternate hours. In other words, the supplier has to run his generator for hour 1, then shut off for hour 2 and then again run for hour 3 and so on. Thermal generators have high start up and shut down cost and to avoid this type of situation, they may not opt for hourly products. It is therefore economically efficient to submit offers in blocks of 4 hours each. So, if he gets into the market for first block and goes out of the market for next block or vice versa, he can save the start up and shut down cost as compared to the hourly products. This may also help him to submit offers at a lower price. The concept of block offers is more useful for suppliers.

The block products can be flexible (ie no. of hours in a block may vary) or standardized. The flexible block products can be customized by the traders as per their convenience and perception of the market. Standardized block products, on the other hand, are exchange specified blocks of hours and are based on the load pattern of the market.

Remark 1: When block products are considered in the auction, it becomes a combinatorial auction. Mixed Integer Linear Programming (MILP) problem for combinatorial auction can be formulated as.

$$\max \sum_{h=1}^{24} \left(\sum_j P_{dj}^h \times \ Q_{dj}^h - \sum_i P_{si}^h \times \ Q_{si}^h \right) - \sum_{k \in \mathcal{B}} P_{sk} \times Q_{sk}$$

subject to:

$$0 \leq Q_{dj}^h \leq Q_{dj}^{h^{max}} \tag{4}$$

$$0 \leq Q_{sj}^h \leq Q_{sj}^{h^{max}} \tag{5}$$

$$Q_{sk} = x_k . Q_{sk}^{max} \quad x_k \in [0, 1] \tag{6}$$

$$\sum_j Q_{dj}^h = \sum_i Q_{si}^h + \sum_{k \in B(h)} Q_{sk} \tag{7}$$

$$\mathcal{B} = \bigcup B(h)$$

$$h \in \{1, 2, \cdots, 24\}$$

Where $B(h)$ is the set of block offer active in h^{th} hour. P_{sk} and Q_{sk} are block offer price and block volume respectively. x_k is a binary variable and assigned a value 1 if the block offer is selected. It can be proved that the power exchange bid matching problem with block bids is an NP-complete i.e. intractable problem.

Remark 2: In the above mentioned MILP problem, hourly or block offers can be rejected paradoxically. The term paradoxically used in the context that even $P_{s\mathcal{R}} < MCP$ for hourly offers (where $\mathcal{R}$ is a set of rejected hourly offers) or $P_{s\mathcal{BR}} < MCP$ for block offers (where $\mathcal{BR}$ is a set of rejected block offers) and still these offers are rejected due to inflexibility in the constraint (7). Some exchanges do not reject hourly offers (if the MCP criteria is met) but allow rejections of block offers. To model Paradoxically Rejected Blocks (PRB), few more constraints are to be added in the above formulation [8].

B. Execution Conditions

PX may also facilitate traders with execution condition specifications i.e. an order (buy or sell) is cleared only according to the execution conditions. On the electronic exchanges, the execution conditions conveys the trader's wish with their orders as they would not be present at the time of execution of their orders. In general, the execution conditions can be applied to both hourly and block bids. For some conditions, hourly or block bids should have flexible time blocks. Some of the popular execution conditions are listed here [9].

1) All-or-None: With this specification, if the order can be executed in total, then it executes. Otherwise it stays in the order book until it can be executed in total. For example, a generator submits a 20 MW sell offer with the all-or-none conditions, then the exchange clearing mechanism can schedule the offer of full quantity any time before expiry of the offer. If the offer is not executed in full in the entire validity period it will be removed from the order book.

2) Full-or-Partial: Orders can be partially matched with opposite orders for smaller quantities, in which case the unexecuted quantity remains in the order book. For example, a generator submits a 20 MW sell offer with the full-or-partial conditions, then the exchange clearing mechanism can clear the offer partially (say 15 MW) in one time block and remaining (5 MW) in other block before expiry of the offer.

3) Fill-or-Kill: FOK orders are canceled if not immediately filled for the total quantity at the specified price or better. For example, a generator submits a 20 MW sell offer with the fill-or-kill conditions, then the exchange clearing mechanism can schedule the offer of full quantity in the specified time block only. If the offer is not executed in full, it will be removed from the order book.

4) Fill-and-Kill: FAK order is immediately filled in whole or in part at the specified price. Any remaining quantity is eliminated. For example, a generator submits a 20 MW sell offer with the fill-and-kill conditions, then the exchange clearing mechanism can schedule the offer of full or partial quantity in the specified time block only. If the offer is not executed, it will be removed from the order book.

5) Minimum Income and Maximum Payment Condition: In this type of execution condition sellers specify minimum income condition and buyers specify maximum payment condition with their orders. The minimum income condition refers to the equation of the number of consecutive hours, the volume and the limiting price. A block bid can be matched in case the limiting price is equal to, or lower than, the average price through out the defined block of hours. A block bid must be matched for the entire volume specified and for all hours. If this is not possible, the block bid is rejected.

C. Demand and Supply Curves

Clearing a single market involves setting the price and consequently matching demand and supply at that price. For matching offers and bids there are some matching rules for total surplus maximization.

- Stepwise clearing
- Piecewise linear clearing

In case of stepwise clearing, the results may not be unique and there may be a qualified range of volume and price. Four possible cases of intersection of demand and supply curves in stepwise clearing are shown in the Figs. 2-5. First two cases (Fig. 2,3) have unique equilibrium point. Fig.4 is a case of vertical intersection of the two curves. The vertical intersection of the curves provide flexibility in the market clearing price. Similarly, the horizontal case (Fig. 5) of intersection provides flexibility in the market clearing volume. To determine the single market clearing price and market clearing volume, the PX has to specify some additional rules. The stepwise clearing scheme is implemented in APX [10]. On the other hand piecewise linear clearing gives the single market equilibrium point (Fig.6). Some exchanges use linear interpolation instead of simple aggregation to get piecewise linear curves. Nord Pool power exchange uses the linear interpolation technique for piecewise clearing [11].

In [12], the four intersection cases of stepwise clearing are discussed and compared with piecewise clearing results. It is also concluded in the paper that unlike stepwise clearing, piecewise clearing does not always maximize wealth for participants.

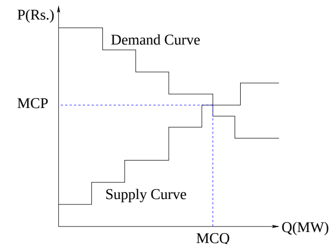

Fig. 2. Single equilibrium point case 1

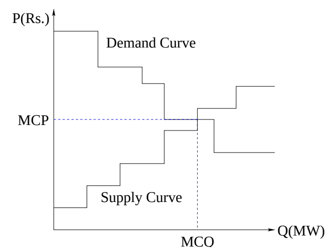

Fig. 3. Single equilibrium point case 2

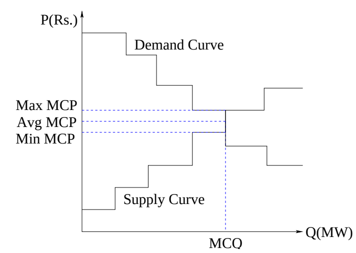

Fig. 4. Multiple MCP in case of Step-wise clearing

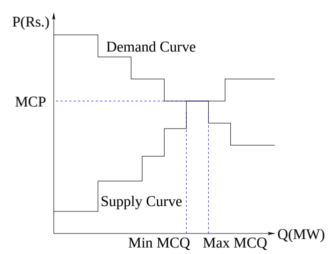

Fig. 5. Multiple MCQ in case of Step-wise clearing

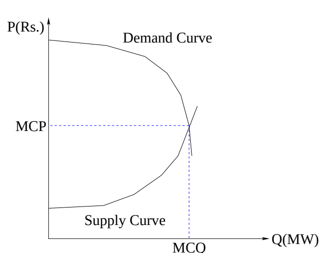

Fig. 6. Piecewise linear curve

IV. International Experience

This section briefly introduces features of power exchanges across the world. Thirteen power exchanges are investigated in this work but only seven exchanges are discussed here with their important features. Other exchanges are not much different from market mechanism aspects. Table I and II summarize the types of markets and bids implemented in power exchanges [7], [10], [11], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24].

A. Nord Pool, Norway/Sweden/Finland

Nord Pool exchange is considered as a model PX in many emerging PX designs [11], [14]. Nord Pool exchange has two segments:

1) Elspot: This segment of market offers day ahead auction for individual hourly contracts and block bids. The block bids are the standardized ones and typically divided into five blocks periods: (BB 1-7), (BB 8-18), (BB 19-24), (BB 1-24) and (BB 8-24).

Along with these products, Nord Pool also provides some interesting mechanisms to the participants. These mechanisms are:

- **Linked Block Bids** All block bids that are linked together must be either only sales or purchase blocks, and all linked block bids must be connected to one bidding portfolio in one bidding area.
- **Flexible Hourly Bids** The flexible hourly bid is a sales bid for a single hour with a fixed price and volume. The hour is not specified, but instead the bid will be accepted in the hour with the highest price in the calculation, given that the price is higher than the limit set in the bid.
- **Conversion of Block Bids** In this mechanism a not activated block bid can be converted to regular hourly bids. This will help in case of under supply offers for hourly products. This is a non-mandatory option for the suppliers.

2) Elbas: The Elbas market provides continuous power trading 24 hours a day, 7 days a week covering individual hours, up to one hour prior to delivery. The traded products are one-hour long power contracts. The time span between the day's Elspot price-fixing and the actual delivery hour of the concluded contracts is quite long (36 hours at the most). As consumption and production situations change, a market player may find a need for trading during these 36 hours. The Elbas Market enables continuous trading with contracts that lead to physical delivery for the hours that have been traded on the Elspot market and are more than one hour from delivery. The Elbas market is open around the clock every day of the year.

B. Amsterdam Power Exchange (APX), The Netherlands

The APX has day ahead spot market and also an adjustment market, ie intra-day market [10]. Day ahead market enables market participants to trade electricity for hours of a day one day in advance. The participants are also allowed to trade for blocks of hours. The blocks offered in the PX are standardized as well as flexible. The block bids are executed under two conditions:

1) FOK
2) Minimum income or Maximum payment condition

The adjustment market at the PX is to minimize the unexpected imbalances. This segment of PX provides continuous trading.

C. European Energy Exchange (EEX), Germany

The EEX offers day ahead market with individual hour contracts and standardized blocks for auction [16]. The EEX also enables market participants for continuous trading. There are several execution conditions selectable to specify the bids. Standardized block products offered in EEX are: (EEX Night Hours 1-6), (EEX Morning Hours 7-10), (Business Hours 9-16), (EEX High Noon Hours 11-14), (EEX Afternoon Hours 15-18), (EEX Rush-Hour Hours 17-20), (EEX Evening Hours 19-24), (Base Load Hours 1-24), (Peak Load Hours 9-20), (Off-Peak Load Hours 1-8 and 21-24), (Off-Peak-1 Hours 1-8) and (Off-Peak-2 Hours 21-24).

D. Powernext, France

Powernext offers standard hourly products in day ahead market and price limited block orders that link a minimum of four hours of a day together [19]. The standard blocks offered by Powernext are:

- **Three hours block bids** (Block Bid 1-4), (BB 5-8), (BB 9-12), (BB 13-16), (BB 17-20) and (BB 21-24)
- **Other block bids** (BB 9-20), (Bb 1-6), (BB 1-8) and (BB 9-16)

E. Belgium Power Exchange(Belpex),Belgium

The Belpex market is subdivided into three segments [15]. These segments are designed for hourly and block bidding one day in advance and for continuous trading.

- **Belpex Day Ahead Market Segment (Belpex DAM)** provides standardized products (hourly instruments). Prices are determined via a double-sided blind auction. It also has Market Coupling Auction.
- **Belpex Continuous Day Ahead Market Segment (Belpex CoDAM)** provides standardized products (multi hourly instruments) to sell and purchase electricity on a continuous basis as from 2 trading days before delivery up to 11:00 am of the day before the delivery.
- **Belpex Continuous Intraday Market Segment (Belpex CIM)** provides standardized products (hourly and multi hourly instruments) to sell and purchase electricity on a continuous basis, and this up to 5 minutes before delivery.

F. Indian Energy Exchange (IEX),India

IEX [17] is the first Indian power exchange established in 2008. It has two sub-markets: Day Ahead Market (DAM) and Term Ahead Market (TAM). DAM offers 24 separate hourly products. Price discovery in DAM is through double side bidding and buyers and suppliers pay/receive uniform price. TAM offers Intra-day, Day-ahead contingency, Daily

TABLE I
TYPES OF MARKETS IN POWER EXCHANGES

Type of Market	Power Exchanges
Day Ahead Market	APX Power, Belpex(DAM), Brozen, EEX, JEPX, KPX, NordPool(Elspot), Polpx, PowerNext, PXIL and WESM
Intraday Market	APX Power, Belpex(CIM), Brozen, EEX, NordPool and PowerNext
Other products (term ahead, day base, day peak, etc.) market	APX Power, Belpex(CoDAM), EEX, PowerNext, PXIL

TABLE II
TYPES OF BIDS IN POWER EXCHANGES

Type of Bids	Time Limits	Power Exchanges
Hourly Bids	Specified time block	All PX
	Flexible (T_s, T_e)	NordPool
Block Bids	Standard block bids	Belpex, Brozen, EEX, Powernext, PXIL
	Flexible block bids	PowerNext
	Linked block bids	NordPool

and Weekly contracts. Matching in Intra-day, Day-ahead and Daily contracts are based on continuous trading sessions while matching in Weekly contracts is through uniform price auction. DAM and TAM operations are carried out in accordance with the CERC guidelines.

G. Power Exchange India Limited (PXIL), India

PXIL [18] is the second Indian power exchange. It offers Day Ahead Market (DAM) and Term Ahead Market (TAM). DAM offers hourly and block bids. The execution criterion for block bids is all-or-none. TAM offers Day-ahead Contingency and Weekly contracts.

V. CONCLUSION

The paper provides overview of PX concepts and its implementation world wide. Issues that need further investigation are congestion management, advanced bid structures, emission trading, etc.

REFERENCES

[1] The Indian electricity act 2003. [Online]. Available: http://www.cercind.gov.in
[2] "Staff paper on developing a common platform for electricity trading," *CERC*, Jul. 2006.
[3] Y. Bichpuriya, S. A. Soman, and P. R. Apte, "Design and testing of heuristic for market splitting in electric power exchange," *TENCON 2009, IEEE Region 10 Conference*, Jan. 2009.
[4] R. Gajbhiye and S. A. Soman, "New bid structures for power exchange with modelling in ilp framework," *European Energy Market Conf. 2009*, 2009.
[5] ——, "Facilitating emission trade within power exchange: Development of conceptual platform," *European Energy Market Conf. 2010*, 2010.
[6] R.S.Pindyck and D. L. Rubinfeld, *Microeconomics*. Delhi: Pearson Education Asia, 2002.
[7] United Kingdom power exchange, UK. [Online]. Available: http://www.ukpx.com
[8] L.Meeus, K. Verhaegen, and R. Belmans, "Block order restrictions in combinatorial electric energy auctions," *European Journal on Operational Research*, vol. 196, no. 3, pp. 1202–1206, 2009.
[9] L. Harris, *Trading and Exchanges: Market Microstructure for Practioners*. Delhi: Oxford University Press, 2008.
[10] Amsterdam power exchange, Netherlands. [Online]. Available: http://www.apx.nl
[11] Nord pool. [Online]. Available: http://www.nordpoolspot.com/
[12] L.Meeus, K. Purchala, and R. Belmans, "Implementation aspects of power exchanges," *CIGRE*, 2004.
[13] R. Madlener and M. Kaufmann, "Power exchange spot market trading in Europe: theoretical considerations and empirical evidence," *OSCOGEN*, Mar. 2002.
[14] "Trade at the Nordic spot market:the world's first international spot power exchange," Apr. 2004.
[15] Belgium power exchange, Belgium. [Online]. Available: http://www.belpex.be
[16] European energy exchange, Germany. [Online]. Available: http://www.eex.com/en
[17] Indian energy exchange, India. [Online]. Available: http://www.iexindia.com
[18] Power exchange India limited, India. [Online]. Available: http://www.powerexindia.com/
[19] Powernext, France. [Online]. Available: http://www.powernext.fr/
[20] Polish power exchange,Polish. [Online]. Available: http://www.polpx.pl/
[21] Korea power exchange, Korea. [Online]. Available: http://www.kpx.or.kr/english
[22] Japan energy power exchange, Japan. [Online]. Available: http://www.jepx.org/English
[23] Brozen, Slovenia. [Online]. Available: http://www.borzen.si/eng/
[24] WESM, Philippines. [Online]. Available: http://www.wesm.ph/