पावर सिस्टम ऑपरेशन कॉर्पोरेशन लिमिटेड
(भारत सरकार का उद्यम)
POWER SYSTEM OPERATION CORPORATION LIMITED
(A Govt. of India Enterprise)
पंजीकृत एवं केन्द्रीय कार्यालय : प्रथम तल, बी-9, कुतुब इंस्टीट्यूशनल एरिया, कटवारिया सराय, नई दिल्ली-110016
Registered & Corporate Office : Ist Floor, B-9, Qutab Institutional Area, Katwaria Sarai, New Delhi -110016
CIN : U40105DL2009GOI188682, Website : www.posoco.in, E-mail : posococc@posoco.in, Tel.: 011- 41035696, Fax : 011- 26536901

पोसोको/ दिनांक: 15 फरवरी 2019

सेवा में,

सचिव
केंद्रीय विद्युत विनियामक आयोग
तृतीय एवं चतुर्थ तल, चंद्रलोक भवन
36 जनपथ
नई दिल्ली-110001

विषय: Comments/Suggestions on CERC discussion Paper on "Market Based Economic Dispatch of Electricity (MBED): Re-designing of Day-ahead Market (DAM) in India".

महोदय,

Please find enclosed herewith the views/suggestions on behalf of RLDCs/NLDC on CERC discussion paper on "Market Based Economic Dispatch of Electricity (MBED): Re-designing of Day-ahead Market (DAM) in India".

सधन्यवाद,

भवदीय,

18/02/19

(देबाशिस दे)

मुख्य महाप्रबंधक, रा. भा. प्रे. के.

संलग्नक: उपरोक्त अनुसार

Power System Operation Corporation Ltd.
New Delhi

CERC Discussion Paper on Market Based Economic Dispatch of Electricity (MBED): Re-designing of Day-ahead Market (DAM) in India

Suggestions on Behalf of RLDCs/NLDC

Dated: 15th February 2019

CERC Staff has brought out a series of Discussion Papers as mentioned below:

- Re-Designing Real Time Electricity Market in India, 25th July 2018
- Re-Designing Ancillary Services Mechanism in India, 6th September 2018
- Market Based Economic Dispatch of Electricity (MBED): Re-designing of Day-Ahead Market (DAM) in India, 31st December 2018

All of the above discussion papers are a step towards further development of the Indian Electricity Market, albeit the changes proposed are revolutionary in nature. The amount of work done by the staff in bringing out these discussion papers is commendable and is appreciated.

Some broad and high-level comments on the MBED Discussion paper are given below for consideration of the Hon'ble Commission.

1. **Fundamental Pillars of Market Design:** The four fundamental pillars of electricity market design, namely *'Scheduling and Despatch', 'Imbalance', 'Congestion Management' and 'Ancillary Service'*, are an essential pre-requisite for an electricity market which complements reliability. At the inter-state level, all of the above pillars are in position and this has facilitated the vibrant electricity market that is presently working in the country. However, at the intra-state level, these fundamental pillars are yet to be put in place. For example, without proper scheduling, boundary metering and settlement mechanisms for each entity insider the state, it would not be possible for that entity to participate in the electricity market at the inter-state level. This issue has been recognized by the Forum of Regulators (FOR) which is already working on the implementation of its report 'Scheduling, Accounting, Metering and Settlement of Transactions in Electricity (SAMAST)' at the intra-state level. The report was published in 2016 and its implementation is being closely monitored by the FOR Technical Committee. Significant progress is yet to be made on this front. The MBED paper envisages participation by all state generators. However, without implementation of SAMAST, participation of intra-state entities will not be possible as the transactions cannot be accounted for and settled.

   It is also pertinent to mention here that large pumped storage plants such as Kadamparai, Srisailam, Purulia are embedded inside the state systems. These plants are very good potential candidates for utilization under ancillary services. However, it has not been possible to harness these plants under the ancillary services because of various reasons which include lack of scheduling, time-block wise metering, accounting and settlement mechanisms inside the state. Another case in point is the fact that no intra-state generator has ever participated in the Power Exchange market till date. These examples amply demonstrate that implementation of SAMAST in letter and spirit is an essential pre-requisite for state entities to participate in the electricity market.

2. **Imbalance Handling or Settlement of Deviations:** Presently, only six states have implemented DSM regulations and in some of these states, state generators are not being subjected to deviation/imbalance settlement. The imbalance of these generators is thus indirectly cross subsidized by the state Discoms. Generators which participate in the market must adhere to market schedules and any deviation from schedule must be accounted for and settled by the generator. Forum of Regulators has recognized this issue and the FOR Technical Committee has also made available Model Regulations at State level. However, majority of the State are yet to notify and implement these. As already mentioned, imbalance settlement is another pre-requisite for participation in the market.

3. **State-wise Transfer Capability (TTC/ATC) Assessment:** The MBED paper envisages participation of inter-state and intra-state generators in the market. In order to facilitate the administration of the market trades, another essential requirement is the need for assessment of transfer capability on a state-wise basis in advance. Few states such as Punjab, Kerala, Uttar Pradesh, etc. have started declaring the TTC/ATC. However, majority of the states are yet to start the assessment and declaration of TTC/ATC.

4. **Introduction of Financial Contracts:** The MBED paper envisages financial settlement of contracts through 'Bilateral Contract Settlement or BCS'. The proposed BCS is akin to a 'Contract for Difference or CfD', which is financial settlement of a physical delivery contract. Hitherto, India has only a physical delivery market. Introduction of financial contracts in the country is a subject by itself and requires a public debate on various associated issues such as types of products, jurisdiction, settlement systems, market monitoring, etc. From the MBED discussion paper, it appears that there is a proposal to implement financial contracts without going through a detailed stakeholder debate. Financial contracts are a separate domain and a complex subject by itself requiring detailed stakeholder deliberations on various aspects of design such as contract specifications, sale/purchase mechanisms, settlement systems, tracking, market monitoring, etc. It is suggested that before linking the physical delivery contract and the financial settlement contract, the financial contract such as CfD should be introduced on a standalone basis for gaining experience.

5. **Implicit Introduction of Financial Transmission Rights (FTRs):** Section 5 of the MBED Discussion Paper deals with settlement of the transactions. Figure 20 for the example given is for settlement in case of Market Splitting. From the methodology proposed it appears that implicit introduction of Financial Transmission Rights (FTRs) in India is being contemplated. The need, if at all it exists, for introduction of FTRs in India requires a thorough debate both in the industry and the academia as it is a complex subject in itself. FTRs cannot be introduced in the country by a passing reference in a Discussion Paper by the staff.

6. **Handling Transition from Legacy PPAs to Market:** The MBED Discussion Paper suggests that all power which was transacted under the legacy PPAs shall henceforth be transacted through the market. All generators will sell in the market and all buyers shall buy from the

market at a market determined price. The difference in the PPA rates and the market determined prices is proposed to be settled through BCS mechanism (akin to CfD). It is important to mention here that the legacy PPAs do not have any existing provision of financial settlement of the contract. There are many aspects in the existing legacy PPAs which need to be revisited if we are to transit to a market-based system as envisaged in the MBED discussion paper. For example, the existing PPAs have fixed charge payments linked to the generator availability, first right of refusal in case of combined procurement by multiple beneficiaries, provisions for incentives, etc. Hence, either these PPAs need to be amended or a supplementary PPAs between the generators and the corresponding beneficiaries need to be signed.

Here it is also pertinent to mention the case histories of New York ISO and California ISOs where legacy contracts were re-negotiated to facilitate the move to market. This aspect was also deliberated in the series of workshops on Electricity Markets organized by National Association of Regulatory Utility Commissioners (NARUC) of USA, a body similar to the Forum of Regulators in India. During these deliberations, it emerged that re-negotiation of existing legacy PPAs is the only way forward to handle transition to market.

In this context, it is also pertinent to mention that if movement to market is desired, then, a policy direction for amending the MOP Standard Bidding Documents (SBD) to include suitable clauses for financial settlement of these PPAs. Further, the bidding documents for procurement of renewables should also be modified suitably to include financial settlement of contracts. This is essential so as to at least ensure that the future PPAs have a built-in provision for financial settlement.

7. **Expected Savings by moving to Market:** The MBED Discussion Paper presents case studies of a few states where the extent of savings has been shown to be of the order of 10-12%. The MBED Discussion Paper also refers to the Greening the Grid Study, where with larger coordination at Regional / National level, the savings vary between 2.8% to 3.5%. In this context, the POSOCO Consultation Paper on Security Constrained Economic Despatch (which was placed for public consultation in accordance with the direction of the Hon'ble Commission) suggests 1-2 % savings if optimization is carried out for inter-state generators which fall under the ambit of RRAS Mechanism. The high quantum of savings shown in the case studies in the MBED Consultation Paper suggests that there is a likelihood of extraneous factors, such generators running at technical minimum levels for maintaining reserves, which are not clearly brought out in the case studies mentioned in the discussion paper. Moreover, the assumptions in the study need further deliberation for better understanding and clarity.

8. **Voluntary versus Mandatory Participation:** The present formulation of the Indian Electricity Market has a voluntary participation model. The MBED Discussion Paper suggests moving to a mandatory participation model. This issue was thoroughly debated when the Power Exchanges were getting introduced in the country in 2008. The relevant extract from the CERC Order in Suo-Motu Petition No. 155/2006 dated 18th January 2007 is quoted below.

   "16. The Commission is of the considered opinion that the main objective of proposing establishment of PX in India is to provide one more option to the utilities/entities and

mandating participation in power exchange shall not be in consonance with the said objective. We would like participation in the power exchange to be voluntary with full freedom to individual utility/entity to decide about it depending on the perceived benefits vis-à-vis other options."

In this context, it is also pertinent that in the early nineties, M/s ECC of USA were commissioned under a grant from Asian Development Bank to undertake a comprehensive study of the Indian power system and recommend a suitable tariff structure. ECC submitted their report in February, 1994, recommending Availability Tariff for generating stations, which was accepted in principle by GOI in November, 1994. A significant recommendation in the ECC Report was the adoption of 'decentralized' scheduling and despatch in the country keeping in view the federal structure of the country and the fact that electricity is a concurrent subject. The present Indian Electricity Market design has evolved over the last two decades keeping the federal structure, decentralized scheduling and despatch, and voluntary participation as the hallmarks of the market design. The mandatory participation model suggested in the discussion paper is not in consonance with this.

9. **Institutional Arrangement and Ring-Fencing of SLDCs:** A significant requirement for ensuring participation by the state entities is the unbundling of generation, transmission and distribution along with ring-fencing of the Load Despatch functions (Power System Operations). The first requirement ensures market participation by multiple entities, competition and enhanced liquidity. The second requirement of having an independent system operator is a pre-requisite to ensure not only non-discriminatory administration of the market but also ensuring adequate focus on reliable and secure operation of the grid. While at the inter-state level, unbundling of generation and transmission and ring fencing of system operation function has taken place in the country, the same needs to be implemented at the state level also. As a matter of fact, some of the SLDCs are involved in the process of placing the bids for procurement of power in the Power Exchanges. Hence, implementation of CABIL Report by the Forum of Regulators is an urgent need of the hour.

10. **Clearing and Settlement by the Power Exchanges:** Presently, the Power Exchanges have adopted 'self-clearing' of the transactions taking place in the Power Exchanges. Volumes in the Power Exchanges shall grow manifold as per the methodology proposed in the MBED discussion paper. Once volumes increase, the money handled on a daily basis shall be huge and full-fledged Clearing House facilities need to be established. Part-6 of the CERC Power Market Regulations, 2010 provides the Regulatory Framework for a Clearing Corporation. To start with, process of establishment of a Clearing Corporation should be initiated by the Hon'ble Commission. In the future, such a Clearing Corporation could also take over the settlement of all kinds of transactions such as long-term, medium-term, short-term bilateral, transmission charges, etc. both at the inter-state and intra-state levels.

11. **Market Monitoring & Surveillance:** The CERC Power Market Regulations, 2010 provide for market monitoring and surveillance committees to be constituted by the Power Exchanges. A Market Monitoring Cell (MMC) has also been constituted by CERC. Presently,

the market monitoring activities are more in the nature of post facto reporting of market related data. With increase in market volumes, more pro-active market monitoring would be required at both the Power Exchange and the regulatory levels. In this context, the requirement for enhanced market monitoring has already been flagged vide a communication dated 11-Feb-2019 to CERC (copy enclosed at Annex – I for ready reference).

12. **Multiple Power Exchanges in India:** The MBED discussion paper proposes moving all trading volumes to the Day-Ahead Market in the Power Exchange(s). India has adopted multiple Power Exchanges in a single physical delivery market and two Power Exchanges are presently operational. It is also understood that a third Power Exchange has made an application for grant of permission. From the MBED discussion paper it is not very clear as to which Power Exchange has been implied while making it mandatory for all participants to go through the day-ahead market.

    India has adopted the European style markets and has borrowed heavily from the Nordic markets. In Europe, multiple Power Exchanges are also allowed. However, it is mandatory for these Power Exchanges to operate as 'market coupling operators or MCO' by rotation and centrally coordinate the trades on behalf of the other Power Exchanges. Sharing of margins is already an issue we have been facing on account of multiple Power Exchanges and one way to address this issue is to have a rotational mechanism similar to the one adopted in the European Markets. A conscious effort is required to be made by all stakeholders including the Regulator, the System Operator and the Power Exchanges.

13. **Gradual versus Radical Changes in Market Design:** The MBED Discussion Paper proposes a radical change in one shot in the country. It is felt that a small success story can be created by implementing a pilot for a few of the willing states in the country for demonstration of the benefits to all other stakeholders. Of course, the pre-requisites as mentioned in the proceeding paragraphs need to be in place. Once the success story has been created, it can be quickly ramped up.

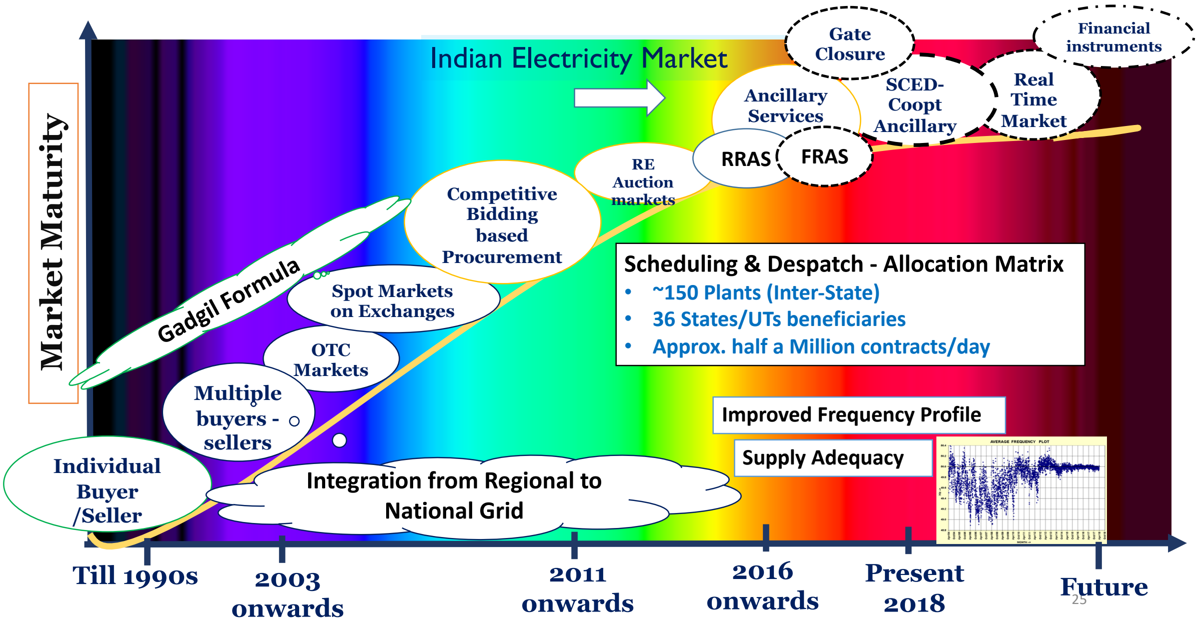
14. **Implementation Modalities and Timelines:** The Discussion Paper proposes implementation of MBED in a fast track mode. It is pertinent to mention here that what can be achieved in the short-term is over-estimated and what can be achieved in the long-term is under-estimated. For running such sophisticated market mechanisms, elaborate 'Market Management Systems (MMS)' are installed along with SCADA/EMS Systems by the system operators worldwide.

    Hitherto in India, software for scheduling, meter data processing, loss administration, accounting and settlement system, open access, interface with power exchange, cross border, ancillary services, etc. (to name a few) are all in-house driven home-grown mechanisms which have their own limitations in handling complex market operations. In fact, NOAR is the first such attempt which is trying to convert the running system into a systematic platform.

    As an example, consider the case of Australian Electricity Market (factsheet enclosed at Annex-II). Since the start of the National Electricity Market (NEM) in 1998, the dispatch process by which generators are scheduled has operated on a 5-minute basis, but the settlement process has operated on a 30-minute basis. The difference in time period was primarily due to historical arrangements prior to market start, including limitations on metering and data communications. The difference in time period, sometimes referred to as the 5/30 problem, is a pricing anomaly that can cause inefficient pricing outcomes and has been identified as a contributing factor to disorderly bidding. In the long-term, the pricing anomaly may lead to inappropriate investment and higher prices for consumers. In November 2017, the Australian Energy Market Commission (AEMC), the rule-maker for the NEM, decided 5 Minute Settlement should be implemented in the NEM and come into effect on 1 July 2021. They tasked AEMO with the role of implementing changes to market procedures and systems necessary to perform 5 Minute settlement, as well as obligations on participants to adopt the changes.

As can be seen from the above example, a 4-year timeline has been given for implementation of the transition from 30-minute settlement based on 5-minute prices to a 5-minute metering and settlement. This is despite the fact that Australia already had a working 5-minute mechanism for the last two decades !!

15. **Road Map for the Future:** The present state of the Indian Electricity Market and the proposed roadmap for the future is shown in the below.



Annex - I

पावर सिस्टम ऑपरेशन कॉर्पोरेशन लिमिटेड
(भारत सरकार का उद्यम)
POWER SYSTEM OPERATION CORPORATION LIMITED
(A Govt. of India Enterprise)

पंजीकृत एवं केन्द्रीय कार्यालय : प्रथम तल, बी-9, कुतुब इंस्टीट्यूशनल एरिया, कटवारिया सराय, नई दिल्ली-110016
Registered & Corporate Office : Ist Floor, B-9, Qutab Institutional Area, Katwaria Sarai, New Delhi -110016
CIN : U40105DL2009GOI188682, Website : www.posoco.in, E-mail : posococc@posoco.in, Tel.: 011- 41035696, Fax : 011- 26536901

POSOCO/Trans.Pricing/CERC/ **दिनांक**: 11 फरवरी 2019

सेवा मे,

सचिव,
केन्द्रीय विद्युत् विनियामक आयोग,
तृतीय और चतुर्थ तल, चंद्रलोक बिल्डिंग
36, जनपथ नई दिल्ली-110001

विषय् : **Feedback to Market Monitoring Cell (MMC)**

महोदय,

1. Central Electricity Regulatory Commission vide order dated 20th November 2018 notified the fourth amendment to Deviation Settlement Mechanism (DSM) regulations. In line with the amended DSM regulations, daily average price is now the market clearing price. The daily average price, earlier used to be regulated vector is now a market linked vector which depends on the price discovery at multiple power exchanges. The price discovery in the Power Exchange(s) become a crucial element in the DSM Price vector and thus, there is a need for implementing effective measures for market monitoring.

2. Hon'ble Commission vide communication dated 6th September 2017 (copy enclosed at Annex – I) directed POSOCO to examine the potential impact of block-bids on Area Clearing Prices and Volumes, among other aspects, in conjunction with the Power Exchange(s). After detailed deliberations which included national and international academia, POSOCO submitted a detailed report vide communication dated 24th May 2018 (copy enclosed at Annex – II). As part of the Recommendations, the following was recommended in the context of enhancing the information dissemination by the Power Exchanges (relevant extracts placed below):

   "(d) The market design principles as laid down in the CERC Power Market Regulations provides for economic principle of social -welfare maximization during price discovery. Minimum information dissemination requirements have been specified in the CERC Power Market Regulations However, there is no bar on additional information dissemination by the Power Exchanges. Hence it is recommended that the following information should be made available on the respective websites by the Power Exchanges:
   a. Producer surplus
   b. Consumer surplus
   c. Total social welfare
   d. Total number of portfolios traded
   e. Percentage contribution of block bids both in terms of number of block bids and market clearing volume (energy)
   f. Bid-Ask spread"

3. The 4th Amendment DSM Regulations mandate that the daily average Area Clearing Price (ACP) be used as the DSM rate at 50 Hz for that bid area. The DSM rate is also frequency dependent and changes in accordance with the methodology specified in the 4th Amendment DSM Regulations. Hence, in order to ensure robustness of the prices being discovered in the Power Exchanges, the area-wise aggregated supply demand curves are required to be made available on the websites

of the Power Exchanges. It is pertinent to mention here that the aggregated supply demand curves on the national level are already being made available by the Power Exchanges and this needs to be extended to include area-wise aggregated supply demand curves.

4. In view of the above, it is submitted that the Power Exchanges may be directed to make available the information as mentioned in Paras 2 and 3 above on the respective websites in the public domain.

Submitted for kind consideration of the Hon'ble Commission and further directions in the matter.

सादर धन्यवाद,

भवदीय,

11/02/19

(देबाशिस दे)

मुख्य महाप्रबन्धक, रा. भा. प्रे. के.

Annex - I

केन्द्रीय विद्युत विनियामक आयोग

CENTRAL ELECTRICITY REGULATORY COMMISSION

सत्यमेव जयते

के वि वि आयोग
CERC

Sanoj Kumar Jha, IAS
Secretary

Ref: PX/Misc/2017

Date : 06/09/2017

The CEO
Power System Operation Corporation Limited (POSOCO)
B-9 (1st Floor)
Qutab Institutional Area,
Katwaria Sarai,
New Delhi

Subject: Increase in maximum quantity of Block Bids from 50 MW to 100 MW at IEX

Sir,

This has reference to the meeting held at CERC on 25th August 2017 regarding increase of maximum quantity for Block Bids from 50 MW to 100 MW by IEX.

2. Based on the discussion held during the meeting, it was decided that POSOCO in co-ordination with IEX and CERC shall examine the potential impact of 100 MW Block Bids inter-alia on the following System and Market operations related issues:

- Impact on ramping and scheduling of power
- Impact on Transmission corridor utilization
- Impact on Market and Area Clearing Price & Volume
- Impact on Smaller Bidders

3. If required, POSOCO may also consult any other academician or professional having expertise in power sector/exchanges to assist them in undertaking the study. POSOCO may submit the findings to the Commission within a month's time for further directions on the above issue.

Yours faithfully

06/09/17

(Sanoj Kumar Jha)

Copy to:
To
The CEO
INDIAN ENERGY EXCHANGE LIMITED (IEX)
Unit No. 3,4,5 and 6, Plot No. 7
Fourth Floor, TDI Centre,
District Center, Jasola,
New Delhi – 110025

तीसरी मंजिल, चन्द्रलोक बिल्डिंग, 36, जनपथ, नई दिल्ली-110 001
Third Floor, Chanderlok Building, 36, Janpath, New Delhi-110 001
Phone : 91-11-2375 3915, Fax : 91-11-2375 3923, E-mail : secy@cercind.gov.in / secyskj@gmail.com

Annex - II

पावर सिस्टम ऑपरेशन कॉर्पोरेशन लिमिटेड

(भारत सरकार का उद्यम)

POWER SYSTEM OPERATION CORPORATION LIMITED

(A Govt. of India Enterprise)

पंजीकृत एवं केन्द्रीय कार्यालय : प्रथम तल, बी–9, कुतुब इंस्टीट्यूशनल एरिया, कटवारिया सराय, नई दिल्ली–110016
Registered & Corporate Office : Ist Floor, B-9, Qutab Institutional Area, Katwaria Sarai, New Delhi -110016
CIN : U40105DL2009GOI188682, Website : www.posoco.in, E-mail : posococc@posoco.in, Tel.: 011- 41035696, Fax : 011- 26536901

CIN: U40105DL2009GOI188682

पोसोको/ के.वि.वि.आ/ **दिनांक :** 24th May, 2018

सेवा में,
सचिव,
केन्द्रीय विद्युत् विनियामक आयोग,
तृतीय और चतुर्थ तल, चंद्रलोक बिल्डिंग
36, जनपथ
नई दिल्ली-110001

विषय: Report on review of Block bids at Power Exchange submitted in compliance to CERC letter dated 6th September, 2017

सँदर्भ: CERC letter No. PX/MISC/2017 dated 06.09.2017

महोदया ,

CERC vide communication dated 6th September 2017 directed POSOCO to examine the potential impact of 100 MW Block Bids inter-alia on the System operation and Market operation related issues in consultation with CERC and IEX. Several meetings were held on 14th June, 2017, 25th August, 2017, 27th September, 2017 and 30th November, 2017 to deliberate on the issues. Professor Soman and his team of researchers from IIT-Mumbai were also invited to deliberate various aspects associated with block bids on the 11th September 2018.

Accordingly, the report on the review of Block bids at Power Exchange prepared in consultation with CERC, IEX is attached for kind perusal of the Hon'ble Commission and further directions, if any. Delay in submission may kindly be condoned.

सादर धन्यवाद,

भवदीय,

एस एस बड़पंडा 24/5/18

(एस. एस. बडपंडा)

महाप्रबन्धक,रा.भा.प्रे.के.

Report on

Review of

Block Bids

At Power Exchanges

May 2018

Submitted in Compliance to CERC Letter dated 6th September 2017

Contents

1. Background

CERC Power Market Regulations, 2010 provides the Principles of Market and Market Design, encompassing Power Exchange functions. In the Day Ahead Market segment, the Power Exchanges offer different types of standardised contracts and the participants can bid using 'single-bids' or 'block-bids' which are spread over multiple time blocks. While single bids provide granularity, block bids are used to fulfil specific technical or commercial requirements of the generator or the loads.

Block bids impact the prices discovered and volume cleared in the Power Exchange markets depending on the quantum and size of block bids participating in the day-ahead market. As provided under the Power Market Regulations, the block bid parameters viz. maximum numbers of block bids, maximum quantity per block bids etc. are notified by the Exchange from time to time as per provisions of Business rules of the Power Exchange duly approved by the Hon'ble Commission. The immediate cause of concern arose when the maximum size of the block bid was revised by IEX from 50 MW to 100 MW as it may potentially impact both Market & System operations.

Some of the issues associated with block bids flagged by POSOCO vide communications dated 27th January 2010, 28th April 2017, 19th May 2017 and 22nd August 2017 (copies enclosed at Annex – I for ready reference) are as follows:

- Size of block bid
- Duration of block bid
- Impact of quantum and size of block bids on Market Clearing Volume, Market Clearing Price & Area Clearing Price
- Impact of maximum/minimum duration on technical minimum considerations
- Impact of maximum size on scheduling, ramping & real time grid operations
- Social welfare
- Paradoxical rejection of block bids
- Inclusion/exclusion of block bids create a more complex optimization problem impacting the overall social Welfare maximization
- Possibilities of squeezing out smaller players in the market

The above issues were deliberated in meetings held at CERC , NLDC and IEX. CERC vide communication dated 6th September 2017 directed POSOCO to examine the potential impact of 100 MW Block Bids inter-alia on the following System operation and Market operation related issues:

- Impact on ramping and scheduling of power
- Impact on transmission corridor allocation
- Impact on Market & Area Clearing Price and Market Clearing Volume
- Impact on smaller bidders

2. Salient Features of Power Exchange Implementation in India

The salient features of Power Exchange implementation in India are as follows:

(a) Voluntary participation

(b) A neutral platform

(c) Anonymous participation

(d) Competitive bidding

(e) Double sided auction

(f) 15 minute bidding

(g) Social Welfare Maximization

The advantages of Power Exchange implementation in India are likewise:

(a) Uniform Pricing

(b) Price discovery

(c) Congestion Management- Market Splitting

(d) Implicit auction

(e) Standardized contracts

(f) Risk management

(g) Investment Signals

(h) Competition amongst Power Exchanges

(i) Regulatory oversight

(j) Transparency and information dissemination

(k) Harnessing of Latent and Captive Generation

(l) Access opportunities for bulk and industrial consumers

3. Different Types of Block Bids and their Salient Features

Single bids will specify multiple sequences of price and quantity pairs for each time block in a portfolio manner. The quantity is assumed to vary linearly between two price pairs. Block Bid if selected will deliver/consume constant volume continuously for specified blocks. Block bid orders are All or None type wherein they are either accepted or rejected in toto. The following types of block bid orders are possible (not all are available in the Indian Power Exchanges):

- **Block bid**: Block bid will specify one price and one quantity for a combination of continuous 15-minutetime blocks. Selection criterion for inclusion/exclusion of the block bid is the average of Area Clearing Price (ACP) for the quoted 15-minute time blocks, of the respective Client's bid area vis-à-vis the quoted price for the block bid. It is a "All or None" type order.

- **Linked Block bids**:
  - All specifications as required by block bid, and,
  - Block bid only on acceptance of which, other bids linked to it can be considered for inculsion.
- **Flexible Hourly Bid**
  - Fixed volume that can be delivered/consumed, and,
  - Limit price

  Bid is considered for schedule in a time slot, which has maximum (for sellers) /minimum (for buyers) MCP. The bid might be rejected if MCP over the day does not meet requirement of limit price. It is a form of All or none type of bid wherein the time flexibility is there but volume is inflexible.

4. Selection criteria for Block Bids

The Block bid selection criterion is that the price quoted by the bidder should be better than the average of Area Clearing Price (ACP) for the quoted 15-minute time blocks, of the respective Client's bid area and it is an "All or None" type of order. The Bid selection based on time priority, in case of similarly placed bids, is considered only for Block bids. The Block bid selection in order of priority is Price followed by Volume and lastly time.

5. Paradoxical rejection of bid

In some cases, a block bid might be rejected by the system even though it would appear to be a valid bid. This can happen in a situation where inclusion of such bid might result in change in MCP at which this bid cannot be accepted. Rejection of such bids is known as paradoxically rejected bids. When block bid exclusion process is finished, it may have resulted in one or more block bids which appear to be rejected even though the bid price is more favorable than the average price. This type of rejection of a Block Bid is "Paradoxically rejected bids". The reason for rejection is that in case if the system accepts these bids, the average price of market changes in such a way that the block bids are no longer justified to be in. This may be both due to price as well as volume balancing.

6. Size of Block Bid

The Power Exchanges in accordance with the Rules, Byelaws and Business Rules of the Exchange, duly approved by the CERC, notify the Maximum Bid Limit for each Block Bid.

Initially, the maximum Block Bid quantity was restricted to 10 MW vide IEX circular dated 23rd June 2008, with a conditionthat it can be revised by the exchange from time to time, for which prior communication would be given to the Members.

Subsequently, the Maximum Bid Limit for each Block Bid was revised from 10 MW to 50 MW with effect from the Trading Day December 7, 2008 (Delivery day December 8, 2008) vide IEX Circular No: IEX/MO/08/ 2008.

The maximum quantity per Block bid has been increased from existing 50 MW to 100 MW starting from 12th April, 2017, trading day vide IEX Circular No: IEX/MO/237/2017.

The size of block bid also needs to be seen in the light of increasing trading volumes in the Power Exchange platform. The daily average cleared volume has increased from less than

1% of All India Demand met during 2008-2009 to about 3% presently.

7. Literature review on Block Bids in Power Exchanges

‘‘Block orders” are all-or-nothing orders of a given amount of electric energy in multiple consecutive hours at constant output, allowing participants to provide an average price for the combination of hours. This way, suppliers can offer lower prices, as the start-up cost is spread throughout the hours in the bid. It is generally assumed that blocks are price-setting orders, meaning that their prices are significantly different from zero and close to real market prices.

The reason block bids are featured in a Power Exchange design is because they allow linkage of bids thereby facilitating continuous running of the generating units and avoiding start/stops. In the absence of contiguous blocks, a supplier that wishes to run continuously may have to offer a very low price for intermediate time blocks, to “commit” so as to keep running the unit. Further, the Block bid by a generating station takes into account start-up and shutdown cost, ramp up and ramp down cost and operational cost. Blocks bid allow participants to provide an average price for a combination of hours. On average generators can offer cheaper prices for delivery in multiple consecutive hours, as the cost gets uniformly spread over a number of consecutive hours.

Introduction of flexible structures in Block bids may provide the volume flexibility, time flexibility along-with Minimum income criteria for bid clearing. Flexible volume block bids allow the market participants to specify their flexibility range i.e. Minimum volume a participant wants to get cleared and the Maximum volume a participant is intending to trade.

Richard P. O’Neill et.al [1]in their working paper titled “Equilibrium Prices in Power Exchanges with Non-convex Bids” discussed that uniform, linear prices in power exchange markets, such as in the Amsterdam Power Exchange (APX) Day-Ahead market or the Nord Pool Elspot market, that allow nonconvex, “fill or kill” block bids by market participants may not result in an equilibrium in an economic sense, nor do they maximize surplus to market participants. They proposed a multi-part, discriminatory, pricing mechanism that achieves a market equilibrium

Leonardo Meeus et.al [2]in their paper titled "Block order restrictions in combinatorial electric energy auctions" discussed the rationale of Block order restrictions. Internationally, the Power Exchanges restrict the size (MWh/h), the type (span in terms of hours) or the number (per participant per day) of blocks that can be introduced. They suggested that there is no significant correlation between restrictions (either size, type or number) and computational complexity (measured in terms of calculation time), likelihood of PRB (paradoxically rejected blocks) or trade efficiency (total gains from trade). The study concluded that the unrestricted use of blocks in immature or illiquid markets would increase price volatility, but as the markets have matured, those restrictions should be omitted or at least relaxed. Hence, liquidity of the market is a measure to gauge the restriction imposed on the size of the Block bid.

Dr Nicholas Ryan, Assistant Professor of Economics, Yale University suggest that plant offering blocks bids may make it easier to exercise market power in some circumstances. Because they "commit" plants to run, there is in effect less flexible competition for those plants that are offering single or flexible bids in a time block. These plants therefore have a greater effect on the time block price.

As per "Making Competition Work in Electricity" by Sally Hunt,

PREDICTING AND DETECTING MARKET POWER: How can we tell in advance whether there is likely to be market power in an electricity market? The first line of attack is to look at market concentration, generally using measures such as the Herfindahl Index, which is the sum of the squares of percentage market shares in a market.

The best solution to market power is to reduce the need for police and monitors by having enough competitors in the first place, by making entry easier, by divestiture, by relieving transmission constraints, and by allowing uneconomic plants to close, together with a price-responsive demand side.

The second best solution is contract cover (particularly during the transition to competitive markets). The third best solution (in fact the last resort) is to rely on forms of partial regulation such as price caps, bidding restrictions, and profit controls. But monitoring will always be necessary.

LIQUID MARKETS

We say the marketplaces are liquid if there are many buyers and sellers who can access each other easily and have access to information about the market prices. In liquid markets, the price settles down quite fast to a market price.

A defining feature of a liquid market is that it can generally absorb the addition or loss of a buyer or seller without a noticeable change in the market price. If there is good information, and the ability to resell, a competitive market comes to a single price for a specific product at a specific time and place.1

Mar Reguant [3] in the paper titled "Complementary Bidding Mechanisms and Start-up Costs in Electricity Markets" in Review of Economic Studies (2014) suggested that Costs of start - up / load adjustment are real and significantly affect generator bidding behaviour.

Paul R. Gribik et.al, [4] in their paper titled "Market-Clearing Electricity Prices and Energy Uplift" dated December 31, 2007, suggested that the general problem block bids try to solve is how to pay generators for "uplift" or start-up costs. Pricing models can differ in how they compensate generators for these costs. The practical consequence, of which system of payments will be best, will depend on the scenario and cannot be stated in general.

Sanchez Maria [5], 2010, in her Master's Thesis, suggested the adoption of **Flexible Hourly Bid (FHB) by Hydro plants.** This concept, firstly introduced in Nord Pool, consists of a price/volume pair that could be activated in a single hour, which is unknown to the bidder. If any market hourly price along the day exceeds the price in the flexible hourly bid, then the bid is accepted and the execution is scheduled for the hour with the highest system price, so that it provides the highest overall social welfare for the market. It gives producers the best price, and is especially suited to hydro generators that have the ability to commit at any given time in substitution to expensive thermal generation.

Professor Shreevardhan A. Soman, Dr. Rajeev and Dr.Somsekhar, Electrical Engineering Department, Indian Institute of Technology Mumbai delivered a session on Advanced Bid Structures at the Power Exchange platform. They suggested that flexible structures in Block bid might be adopted by means of allowing Volume flexibility, Time flexibility and Minimum income criteria for bid clearing. Mixed Integer Linear Programming (MILP) techniques such as constant volume (Volume scheduling constraint with minimum and maximum limits, Minimum cost recovering constraint),variable volume schedule, stepped marginal cost, variable volume operation with ramping cost and multiple start-up and shutdown were discussed as alternative to the existing Block bids.

8. Meetings and deliberations

POSOCO had communicated to CERC, the likely issues that emerge out of increasing the Block Bid size vide several communication dated 27th January, 2010, 28th April, 2017, 19th May, 2017 and 22nd August 2017(**Copy enclosed at Annexure-1**) **.**Subsequently, A meeting was held at CERC on 14th June 2017, wherein Indian Energy Exchange gave a presentation on the highlighted issues. The presentation highlighted that the block bids with quantity greater than 50 MW (period considered – 13th April, 2017 to 31st May 2017) accounted for 11-26 percent out of the total block bid traded quantity, which is a sizeable number. Subsequently, another meeting was held on 25th August, 2017 regarding the subject matter. Finally, CERC vide its letter dated 6th September 2017(**Copy enclosed at Annexure-2**) , directed that POSOCO along-with CERC and IEX are required to examine the potential impact of 100 MW Block Bids on the System and Market Operation related aspects.

Several meetings were held on 14th June, 2017, 25th August, 2017, 11th September, 2017, 27th September, 2017 and 30th November, 2017 to deliberate on the issues. The summary of the deliberations held during the meetings are as detailed below:

- **Meeting on 14th June, 2017:**

  A meeting was held on 14th June 2017 at CERC to discuss on the Block bid aspects flagged by POSOCO vide letter dated 27th January, 2010 and28th April, 2017. IEX gave a presentation on the impact of 100 MW Block bid on schedule and ramping. They mentioned that they introduced 100 MW Block Bid size as a few generator clients wish to place Block bid size greater than 50 MW. Post introduction of 100 MW Block bid at the IEX from 12th April, 2017 (Period: 13th April, 2017-31st May, 2017), IEX observed the following:

- Block Bids with quantity greater than 50 MW to the total number of Block Bids: around 1 percent
- Number of Portfolios with Block Bids quantity greater than 50 MW to the total number of Portfolios with Block Bids: 0.81 percent
- Block Bids Trade quantity with bid greater than 50 MW to the trade quantity of the total number of Block Bids: 11 percent on an average, 26 percent as maximum
- Time Block-wise analysis of Single bid and Block bid depicting that Block Bid has smooth curve as compared to Single Bid curve
- Ramping analysis of IEX trade at State level(Period: 8th April, 2017-17th April, 2017)
- States DAM schedule compared with ISGS, LTA+MTOA and Bilateral transaction

Few other issues were deliberated like difference between MCP and ACP when there is no market splitting, final Area Clearing Volume greater than Market Clearing volume in no. of days. The copy of the presentation is attached at **Annexure-3**.

- **Meeting on 25thAugust 2017 at CERC**:

  IEX deliberated that in order to evaluate the impact of performance of Block Bid with size greater than 50 MW, they analysed data for 49 days (13th April, 2017- 30th June, 2017) and communicated their observations to the CERC vide letter dated 24th July, 2017(copy enclosed at **Annexure-4**). The salient points of their observations during the meeting are as follows:

  - **International Benchmark :** Block bid size in other International markets are as follows

Electricity Market	Countries	Max. Block Bid Size(MW)	Annual Trade (TWhr)
EPEXDE/AT	Germany/Austria	600	229 (Jun'16-Jul'17)
EPEXFR	France	600	105 (Jun'16-Jul'17)

Nord Pool	Nordic & Baltic Countries	500	390 (Jan'16-Dec'16)
N2EXUK	United Kingdom	500	108 (Jan'16-Dec'16)
EPEXNL	Netherlands	400	32 (Jun'16-Jul'17)
EPEXBL	Belgium	400	20 (Jun'16-Jul'17)
EPEXCH	Switzerland	150	23 (Jun'16-Jul'17)
IEX	India	100	42 (Jun'16-Jul'17)

Table 1: Block bid size Internationally

It is also important to mention here that in the European markets mentioned above, the Power Exchange volumes comprise of 50% and more of the total demand being served. In India, the Power Exchange volumes comprise of about 3% of all India demand met and thus, in percentage terms, itis considerably smaller as compared to European markets however in volume terms it is comparable with some European countries.

- **Price difference between Market Clearing Price(MCP) and Area Clearing Price (ACP) in no Congestion blocks**: Due to Congestion in some of the blocks during the day, there might be a possibility in change in the prices of non-congested blocks as well. It was mentioned that due to congestion in certain blocks of the day, the demand and supply situation changes not only in congested time blocks but also in non-congested time blocks, due to inclusion/rejection of earlier rejected/included marginal bids. This may result in price difference between MCP and ACP. The phenomenon was illustrated with an example showing that on several days the Block Bid with quantity >50 MW has not changed its status (i.e. Block Bid selected in Provisional remained selected in Final and/or Block Bid rejected in Provisional remained rejected in Final) in Provisional and Final results but still difference in MCP and ACPs has been noted in uncongested blocks. Internationally, it was pointed out that the sample price of Nord-Pool for a typical day wherein all price areas (ACPs) are same indicating no congestion for the above mentioned time blocks, however system price i.e. MCP ("SYS" price) is different from ACPs.

- **Final Cleared Volume greater than Market clearing volume on number of days**: IEX mentioned that due to congestion, the changes in prices in upstream and downstream of congestion might result in final ACV greater than the MCV. This may happen due to selection of Buy (single/Block) bid in the Upstream, which was rejected in unconstrained result, and selection of Sell (single/Block) bid in the downstream, which was rejected in unconstrained results. They had observed that on several days the Block bid with quantity greater than 50 MW has not changed its status in provisional and final results but still there are situation where ACV>MCV occurred.

- **Contribution of ramping in DAM schedule of Collective transactions** is insignificant as compared to other contract types.
  However, POSOCO clarified that ramping of conventional generation stations is going to be a major technical consideration to address the intermittent generation of renewable energy. Hence, ramping needs to be considered , which can be deliberated separately in details. It is also pertinent to mention that unlike other Power Exchanges worldwide, the volumes in the Indian Power Exchange(s) are lower in terms of the percentage of total demand met i.e., in India PX volumes are of the order of 3% only. Further, it is also then evident that the participants, including generators, in the Power Exchange(s) are having a portfolio comprising of different types of transactions. Thus, it is less likely that unit commitment decisions are solely based on the Power Exchange trades.

- **Meeting on 27th September, 2017 at NLDC**
  Discussions were held on various Market Design aspects related to Block Bids, some of them are enumerated below:
  - Optimal size of block bids and its impact on prices, volumes and social welfare with reference to the International best practises was discussed. In addition, it emerged that computation of Social Welfare is carried out in the Power Exchanges on a daily basis and may be posted regularly at their website.

- **Liquidity of Indian Electricity Market**: Liquidity is one of the decision criteria for the size of block bids. There were discussions on the various measures to measure liquidity of the electricity market.

    - **Herfindahl-Hirschman Index (HHI):**

      The Herfindahl index (also known as Herfindahl–Hirschman Index, HHI, or sometimes HHI-score) is a measure of the size of firms in relation to the industry and an indicator of the amount of competition among them. Named after economists Orris C. Herfindahl and Albert O. Hirschman, it is an economic concept widely used to measure concentration. It is defined as the sum of the squares of the market shares of the firms within the industry (sometimes limited to the 50 largest firms), where the market shares are expressed as fractions. The result is proportional to the average market share, weighted by market share. As such, it can range from 0 to 1.0, moving from a huge number of very small firms to a single monopolistic producer. Increases in the Herfindahl index generally indicate a decrease in competition and an increase of market power, whereas decreases indicate the opposite.

      CERC calculates the ratio for Market Monitoring purpose to arrive at the Market concentration of the Trading Licensees. The HHI of IEX Day-Ahead Market for Buyers and Sellers illustrated by IEX (As per CERC Market Surveillance Committee Report July’17 to Sep’17)

Figure 1: HHI Buyers

Figure 2: HHI Sellers

The description of HHI Index is as below:-

- *A HHI index below 0.01 (or 100) indicates a highly competitive index.*
- *A HHI index below 0.15 (or 1,500) indicates an unconcentrated index.*
- *A HHI index between 0.15 to 0.25 (or 1,500 to 2,500) indicates moderate concentration.*
- *A HHI index above 0.25 (above 2,500) indicates high concentration.*

- **Contribution of Top ten Buyers/ Sellers**

  The percentage contribution of Top ten Buyers/Sellers in Day Ahead Market (Collective transactions) for the period 1st September, 2017- 29th March, 2018 is shown below. It is observed that the Top ten Sellers have an average contribution of 51 percent and the Top ten Buyers have an average contribution of 81 percent in the total trade during the above-mentioned period, indicating some degree of concentration in the Day Ahead Market(Collective transactions). This is also evident from the figure below.

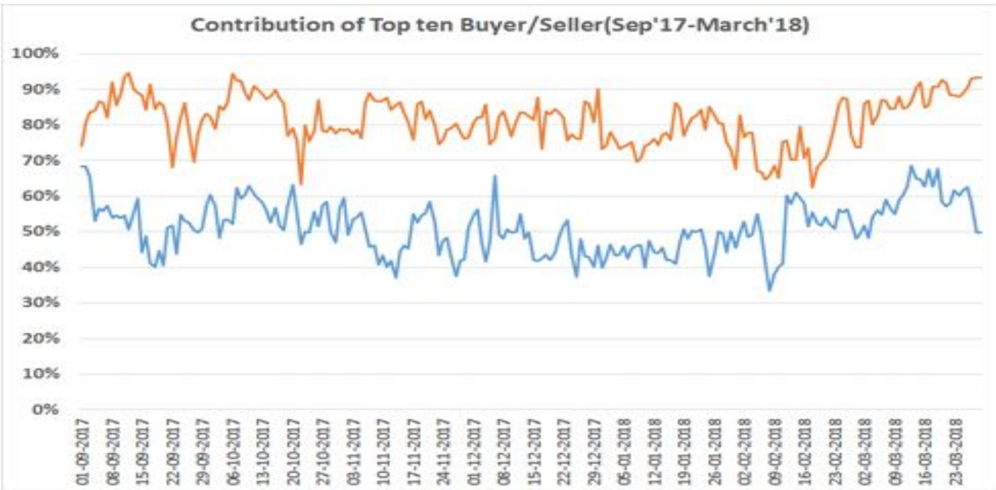


Figure 3: Contribution of Top ten Buyer/Seller

- In IEX, a maximum 60 Block Bids are allowed to each participant. Internationally, the limits on size and no. of block bids per participant are as below:

Electricity Market	Country	Max. Block Bid Size (MW)	Max. No. of Block Bids per participant
EPEX DE/AT	Germany/ Austria	600	100
EPEX FR	France	600	40
Nord Pool	Nordic & Baltic Countries	500	50
EPEX UK	United Kingdom	500	80
N2EX UK	United Kingdom	500	80
EPEX NL	Netherlands	400	40
EPEX BL	Belgium	400	40
EPEX CH	Switzerland	150	40
IEX	India	100	60

Table 2: Block bid per participant

- Block bids were primarily introduced to take care of the technical requirements of generators e.g., technical minimum generation, etc. The merit of allowing block bids for buyers was deliberated and it emerged that due to State Open Access Regulations (like in Rajasthan, Haryana, Punjab) the Open Access Industries need power on firm basis; hence it cannot be restricted to sellers only.
- Internationally, Power Exchanges are deciding the size of Block Bid on liquidity basis.The Block Bid size limit and liquidity in major Power Exchanges are as follows:

- **Impact on Real time System operation – Ramping, scheduling and corridor utilization**

NLDC mentioned that IEGC provisions stipulate that no generator/user shall cause a sudden variation (step change) of 100 MW and more. Presently, there are no such restrictions imposed in the Power Exchange. It was also mentioned by NLDC that trades cleared in the Power Exchange thus have an impact on scheduling and consequently, on real time operation. IEX clarified that collective transactions are only one of the components in the portfolio and a view needs to be taken in totality. It was felt, that there is a need of detailed discussion on this subject wherein schedules arising out of Exchange Transactions as well as other modes of transactions will have to be considered in totality. In future, if need arises, ramping requirements may be imposed in the Power Exchange bidding process.

NLDC also mentioned that exclusion of a marginal block bid on a congested corridor may lead to under-utilization of the corridor. This under-utilization will increase as the size of the block bid increases (50 MW or 100 MW) and is a matter of concern. IEX mentioned that presently, it has been observed that mostly the block – bids are not the marginal bids generally and also that there is hardly any under-utilization of the congested corridor. In past four years in only two time blocks (30 minutes) there was under utilisation of 0.01 MW each, that too due to rounding off as may be seen from the table below. A watch need to kept to see if there are any cases of under-utilisation after increase in block bid size.

Assessment Period 01-04-13 to 19-09-17		
Region/Area	**Blocks of Congestion**	**Max. under-utilization in a time block (MW)**
SR Import	102903	0.01 (2 Blocks)
NR Import	22638	Nil
N3 Import	11596	Nil
S2 Import	35794	Nil
W3 Export	6952	Nil

- **Meeting on 30th November 2017**

  The last meeting took place at the IEX Premises on 30th November, 2017. IEX presented the entire market clearing process including block bids. The following was agreed during the meeting:

  - The subject of block bids, their usage and impact on market in terms of prices and volumes is complex
  - It was agreed that a formal consultation would be carried out by the Power Exchange(s) in case any change in size of the block bid in future.

- It was also agreed that any change in Power Exchange Market design which has a material impact on the price discovery, volumes cleared and social welfare will need to be approved by the Hon'ble Commission.
- Impact on Smaller Market Participants -Concerns were raised by NLDC, regarding the usage of large size block bids and their impact on the market clearing, specially regarding possible exclusion of the smaller market participants. IEX e*xplained that, during each step of* Price Calculation, the system is unbiased to quantity and considers the price of individual portfolios for deriving the Clearing Price. Hence large block bid size may have no impact on smaller participants.
- The economic principle suggests that the market outcomes are most efficient when the price is discovered based on social welfare maximization principles. Regulation 11 A of Power Market Regulations has also mandated the exchange to carry out the price discovery based on the economic principle of social welfare maximization principles while creating surplus for both buyers & sellers. Accordingly, the exchange must ensure that while matching the buy/sell bids for price discovery the social welfare maximization should also be met. The problem of determining the MCP by matching the bidders to maximize social welfare is complex in many respects, particularly the inclusion of block bids with a 'All or None' characteristics make the problem a combinatorial one. This can be suitably addressed if the algorithm is modelled as an optimization problem with its objective function as social welfare maximization. This would give flexibility to the algorithm which can be changed by adding or relaxing few constraints.
- IEX is submitting the surveillance reports to the Hon'ble Commission on a quarterly basis in which it is providing the month-wise HHI index giving an measure of the level of competition in the exchange. Some additional parameters viz. time block-wise or day-wise HHIs, bid-ask spread etc. may be captured which would give a better understanding of the level of competition in the market. Further, the social welfare achieved along with a consumer and producer surplus may also be captured giving an indication of market efficiency.

9. Interaction with Academia (IIT Mumbai) on 11th September, 2017

CERC in the communication to POSOCO suggested that academician/professional having experience in Power Exchanges may be consulted for the study. In this connection, POSOCO invited **Professor Shreevardhan A. Soman**, Electrical Engineering Department, Indian Institute of Technology Mumbai for an interactive session on “Impact of Block bid on price discovery and volumes cleared at Power Exchanges” on 11th September 2017 at National Load Despatch Centre**.** He was accompanied by two of his Research Scholars viz. Dr. Rajeev and Dr.Somsekhar.

Block bid features

They presented the concept of Market clearing with Block bids in DAM. They mentioned that Block Bids are Fill or Kill type Bid order. Various types of Block bids were explained such as linked bid (Mother-Child bids), Flexible bids etc. The reason for Introduction of Block Bid is that they encourage participation of generators with high start-up and shutdown cost and guarantee operational volumes over consecutive hours, allowing them to bid at competitive price. However, the problem with Block bids is that there is a possibility of Paradoxical Rejection of Bids (PRB). They also suggested that segregation of cost components like start up, shutdown, running, ramping and marginal cost allows block bidders to be even more competitive and probability of PRB comes down.

Suggested New Features to address the issues related with Block bid

They suggested that in order to address the issues related with Block Bids, flexible Bid structures may be introduced. The flexible bids have the inherent advantages, as follows:

- Volume flexibility
- Time flexibility
- Minimum income criteria for bid clearing

The relevant papers shared by the eminent faculty from IIT Mumbai and the presentation enclosed at **Annexure-5.**

10.Recommendations

The recommendations are as follows:

(a) The subject of block bids and associated market design issues are complex and more study/analysis needs to be done. Design parameters such as liquidity, concentration in the market, etc. may be considered before undertaking any change in the block bid specifications.

(b) A formal consultation would be carried out by the Power Exchange(s) with NLDC and CERC in case of change in block bid size in future.

(c) It was also agreed that any change in Power Exchange Market design which has a material impact on the price discovery, volumes cleared and social welfare will need to be approved by the Hon'ble CommissionRamping requirements in system operation need to be taken care of and any step changes should be avoided as envisaged in the Grid Code. In future, detailed discussion on ramping restrictions on all segments of marketcould be taken up separately as need arises.

(d) The market design principles as laid down in the CERC Power Market Regulations provides for economic principle of social -welfare maximisation during price discovery. Minimum information dissemination requiements have been specified in the CERC Power Market Regulations However, there is no bar on additional information dissemination by the Power Exchanges. Hence it is recommended that the following information should be made available on the respective websites by the Power Exchanges:

a. Producer surplus
b. Consumer surplus
c. Total social welfare
d. Total number of portfolios traded
e. Percentage contribution of block bids both in terms of number of block bids and market clearing volume (energy)Bid-Ask spread

(e) The economic principle suggests that the market outcomes are most efficient when the price is discovered based on social welfare maximization principles. Regulation 11 A of Power Market Regulations has also mandated the exchange to carry out the price discovery based on the economic principle of social welfare maximization principles while creating surplus for both buyers & sellers. Accordingly, the exchange must ensure that while matching the buy/sell bids for price discovery the social welfare maximization should also be met. The problem of determining the MCP by matching the bidders to maximize social welfare is complex in many respects, particularly the inclusion of block bids with a 'All or None' characteristics make the problem a combinatorial one. This can be suitably addressed if the algorithm is modelled as an optimization problem with its objective function as social welfare maximization. This would give flexibility to the algorithm which can be changed by adding or relaxing few constraints.

(f) IEX is submitting the surveillance reports to the Hon'ble Commission on a quarterly basis in which it is providing the month-wise HHI index giving an measure of the level of competition and liquidity in the exchange. Some additional parameters viz. time block-wise or day-wise HHIs, bid-ask spread etc. may be captured which would give a better understanding of the level of competition in the market. Further, the social welfare achieved along with a consumer and producer surplus may also be captured giving an indication of market efficiency.

(g) New types of bids, 'exotic bids' should be examined to cater to specific requirements of the different types of participants in market. For example, while placing bids, the Hydro generators may give energy on RTC/ defined time blocks, and allow for flexibility in the volume cleared in each time block depending on say, the price (high prices would indicate higher demand to be met & hydro optimization will help).

References of Literature Survey

S. No	Title of the Paper/Document/Article	Author/Group/Copyright Holder	Year of Publication
1	"Equilibrium Prices in Power Exchanges withNon-convex Bids" IEEE working paper	Richard P. O'Neill, Paul M. Sotkiewicz, and Michael H. Rothkopf	January 2006, revised July 2007
2	"Block order restrictions in combinatorial electric energy auctions" European Journal of Operational Research 196 (2009) 1202–1206	Leonardo Meeus, KarolienVerhaegen, Ronnie Belmans	2009
3	"Complementary Bidding Mechanisms and Start-up Costs in Electricity Markets"Review of Economic Studies (2014) 81, 1708–1742,	Mar Reguant	2014
4	"Market-Clearing Electricity Prices and Energy Uplift" dated December 31, 2007	Paul R. Gribik, William W. Hogan, and Susan L. Popei	2007
5	"Day-Ahead Electricity Market: Proposals to adapt complex conditions in OMEL"submitted in partial fulfilment of Master's thesis at Comillas Pontifical University, Spain	Sanchez Maria	2010

List of Annexures

Annexure No.	Detail of Annexure
1	NLDC Communications to CERC regarding Block Bids
2	CERC Letter dated 6th September 2017 regarding constitution of Committee to study impact of increase in maximum quantity of Block bids from 50 MW to 100 MW
3	IEX Presentation on Block bids at CERC on 14th June 2017
4	IEX Letter to CERC dated 24th July 2017 regarding increase in maximum quantity of Block bids from 50 MW to 100 MW
5	Presentations and literature on Block bids made by Professor Shreevardhan A. Soman, Dr. Rajeev and Dr.Somsekhar,Electrical Engineering Department, Indian Institute of Technology Mumbai

केन्द्रीय विद्युत विनियामक आयोग

CENTRAL ELECTRICITY REGULATORY COMMISSION

Sanoj Kumar Jha, IAS
Secretary

Ref: PX/Misc/2017

Date : 06/09/2017

The CEO
Power System Operation Corporation Limited (POSOCO)
B-9 (1st Floor)
Qutab Institutional Area,
Katwaria Sarai,
New Delhi

Subject: Increase in maximum quantity of Block Bids from 50 MW to 100 MW at IEX

Sir,

This has reference to the meeting held at CERC on 25th August 2017 regarding increase of maximum quantity for Block Bids from 50 MW to 100 MW by IEX.

2. Based on the discussion held during the meeting, it was decided that POSOCO in co-ordination with IEX and CERC shall examine the potential impact of 100 MW Block Bids inter-alia on the following System and Market operations related issues:

- Impact on ramping and scheduling of power
- Impact on Transmission corridor utilization
- Impact on Market and Area Clearing Price & Volume
- Impact on Smaller Bidders

3. If required, POSOCO may also consult any other academician or professional having expertise in power sector/exchanges to assist them in undertaking the study. POSOCO may submit the findings to the Commission within a month's time for further directions on the above issue.

Yours faithfully

०६/०९/१७

(Sanoj Kumar Jha)

Copy to:

To

The CEO
INDIAN ENERGY EXCHANGE LIMITED (IEX)
Unit No. 3,4,5 and 6, Plot No. 7
Fourth Floor, TDI Centre,
District Center, Jasola,
New Delhi – 110025

तीसरी मंजिल, चन्द्रलोक बिल्डिंग, 36, जनपथ, नई दिल्ली-110 001
Third Floor, Chanderlok Building, 36, Janpath, New Delhi-110 001
Phone : 91-11-2375 3915, Fax : 91-11-2375 3923, E-mail : secy@cercind.gov.in / secyskj@gmail.com

ANNEXURE-2

POWER GRID CORPORATION OF INDIA LIMITED
NATIONAL LOAD DESPATCH CENTRE

Dated: 27th January 2010

The Managing Director
Indian Energy Exchange Limited
100A/1 Ground Floor, Capital Court,
Olof Palme Marg, Munirka,
New Delhi-110067

Subject: Prices in IEX – Impact of Block Bids

Sir,

This has reference to the prices discovered on the IEX Platform for the delivery date 17th January 2010. On this day, congestion was present in the import towards Northern Region and the Market Split in the IEX into 'Northern Region' (deficit region) and 'Rest of India' (surplus region). From the prices published on the IEX Website, it is observed that during 0000 to 0600 Hrs, the prices in the surplus area are higher than the unconstrained market price. A similar phenomenon is observed again during the period 1700 Hrs to 2400 Hrs.

It is understood that such behavior is normally associated with inclusion/exclusion of block bids (if exclusion of trades on account of inadequate margins is not considered). In this context, the following issues need further deliberation for a better understanding:

(a) Specific provisions in the CERC Regulations (including Power Market Regulations) and the Business Rules / Bye Laws / Rules of IEX in respect of Block Bids, if any.
(b) Initially, as given to understand by IEX, the maximum block bid quantum was restricted to 10 MW. This was modified to 50 MW by IEX through a Circular dated 6th December 2008. The rationale which necessitated this modification need to be understood by all.
(c) Block Bids is mentioned in the Business Rules of IEX at Para 17.1(b) and 18.3(e). However, the tick size is also relevant.
(d) Maximum/minimum duration also needs to be deliberated for the Block Bids based on the technical minimum considerations.
(e) The kind of utilities (generators, consumers, captives, portfolio bidders) placing such kind of block bids and their bidding behavior.
(f) The proportion of block bids on a daily basis (pattern).

It is a well established fact that the inclusion/exclusion of block bids creates a more complex optimization problem thereby impacting the overall social welfare maximization. There can be peculiar price movements if a high proportion of block bids is present.

As the market is maturing, it is requested that the above issues may kindly be addressed and a discussion could be organized.

Thanking you,

Yours faithfully,

S. K.Soonee
Executive Director (SO & NLDC)

CC: 1 Secretary, CERC
2 All RLDC Heads

पावर सिस्टम ऑपरेशन कारपोरेशन लिमिटेड
(भारत सरकार का उद्यम)

POWER SYSTEM OPERATION CORPORATION LIMITED
(A Govt. of India Enterprise)

पंजीकृत एवं केन्द्रीय कार्यालय : प्रथम तल, बी-9, कुतुब इंस्टीट्यूशनल एरिया, कटवारिया सराय, नई दिल्ली-110016
Registered & Corporate Office : Ist Floor, B-9, Qutab Institutional Area, Katwaria Sarai, New Delhi -110016
CIN : U40105DL2009GOI188682, Website : www.posoco.in, E-mail : posococc@posoco.in,Tel.: 011- 41035696, Fax : 011- 26536901

संदर्भ संख्या: पोसोको/एनएलडीसी/आई-ई-एक्स-/२०१७/ 105 दिनांक: 28th अप्रैल 2017

सेवा मे,

निदेशक (मार्केट ऑपरेशन)
इंडियन एनेर्जी एक्सचेंज (आई- ई- एक्स-)
चतुर्थ तल, टी- डी- आई- सेन्टर, प्लॉट सं- – 7, जसोला, नई दिल्ली-110025

विषय: Increase in Maximum Quantity per Block Bid from 50 MW to 100 MW.

संदर्भ: IEX circular no. IEX/MO/237/2017 dated 11th April 2017

महोदय,

This has reference to the circular no. IEX/MO/237/2017 dated 11th April 2017 vide which the maximum quantity per Block bid was increased from 50 MW to 100 MW w.e.f. 12th April 2017. In this context, it is pertinent to mention that sub-clause (j) of clause 5.2 of CERC (Indian Electricity Grid Code) Regulations, 2010 provides as under:

"Except under an emergency, or to prevent an imminent damage to a costly equipment, no User shall suddenly reduce his generating unit output by more than one hundred (100) MW (20 MW in case of NER) without prior intimation to and consent of the RLDC, particularly when frequency is falling or is below 49.5 Hz.. Similarly, no User / SEB shall cause a sudden variation in its load by more than one hundred (100 MW) without prior intimation to and consent of the RLDC."

A step change in generation and demand quantum of the order of 100 MW or more has an impact on scheduling and ramping requirements.

It has also been observed that during the last one month final cleared volume was more than the unconstrained market clearing volume on a number of days. It is understood that one of the possible reasons for such phenomenon is block bids.

It is suggested that we may hold a meeting at a mutually convenient date/time to discuss and better understand the associated issues.

सादर धन्यवाद,

भवदीय,
(एस.एस. बड़पंडा)
अपर महाप्रबंधक

प्रतिलिपि: सचिव, केंद्रीय विद्युत विनियामक आयोग
तीसरी मंजिल, चंद्रलोक बिल्डिंग,३६ जनपथ,नई दिल्ली -११०००१

पावर सिस्टम ऑपरेशन कारपोरेशन लिमिटेड
(भारत सरकार का उद्यम)

POWER SYSTEM OPERATION CORPORATION LIMITED
(A Govt. of India Enterprise)

पंजीकृत एवं केन्द्रीय कार्यालय : प्रथम तल, बी-9, कुतुब इंस्टीट्यूशनल एरिया, कटवारिया सराय, नई दिल्ली-110016
Registered & Corporate Office : Ist Floor, B-9, Qutab Institutional Area, Katwaria Sarai, New Delhi -110016
CIN : U40105DL2009GOI188682, Website : www.posoco.in, E-mail : posococc@posoco.in Tel.: 011- 41035696, Fax : 011- 26536901

संदर्भ संख्या: पोसोको/एनएलडीसी/आई-ई-एक्स-/२०१७/ दिनांक: 19th May, 2017

सेवा में,

निदेशक (मार्केट ऑपरेशन)
इंडियन एनेर्जी एक्सचेंज (आई- ई- एक्स-)
चतुर्थ तल, टी- डी- आई- सेन्टर, प्लॉट सं- – 7, जसोला, नई दिल्ली-110025

विषय: Difference between ACP and MCP during time blocks with no Market splitting

संदर्भ: Letter to IEX No: पोसोको/एनएलडीसी/आई-ई-एक्स-/२०१७/105 dated 28th April, 2017

महोदय,

This has reference to the above-mentioned letter to IEX wherein the maximum quantity per Block bid was increased from 50 MW to 100 MW w.e.f. 12th April 2017.

In this context, it is pertinent to mention that for the past few months, it has been observed that there is a price differential between the Area Clearing price and Market Clearing price, even for the time blocks where market splitting has not occurred in Day Ahead Market Collective transaction. After 12th April, 2017, the phenomenon occurred more frequently. The details for the period 1st January 2017-19th May, 2017 are enclosed at Annexure-I.

Such type of phenomenon is counter-intuitive, because as per the market design principles of Power Market Regulations, it is expected that there will be no price differential between the Area Clearing price and Market Clearing price, for the periods when there is no market splitting. One of the possible reasons for such phenomenon could be large size of block bids.

The matter needs in depth analysis and further discussion.

सादर धन्यवाद,

भवदीय,
एस एस बर्पंडा
19/5/17
(एस.एस. बर्पंडा)
अपर महाप्रबंधक

प्रतिलिपि: सचिव, केंद्रीय विद्युत विनियामक आयोग
तीसरी मंजिल, चंद्रलोक बिल्डिंग, ३६ जनपथ, नई दिल्ली -११०००११

Annexure-I

Month	Count of Time blocks (Price difference b/w MCP and ACP when there is no market splitting)				
	Less than 10 paise	10-20 paise	20-30 paise	Difference greater than 30 paise	Total Time Blocks in Month
January, 2017	859	52	9	3	2976
February, 2017	531	33	13	4	2688
March, 2017	872	34	9	3	2976
1-12th April, 2017	322	20	1	0	1152
13th April-19th May, 2017	1391	61	12	8	3552

पावर सिस्टम ऑपरेशन कारपोरेशन लिमिटेड
(भारत सरकार का उद्यम)
POWER SYSTEM OPERATION CORPORATION LIMITED
(A Govt. of India Enterprise)

पंजीकृत एवं केंद्रीय कार्यालय : प्रथम तल, बी-9, कुतुब इंस्टीट्यूशनल एरिया, कटवारिया सराय, नई दिल्ली-110016
Registered & Corporate Office : Ist Floor, B-9, Qutab Institutional Area, Katwaria Sarai, New Delhi -110016
CIN : U40105DL2009GOI188682, Website : www.posoco.in, E-mail : posococc@posoco.in, Tel.: 011- 41035696, Fax : 011- 26536901

संदर्भ संख्या: पोसोको/एनएलडीसी/के.वि.वि.आ/2017/ दिनांक: 22nd August,2017

सेवा में,
सचिव
केंद्रीय विद्युत विनियामक आयोग
तीसरी मंजिल, चंद्रलोक बिल्डिंग, ३६ जनपथ, नई दिल्ली -११०००१

विषय: Increase in maximum quantity of Block bid from 50 MW to 100 MW at Indian Energy Exchange

संदर्भ:
1. Discussion Meeting at CERC dated 14th June 2017
2. POSOCO Letter to IEX dated 28th April 2017
3. IEX circular no. IEX/MO/237/2017 dated 11th April 2017
4. NLDC Letter to IEX dated 27th January 2010

महोदय,

Indian Energy Exchange Ltd (IEX) recently increased the block bid size from 50 MW to 100 MW from trading date 12th April, 2017 vide circular No. 237 dated 11th April, 2017. National Load Despatch Centre (NLDC) had flagged some of the relevant issues related to Block bids in the earlier communications to CERC and IEX dated 27th January, 2010 and 28th April, 2017(Copy enclosed at Annexure –I & II).

Any change in the bidding structure by the Power Exchange(s), such as increasing the block bid size from 50 MW to 100 MW, requires consultation with NLDC, being the Nodal agency for Collective transactions as per CERC Regulations. In this case, the consultative approach was missing on part of IEX. NLDC observed the behavior and subsequently vide letter dated 28th April, 2017 pointed out the issues related to the subject matter to IEX. A meeting was also held at CERC on 14th June 2017, wherein Indian Energy Exchange gave a presentation on the highlighted issues. The presentation highlighted that the block bids with quantity greater than 50 MW (period considered - 13th April, 2017 to 31st May 2017) accounted for 11-26 percent out of the total block bid traded quantity, which is a sizeable number. It may be worthwhile to mention that any inclusion or exclusion of a block bid has an impact on the price discovery mechanism, volumes cleared and the consequential social welfare maximization. The important points which need to be considered in view of these facts are as follows:

- A step change in generation and demand quantum of the order of 100 MW or more has an impact on scheduling, ramping requirements and the real time grid operation
- Final cleared volume in Collective transactions is observed to be more than the Unconstrained market clearing volume on a number of days
- In case if there is no congestion in a time block, the selection/rejection of block bids leads to change in Market Clearing Price and Area Clearing Price(s)
- A particular set of market participants, bidding more than 100 MW and above, may squeeze out a substantial percentage of small quantum sized players.

Since the Electricity market is evolving, any change in market design principles such as increase in quantum of block bids needs to be studied in depth for better understanding and effective market monitoring.
Submitted for consideration of the Honorable Commission and further directions, if any.

सादर धन्यवाद,

भवदीय,
एस एस बरपंडा
(एस.एस. बरपंडा)
महाप्रबंधक

14-06-2017

All letters on Block Bids from NLDC to CERC to be taken out

Discussion Meeting
14th June 2017

Akhilesh Awasthy
Director, Market Operations

Points for Discussion

- Difference between MCP and ACP when no Market Splitting (Letter ref. No.:- POSOCO/IEX/2017)
- Final ACV is greater than MCV in no. of days (Letter ref. No.:- POSOCO/IEX/2017/105)
- Impact of 100 MW Block Bid on Schedule and Ramping (Letter ref. No.:- POSOCO/IEX/2017/105)
- Treatment of Greenko Budhil Hydro Power Plant (Letter ref. No.:- POSOCO/MO/101)

Difference between MCP and ACP when no Market Splitting

Understanding the Cause with an Example
Case 1:- ACP>MCP with no Market Split

Portfolios	Bid Type	Quantity (MW) @ Price(Rs./kWhr)
Buyer-SR	Single	100@5, 90@5.50 to 6
Seller-SR	Single	-90@4 to 5, -100@5.5
Seller-SR	Single	-10@5
Seller-ER	Block	-10@3

- 2 Time Period Sets considered where above bids are available for both time sets
- Provisional result (with No Constrained)----

Time Set1

Price (Rs./kWhr) →		0	4	5	5.5	6
Buyer-SR	Single	100	100	100	90	90
Seller-SR	Single	0	-90	-90	-100	-100
Seller-SR	Single	0	0	-10	-10	-10
Seller-ER	Block	-10	-10	-10	-10	-10
Net (Buy-Sell)		90	0	-10	-30	-30

Time Set2

Price (Rs./kWhr) →		0	4	5	5.5	6
Buyer-SR	Single	100	100	100	90	90
Seller-SR	Single	0	-90	-90	-100	-100
Seller-SR	Single	0	0	-10	-10	-10
Seller-ER	Block	-10	-10	-10	-10	-10
Net (Buy-Sell)		90	0	-10	-30	-30

Provisional Result- MCP for both Time Blocks is Rs. 4/kWhr

Seller Block Bid will be selected since Sell Bid Price<Avg. MCP for both time sets.

Corridor Requisition in both time blocks from ER->SR is 10 MW.

Case 1:- ACP>MCP with no Market Split

Time Set	Requisition ER->SR	Availability in Exception report ER->SR
Set1	10	<10
Set2	10	>10

- Final Result (with Constrained)- Sell Block Bid will be rejected for both time sets.

Time Set 1; Congestion

Price (Rs./kWhr)	→	0	4	**5**	5.5	6	6001
Buyer-SR	Single	100	100	100	90	90	0
Seller-SR	Single	0	-90	-90	-100	-100	-100
Seller-SR	Single	0	0	-10	-10	-10	-10
Net (Buy-Sell)		100	10	0	-20	-20	-110

Time Set 2; No Congestion

Price (Rs./kWhr)	→	0	4	**5**	5.5	6
Buyer-SR	Single	100	100	100	90	90
Seller-SR	Single	0	-90	-90	-100	-100
Seller-SR	Single	0	0	-10	-10	-10
Seller-ER	Block	0	0	0	0	0
Net (Buy-Sell)		100	10	0	-20	-20

- For 2nd Time Set, there was no congestion and no market split but ACP(5/u)>MCP (4/u)

Case 2:- ACP<MCP with no Market Split

Portfolios	Bid Type	Quantity (MW) @ Price(Rs./kWhr)
Buyer-SR	Single	100@5, 90@5.5 to 6
Seller-SR	Single	-90@4 to 5, -100@5.5
Buyer-SR	Single	10@5.5
Buyer-ER	Block	10@7

- 2 Time Period Sets considered where above bids are available for both time sets
- Provisional result (with No Constrained)----

Time Set1

Price (Rs./kWhr)	→	0	4	5	5.5	**6**	6001
Buyer-SR	Single	100	100	100	90	90	0
Seller-SR	Single	0	-90	-90	-100	-100	-100
Buyer-SR	Single	10	10	10	10	0	0
Buyer-ER	Block	10	10	10	10	10	10
Net (Buy-Sell)		120	30	30	10	0	-90

Time Set 2

Price (Rs./kWhr)	→	0	4	5	5.5	**6**	6001
Buyer-SR	Single	100	100	100	90	90	0
Seller-SR	Single	0	-90	-90	-100	-100	-100
Buyer-SR	Single	10	10	10	10	0	0
Buyer-ER	Block	10	10	10	10	10	10
Net (Buy-Sell)		120	30	30	10	0	-90

Provisional Result- MCP for both Time Blocks is Rs. 6/kWhr

Buyer Block Bid will be selected since Buy Bid Price>Avg. MCP for both time sets.

Corridor Requisition in both time blocks from SR->ER is 10 MW.

Case 2:- ACP<MCP with no Market Split

Time Set	Requisition SR->ER	Availability in Exception report SR->ER
Set 1	10	<10
Set 2	10	>10

- Final Result (with Constrained)- Buy Block Bid will be rejected for both time sets.

Time Set 1; Congestion

Price (Rs./kWhr) →		0	4	5	5.5	6
Buyer-SR	Single	100	100	90	90	90
Seller-SR	Single	0	-90	-90	-100	-100
Buyer-SR	Single	10	10	10	10	0
Net (Buy-Sell)		110	20	10	0	-10

Time Set 2; No Congestion

Price (Rs./kWhr) →		0	4	5	5.5	6
Buyer-SR	Single	100	100	90	90	90
Seller-SR	Single	0	-90	-90	-100	-100
Buyer-SR	Single	10	10	10	10	0
Buyer-ER	Block	0	0	0	0	0
Net (Buy-Sell)		110	20	10	0	-10

- For 2nd Time Set there was no congestion and no market split but ACP(5.5/u)<MCP (4/u)

For Date 22nd May '17

- In 77th Time Block Exception Received, SR Import Required=1060.1 MW, Received=974.68 MW
- Change in Result for two block bids: -

Area Type	Bid Area	Bid Quantity	Bid Type	Duration of Time Block	Provisional/Final Status	Bid Price	Average System Price	Result
Deficit	S1	0.6	Buy	73-88	Provisional	3600	3591.71	Included
					Final	3600	3601.01	Excluded
Surplus	N2	7.3	Buy	79-80	Provisional	3800	3777.79	Paradoxically Rejected
					Final	3800	3790.25	Reincluded

Block	MCP	Exception Received	ACP-SR	ACP-Rol	Price Diff (ACPSR-ACPRol)	No Congestion but MCP<>ACP	Price Diff.
73	2469.78	No	2469.77	2469.77	0.00	MCP<>ACP	0.01
74	2459.61	No	2459.61	2459.61	0.00		0
75	2669.9	No	2669.9	2669.9	0.00		0
76	3235.29	No	3235.29	3235.29	0.00		0
77	3299.66	Yes	3423.73	3299.19	124.54		
78	3549.03	No	3549	3549	0.00	MCP<>ACP	0.03
79	3750.75	No	3775.5	3775.5	0.00	MCP<>ACP	-24.75
80	3804.82	No	3804.99	3804.99	0.00	MCP<>ACP	-0.17
81	3802.43	No	3802.42	3802.42	0.00	MCP<>ACP	0.01
82	3802.39	No	3802.38	3802.38	0.00	MCP<>ACP	0.01
83	3802.47	No	3802.46	3802.46	0.00	MCP<>ACP	0.01
84	4001.17	No	4001.16	4001.16	0.00	MCP<>ACP	0.01
85	4206.3	No	4206.29	4206.29	0.00	MCP<>ACP	0.01
86	4206.46	No	4206.45	4206.45	0.00	MCP<>ACP	0.01
87	4204.53	No	4204.51	4204.51	0.00	MCP<>ACP	0.02
88	4202.75	No	4202.73	4202.73	0.00	MCP<>ACP	0.02

Congestion Scenario (Jan-16 to June-17)

Month	No. of Blocks when Exception Received	% Time Block When Exception received	Avg. Volume Constraint in NR (MW)	Avg. Volume Constraint in SR (MW)
Jan_16	1918	64.45%	299	201
Feb_16	1698	60.99%	254	120
Mar_16	2362	79.37%	117	466
Apr_16	2518	87.43%	171	490
May_16	2507	84.24%	338	246
Jun_16	1629	56.56%	260	43
Jul_16	1270	42.67%	32	164
Aug_16	1507	50.64%	41	150
Sep_16	1399	48.58%	298	16
Oct_16	1569	52.72%	81	243
Nov_16	1869	64.90%	39	365
Dec_16	1868	62.77%	200	256
Jan_17	1998	67.14%	247	233
Feb_17	2100	78.13%	301	200
Mar_17	1761	59.17%	115	374
1st to 12th Apr'17	495	42.97%	0	198
13th to 30th Apr'17	1043	60.36%	0	441
May_17	392	13.17%	11	55
1st to 12th Jun'17	0	0.00%	0	0

- Congestion decreased this season.

Price Difference between MCP and ACP when there is no Market Splitting

Month	<10 paise	10-20 paise	20-30 paise	Difference greater than 30 paise	Total Blocks when MCP<>ACP with No Split	No. of Blocks when No Exception Received	Avg. Volume Constraint in NR (MW)	Avg. Volume Constraint in SR (MW)
Jan-16	582	42	25	13	**662**	1058	299	201
Feb-16	896	57	6	5	**964**	1086	254	120
Mar-16	586	9	1	0	**596**	614	117	466
Apr-16	319	27	8	6	**360**	362	171	490
May-16	400	36	10	8	**454**	469	338	246
Jun-16	674	47	10	18	**749**	1251	260	43
Jul-16	816	76	20	6	**918**	1706	32	164
Aug-16	805	75	33	26	**939**	1469	41	150
Sep-16	918	47	12	7	**984**	1481	298	16
Oct-16	672	22	3	1	**698**	1407	81	243
Nov-16	791	40	23	4	**858**	1011	39	365
Dec-16	690	14	18	7	**729**	1108	200	256
Jan-17	858	53	9	3	**923**	978	247	233
Feb-17	531	33	13	4	**581**	588	301	200
Mar-17	872	34	9	3	**918**	1215	115	374
1-12 Apr 17	322	20	1	0	**343**	657	0	198
13-31 Apr 17	515	39	8	4	**566**	685	0	441
May-17	621	30	4	4	**659**	2584	11	55
1-12 Jun 17	0	0	0	0	**0**	1152	0	0

Trend Analysis of MCP<>ACP when No Market Split

No Regular Pattern available since Jan-16, in May-17 reduced to 25.5%.

Month	Total no. of Blocks	No. of Blocks with No Congestion	Blocks with No Congestion but MCP<>ACP	% Blocks where MCP<>ACP out of total no. congestion blocks
Jan-16	2976	1058	662	62.57%
Feb-16	2784	1086	964	88.77%
Mar-16	2976	614	596	97.07%
Apr-16	2880	362	360	99.45%
May-16	2976	469	454	96.80%
Jun-16	2880	1251	749	59.87%
Jul-16	2976	1706	918	53.81%
Aug-16	2976	1469	939	63.92%
Sep-16	2880	1481	984	66.44%
Oct-16	2976	1407	698	49.61%
Nov-16	2880	1011	858	84.87%
Dec-16	2976	1108	729	65.79%
Jan-17	2976	978	923	94.38%
Feb-17	2688	588	581	98.81%
Mar-17	2976	1215	918	75.56%
1st to 12th Apr	1152	657	343	52.21%
13th to 30th Apr	1728	685	566	82.63%
May-17	2976	2584	659	25.50%
1 to 12th Jun 17	1152	1152	0	0.00%

Trend of Block Bids>50 MW with difference between MCP and ACP when No Congestion

Delivery Date	Total No. of Block Bids>50 MW	No. of Block Bids>50 MW selected in Provisional result	No. of Block Bids >50 MW Selected in Final result	No. of Block Bids>50 MW rejected in Provisional result	No. of Block Bids>50 MW rejected in Final result	Block Bids selected in Prov. but not final or vice-versa
13-Apr-2017	5	5	5	0	0	**0**
14-Apr-2017	16	10	10	6	6	**0**
15-Apr-2017	10	8	8	2	2	**0**
16-Apr-2017	7	6	6	1	1	**0**
17-Apr-2017	8	8	8	0	0	**0**
18-Apr-2017	12	10	10	2	2	**0**
19-Apr-2017	12	10	10	2	2	**0**
20-Apr-2017	9	9	9	0	0	**0**
21-Apr-2017	9	8	7	1	2	**1**
22-Apr-2017	10	9	9	1	1	**0**
23-Apr-2017	12	6	6	6	6	**0**
24-Apr-2017	9	9	9	0	0	**0**
25-Apr-2017	9	6	5	3	4	**1**
26-Apr-2017	42	33	33	9	9	**0**
27-Apr-2017	38	28	30	10	8	**2**
28-Apr-2017	46	24	28	22	18	**4**
29-Apr-2017	33	9	11	24	22	**2**
30-Apr-2017	13	4	4	9	9	**0**
01-May-2017	1	1	1	0	0	**0**
02-May-2017	17	12	12	5	5	**0**
03-May-2017	10	10	10	0	0	**0**
04-May-2017	11	11	11	0	0	**0**
05-May-2017	27	23	23	4	4	**0**
06-May-2017	36	31	31	5	5	**0**
07-May-2017	59	47	47	12	12	**0**

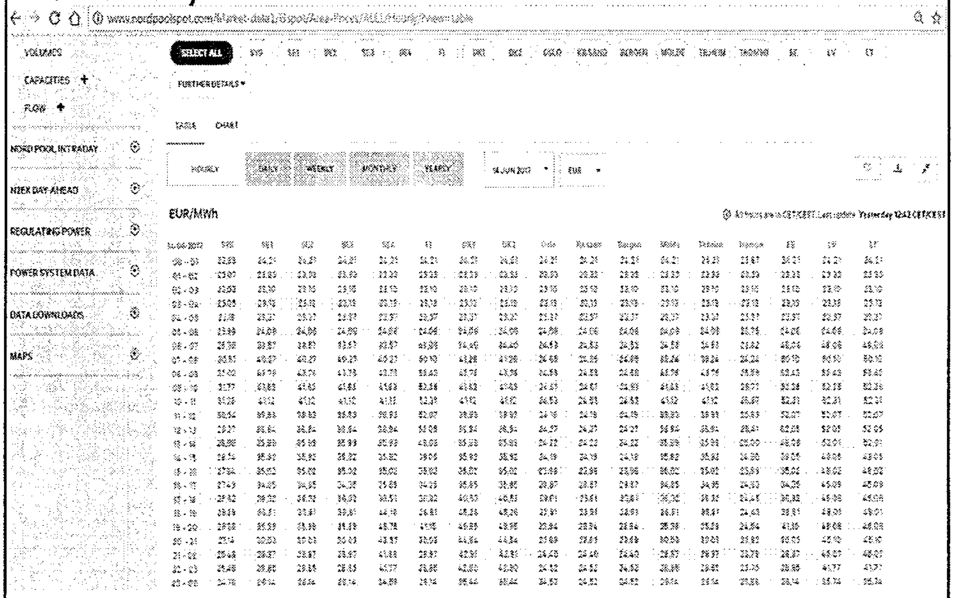
Trend of Block Bids>50 MW with difference between MCP and ACP when No Congestion

Delivery Date	Total No. of Block Bids>50 MW	No. of Block Bids>50 MW selected in Provisional result	No. of Block Bids >50 MW Selected in Final result	No. of Block Bids>50 MW rejected in Provisional result	No. of Block Bids>50 MW rejected in Final result	Block Bids selected in Prov. but not final or vice-versa
08-May-2017	41	33	32	8	9	1
09-May-2017	39	29	29	10	10	0
10-May-2017	67	49	49	18	18	0
11-May-2017	52	37	37	15	15	0
12-May-2017	75	56	56	19	19	0
13-May-2017	44	42	42	2	2	0
14-May-2017	50	45	45	5	5	0
15-May-2017	78	55	55	23	23	0
16-May-2017	63	57	57	6	6	0
17-May-2017	42	38	38	4	4	0
18-May-2017	64	44	44	20	20	0
19-May-2017	71	53	53	18	18	0
20-May-2017	74	55	55	19	19	0
21-May-2017	72	42	36	30	36	6
22-May-2017	55	41	41	14	14	0
23-May-2017	70	37	37	33	33	0
24-May-2017	62	55	55	7	7	0
25-May-2017	42	40	40	2	2	0
26-May-2017	41	39	39	2	2	0
27-May-2017	43	40	40	3	3	0
28-May-2017	53	29	29	24	24	0
29-May-2017	58	39	39	19	19	0
30-May-2017	65	32	31	33	34	1
31-May-2017	53	37	37	16	16	0
Average	**37.45**	**27.78**	**27.73**	**9.67**	**9.71**	**0.37**

Summary

- Two Reasons for Price Difference between MCP and ACP: -
  - ➢ Exception and hence Market Split in a day
  - ➢ Presence of Block Bid where bid size is not relevant but duration of block bids at margin are relevant.
- Due to exception received, the duration of Block Bids included/rejected (which are at margin) will determine the no. of 15-min. blocks where diff. between MCP and ACP will arise.

Nord Pool Spot Price for 14-06-17 (Hr. 01 to 05)



Final ACV is greater than MCV on no. of days

Understanding the Cause with an Example

Unconstrained Solution (Illustration with Single Bid)

Region 1
Sell Bid of 100 MW@ Rs. 3/unit
Buy Bid of 100 MW @ Rs. 4/Unit

100 MW ↓

Region 2
Buy Bid of 100 MW@ Rs. 7/unit
Sell Bid of 100 MW @ Rs. 6/Unit

Unconstrained MCP =Rs. 5 and MCV=100 MW

Price (Rs./kWhr)	→	0	2.99	3	4	**4.01**	**5.99**	6	7	7.01
Region 1 Sell Bid	100 @3/	0	0	-100	-100	-100	-100	-100	-100	-100
Region 1 Buy Bid	100@4/	100	100	100	100	0	0	0	0	0
Region 2 Buy Bid	100@7/	100	100	100	100	100	100	100	100	0
Region 2 Sell Bid	100@6/	0	0	0	0	0	0	-100	-100	-100
Net (Buy-Sell)		200	200	100	100	0	0	-100	-100	-200

Constrained Solution (0 Corridor from region 1 to region 2)

Region 1
Sell Bid of 100 MW@ Rs. 3/Unit
Buy Bid of 100 MW @ Rs. 4/Unit

Price (Rs./kWhr)		0	2.99	**3**	**4**	4.01
Region 1 Sell Bid	100 @3/	0	0	-100	-100	-100
Region 1 Buy Bid	100@4/	100	100	100	100	0
Net (Buy-Sell)		100	100	0	0	-100

Region 1-
ACV - **100**
ACP- 3.5

Region 2
Buy Bid of 100 MW@ Rs. 7/unit
Sell Bid of 100 MW @ Rs. 6/Unit

Price (Rs./kWhr)		0	5.99	**6**	**7**	7.01
Region 2 Buy Bid	100@7/	100	100	100	100	0
Region 2 Sell Bid	100@6/	0	0	-100	-100	-100
Net (Buy-Sell)		100	100	0	0	-100

Region 2-
ACV - **100**
ACP- 6.5

- Sum of ACV 200 MW is greater than MCV of 100 MW
- Both Single and Block Bid can create such instances

Congestion and ACV>MCV

Delivery Date	No. of Blocks of Congestion	Volume Constraint in NR (MW)	Volume Constraint in SR (MW)	ACV>MCV (MWhr)
01/Feb/2017	82	419	130	323
02/Feb/2017	84	530	138	3155
03/Feb/2017	96	1118	209	709
04/Feb/2017	94	558	73	1460
05/Feb/2017	69	593	129	278
06/Feb/2017	77	527	115	3390
07/Feb/2017	57	208	130	1563
08/Feb/2017	37	151	26	2386
09/Feb/2017	67	294	95	3824
10/Feb/2017	83	173	168	671
11/Feb/2017	76	178	185	876
12/Feb/2017	95	263	240	146
13/Feb/2017	91	254	324	1032
14/Feb/2017	76	284	378	2005
15/Feb/2017	73	390	75	232
16/Feb/2017	75	520	64	112
17/Feb/2017	69	270	18	1265
18/Feb/2017	68	237	14	980
19/Feb/2017	60	196	19	537
20/Feb/2017	67	190	44	871
21/Feb/2017	72	106	164	1438
22/Feb/2017	89	148	267	1074
23/Feb/2017	75	229	317	839
24/Feb/2017	76	43	853	362
25/Feb/2017	76	209	530	124
26/Feb/2017	73	66	431	150
27/Feb/2017	72	136	278	237
28/Feb/2017	71	144	174	249

Delivery Date	No. of Blocks of Congestion	Volume Constraint in NR (MW)	Volume Constraint in SR (MW)	ACV>MCV (MWhr)
01/Mar/2017	76	478	225	185
02/Mar/2017	91	803	3	780
03/Mar/2017	78	305	63	880
04/Mar/2017	38	56	44	250
05/Mar/2017	5	16		112
06/Mar/2017	80	25	990	
07/Mar/2017	96	58	1131	65
08/Mar/2017	96	75	1221	
09/Mar/2017	96	222	1294	
10/Mar/2017	96	9	1182	
11/Mar/2017	96		1049	
12/Mar/2017	0			
13/Mar/2017	68		173	10
14/Mar/2017	40		115	125
15/Mar/2017	38	14	114	164
16/Mar/2017	76	207	786	776
17/Mar/2017	96	152	1002	422
18/Mar/2017	67	82	448	2152
19/Mar/2017	96	80	539	78
20/Mar/2017	95	138	609	312
21/Mar/2017	62	432	3	1271
22/Mar/2017	27	45	32	1874
23/Mar/2017	9	28		63
24/Mar/2017	46	338		1719
25/Mar/2017	8		5	2
26/Mar/2017	15		9	57
27/Mar/2017	31		37	42
28/Mar/2017	37		54	343
29/Mar/2017	0			
30/Mar/2017	58		278	360
31/Mar/2017	44		178	125

Congestion and ACV>MCV

Delivery Date	No. of Blocks of Congestion	Volume Constraint in NR (MW)	Volume Constraint in SR (MW)	ACV>MCV (MWhr)
01/Apr/2017	32		140.34	2002
02/Apr/2017	0			
03/Apr/2017	0			
04/Apr/2017	33		69.97	13
05/Apr/2017	10		14.02	482
06/Apr/2017	33		75.53	760
07/Apr/2017	0			
08/Apr/2017	68		499.29	1022
09/Apr/2017	79		282.56	189
10/Apr/2017	80		368.36	898
11/Apr/2017	85		420.43	394
12/Apr/2017	75		509.18	473
13/Apr/2017	64		405.56	662
14/Apr/2017	69		385.94	495
15/Apr/2017	46		185.11	1036
16/Apr/2017	53		195.00	186
17/Apr/2017	85		785.22	416
18/Apr/2017	82		533.28	504
19/Apr/2017	84		868.74	2176
20/Apr/2017	90		959.24	1139
21/Apr/2017	81		907.57	789
22/Apr/2017	70		887.18	2091
23/Apr/2017	30		51.29	62
24/Apr/2017	0			
25/Apr/2017	43		137.87	21
26/Apr/2017	55		286.95	743
27/Apr/2017	46		316.54	2494
28/Apr/2017	44		252.42	2041
29/Apr/2017	35		92.44	2342
30/Apr/2017	66		687.60	1012

Delivery Date	No. of Blocks of Congestion	Volume Constraint in NR (MW)	Volume Constraint in SR (MW)	ACV>MCV (MWhr)
01/May/2017	0			
02/May/2017	0			
03/May/2017	8	27.23		245
04/May/2017	57	130.68	92.61	744
05/May/2017	70		402.58	800
06/May/2017	17		49.12	
07/May/2017	27	16.09	64.75	943
08/May/2017	14	0.73	9.54	9
09/May/2017	13		14.57	70
10/May/2017	15		100.13	286
11/May/2017	0			
12/May/2017	0			
13/May/2017	0			
14/May/2017	26	22.69	40.29	807
15/May/2017	8	61.45		419
16/May/2017	9		5.63	5
17/May/2017	52	67.82	113.69	340
18/May/2017	0			
19/May/2017	0			
20/May/2017	0			
21/May/2017	72		792.07	1263
22/May/2017	1		0.89	2
23/May/2017	0			
24/May/2017	0			
25/May/2017	0			
26/May/2017	0			
27/May/2017	0			
28/May/2017	0			
29/May/2017	0			
30/May/2017	3		3.82	
31/May/2017	0			

Impact of 100 MW Block Bid on Schedule and Ramping

No. of Block Bids>50 MW

Delivery Date	Total no. of Bids	No. of Single Bids	No. of Block Bids	Blocks Bids with Bid Qty. >50 MW	% Block Bids with Q>50 MW to total no. of block bids
13-Apr-17	4425	461	3964	5	0.13%
14-Apr-17	4301	456	3845	16	0.42%
15-Apr-17	4102	451	3651	10	0.27%
16-Apr-17	3900	420	3480	7	0.20%
17-Apr-17	4165	456	3709	8	0.22%
18-Apr-17	4413	470	3943	12	0.30%
19-Apr-17	4433	471	3962	12	0.30%
20-Apr-17	4265	479	3786	9	0.24%
21-Apr-17	4316	480	3836	9	0.23%
22-Apr-17	4351	477	3874	10	0.26%
23-Apr-17	3978	443	3535	12	0.34%
24-Apr-17	4328	470	3858	9	0.23%
25-Apr-17	4590	488	4102	9	0.22%
26-Apr-17	4613	491	4122	42	1.02%
27-Apr-17	4497	489	4008	38	0.95%
28-Apr-17	4453	472	3981	46	1.16%
29-Apr-17	4220	474	3746	33	0.88%
30-Apr-17	3879	437	3442	13	0.38%
1-May-17	3186	328	2858	1	0.03%
2-May-17	3751	371	3380	17	0.50%
3-May-17	4196	443	3753	10	0.27%
4-May-17	4095	441	3654	11	0.30%
5-May-17	4074	428	3646	27	0.74%
6-May-17	4248	441	3807	36	0.95%
7-May-17	3968	399	3569	59	1.65%

Delivery Date	Total no. of Bids	No. of Single Bids	No. of Block Bids	Blocks Bids with Bid Qty. >50 MW	% Block Bids with Q>50 MW to total no. of block bids
8-May-17	4131	428	3703	41	1.11%
9-May-17	4167	425	3742	39	1.04%
10-May-17	4340	434	3906	67	1.72%
11-May-17	4472	449	4023	52	1.29%
12-May-17	4437	458	3979	75	1.88%
13-May-17	4320	440	3880	44	1.13%
14-May-17	3916	421	3495	50	1.43%
15-May-17	4082	443	3639	78	2.14%
16-May-17	4414	438	3976	63	1.58%
17-May-17	4415	452	3963	42	1.06%
18-May-17	4485	452	4033	64	1.59%
19-May-17	4358	461	3897	71	1.82%
20-May-17	4280	467	3813	74	1.94%
21-May-17	4105	435	3670	72	1.96%
22-May-17	4219	446	3773	55	1.46%
23-May-17	4391	451	3940	70	1.78%
24-May-17	4360	462	3898	62	1.59%
25-May-17	4412	455	3957	42	1.06%
26-May-17	4399	450	3949	41	1.04%
27-May-17	4361	442	3919	43	1.10%
28-May-17	4127	420	3707	53	1.43%
29-May-17	4253	445	3808	58	1.52%
30-May-17	4292	452	3840	65	1.69%
31-May-17	4427	461	3966	53	1.34%
Average	**4243**	**447**	**3796**	**37**	**0.98%**

No. of Portfolios with Block Bids>50 MW

Delivery Date	Total no. of Portfolios	No. of Portfolios with Single Bids	No. of Portfolio with Block Bids	No. of Portfolios with Blocks Bids Qty. >50 MW	% Block Bids Q>50 MW to total no. of Block Bids
13-Apr-17	1127	461	704	1	0.14%
14-Apr-17	1118	456	697	3	0.43%
15-Apr-17	1129	451	708	4	0.56%
16-Apr-17	1061	420	667	3	0.45%
17-Apr-17	1092	456	665	3	0.45%
18-Apr-17	1145	470	707	4	0.57%
19-Apr-17	1147	471	712	4	0.56%
20-Apr-17	1145	479	699	3	0.43%
21-Apr-17	1136	480	690	3	0.43%
22-Apr-17	1144	477	704	4	0.57%
23-Apr-17	1072	443	664	3	0.45%
24-Apr-17	1101	470	668	3	0.45%
25-Apr-17	1166	488	714	4	0.56%
26-Apr-17	1173	491	717	4	0.56%
27-Apr-17	1178	489	725	4	0.55%
28-Apr-17	1139	472	703	6	0.85%
29-Apr-17	1138	474	700	4	0.57%
30-Apr-17	1058	437	649	2	0.31%
1-May-17	835	328	529	1	0.19%
2-May-17	923	371	580	3	0.52%
3-May-17	1042	443	626	2	0.32%
4-May-17	1042	441	627	2	0.32%
5-May-17	973	428	572	7	1.22%
6-May-17	1004	441	592	6	1.01%
7-May-17	941	399	571	6	1.05%

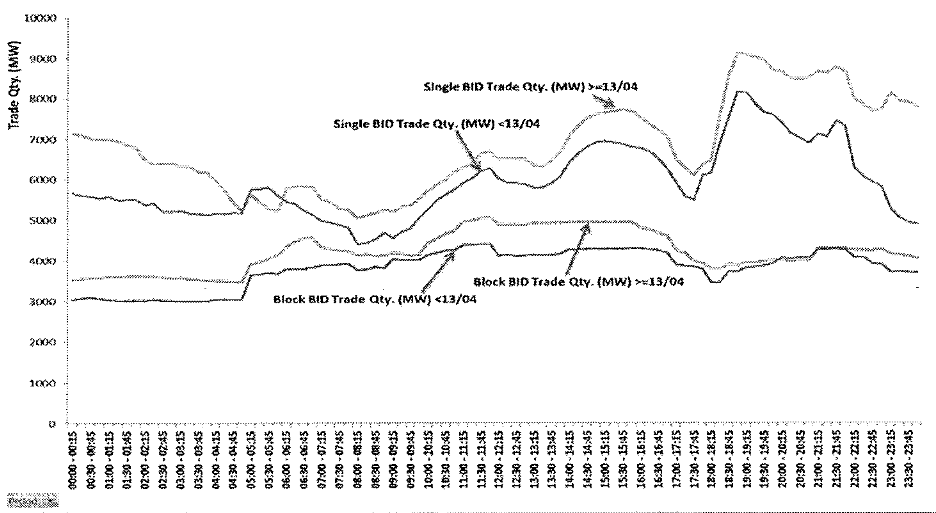
Delivery Date	Total no. of Portfolios	No. of Portfolios with Single Bids	No. of Portfolio with Block Bids	No. of Portfolios with Blocks Bids Qty. >50 MW	% Block Bids Q>50 MW to total no. of Block Bids
8-May-17	975	428	579	5	0.86%
9-May-17	970	425	572	6	1.05%
10-May-17	1020	434	615	7	1.14%
11-May-17	1082	449	661	6	0.91%
12-May-17	1090	458	663	8	1.21%
13-May-17	1045	440	633	7	1.11%
14-May-17	989	421	597	7	1.17%
15-May-17	1016	443	606	7	1.16%
16-May-17	999	438	595	9	1.51%
17-May-17	1035	452	613	8	1.31%
18-May-17	1054	452	633	9	1.42%
19-May-17	1041	461	610	9	1.48%
20-May-17	1056	467	616	8	1.30%
21-May-17	998	435	590	7	1.19%
22-May-17	1021	446	603	5	0.83%
23-May-17	1027	451	602	5	0.83%
24-May-17	1043	462	609	6	0.99%
25-May-17	1038	455	612	4	0.65%
26-May-17	1011	450	591	5	0.85%
27-May-17	989	442	576	5	0.87%
28-May-17	971	420	581	6	1.03%
29-May-17	999	445	584	7	1.20%
30-May-17	1025	452	604	8	1.32%
31-May-17	1056	461	628	5	0.80%
Average	**1053**	**447**	**636**	**5**	**0.81%**

Quantity Selection of Block Bids>50 MW

Delivery Date	Total Trade Qty. (MUs)	Single Bid Trade Qty. (MUs)	Block Bid Trade Qty. (MUs)	Block Bid Trade Qty. with Bid >50 MW(MUs)	% Block Bids Q>50 MW to total no. of Block Bids
13-Apr-17	225	134	91	7	7.73%
14-Apr-17	232	135	97	10	9.90%
15-Apr-17	254	156	98	8	8.49%
16-Apr-17	187	106	81	6	7.04%
17-Apr-17	228	139	90	8	8.65%
18-Apr-17	263	160	102	12	11.83%
19-Apr-17	298	183	116	12	10.66%
20-Apr-17	316	200	116	12	10.60%
21-Apr-17	297	184	113	10	9.15%
22-Apr-17	293	169	124	10	7.65%
23-Apr-17	238	157	81	5	6.49%
24-Apr-17	272	172	100	11	11.38%
25-Apr-17	258	163	95	7	7.49%
26-Apr-17	260	149	111	29	25.89%
27-Apr-17	268	160	109	25	23.35%
28-Apr-17	261	147	113	22	19.61%
29-Apr-17	264	155	109	10	9.15%
30-Apr-17	262	137	125	2	1.40%
1-May-17	229	132	96	2	1.90%
2-May-17	263	149	114	7	5.83%
3-May-17	257	148	109	6	5.75%
4-May-17	225	156	69	4	6.34%
5-May-17	245	157	89	7	7.96%
6-May-17	258	168	90	8	8.88%
7-May-17	281	158	123	13	10.24%

Delivery Date	Total Trade Qty. (MUs)	Single Bid Trade Qty. (MUs)	Block Bid Trade Qty. (MUs)	Block Bid Trade Qty. with Bid >50 MW(MUs)	% Block Bids Q>50 MW to total no. of Block Bids
8-May-17	297	174	123	14	11.13%
9-May-17	256	156	100	10	9.58%
10-May-17	256	148	108	19	17.38%
11-May-17	260	156	104	9	8.31%
12-May-17	281	175	106	13	12.70%
13-May-17	297	175	122	10	8.30%
14-May-17	270	161	108	12	11.46%
15-May-17	304	178	126	15	12.10%
16-May-17	286	169	117	14	11.88%
17-May-17	288	173	115	13	11.17%
18-May-17	296	173	122	13	10.95%
19-May-17	295	171	124	18	14.77%
20-May-17	289	178	111	12	10.74%
21-May-17	231	142	89	6	6.61%
22-May-17	287	174	113	10	8.51%
23-May-17	267	175	92	8	9.08%
24-May-17	255	159	96	20	21.13%
25-May-17	252	164	88	9	10.39%
26-May-17	273	185	88	9	10.06%
27-May-17	278	179	100	10	10.22%
28-May-17	203	133	70	3	4.20%
29-May-17	254	176	78	8	10.84%
30-May-17	241	166	75	13	17.50%
31-May-17	236	161	75	16	20.83%
Average	**263**	**161**	**102**	**11**	**10.68%**

Trade Pattern Analysis on Time Block Basis

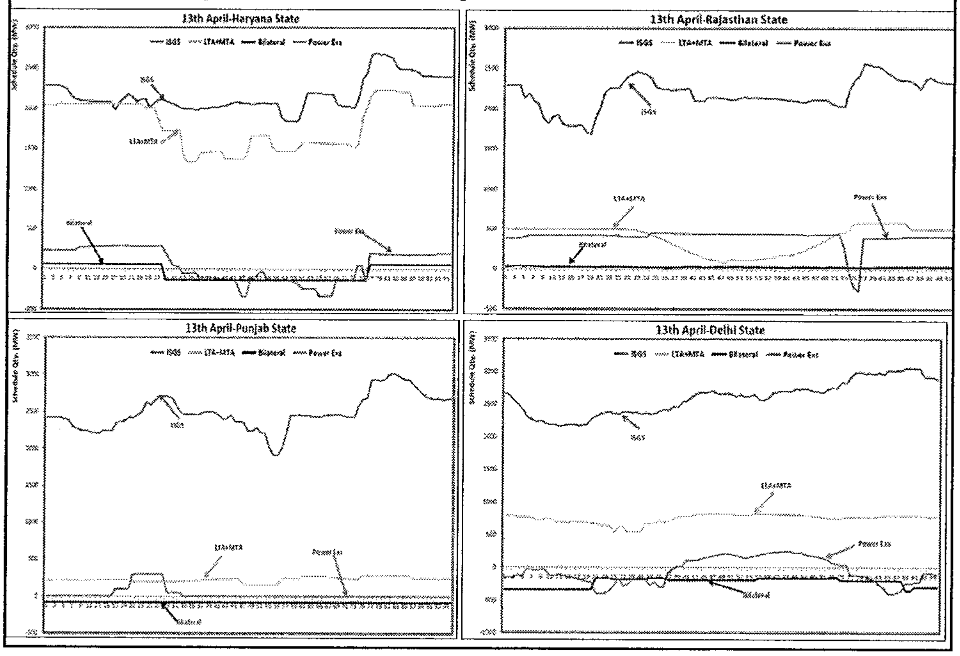


<< Time Block wise analysis of Single Bid and Block Bid Selected Qty. for two time periods-
i) <13/04=For Period 08/04 to 12/04 (-5 days) (ii)>=13/04=For Period 13/04 to 17/04 (+5 days)
Depicts that Block Bid has smooth curve as compared to Single Bid Curve.

Ramping Analysis of IEX Trade at State Level

- Analyzed for States in NR Region- Haryana, Rajasthan, Punjab, Delhi and UP.
- State's PXs Schedule compared with ISGS, LTA+MTA and Bilateral Transaction.
- Analysis Period-8th to 17th April (-5 to +5 days)
- <<Excel Sheet-Ramping North Region will be hyper linked>>

For Sample Date-13th April



Treatment of Greenko Budhil Hydro Power Plant

Letter Query Points

- Query a) NoC has been issued to M/s Greenko Budhil by NRLDC and no NoC has been issued for sale of power by HP State at M/s Greenko Budhil Periphery.
- Query b) Power presently is being sold by two different grid connected entities i.e. HP state and M/s Greenko Budhil from the same generator periphery
- Query c) Any grid connected can sell or buy power at his own grid periphery only.

Status of Greenko Budhil

- The Budhil Hydro Electric Project (BHEP) is a run-of-the river hydro project in the Chamba district of the state of Himachal Pradesh in India. The project having an installed capacity of 70MW has been in operation since May 2012.

- The Power Plant is a Regional Entity and as per Procedure for Scheduling of Collective Transactions:-
  All Entities, whose metering and energy accounting is presently carried out by Regional Load Despatch Centres (RLDCs)/Regional Power Committees (RPCs) shall be deemed to be Regional Entities of the respective Region. Any new Entity, who satisfies the conditions for scheduling by Regional Load Despatch Centres, as per Indian Electricity Grid Code, 2006 and amendments thereof, and is intending to participate in trade through Power Exchange, as a Regional Entity shall obtain prior approval from the respective RLDCs/RPCs, by making an application.

- NRLDC Letter received on Date 25th Sep 2012 and after confirmation mail from NLDC, Budhil started trading from 27th Sep 2012 onwards at IEX Platform. Extract of NRLDC Letter:-
  It shall be ensured that total schedule of plant under all categories of transaction i.e. Long-term, Medium term open access (MTOA), STOA (bilateral) and STOA (PX) shall be within above limit. The station would also be following all the other rules and regulations as specified in various regulations of the Hon'ble CERC.

- The project after acquired from Lanco group is being referred as Greenko Budhil Hydro Power Private Limited. IEX received ROC, GoI and changed the name from 31st May'15 onwards.

Treatment of Greenko Budhil Power Plant

- As per Himachal Pradesh Hydro Policy 2006, Greenko Budhil Hydro Plant is providing Royalty Power of 12% for water usage in shape of free power to GoHP.
  25 Years of Agreement between GoHP and PTC India to sale the free power of Royalty through PTC India.

- For Regional Entity Generator M/s Budhil Hydro Power Plant, two Seller Clients:-
  i. Client Greenko Budhil thru Member NETS to trade 61.60 MW
  ii. Client GoHP (12% free power thru Greenko Budhil) thru Member PTC to trade 8.40 MW

- Extracts from IEX Business Rules:-
  18. Dealing with Clients 18.1 There are two categories of Clients for Electricity Contracts.
  ***a. Grid-connected Client:** A Client who is eligible to buy or sell electricity and is connected to the grid. The entities including but not limited to, Distribution Licensees, Generators, Consumers and Open Access Users can become Grid connected Clients.*
  ***b. Trader Client:** A Client who is eligible to trade in electricity under the Electricity Act, 2003 and has a legally valid power purchase/sale agreement, which gives the Client the right to purchase and sell electricity. A Trader Client will register each power purchase/sale agreement with the Member who will be registering the same with the Exchange and receive a separate registration identification code. The entities such as trading licensees can become Trader Clients*

Treatment of Greenko Budhil Power Plant

- Budhil Hydro Power is the Grid Connected Entity for which NoC by NRLDC, Scheduling by NRLDC and Settlement by NRPC is happening.

Thank You

www.iexindia.com

ANNEXURE 4

Ref No.: IEX/CERC/MO/17-18/014 24th July 2017

To,
The Secretary,
Central Electricity Regulatory Commission,
3rd & 4th Floor, Chanderlok Building,
36, Janpath, New Delhi – 110 001

Subject: - Increase in Maximum Quantity of Block Bid from 50 to 100 MW

Reference: - (i) POSOCO letter with Ref. No. POSOCO/NLDC/IEX/2017/105 on date 28th April'17
(ii)POSOCO letter with Ref. No. POSOCO/NLDC/IEX/2017 on date 19th May'17
(iii) POSOCO letter with Ref. No. POSOCO/MO/101 on date 8th June'17

Dear Sir,

In reference to above letters received from M/s POSOCO, hon'ble CERC had arranged a meeting on date 14th June 2017 to discuss following agenda points:-

a) Increase of Block Bid maximum size from 50 MW to 100 MW and its performance.
b) Reason(s) for Price Difference between Market Clearing Price and Area Clearing Price(s) in no congestion blocks.
c) Reason(s) for Final Cleared Volume greater than Market Clearing Volume on number of days.
d) Impact of increase in block bid size in Scheduling and Ramping.
e) Explanation on M/s Greenko Budhil Hydro Power Plant

Detailed presentation was made on date 14th June 17 to the staff of hon'ble Commission along with officials of NLDC on first four agenda points, however item (e) could not be discussed in the meeting due to paucity of time.

In order to evaluate the performance of Block Bid with size greater than 50 MW, data set in the meeting was taken for 49 days (13th April to 31st May '17), which has now been updated for a larger time frame i.e. for 79 days (13th April to 30th June '17).

Indian Energy Exchange Limited
Registered & Corporate Office: Unit No. 3, 4, 5 & 6, Plot No.7, Fourth Floor, TDI Centre, District Centre, Jasola, New Delhi – 110025
Tel: +91-11-4300 4000 | Fax: +91-11-4300 4015
CIN: U74999DL2007PLC277039

Further since the last agenda point could not be discussed the same has been explained in detail and attached as annexure to this letter. Also as desired in the meeting following additional information asked for has also been included in the note:-

a) Letter from M/s NVVNL Ltd. for increasing the Block Bid Size
b) Test Summary Report
c) Schedule Ramping Status of States putting Block Bid Size greater than 50 MW

Block Bid Size in other International Market(s) is mentioned as below:-

Electricity Market	Countries	Max. Block Bid Size (MW)	Annual Trade (TWhr)
EPEX DE/AT	Germany/ Austria	600	229 (Jun'16-Jul'17)
EPEX FR	France	600	105 (Jun'16-Jul'17)
Nord Pool	Nordic & Baltic Countries	500	390 (Jan'16-Dec'16)
N2EX UK	United Kingdom	500	108 (Jan'16-Dec'16)
EPEX NL	Netherlands	400	32 (Jun'16-Jul'17)
EPEX BL	Belgium	400	20 (Jun'16-Jul'17)
EPEX CH	Switzerland	150	23 (Jun'16-Jul'17)
IEX	India	100	42 (Jun'16-Jul'17)

We would be happy to respond for any more queries in this respect.

Thanking you,

Yours Faithfully

Akhilesh Awasthy
Director (Market Operations)

Cc:- HOD, Market Operations, POSOCO, Katwaria Sarai, New Delhi

INDIAN ENERGY EXCHANGE
India's No.1 Power Exchange

Annexure-I

Increase of Block Bid maximum size from 50 MW to 100 MW and its performance- IEX vide its Circular No. 237 dated 11th April 2017 has increased the Block Bid Size from 50 MW to 100 MW from trading date 12th April 2017. This change was made on the request of members of IEX, so that they can have efficient power plant management and load management of Discoms. (Copy of letter received from M/s NVVNL is attached as Annexure-IA). Functional and Performance testing was conducted and test summary report for the same is attached as Annexure-IB.
Post successful testing, the Circular was issued and posted at our website on date 11th April 2017.

The impact of Block Bid>50 MW was analyzed for 79 days which is as under:-

i) On an average only 7 portfolios out of 1040 portfolios are putting block bid>50 MW. Also total number of portfolios who have used this facility till 30th June is 34. Daily status is attached as Annexure IC.

ii) On an average 68 number of Block Bids were submitted with quantity>50 MW out of 3825 number of block bids. Daily status is attached as Annexure ID.

It may be seen under Annexure IE that most of the time these bids are not the marginal bids which get affected due to congestion, as such the results would not have changed had the client submitted two bids of say 50 MW each in place of a single 100 MW Block bid.

Impact of this change on the prices or clearing volume (both unconstrained and constrained), as shown in Annexures indicates that there is no adverse impact on these results. Further discussion on these issues is in the subsequent Annexures.

Annexure-II

Reason(s) for Price Difference between Market Clearing Price and Area Clearing(s) in no congestion blocks- In the presentation the reason for such changes was explained with an example and also the same was illustrated with the Day-Ahead Market results for date 22nd May 2017, the same is reproduced as under:-

(i) Due to Congestion in some of the blocks of the day there might be a possibility in change in the prices of non-congested blocks might as well. If there is no congestion and hence no market split in any of the time blocks of the day such situation will not arise.

(ii) Presence of marginal Block Bid in bid set results in such situations, which gets manifested when congestion occurs. It may be noted that the bid size is not the only reason for such occurrence, however number of blocks in which such bids at margin is present is more relevant. Due to congestion in certain blocks of the day, the demand and supply situation changes not only in congested time blocks but also in congestion free time blocks, due to inclusion of earlier rejected or rejection of earlier included marginal block bids, in both congested and non-congested time blocks. This may result in price difference between MCP and ACPs in congested as well as non-congested time blocks.

In this respect data in Annexure-IIA needs to be analyzed, where on several days the Block Bid with quantity >50 MW has not changed its status (i.e. Block Bid selected in Provisional remained selected in Final and/or Block Bid rejected in Provisional remained rejected in Final) in Provisional and Final results but still difference in MCP and ACPs has been noted in uncongested blocks.

As such the occurrences of Price difference between MCP and ACPs in uncongested blocks is not entirely associated with increase in Block Bid size. This has happened in the past as well when block bid size was maximum up to 50 MW. The monthly trend is attached as Annexure-IIB.

This phenomenon is neither counter-intuitive nor against power market regulations because in Day-Ahead Market the price results can be described under two outcomes:-

i) In case of no congestion and hence no market split in any time block of the day the MCP is relevant and Area Clearing Price(s) of Bid Area will always be equal to MCP.

ii) In case of congestion and hence market split in any time block of the day the ACP will be relevant for the day with following demarcation:-

- For congested time blocks of the day, the Area Clearing Prices will be different, for upstream and downstream of Congestion. Generally ACPs would be lower in surplus area as compared to MCP and higher in deficit area as compared to MCP, however in some special cases ACPs can be higher in Surplus area as compared to MCP or vice versa for the deficit area.
- For non-congested time blocks of the day, the Area Clearing Prices will be same for all price areas.

Such situations occur in other international day-ahead spot market as well. Sample for Nord Pool for date 14th June' 17 (from 0100 to 0500 hours) is produced as below. It may be seen that although in all price areas ACPs are same indicating no congestion for the above mentioned time blocks, however system price i.e. MCP ("SYS" price) is different from ACPs.

Website Link:- http://www.nordpoolspot.com/Market-data1/Elspot/Area-Prices/ALL1/Hourly/?view=table

TABLE CHART

HOURLY DAILY WEEKLY MONTHLY YEARLY 14 JUN 2017 EUR

EUR/MWh

All hours are in CET/CEST Last update: Today 12:42 CET/CEST

14.06.2017	SYS	SE1	SE2	SE3	SE4	FI	DK1	DK2	Oslo	Kr.sand	Bergen	Molde	Tr.heim	Tromsø	EE	LV	LT
00 - 01	23,99	24,21	24,21	24,21	24,21	24,21	24,21	24,21	24,21	24,21	24,21	24,21	24,21	23,67	24,21	24,21	24,21
01 - 02	23,07	23,33	23,33	23,33	23,33	23,33	23,33	23,33	23,33	23,33	23,33	23,33	23,33	23,33	23,33	23,33	23,33
02 - 03	23,03	23,10	23,10	23,10	23,10	23,10	23,10	23,10	23,10	23,10	23,10	23,10	23,10	23,10	23,10	23,10	23,10
04 - 05	23,18	23,37	23,37	23,37	23,37	23,37	23,37	23,37	23,37	23,37	23,37	23,37	23,37	23,37	23,37	23,37	23,37
05 - 06	23,95	24,06	24,06	24,06	24,06	24,06	24,06	24,06	24,06	24,06	24,06	24,06	24,06	23,75	24,06	24,06	24,06
06 - 07	25,99	33,57	33,57	33,57	33,57	48,06	34,40	34,40	24,53	24,53	24,53	24,53	24,53	23,82	48,06	48,06	48,06
07 - 08	30,51	40,27	40,27	40,27	40,27	50,10	41,26	41,26	24,65	24,65	24,65	39,24	39,24	24,24	50,10	50,10	50,10
09	31,77	41,63	41,63	41,63	41,63	52,38	41,63	41,63	24,61	24,61	24,61	41,63	41,63	26,77	52,38	52,38	52,38
10	31,36	41,12	41,12	41,12	41,12	52,31	41,12	41,12	24,53	24,53	24,53	41,12	41,12	25,67	52,31	52,31	52,31
11	30,54	39,93	39,93	39,93	39,93	52,07	39,93	39,93	24,19	24,19	24,19	39,93	39,93	25,63	52,07	52,07	52,07
12	29,27	36,94	36,94	36,94	36,94	52,05	36,94	36,94	24,27	24,27	24,27	36,94	36,94	25,41	52,05	52,05	52,05
13	26,99	35,99	35,99	35,99	35,99	48,08	35,99	35,99	24,22	24,22	24,22	35,99	35,99	25,00	48,08	52,01	52,01
14	26,74	35,92	35,92	35,92	35,92	39,05	35,92	35,92	24,19	24,19	24,19	35,92	35,92	24,90	39,05	49,05	49,05
15	27,64	35,02	35,02	35,02	35,02	35,02	35,02	35,02	23,96	23,96	23,96	35,02	35,02	23,99	35,02	48,02	48,02
16	27,49	34,35	34,35	34,35	35,85	34,35	35,85	35,85	23,87	23,87	23,87	34,35	34,35	24,63	34,35	45,09	45,09
17	28,62	36,32	36,32	36,32	39,56	36,32	40,53	40,53	23,61	23,61	23,61	36,32	36,32	24,45	36,32	45,08	45,08
18	29,39	36,81	36,81	36,81	44,13	36,81	45,26	45,26	23,91	23,91	23,91	36,81	36,81	24,43	36,81	48,01	48,01
19	29,36	35,39	35,39	35,39	48,75	41,15	40,95	40,95	23,94	23,94	23,94	35,39	35,39	24,54	41,15	48,08	48,06
20	27,14	30,03	30,03	30,03	43,57	30,03	44,64	44,64	23,69	23,69	23,69	30,03	30,03	23,82	30,03	45,10	45,10
21	25,49	28,97	28,97	28,97	41,88	28,97	42,91	42,91	24,40	24,40	24,40	28,97	28,97	23,79	28,97	45,07	45,07
22	25,48	28,85	28,85	28,85	41,77	28,85	42,80	42,80	24,52	24,52	24,52	28,85	28,85	23,75	28,85	41,77	41,77
23	24,78	26,14	26,14	26,14	34,59	26,14	35,44	35,44	24,52	24,52	24,52	26,14	26,14	23,68	26,14	35,74	35,74

INDIAN ENERGY EXCHANGE
India's No.1 Power Exchange

Annexure-III

Reason(s) for Final Cleared Volume greater than Market Clearing Volume on number of days- In the presentation it was explained that such occurrences would take place when there is Congestion and hence Market Split in the day. For no congestion and hence no market split in any time block of the day such situation will not happen.

Due to congestion, the change in prices in Upstream and Downstream of congestion may result in final ACV being greater than MCV. This may happen due to selection of buy Single Bid and/or Block Bid in the Upstream which were rejected in unconstrained results and selection of Sell Single Bid and/or Block Bid in downstream of Congestion, which were rejected in unconstrained results.

Such occurrence(s) have also been noted in past and no direct relation between increase in Block Bid size and such occurrences were evident. In this case the size of block bid is not the only relevant factor which can be easily examined under Annexure-IIIA where on several days the Block Bid with quantity >50 MW has not changed its status in provisional and final results but still the situation where ACV>MCV had occurred.

In Nord Pool Spot Day-Ahead Market also such incidences have been noticed.

As such these occurrences is neither counter-intuitive nor has any direct has relation with change in the size of Block Bid.

Annexure-IV

Impact of increase in block bid size in Scheduling and Ramping: - In reference to the letter No. POSOCO/NLDC/IEX/2017/105 vide which it was observed that increase in block bid size may adversely impact the ramping profile. In this regard following may please be noted:-

i) The market size of collective transactions is merely 3%. For a particular participant there are various possibilities to meet their requirement of buying/selling under LTA and MTOA and in Short-term Bilateral and Collective transactions. It was shown in the presentation that ramping in schedules of Northern region states like Haryana, Rajasthan, Punjab and Delhi is insignificant in collective transactions as compared to other contract types. Currently State utility & Discoms of Delhi, Punjab, Uttarakhand, Maharashtra, Gujarat, Madhya Pradesh, DNH and West Bengal are putting block bid with greater than 50 MW. The Scheduling Ramping of these states is represented under Annexure IVA.

It may be seen that in case of these states as well, the schedule ramping in collective transactions as compared to other transactions is insignificant. In fact in many cases ramping in the Collective Transactions is seen as nullifying severe ramping of other transactions, thus improving overall ramping profile.

ii) It was demonstrated that for overall Schedule of any particular day, schedule through block bids has better ramping profile as compared to the ramping profile of selected single bids. A block bid is used by a participant for the procurement or sale of power which is specific to several blocks of period, while single bid allows partial execution of bids hence a block bid will have no ramping for those block of hours as compared to the single bid. Under Annexure IVB, Analysis of Single bid trade quantity vs. Block bid trade quantity for a 3 day period before and after the date on which Block Bid size was increased i.e. from 10th to 12th April and 13th to 15th April, establishes this assertion. As such the change in maximum quantity of Block Bid has no adverse impact on the ramping profile.

Annexure-V

Explanation on M/s Greenko Budhil Hydro Power Plant: - Due to paucity of time this agenda point could not be discussed in the meeting. In the letter no. POSOCO/MO/101 dated 8th June '17 it was mentioned that NoC to M/s Greenko Budhil was issued by NRLDC and no NoC was issued for sale of power by HP State at M/s Greenko Budhil Periphery, but power presently is being sold by two different grid connected entities i.e. M/s HP state and M/s Greenko Budhil from the same generator periphery. The explanation in this regards is mentioned as under:-

i) Status of Plant-Budhil Hydro Electric Project (now Greenko Budhil Hydro Power Private Limited) is a Regional Entity and as per "Procedure for Scheduling of Collective Transactions" it obtained first NoC for 70 MW quantity from NRLDC on date 25th Sep 2012 and started trading from 27th Sep 2012 onwards at IEX Platform, extract of NRLDC Letter is as below:-

It shall be ensured that total schedule of plant under all categories of transaction i.e. Long-term, Medium term open access (MTOA), STOA (bilateral) and STOA (PX) shall be within above limit. The station would also be following all the other rules and regulations as specified in various regulations of the Hon'ble CERC.

At Generator level, the plant export limit is therefore set as per the quantity specified in NoC from NRLDC.

ii) As per Himachal Pradesh Hydro Policy 2006, this Plant is providing Royalty Power of 12% for water usage as free power to GoHP, who have appointed a trading Licensee (M/s PTC India Ltd.) to sell this Royalty Power.

iii) To understand the treatment given to this royalty power we would like to draw your attention to Clause 18 of IEX Business Rules which is reproduced as under:-

18. Dealing with Clients 18.1 There are two categories of Clients for Electricity Contracts.

a. Grid-connected Client: *A Client who is eligible to buy or sell electricity and is connected to the grid. The entities including but not limited to,* *Distribution Licensees, Generators, Consumers and Open Access Users can become Grid connected Clients.*

b. Trader Client: *A Client who is eligible to trade in electricity under the Electricity Act, 2003 and has a legally valid power purchase/sale agreement, which gives the Client the right to purchase and sell electricity. A Trader Client will register each power purchase/sale agreement with the Member who will be registering the same with the Exchange and receive a separate registration identification code. The entities such as trading licensees can become Trader Clients.*

Therefore for the generator M/s Greenko Budhil Power Plant with 70 MW allowed quantum, two clients are selling the power of the generator-

a) Grid Connected Client-M/s Greenko Budhil Power Plant;
b) Trader Client: - PTC selling royalty power of GoHP.

NoC issued by the generator M/s Greenko Budhil Power Plant (within the overall quantity limit permitted by NRLDC to this regional entity to sell the electricity generated) provides the bifurcation of quantity limit for the above two clients.

This arrangement is done as per hon'ble CERC approved Business Rules where a generator can sell its power by registering more than one client depending upon its commercial/regulatory requirements. Same practice is followed for other generators as well e.g. Allian Duhangan Hydro Power Project, Meenakshi Energy Limited, Karcham Wangtoo Power Plant etc.

As such GoHP, although not a Grid Connected entity, is selling its Royalty Power at the periphery of the generator as a trader client through M/s PTC India Ltd.

ANNEXURE- IA

एनटीपीसी विद्युत व्यापार निगम लिमिटेड

NTPC Vidyut Vyapar Nigam Limited

(A wholly owned subsidiary of NTPC)

केन्द्रीय कार्यालय/ Corporate Centre

Ref. No.: 01/NVVN/PX/IEX/201702-01

Date: 10-02-2017

To,

India Energy Exchange Limited
Fourth Floor, TDI Centre,
Plot No. 7, Jasola
New Delhi – 110025

Attn.: Mr. Prasanna Rao, Vice President (Market Operations)

Subject: Increase in Block Bid Size

Dear Sir/Madam,

Some of our generator clients wish to place single block bid for 200 MW but are unable to do so as the block bid size allowed presently is 50 MW.

You are requested to increase the block bid size accordingly.

Thanking You,
Yours Faithfully

(ANIL BAWEJA)
AGM (PX & IT)

Annexure-IB

USER ACCEPTANCE TEST SUMMARY REPORT

< Increase in Maximum Quantity per Block Bid in PowerARMS™ DAM segment from 50 to 100 MW>

Document Control

Document Name	UAT Summary Report- Increase in Maximum Quantity per Block Bid in PowerARMS™ DAM segment from 50 to 100 MW
System Version No.	3.7.6.1

	Particulars
Test Performed By	Sudhir Bharti, AVP (MO)
Test Start Date	20th March 2017
Reviewed By	VP (MO)
Approved By	Director(MO)

Classification	Internal Use

TABLE OF CONTENTS

1 INTRODUCTION

1.1 PURPOSE

This Test Report provides a summary of the results of test performed by the Surveillance Team.

2 TEST SUMMARY

The testing is performed to evaluate the performance of Power Arms Front Office system while changing the Block Bid Size from 50 to 100 MW as users of the system and for Operational Acceptance Testing.

2.1 TEST CASE 1: - The testing is performed for live delivery date 25th February 2017 with following activities-

All Single and Block Bids of Live Date 25th February are imported in the Test System and following 8 bids of 50 MW is modified as below:-

Portfolio ID	Portfolio Name	From Period	To Period	Buy/Sell	Bid Price	Earlier BID Quantity (MW)	New Bid Quantity (MW)
S1TH0TPI0001	Thermal Powertech Corporation India Ltd.	0:00	7:00	Sell	2800	-50	-100
S1TH0TPI0001	Thermal Powertech Corporation India Ltd.	0:00	7:00	Sell	2800	-50	
W2MH0RIF0001	Reliance Infrastructure Limited	8:45	23:00	Buy	5500	50	100
W2MH0RIF0001	Reliance Infrastructure Limited	8:45	23:00	Buy	5500	50	
W1MP0MPT0001	MPPTC	0:00	6:00	Buy	1440	50	100
W1MP0MPT0001	MPPTC	0:00	6:00	Buy	1440	50	
W3RK0PTC0522	R K M Powergen Pvt Ltd	0:00	24:00	Sell	1740	-50	-100
W3RK0PTC0522	R K M Powergen Pvt Ltd	0:00	24:00	Sell	1740	-50	

Hence eight numbers of 50 MW Block Bid is changed in 4 numbers of 100 MW Block Bid. Prices, Duration etc. are not changed.

i) Provisional Result: - With Unconstrained Capacity, following are results:-

a) Production Live, 8 No. of 50 MW Block Bids-

System Average Price=2506.13, System Total Volume = 107.06 MUs,

Results of 8 Block Bids:-

Portfolio Code	From Period	To Period	Buy/Sell	Bid Price	BID Quantity (MW)	System Average Price	Matching Status
S1THOTPI0001	0:00	7:00	Sell	2800	-50	1994.56	Excluded
S1THOTPI0001	0:00	7:00	Sell	2800	-50	1994.56	Excluded
W2MHORIF0001	8:45	23:00	Buy	5500	50	2715.51	Included
W2MHORIF0001	8:45	23:00	Buy	5500	50	2715.51	Included
W1MP0MPT0001	0:00	6:00	Buy	1440	50	1951.2	Excluded
W1MP0MPT0001	0:00	6:00	Buy	1440	50	1951.2	Excluded
W3RK0PTC0522	0:00	0:00	Sell	1740	-50	2506.13	Included
W3RK0PTC0522	0:00	0:00	Sell	1740	-50	2506.13	Included

b) Test Environment, 4 No. of 100 MW Block Bids-

System Average Price=2506.13, System Total Volume = 107.06 MUs, Results of 4 Block Bids:-

Portfolio Code	From Period	To Period	Buy/Sell	Bid Price	BID Quantity (MW)	System Average Price	Matching Status
S1THOTPI0001	0:00	7:00	Sell	2800	-100	1994.56	Excluded
W2MHORIF0001	8:45	23:00	Buy	5500	100	2715.51	Included
W1MP0MPT0001	0:00	6:00	Buy	1440	100	1951.2	Excluded
W3RK0PTC0522	0:00	0:00	Sell	1740	-100	2506.13	Included

So, during Provisional Calculation, No Change in Price, Volume and Block Bid Results.

ii) Final Result:- Capacity available under NLDC Exception report is imported in the System, following are the results:-

a) Production Live, With 8 No. of 50 MW Block Bids- NR Import congestion in 61 blocks and SR Import congestion in 76 blocks

Rest of India Price-2317.66; NR Average Price-3002.13; SR Average Price-3308.11

Results of 8 Block Bids:-

Portfolio Code	From Period	To Period	Buy/Sell	Bid Price	BID Quantity (MW)	System Average Price	Matching Status
S1TH0TPI0001	0:00	7:00	Sell	2800	-50	2269.52	Excluded
S1TH0TPI0001	0:00	7:00	Sell	2800	-50	2269.52	Excluded
W2MH0RIF0001	8:45	23:00	Buy	5500	50	2460.6	Included
W2MH0RIF0001	8:45	23:00	Buy	5500	50	2460.6	Included
W1MP0MPT0001	0:00	6:00	Buy	1440	50	1947.49	Excluded
W1MP0MPT0001	0:00	6:00	Buy	1440	50	1947.49	Excluded
W3RK0PTC0522	0:00	0:00	Sell	1740	-50	2317.66	Included
W3RK0PTC0522	0:00	0:00	Sell	1740	-50	2317.66	Included

b) Test Environment, 4 No. of 100 MW Block Bids- NR Import congestion in 61 blocks and SR Import congestion in 76 blocks,

Rest of India Price-2317.21; NR Average Price-2999.97; SR Average Price-3308.2; Results of 4 Block Bids:-

Portfolio Code	From Period	To Period	Buy/Sell	Bid Price	BID Quantity (MW)	System Average Price	Matching Status
S1TH0TPI0001	0:00	7:00	Sell	2800	-100	2269.85	Excluded
W2MH0RIF0001	8:45	23:00	Buy	5500	100	2460.78	Included
W1MP0MPT0001	0:00	6:00	Buy	1440	100	1944.56	Excluded
W3RK0PTC0522	0:00	0:00	Sell	1740	-100	2317.21	Included

Status of Block Bids has not changed in both the cases, Status of Congestion in NR and SR not changed, no significant price change observed.

Output Summary: - In case if the Block Bids are not at margin of the demand-supply curve i.e. there is a significant price difference between Bid Price and System Average Price; then increase in the size of block bid from 50 to 100 MW will make negligible changes in the output in terms of Price and Volume.

Test Case 2: - The testing is performed on Live Delivery Date 29th January 2017 with following activities:-

All Single and Block Bids are imported in the Test System and following 12 bids of 50 MW is modified as below:-

Portfolio ID	Portfolio Name	From Period	To Period	Buy/Sell	Bid Price	Earlier BID Quantity (MW)	New Bid Quantity (MW)
N3PB0PTC0003	Punjab State Power Corporation Ltd	17:00	22:00	Sell	3080	-50	-100
N3PB0PTC0003	Punjab State Power Corporation Ltd	17:00	22:00	Sell	3080	-50	
N3PB0PTC0003	Punjab State Power Corporation Ltd	17:00	22:00	Sell	3080	-50	-100
N3PB0PTC0003	Punjab State Power Corporation Ltd	17:00	22:00	Sell	3080	-50	
W2MH0MSE0001	MSEDCL	08:00	17:00	Buy	3000	50	100
W2MH0MSE0001	MSEDCL	08:00	17:00	Buy	3000	50	
W2MH0MSE0001	MSEDCL	07:30	16:30	Buy	3000	50	100
W2MH0MSE0001	MSEDCL	07:30	16:30	Buy	3000	50	
W3KR0ADN0021	KORBA_WEST_POWER _COMPANY_LTD	08:00	18:00	Sell	2200	-50	-100
W3KR0ADN0021	KORBA_WEST_POWER _COMPANY_LTD	08:00	18:00	Sell	2200	-50	
W2MH0TPC0001	TPCL	00:00	24:00	Buy	2809	50	100
W2MH0TPC0001	TPCL	00:00	24:00	Buy	2809	50	

Hence twelve numbers of 50 MW Block Bid is changed in six numbers of 100 MW Block Bid. Price, Duration etc. are not changed.

i) Provisional Result: - With Unconstrained Capacity, following are results:-

a) Production Live, 12 No. of 50 MW Block Bids-

System Average Price=2332.34, System Total Volume = 96.875 MUs,

Results of 12 Block Bids:-

Portfolio Code	From Period	To Period	Buy/Sell	Bid Price	BID Quantity (MW)	System Average Price	Matching Status
N3PB0PTC0003	17:00	22:00	Sell	3080	-50	2528.15	Excluded
N3PB0PTC0003	17:00	22:00	Sell	3080	-50	2528.15	Excluded
N3PB0PTC0003	17:00	22:00	Sell	3080	-50	2528.15	Excluded
N3PB0PTC0003	17:00	22:00	Sell	3080	-50	2528.15	Excluded
W2MH0MSE0001	8:00	17:00	Buy	3000	50	2547.35	Included
W2MH0MSE0001	8:00	17:00	Buy	3000	50	2547.35	Included
W2MH0MSE0001	7:30	16:30	Buy	3000	50	2564.79	Included
W2MH0MSE0001	7:30	16:30	Buy	3000	50	2564.79	Included
W3KR0ADN0021	8:00	18:00	Sell	2200	-50	2529.6	Included
W3KR0ADN0021	8:00	18:00	Sell	2200	-50	2529.6	Included
W2MH0TPC0001	0:00	24:00:00	Buy	2809	50	2332.34	Included
W2MH0TPC0001	0:00	24:00:00	Buy	2809	50	2332.34	Included

b) Test Environment, 6 No. of 100 MW Block Bids-

System Average Price=2332.34, System Total Volume = 96.875 MUs,

Results of 6 Block Bids:-

Portfolio Code	From Period	To Period	Buy/Sell	Bid Price	BID Quantity (MW)	System Average Price	Matching Status
N3PB0PTC0003	17:00	22:00	Sell	3080	-100	2528.15	Excluded
N3PB0PTC0003	17:00	22:00	Sell	3080	-100	2528.15	Excluded
W2MH0MSE0001	8:00	17:00	Buy	3000	100	2547.35	Included
W2MH0MSE0001	7:30	16:30	Buy	3000	100	2564.79	Included
W3KR0ADN0021	8:00	18:00	Sell	2200	-100	2529.6	Included
W2MH0TPC0001	0:00	24:00:00	Buy	2809	100	2332.34	Included

No Change in Price, Volume and Block Bid Results.

ii) Final Result:- Capacity available under NLDC Exception report is imported in the System, following are the results:-

a) Production Live, With 12 No. of 50 MW Block Bids- NR Import congestion in 46 blocks and SR Import congestion in 55 blocks,

Rest of India Price-2261.30; NR Average Price-2607.70; SR Average Price-2608.21

Results of 12 Block Bids:-

Portfolio Code	From Period	To Period	Buy/Sell	Bid Price	BID Quantity (MW)	System Average Price	Matching Status
N3PB0PTC0003	**17:00**	**22:00**	**Sell**	**3080**	**-50**	**3136.93**	**Included**
N3PB0PTC0003	**17:00**	**22:00**	**Sell**	**3080**	**-50**	**3136.93**	**Included**
N3PB0PTC0003	**17:00**	**22:00**	**Sell**	**3080**	**-50**	**3136.93**	**Paradoxically Rejected**
N3PB0PTC0003	**17:00**	**22:00**	**Sell**	**3080**	**-50**	**3136.93**	**Paradoxically Rejected**
W2MH0MSE0001	8:00	17:00	Buy	3000	50	2544.26	Included
W2MH0MSE0001	8:00	17:00	Buy	3000	50	2544.26	Included
W2MH0MSE0001	7:30	16:30	Buy	3000	50	2557.6	Included
W2MH0MSE0001	7:30	16:30	Buy	3000	50	2557.6	Included
W3KR0ADN0021	8:00	18:00	Sell	2200	-50	2523.67	Included
W3KR0ADN0021	8:00	18:00	Sell	2200	-50	2523.67	Included
W2MH0TPC0001	0:00	24:00:00	Buy	2809	50	2261.3	Included
W2MH0TPC0001	0:00	24:00:00	Buy	2809	50	2261.3	Included

b) Test Environment, 6 No. of 100 MW Block Bids- NR Import congestion in 46 blocks and SR Import congestion in 55 blocks,

Rest of India Price-2262.35; NR Average Price-2630.54; SR Average Price-2608.21;

Results of 6 Block Bids:-

Portfolio Code	From Period	To Period	Buy/Sell	Bid Price	BID Quantity (MW)	System Average Price	Matching Status
N3PB0PTC0003	**17:00**	**22:00**	**Sell**	**3080**	**-100**	**3246.57**	**Paradoxically Rejected**
N3PB0PTC0003	**17:00**	**22:00**	**Sell**	**3080**	**-100**	**3246.57**	**Paradoxically Rejected**
W2MH0MSE0001	8:00	17:00	Buy	3000	100	2544.26	Included

W2MH0MSE0001	7:30	16:30	Buy	3000	100	2557.59	Included
W3KR0ADN0021	8:00	18:00	Sell	2200	-100	2526.17	Included
W2MH0TPC0001	0:00	24:00:00	Buy	2809	100	2262.32	Included

Status of Block Bid of N3PB0PTC0003 has changed since at Margin

Output Summary: - During Provisional Solution since the Block Bids were not at margin i.e. there were significant price difference between Bid price and System Average Price hence changing the size of block bid from 50 to 100 MW has not made any changes in system price and results.
In Final Solution due to congestion and hence market split the Block Bid of N3PB0PTC0003 became marginal block bid and due to increased size of Block Bid both the block bids of 100 MW got rejected.
While if the block bid were for 50 MW then two block bids were included and two block bids were paradoxically rejected. Hence Block Bid Rejection occurred due to increase in Block Bid Size increased.

Test Case 3: - In this test, quantities of several block bids are changed to 100 MW and then performance of the system is checked. The testing is performed on Live Delivery Date 16th March 2017 with following activities:-

i) All Single and Block Bids are imported in the Test System and certain block bids with quantity 40 to 50 MW is modified to 30 bids of 100 MW.

ii) Provisional Result: - With Unconstrained Capacity, following are results:-
   a) Production Live-
   System Average Price=2494.28, System Total Volume =115.13 MUs,

   b) Test Environment, 30 Number of Block Bids-
   System Average Price=2499.61, System Total Volume = 114.73 MUs,

iii) Final Result:- Capacity available under NLDC Exception report is imported in the System, following are the results:-
   a) Production Live- NR Import congestion in 65 blocks and SR Import congestion in 76 blocks,
   Rest of India Price-2299.48; NR Average Price-2676.15; SR Average Price-3285.09

   b) Test Environment, 30 No. of 100 MW Block Bids- NR Import congestion in 65 blocks and SR Import congestion in 76 blocks,
   Rest of India Price-2293.39; NR Average Price-2678.67; SR Average Price-3278.93;

Output Summary: - While changing the Block Bid size of 40 MW & 50 MW to 100 MW it is observed that no significant change has occurred in Price during Provisional and Final Price Results. Also the Performance of System was also similar (like time taken by the System to perform the Price Calculation).

3 SUGGESTED ACTIONS

The Test is performed for 3 Production Live Dates wherein certain block bids were changed to 100 MW and it is observed that no significant changes were detected in following parameters:-

I) Performance of System

II) Market Clearing Price and Volume

III) Area Clearing Price and Volume

IV) No. of Blocks of Market Split

Hence it is suggested that we can go-ahead with the parameter change i.e. from 50 MW to 100 MW.

Appendix A: Test Summary Report Approval

The undersigned acknowledge they have reviewed the **Test Summary Report** and agree with the approach it is presented

Signature: [signature] Date: 7/4/17

Name: SUDHIR BHARTI

Signature: [signature] Date: 8/4/17

Name: PRASANNA RAO

Signature: [signature] Date: 10/4/17.

Name: Akhilesh Awasthy

NETWORK PATH WHERE DOCUMENT IS LOCATED: -

1) For Test Case1:- 172.16.29.221/M:\Powerarms Testing\Testing_50-100MW\Final\120170225_D

2) For Test case 2:- 172.16.29.221/M:\Powerarms Testing\Testing_50-100MW\Final\220170129

3) For Test case 3:- 172.16.29.221/M:\Powerarms Testing\Testing_50-100MW\Final\15032017_OK

Annexure-IC

Delivery Date	Total no. of Portfolios	No. of Portfolios with Single Bids	No. of Portfolio with Block Bids	No. of Portfolios with Blocks Bids Qty. >50 MW	% Portfolios with Block Bids Q>50 MW to total no. of Portfolios
13-Apr-17	1127	461	704	1	0.09%
14-Apr-17	1118	456	697	3	0.27%
15-Apr-17	1129	451	708	4	0.35%
16-Apr-17	1061	420	667	3	0.28%
17-Apr-17	1092	456	665	3	0.27%
18-Apr-17	1145	470	707	4	0.35%
19-Apr-17	1147	471	712	4	0.35%
20-Apr-17	1145	479	699	3	0.26%
21-Apr-17	1136	480	690	3	0.26%
22-Apr-17	1144	477	704	4	0.35%
23-Apr-17	1072	443	664	3	0.28%
24-Apr-17	1101	470	668	3	0.27%
25-Apr-17	1166	488	714	4	0.34%
26-Apr-17	1173	491	717	4	0.34%
27-Apr-17	1178	489	725	4	0.34%
28-Apr-17	1139	472	703	6	0.53%
29-Apr-17	1138	474	700	4	0.35%
30-Apr-17	1058	437	649	2	0.19%
1-May-17	835	328	529	1	0.12%
2-May-17	923	371	580	3	0.33%
3-May-17	1042	443	626	2	0.19%
4-May-17	1042	441	627	2	0.19%
5-May-17	973	428	572	7	0.72%
6-May-17	1004	441	592	6	0.60%
7-May-17	941	399	571	6	0.64%
8-May-17	975	428	579	5	0.51%
9-May-17	970	425	572	6	0.62%
10-May-17	1020	434	615	7	0.69%
11-May-17	1082	449	661	6	0.55%
12-May-17	1090	458	663	8	0.73%
13-May-17	1045	440	633	7	0.67%
14-May-17	989	421	597	7	0.71%
15-May-17	1016	443	606	7	0.69%
16-May-17	999	438	595	9	0.90%
17-May-17	1035	452	613	8	0.77%
18-May-17	1054	452	633	9	0.85%
19-May-17	1041	461	610	9	0.86%
20-May-17	1056	467	616	8	0.76%
21-May-17	998	435	590	7	0.70%
22-May-17	1021	446	603	5	0.49%
23-May-17	1027	451	602	5	0.49%
24-May-17	1043	462	609	6	0.58%
25-May-17	1038	455	612	4	0.39%
26-May-17	1011	450	591	5	0.49%
27-May-17	989	442	576	5	0.51%
28-May-17	971	420	581	6	0.62%

Delivery Date	Total no. of Portfolios	No. of Portfolios with Single Bids	No. of Portfolio with Block Bids	No. of Portfolios with Blocks Bids Qty. >50 MW	% Portfolios with Block Bids Q>50 MW to total no. of Portfolios
29-May-17	999	445	584	7	0.70%
30-May-17	1025	452	604	8	0.78%
31-May-17	1056	461	628	5	0.47%
1-Jun-17	915	410	532	6	0.66%
2-Jun-17	1011	458	584	9	0.89%
3-Jun-17	1043	464	612	10	0.96%
4-Jun-17	987	423	597	10	1.01%
5-Jun-17	1000	443	593	11	1.10%
6-Jun-17	982	446	569	8	0.81%
7-Jun-17	969	448	554	8	0.83%
8-Jun-17	1048	463	617	8	0.76%
9-Jun-17	1051	463	620	9	0.86%
10-Jun-17	1048	455	626	10	0.95%
11-Jun-17	987	421	599	11	1.11%
12-Jun-17	1005	441	602	10	1.00%
13-Jun-17	1036	458	614	13	1.25%
14-Jun-17	1060	470	623	11	1.04%
15-Jun-17	1063	472	627	8	0.75%
16-Jun-17	1047	466	615	11	1.05%
17-Jun-17	983	447	568	8	0.81%
18-Jun-17	947	419	560	7	0.74%
19-Jun-17	1010	455	591	9	0.89%
20-Jun-17	1038	469	606	11	1.06%
21-Jun-17	1040	474	600	9	0.87%
22-Jun-17	1060	473	622	12	1.13%
23-Jun-17	1050	471	616	11	1.05%
24-Jun-17	1062	464	637	13	1.22%
25-Jun-17	986	415	605	13	1.32%
26-Jun-17	999	440	595	10	1.00%
27-Jun-17	1033	460	609	12	1.16%
28-Jun-17	1036	466	603	10	0.97%
29-Jun-17	1028	456	601	8	0.78%
30-Jun-17	1023	453	604	9	0.88%
Average	**1040**	**449**	**622**	**7**	**0.67%**

Annexure-ID

Delivery Date	Total no. of Bids	No. of Single Bids	No. of Block Bids	Blocks Bids with Bid Qty. >50 MW	% Block Bids with Q>50 MW to total no. of block bids
13-Apr-17	4425	461	3964	5	0.13%
14-Apr-17	4301	456	3845	16	0.42%
15-Apr-17	4102	451	3651	10	0.27%
16-Apr-17	3900	420	3480	7	0.20%
17-Apr-17	4165	456	3709	8	0.22%
18-Apr-17	4413	470	3943	12	0.30%
19-Apr-17	4433	471	3962	12	0.30%
20-Apr-17	4265	479	3786	9	0.24%
21-Apr-17	4316	480	3836	9	0.23%
22-Apr-17	4351	477	3874	10	0.26%
23-Apr-17	3978	443	3535	12	0.34%
24-Apr-17	4328	470	3858	9	0.23%
25-Apr-17	4590	488	4102	9	0.22%
26-Apr-17	4613	491	4122	42	1.02%
27-Apr-17	4497	489	4008	38	0.95%
28-Apr-17	4453	472	3981	46	1.16%
29-Apr-17	4220	474	3746	33	0.88%
30-Apr-17	3879	437	3442	13	0.38%
1-May-17	3186	328	2858	1	0.03%
2-May-17	3751	371	3380	17	0.50%
3-May-17	4196	443	3753	10	0.27%
4-May-17	4095	441	3654	11	0.30%
5-May-17	4074	428	3646	27	0.74%
6-May-17	4248	441	3807	36	0.95%
7-May-17	3968	399	3569	59	1.65%
8-May-17	4131	428	3703	41	1.11%
9-May-17	4167	425	3742	39	1.04%
10-May-17	4340	434	3906	67	1.72%
11-May-17	4472	449	4023	52	1.29%
12-May-17	4437	458	3979	75	1.88%
13-May-17	4320	440	3880	44	1.13%
14-May-17	3916	421	3495	50	1.43%
15-May-17	4082	443	3639	78	2.14%
16-May-17	4414	438	3976	63	1.58%
17-May-17	4415	452	3963	42	1.06%
18-May-17	4485	452	4033	64	1.59%
19-May-17	4358	461	3897	71	1.82%
20-May-17	4280	467	3813	74	1.94%
21-May-17	4105	435	3670	72	1.96%
22-May-17	4219	446	3773	55	1.46%
23-May-17	4391	451	3940	70	1.78%
24-May-17	4360	462	3898	62	1.59%

Delivery Date	Total no. of Bids	No. of Single Bids	No. of Block Bids	Blocks Bids with Bid Qty. >50 MW	% Block Bids with Q>50 MW to total no. of block bids
25-May-17	4412	455	3957	42	1.06%
26-May-17	4399	450	3949	41	1.04%
27-May-17	4361	442	3919	43	1.10%
28-May-17	4127	420	3707	53	1.43%
29-May-17	4253	445	3808	58	1.52%
30-May-17	4292	452	3840	65	1.69%
31-May-17	4427	461	3966	53	1.34%
1-Jun-17	3883	410	3473	33	0.95%
2-Jun-17	4312	458	3854	90	2.34%
3-Jun-17	4452	464	3988	67	1.68%
4-Jun-17	4140	423	3717	86	2.31%
5-Jun-17	4289	443	3846	77	2.00%
6-Jun-17	4351	446	3905	69	1.77%
7-Jun-17	4315	448	3867	99	2.56%
8-Jun-17	4493	463	4030	137	3.40%
9-Jun-17	4546	463	4083	126	3.09%
10-Jun-17	4453	455	3998	134	3.35%
11-Jun-17	4192	421	3771	145	3.85%
12-Jun-17	4349	441	3908	145	3.71%
13-Jun-17	4579	458	4121	153	3.71%
14-Jun-17	4564	470	4094	157	3.83%
15-Jun-17	4553	472	4081	126	3.09%
16-Jun-17	4534	466	4068	131	3.22%
17-Jun-17	4413	447	3966	138	3.48%
18-Jun-17	4083	419	3664	116	3.17%
19-Jun-17	4293	455	3838	137	3.57%
20-Jun-17	4436	469	3967	138	3.48%
21-Jun-17	4431	474	3957	156	3.94%
22-Jun-17	4467	473	3994	196	4.91%
23-Jun-17	4402	471	3931	148	3.76%
24-Jun-17	4330	464	3866	136	3.52%
25-Jun-17	3936	415	3521	144	4.09%
26-Jun-17	4180	440	3740	79	2.11%
27-Jun-17	4299	460	3839	117	3.05%
28-Jun-17	4203	466	3737	101	2.70%
29-Jun-17	4162	456	3706	81	2.19%
30-Jun-17	4123	453	3670	70	1.91%
Average	**4274**	**449**	**3825**	**68**	**1.75%**

Annexure-IE

Delivery Date	Total No. of Block Bids>50 MW	No. of Block Bids>50 MW selected in Provisional result	No. of Block Bids >50 MW Selected in Final result	No. of Block Bids>50 MW rejected in Provisional result	No. of Block Bids>50 MW rejected in Final result	Block Bids selected in Prov. but not in final	Block Bids selected in Final but not in Provisional
13-Apr-17	5	5	5	0	0	0	0
14-Apr-17	16	10	10	6	6	0	0
15-Apr-17	10	8	8	2	2	0	0
16-Apr-17	7	6	6	1	1	0	0
17-Apr-17	8	8	8	0	0	0	0
18-Apr-17	12	10	10	2	2	0	0
19-Apr-17	12	10	10	2	2	0	0
20-Apr-17	9	9	9	0	0	0	0
21-Apr-17	9	8	7	1	2	1	0
22-Apr-17	10	9	9	1	1	0	0
23-Apr-17	12	6	6	6	6	0	0
24-Apr-17	9	9	9	0	0	0	0
25-Apr-17	9	6	5	3	4	1	0
26-Apr-17	42	33	33	9	9	0	0
27-Apr-17	38	28	30	10	8	0	2
28-Apr-17	46	24	28	22	18	0	4
29-Apr-17	33	9	11	24	22	0	2
30-Apr-17	13	4	4	9	9	0	0
1-May-17	1	1	1	0	0	0	0
2-May-17	17	12	12	5	5	0	0
3-May-17	10	10	10	0	0	0	0
4-May-17	11	11	11	0	0	0	0
5-May-17	27	23	23	4	4	0	0
6-May-17	36	31	31	5	5	0	0
7-May-17	59	47	47	12	12	0	0
8-May-17	41	33	32	8	9	1	0
9-May-17	39	29	29	10	10	0	0
10-May-17	67	49	49	18	18	0	0
11-May-17	52	37	37	15	15	0	0
12-May-17	75	56	56	19	19	0	0
13-May-17	44	42	42	2	2	0	0
14-May-17	50	45	45	5	5	0	0
15-May-17	78	55	55	23	23	0	0
16-May-17	63	57	57	6	6	0	0
17-May-17	42	38	38	4	4	0	0
18-May-17	64	44	44	20	20	0	0
19-May-17	71	53	53	18	18	0	0
20-May-17	74	55	55	19	19	0	0
21-May-17	72	42	36	30	36	6	0
22-May-17	55	41	41	14	14	0	0
23-May-17	70	37	37	33	33	0	0
24-May-17	62	55	55	7	7	0	0
25-May-17	42	40	40	2	2	0	0
26-May-17	41	39	39	2	2	0	0
27-May-17	43	40	40	3	3	0	0
28-May-17	53	29	29	24	24	0	0
29-May-17	58	39	39	19	19	0	0
30-May-17	65	32	31	33	34	1	0

Delivery Date	Total No. of Block Bids>50 MW	No. of Block Bids>50 MW selected in Provisional result	No. of Block Bids >50 MW Selected in Final result	No. of Block Bids>50 MW rejected in Provisional result	No. of Block Bids>50 MW rejected in Final result	Block Bids selected in Prov. but not in final	Block Bids selected in Final but not in Provisional
31-May-17	53	37	37	16	16	0	0
1-Jun-17	33	30	30	3	3	0	0
2-Jun-17	90	40	40	50	50	0	0
3-Jun-17	67	53	53	14	14	0	0
4-Jun-17	86	64	64	22	22	0	0
5-Jun-17	77	65	65	12	12	0	0
6-Jun-17	69	65	65	4	4	0	0
7-Jun-17	99	28	28	71	71	0	0
8-Jun-17	137	47	47	90	90	0	0
9-Jun-17	126	64	64	62	62	0	0
10-Jun-17	134	60	60	74	74	0	0
11-Jun-17	145	38	38	107	107	0	0
12-Jun-17	145	56	56	89	89	0	0
13-Jun-17	153	70	70	83	83	0	0
14-Jun-17	157	74	74	83	83	0	0
15-Jun-17	126	68	68	58	58	0	0
16-Jun-17	131	90	90	41	41	0	0
17-Jun-17	138	68	61	70	77	7	0
18-Jun-17	116	86	86	30	30	0	0
19-Jun-17	137	91	91	46	46	0	0
20-Jun-17	138	93	93	45	45	0	0
21-Jun-17	156	60	60	96	96	0	0
22-Jun-17	196	78	78	118	118	0	0
23-Jun-17	148	66	66	82	82	0	0
24-Jun-17	136	80	80	56	56	0	0
25-Jun-17	144	51	51	93	93	0	0
26-Jun-17	79	49	49	30	30	0	0
27-Jun-17	117	37	37	80	80	0	0
28-Jun-17	101	52	46	49	55	6	0
29-Jun-17	81	41	41	40	40	0	0
30-Jun-17	70	31	31	39	39	0	0

Annexure-IIA

Delivery Date	Total No. of Block Bids>50 MW	No. of Block Bids>50 MW selected in Provisional result	No. of Block Bids >50 MW Selected in Final result	No. of Block Bids>50 MW rejected in Provisional result	No. of Block Bids>50 MW rejected in Final result	Block Bids selected in Prov. but not in final	Block Bids selected in Final but not in Provisional	Total time Blocks when MCP<>ACP with No Split
13-Apr-17	5	5	5	0	0	**0**	**0**	**31**
14-Apr-17	16	10	10	6	6	**0**	**0**	**27**
15-Apr-17	10	8	8	2	2	**0**	**0**	**50**
16-Apr-17	7	6	6	1	1	**0**	**0**	**43**
17-Apr-17	8	8	8	0	0	**0**	**0**	**11**
18-Apr-17	12	10	10	2	2	**0**	**0**	**14**
19-Apr-17	12	10	10	2	2	**0**	**0**	**12**
20-Apr-17	9	9	9	0	0	**0**	**0**	**6**
21-Apr-17	9	8	7	1	2	**1**	**0**	**15**
22-Apr-17	10	9	9	1	1	**0**	**0**	**26**
23-Apr-17	12	6	6	6	6	**0**	**0**	**45**
24-Apr-17	9	9	9	0	0	**0**	**0**	**0**
25-Apr-17	9	6	5	3	4	**1**	**0**	**53**
26-Apr-17	42	33	33	9	9	**0**	**0**	**40**
27-Apr-17	38	28	30	10	8	**0**	**2**	**50**
28-Apr-17	46	24	28	22	18	**0**	**4**	**52**
29-Apr-17	33	9	11	24	22	**0**	**2**	**61**
30-Apr-17	13	4	4	9	9	**0**	**0**	**30**
1-May-17	1	1	1	0	0	**0**	**0**	**0**
2-May-17	17	12	12	5	5	**0**	**0**	**0**
3-May-17	10	10	10	0	0	**0**	**0**	**76**
4-May-17	11	11	11	0	0	**0**	**0**	**39**
5-May-17	27	23	23	4	4	**0**	**0**	**26**
6-May-17	36	31	31	5	5	**0**	**0**	**78**
7-May-17	59	47	47	12	12	**0**	**0**	**69**
8-May-17	41	33	32	8	9	**1**	**0**	**7**
9-May-17	39	29	29	10	10	**0**	**0**	**26**
10-May-17	67	49	49	18	18	**0**	**0**	**81**
11-May-17	52	37	37	15	15	**0**	**0**	**0**
12-May-17	75	56	56	19	19	**0**	**0**	**0**
13-May-17	44	42	42	2	2	**0**	**0**	**0**
14-May-17	50	45	45	5	5	**0**	**0**	**70**
15-May-17	78	55	55	23	23	**0**	**0**	**88**
16-May-17	63	57	57	6	6	**0**	**0**	**17**
17-May-17	42	38	38	4	4	**0**	**0**	**44**
18-May-17	64	44	44	20	20	**0**	**0**	**0**
19-May-17	71	53	53	18	18	**0**	**0**	**0**
20-May-17	74	55	55	19	19	**0**	**0**	**0**
21-May-17	72	42	36	30	36	**6**	**0**	**24**
22-May-17	55	41	41	14	14	**0**	**0**	**12**
23-May-17	70	37	37	33	33	**0**	**0**	**0**
24-May-17	62	55	55	7	7	**0**	**0**	**0**
25-May-17	42	40	40	2	2	**0**	**0**	**0**
26-May-17	41	39	39	2	2	**0**	**0**	**0**
27-May-17	43	40	40	3	3	**0**	**0**	**0**
28-May-17	53	29	29	24	24	**0**	**0**	**0**
29-May-17	58	39	39	19	19	**0**	**0**	**0**
30-May-17	65	32	31	33	34	**1**	**0**	**2**
31-May-17	53	37	37	16	16	**0**	**0**	**0**
1-Jun-17	33	30	30	3	3	**0**	**0**	**0**
2-Jun-17	90	40	40	50	50	**0**	**0**	**0**
3-Jun-17	67	53	53	14	14	**0**	**0**	**0**
4-Jun-17	86	64	64	22	22	**0**	**0**	**0**
5-Jun-17	77	65	65	12	12	**0**	**0**	**0**
6-Jun-17	69	65	65	4	4	**0**	**0**	**0**

Delivery Date	Total No. of Block Bids>50 MW	No. of Block Bids>50 MW selected in Provisional result	No. of Block Bids >50 MW Selected in Final result	No. of Block Bids>50 MW rejected in Provisional result	No. of Block Bids>50 MW rejected in Final result	Block Bids selected in Prov. but not in final	Block Bids selected in Final but not in Provisional	Total time Blocks when MCP<>ACP with No Split
7-Jun-17	99	28	28	71	71	0	0	0
8-Jun-17	137	47	47	90	90	0	0	0
9-Jun-17	126	64	64	62	62	0	0	0
10-Jun-17	134	60	60	74	74	0	0	0
11-Jun-17	145	38	38	107	107	0	0	0
12-Jun-17	145	56	56	89	89	0	0	0
13-Jun-17	153	70	70	83	83	0	0	0
14-Jun-17	157	74	74	83	83	0	0	4
15-Jun-17	126	68	68	58	58	0	0	0
16-Jun-17	131	90	90	41	41	0	0	49
17-Jun-17	138	68	61	70	77	7	0	70
18-Jun-17	116	86	86	30	30	0	0	0
19-Jun-17	137	91	91	46	46	0	0	0
20-Jun-17	138	93	93	45	45	0	0	0
21-Jun-17	156	60	60	96	96	0	0	0
22-Jun-17	196	78	78	118	118	0	0	0
23-Jun-17	148	66	66	82	82	0	0	0
24-Jun-17	136	80	80	56	56	0	0	0
25-Jun-17	144	51	51	93	93	0	0	0
26-Jun-17	79	49	49	30	30	0	0	0
27-Jun-17	117	37	37	80	80	0	0	0
28-Jun-17	101	52	46	49	55	6	0	75
29-Jun-17	81	41	41	40	40	0	0	0
30-Jun-17	70	31	31	39	39	0	0	0

Annexure-IIB

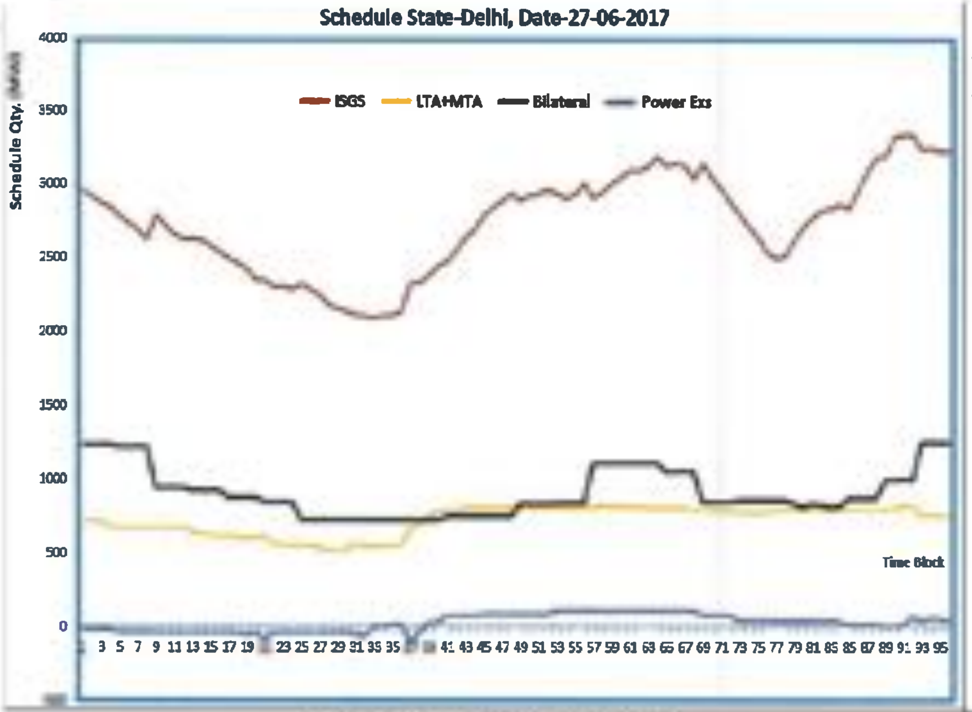
Month	Price Diff. <10 paise	Price Diff. 10-20 paise	Price Diff. 20-30 paise	Difference greater than 30 paise	Total Blocks when MCP<>ACP with No Split	No. of Blocks when Exception Received
Jan-17	582	42	25	13	662	1058
Feb-17	896	57	6	5	964	1086
Mar-17	586	9	1	0	596	614
Apr-17	319	27	8	6	360	362
May-17	400	36	10	8	454	469
Jun-17	674	47	10	18	749	1251
Jul-17	816	76	20	6	918	1706
Aug-17	805	75	33	26	939	1469
Sep-17	918	47	12	7	984	1481
Oct-17	672	22	3	1	698	1407
Nov-17	791	40	23	4	858	1011
Dec-17	690	14	18	7	729	1108
Jan-17	858	53	9	3	923	978
Feb-17	531	33	13	4	581	588
Mar-17	872	34	9	3	918	1215
1-12 Apr 17	322	20	1	0	343	657
13-31 Apr 17	515	39	8	4	566	685
May-17	621	30	4	4	659	2584
Jun-17	177	8	2	1	188	108

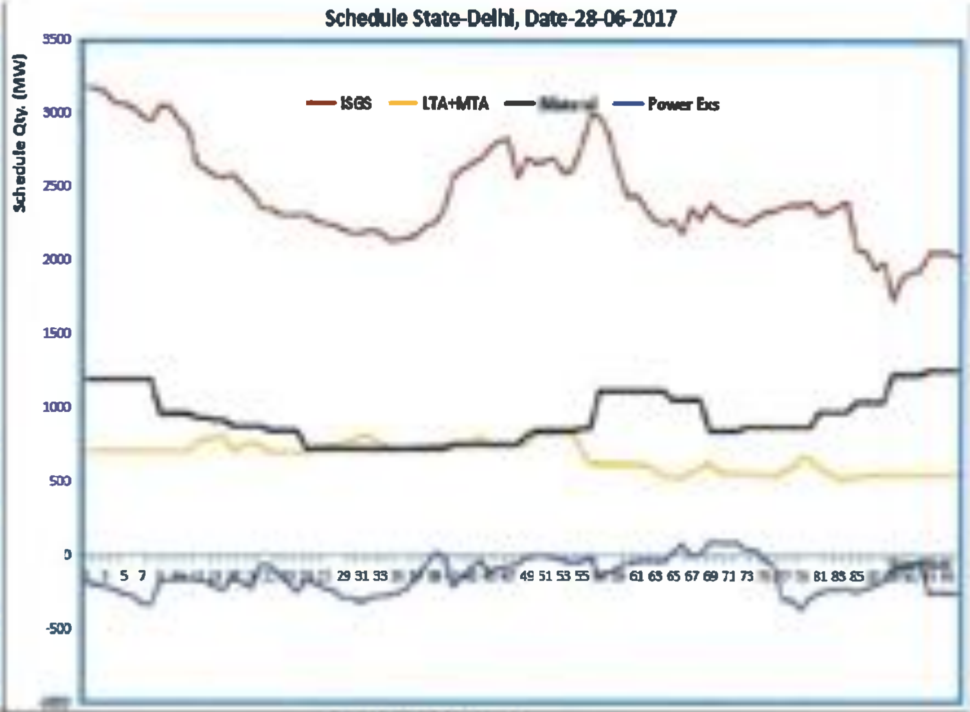
Annexure IIIA

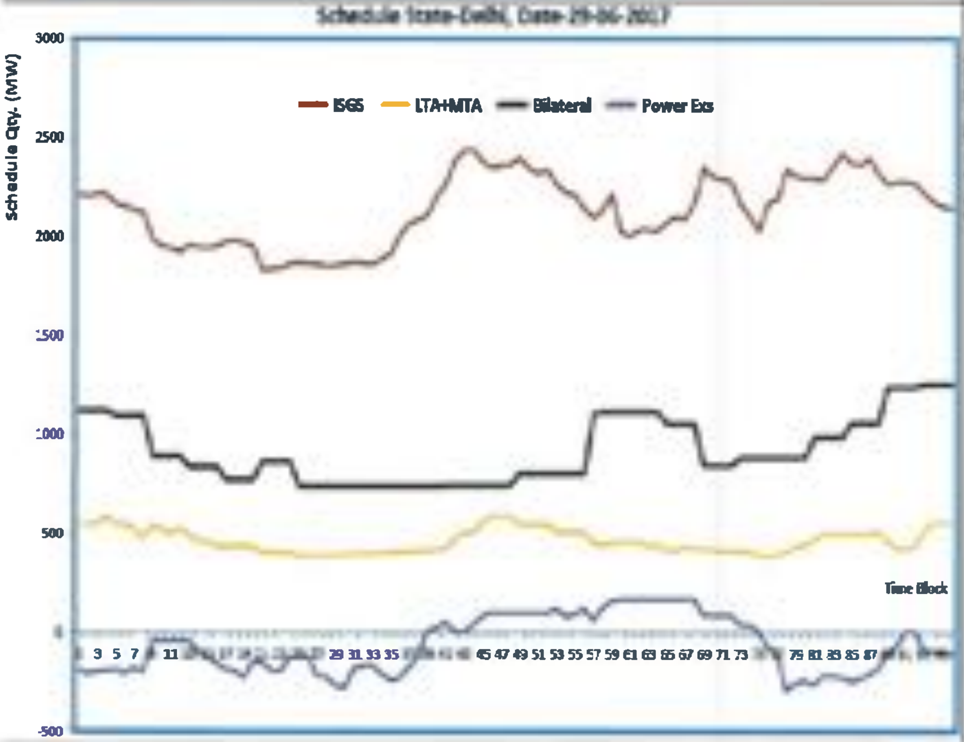
Delivery Date	Total No. of Block Bids>50 MW	No. of Block Bids>50 MW selected in Provisional result	No. of Block Bids >50 MW Selected in Final result	No. of Block Bids>50 MW rejected in Provisional result	No. of Block Bids>50 MW rejected in Final result	Block Bids selected in Prov. but not in final	Block Bids selected in Final but not in Provisional	Sum of ∑ACV-MCV for Blocks where ∑ACV>MCV in MWhr
13-Apr-17	5	5	5	0	0	0	0	662
14-Apr-17	16	10	10	6	6	0	0	495
15-Apr-17	10	8	8	2	2	0	0	1036
16-Apr-17	7	6	6	1	1	0	0	186
17-Apr-17	8	8	8	0	0	0	0	416
18-Apr-17	12	10	10	2	2	0	0	504
19-Apr-17	12	10	10	2	2	0	0	2176
20-Apr-17	9	9	9	0	0	0	0	1139
21-Apr-17	9	8	7	1	2	1	0	789
22-Apr-17	10	9	9	1	1	0	0	2091
23-Apr-17	12	6	6	6	6	0	0	62
24-Apr-17	9	9	9	0	0	0	0	
25-Apr-17	9	6	5	3	4	1	0	21
26-Apr-17	42	33	33	9	9	0	0	743
27-Apr-17	38	28	30	10	8	0	2	2494
28-Apr-17	46	24	28	22	18	0	4	2041
29-Apr-17	33	9	11	24	22	0	2	2342
30-Apr-17	13	4	4	9	9	0	0	1012
1-May-17	1	1	1	0	0	0	0	
2-May-17	17	12	12	5	5	0	0	
3-May-17	10	10	10	0	0	0	0	245
4-May-17	11	11	11	0	0	0	0	744
5-May-17	27	23	23	4	4	0	0	800
6-May-17	36	31	31	5	5	0	0	
7-May-17	59	47	47	12	12	0	0	943
8-May-17	41	33	32	8	9	1	0	9
9-May-17	39	29	29	10	10	0	0	70
10-May-17	67	49	49	18	18	0	0	286
11-May-17	52	37	37	15	15	0	0	
12-May-17	75	56	56	19	19	0	0	
13-May-17	44	42	42	2	2	0	0	
14-May-17	50	45	45	5	5	0	0	807
15-May-17	78	55	55	23	23	0	0	419
16-May-17	63	57	57	6	6	0	0	5
17-May-17	42	38	38	4	4	0	0	340
18-May-17	64	44	44	20	20	0	0	
19-May-17	71	53	53	18	18	0	0	
20-May-17	74	55	55	19	19	0	0	
21-May-17	72	42	36	30	36	6	0	1263
22-May-17	55	41	41	14	14	0	0	2
23-May-17	70	37	37	33	33	0	0	
24-May-17	62	55	55	7	7	0	0	
25-May-17	42	40	40	2	2	0	0	
26-May-17	41	39	39	2	2	0	0	
27-May-17	43	40	40	3	3	0	0	
28-May-17	53	29	29	24	24	0	0	
29-May-17	58	39	39	19	19	0	0	
30-May-17	65	32	31	33	34	1	0	
31-May-17	53	37	37	16	16	0	0	
1-Jun-17	33	30	30	3	3	0	0	
2-Jun-17	90	40	40	50	50	0	0	
3-Jun-17	67	53	53	14	14	0	0	
4-Jun-17	86	64	64	22	22	0	0	
5-Jun-17	77	65	65	12	12	0	0	
6-Jun-17	69	65	65	4	4	0	0	
7-Jun-17	99	28	28	71	71	0	0	
8-Jun-17	137	47	47	90	90	0	0	
9-Jun-17	126	64	64	62	62	0	0	
10-Jun-17	134	60	60	74	74	0	0	
11-Jun-17	145	38	38	107	107	0	0	
12-Jun-17	145	56	56	89	89	0	0	
13-Jun-17	153	70	70	83	83	0	0	
14-Jun-17	157	74	74	83	83	0	0	
15-Jun-17	126	68	68	58	58	0	0	
16-Jun-17	131	90	90	41	41	0	0	
17-Jun-17	138	68	61	70	77	7	0	
18-Jun-17	116	86	86	30	30	0	0	
19-Jun-17	137	91	91	46	46	0	0	

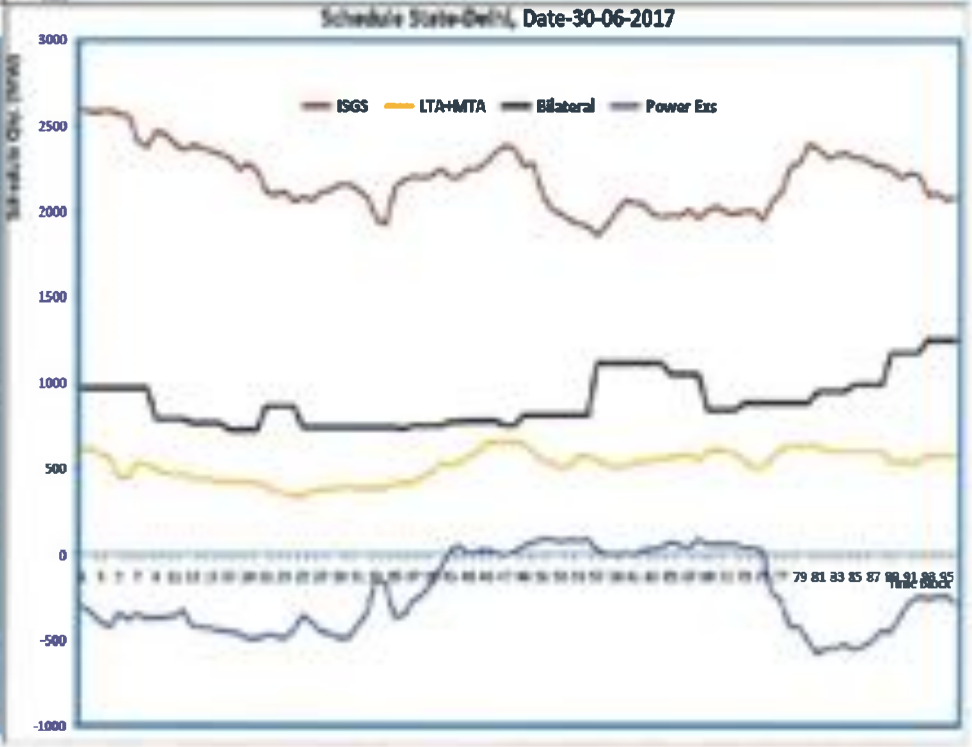
Delivery Date	Total No. of Block Bids>50 MW	No. of Block Bids>50 MW selected in Provisional result	No. of Block Bids >50 MW Selected in Final result	No. of Block Bids>50 MW rejected in Provisional result	No. of Block Bids>50 MW rejected in Final result	Block Bids selected in Prov. but not in final	Block Bids selected in Final but not in Provisional	Sum of ∑ACV-MCV for Blocks where ∑ACV>MCV in MWhr
20-Jun-17	138	93	93	45	45	0	0	
21-Jun-17	156	60	60	96	96	0	0	
22-Jun-17	196	78	78	118	118	0	0	
23-Jun-17	148	66	66	82	82	0	0	
24-Jun-17	136	80	80	56	56	0	0	
25-Jun-17	144	51	51	93	93	0	0	
26-Jun-17	79	49	49	30	30	0	0	
27-Jun-17	117	37	37	80	80	0	0	
28-Jun-17	101	52	46	49	55	6	0	
29-Jun-17	81	41	41	40	40	0	0	
30-Jun-17	70	31	31	39	39	0	0	

ANNEXURE - IV A.

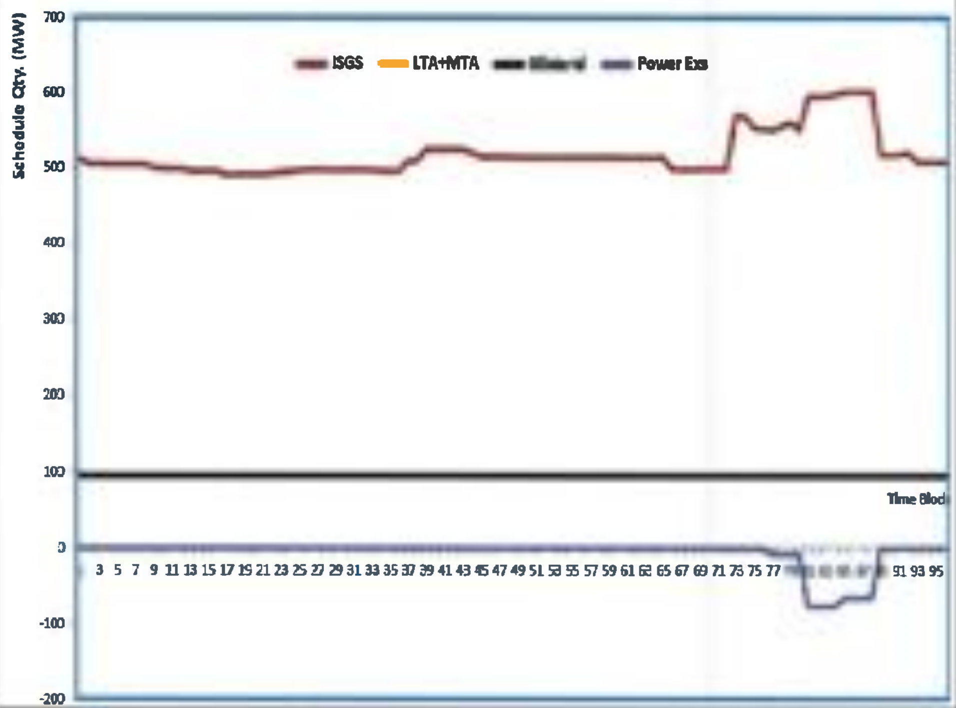




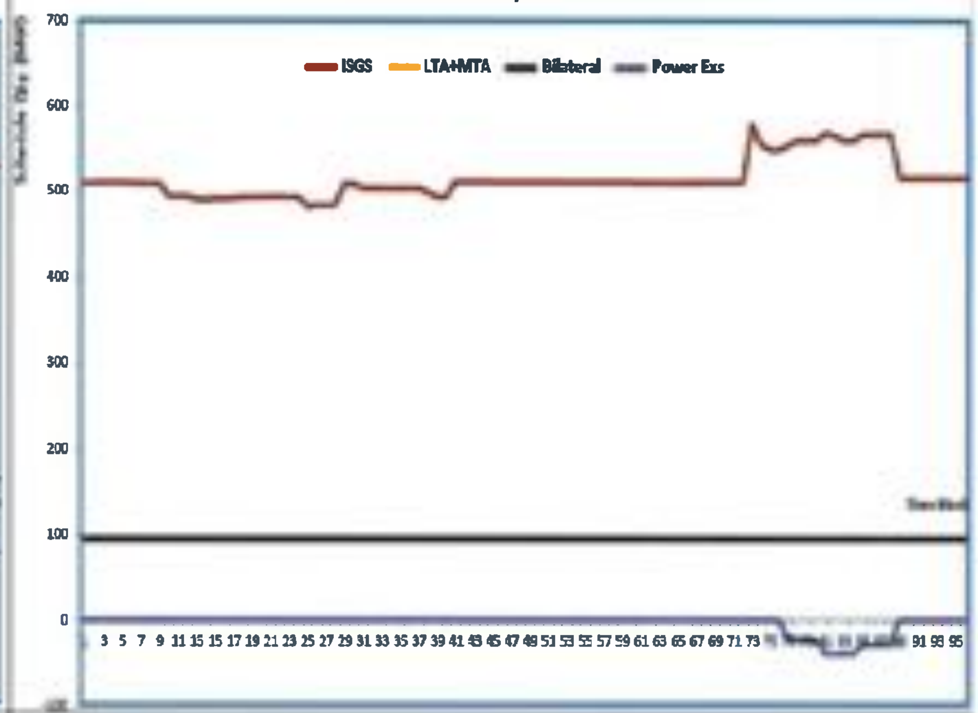




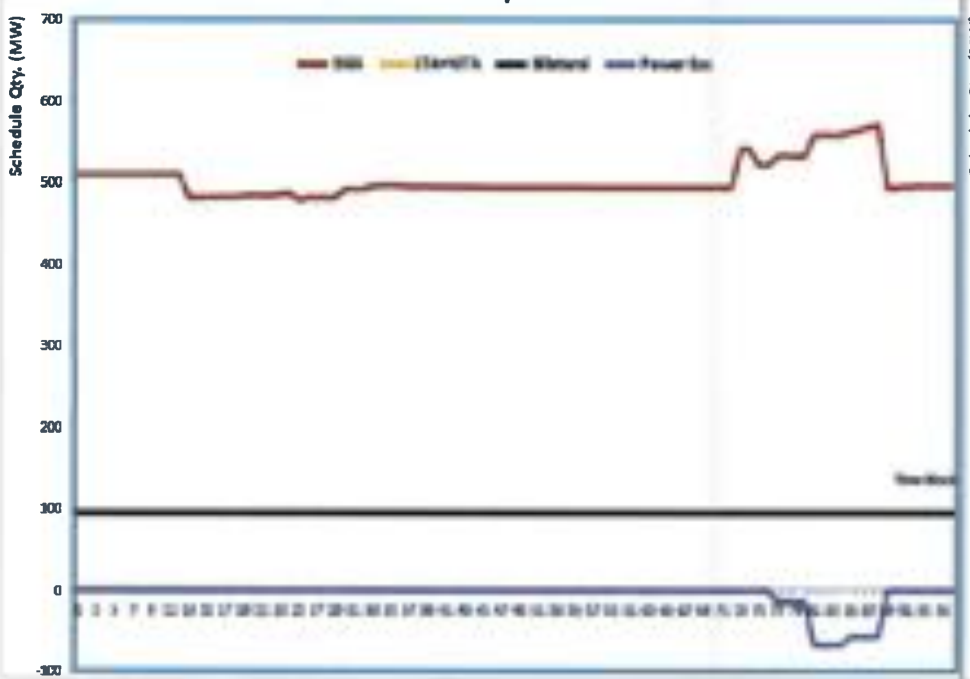
Schedule State-DNH, Date-27-06-2017



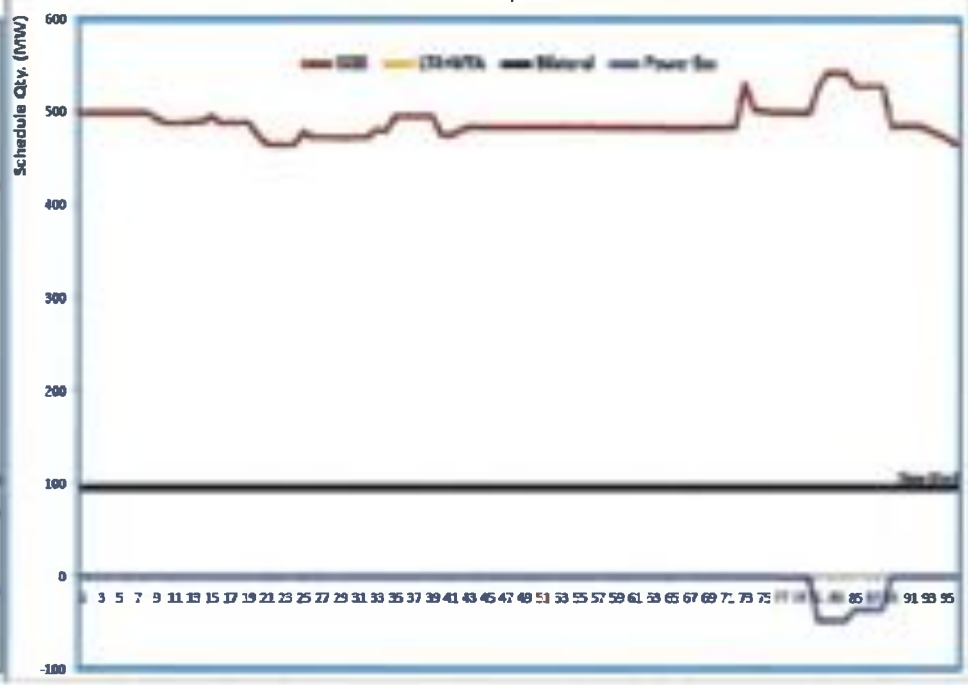
Schedule State-DNH, Date-28-06-2017



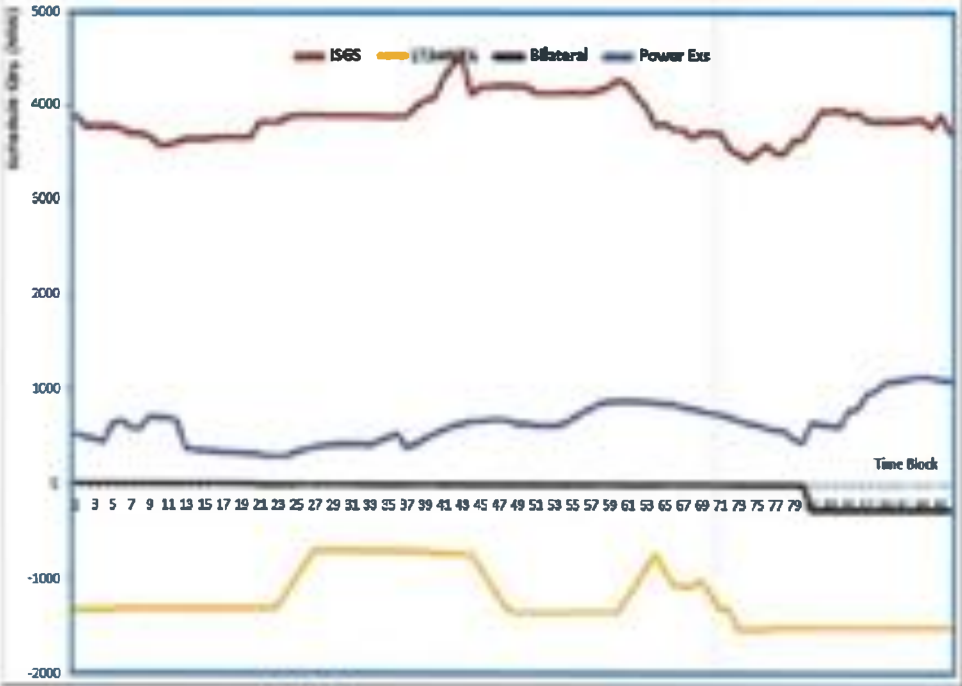
Schedule State-DNH, Date-29-06-2017



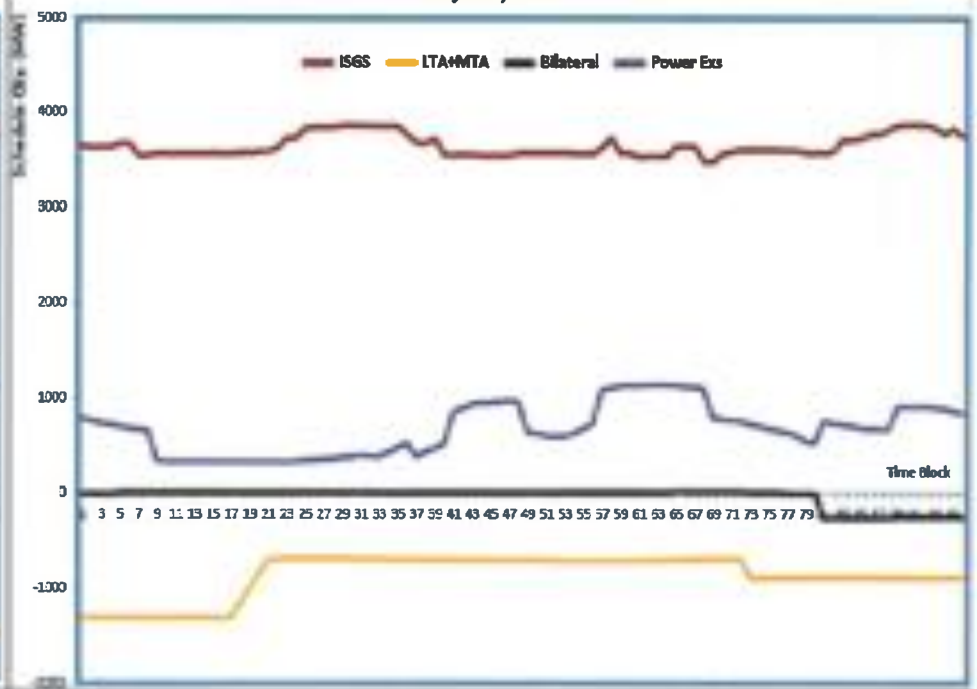
Schedule State-DNH, Date-30-06-2017



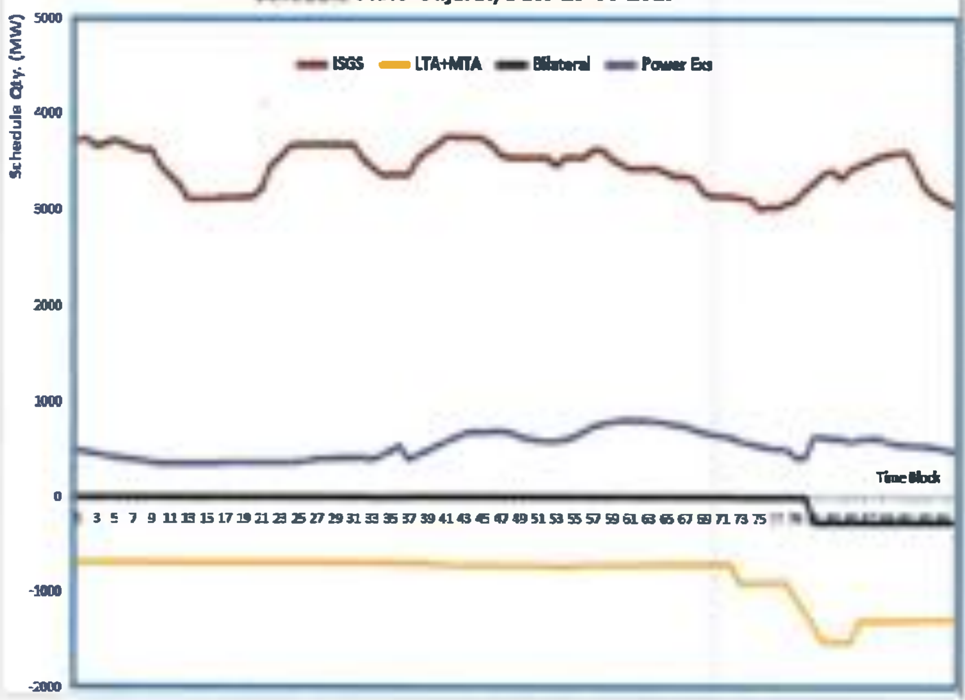
Schedule State-Gujarat, Date-27-06-2017



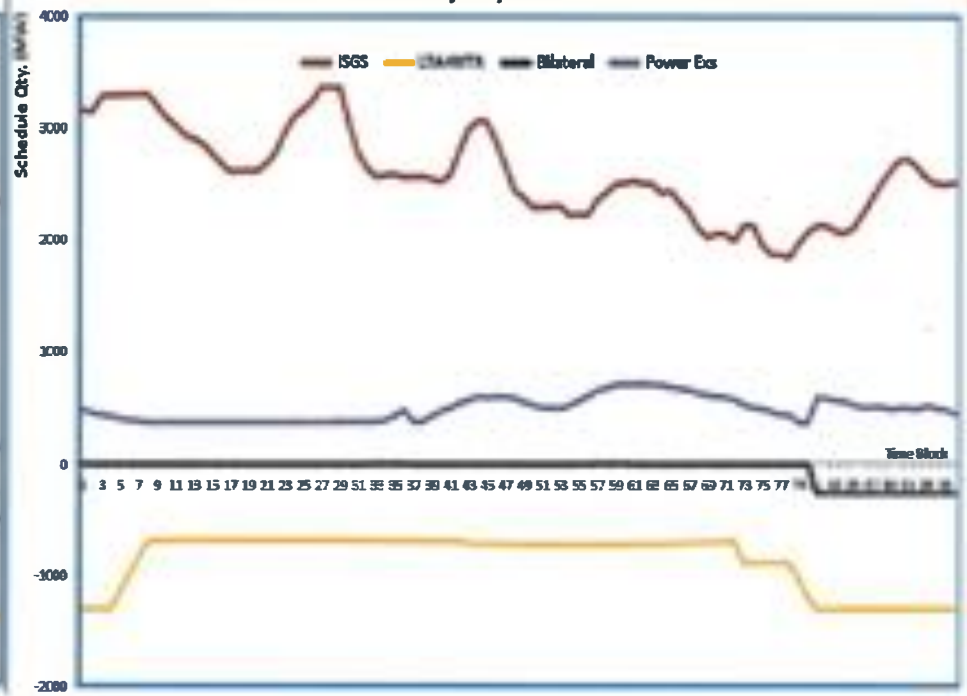
Schedule State-Gujarat, Date-28-06-2017



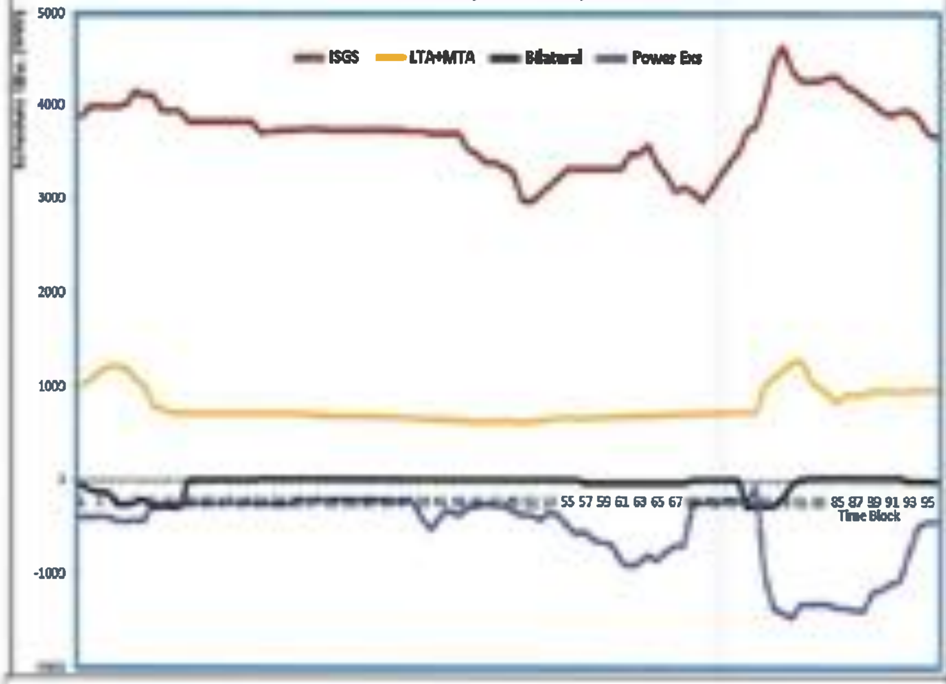
Schedule State-Gujarat, Date-29-06-2017



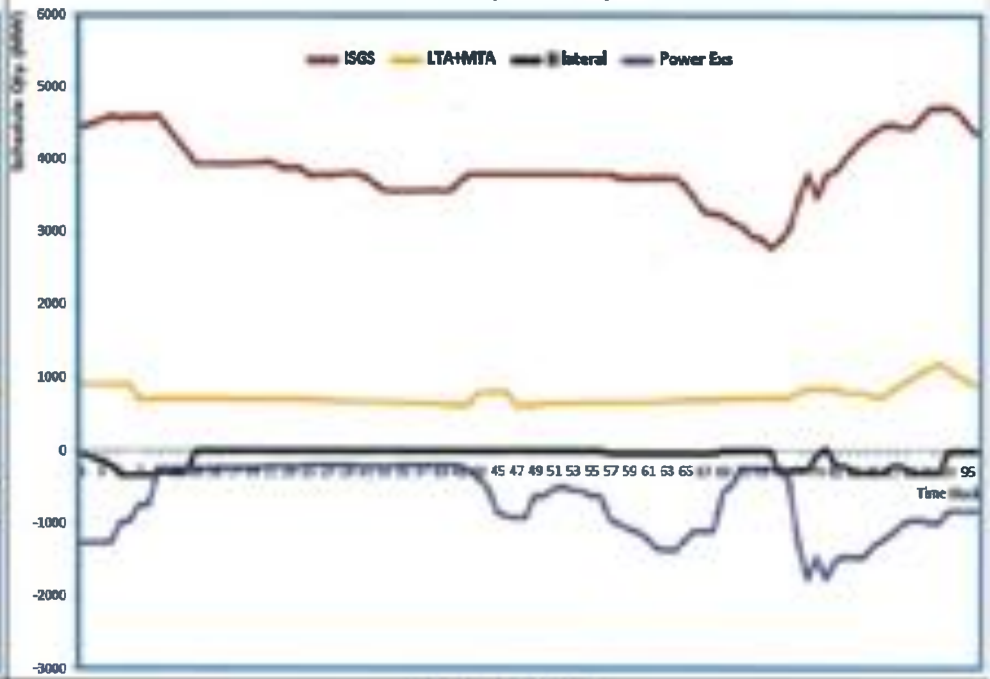
Schedule State-Gujarat, Date-30-06-2017



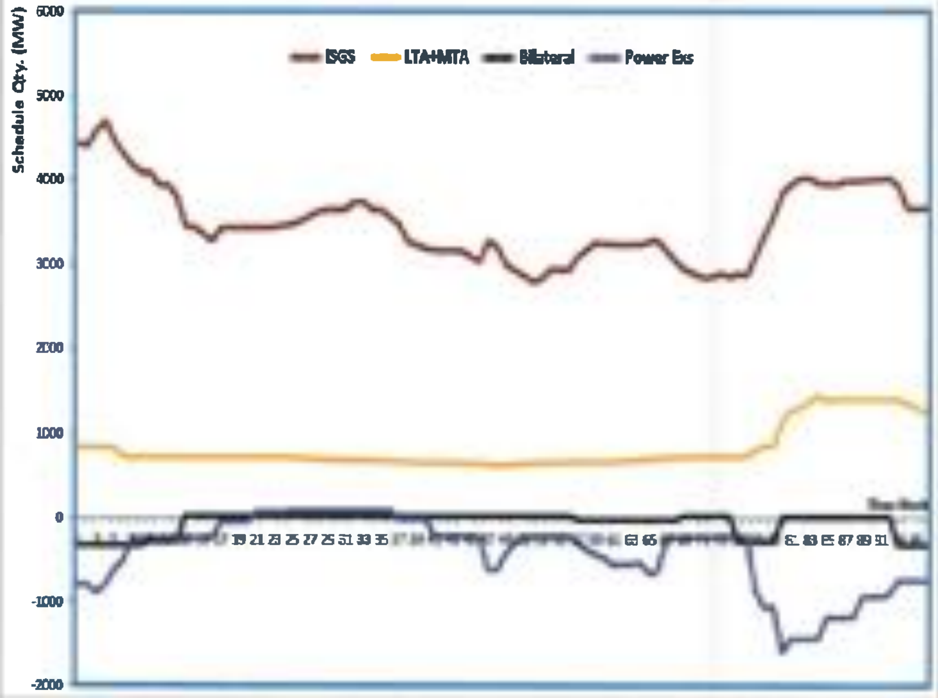
Schedule State-Madhya Pradesh, Date-27-06-2017



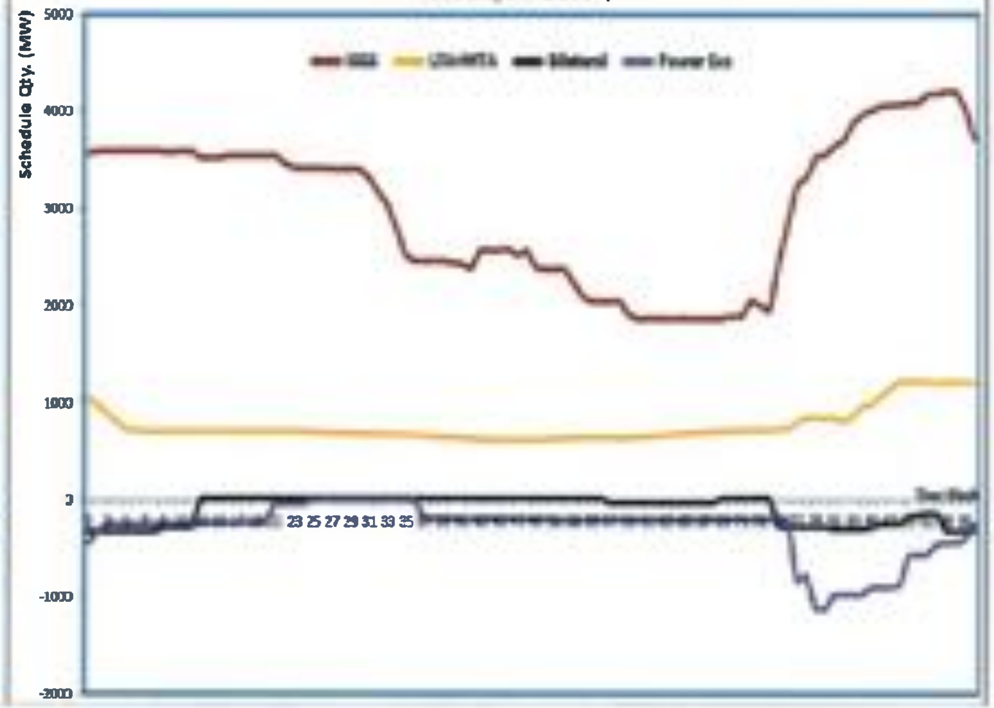
Schedule State-Madhya Pradesh, Date-28-06-2017

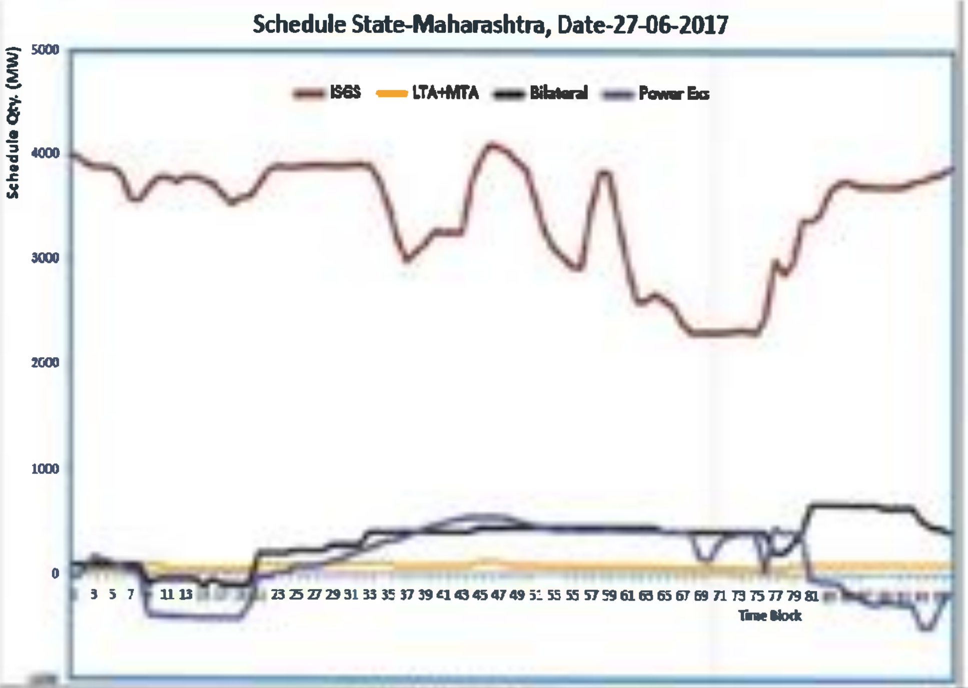


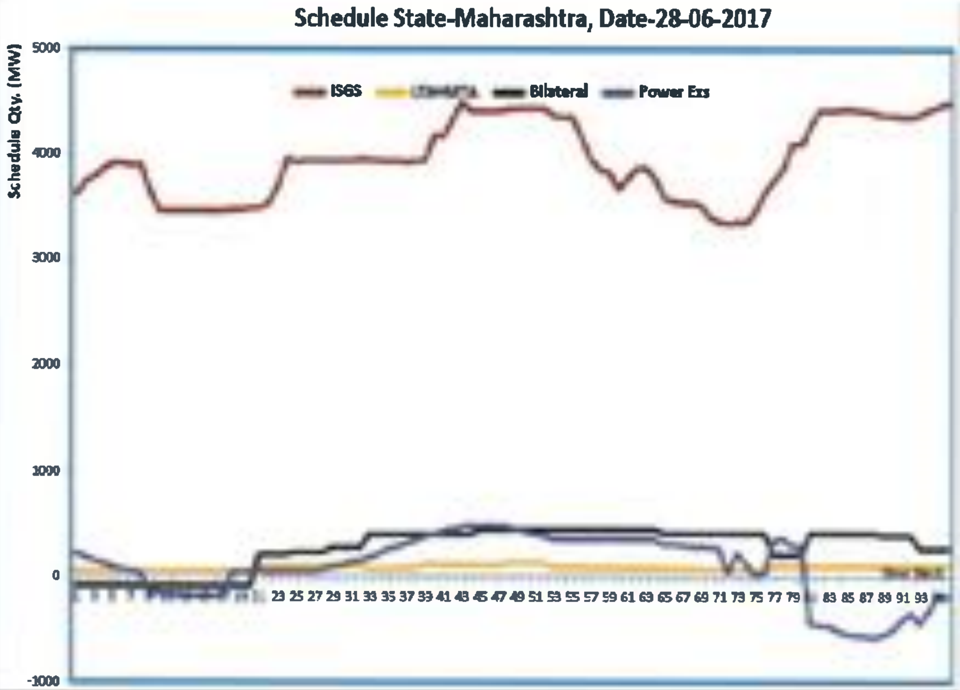
Schedule State-Madhya Pradesh, Date-29-06-2017

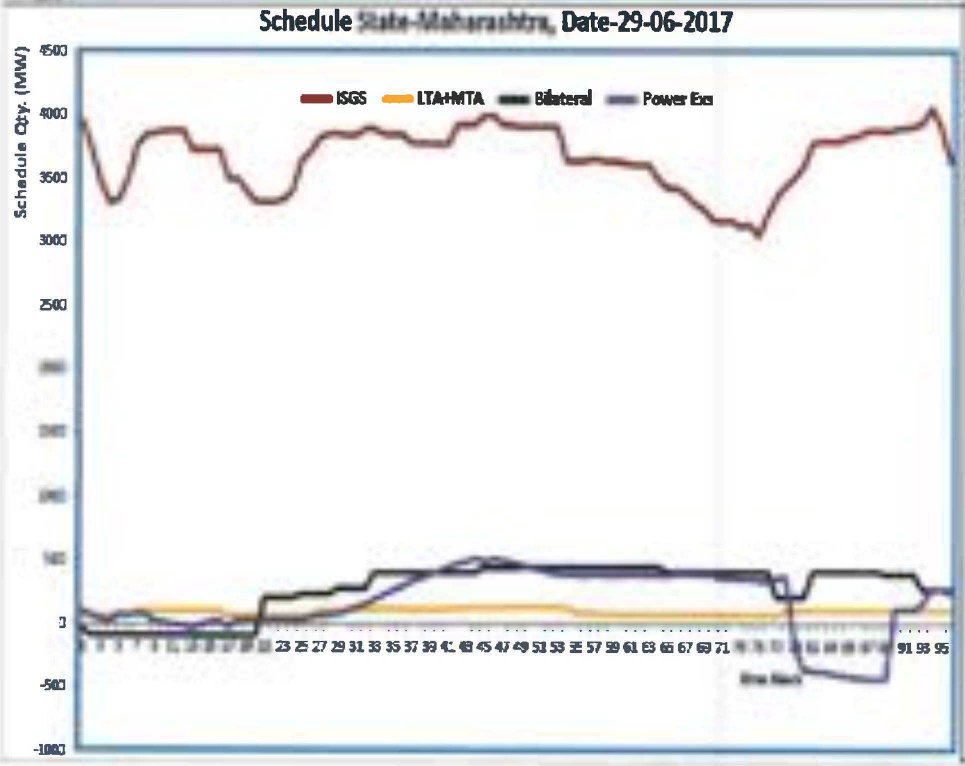


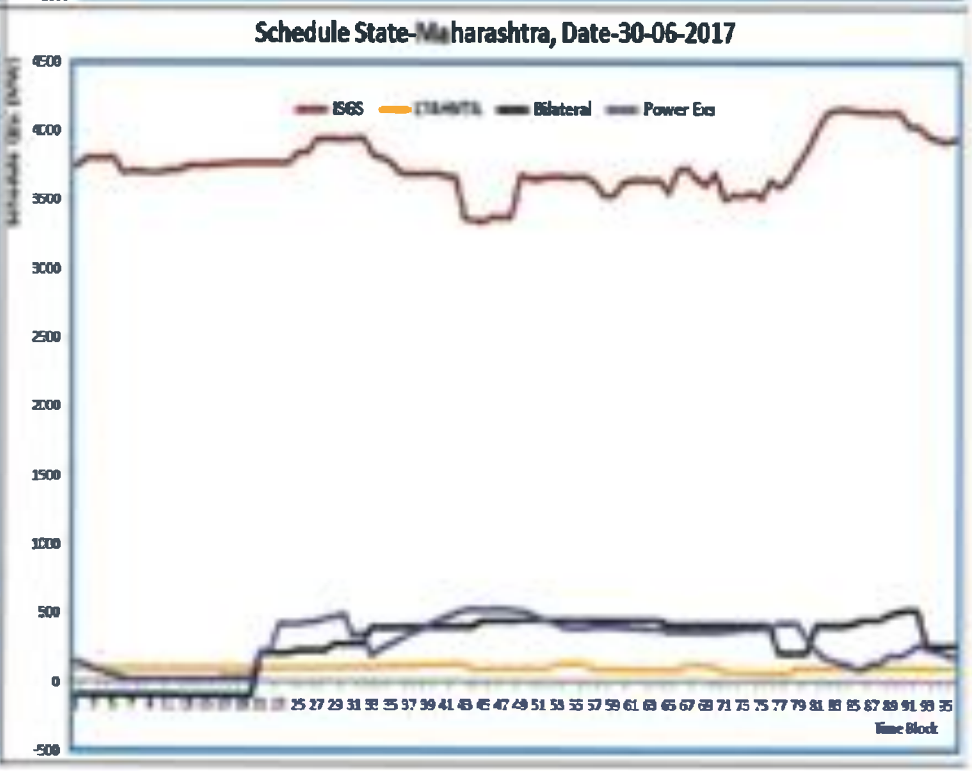
Schedule State-Madhya Pradesh, Date-30-06-2017



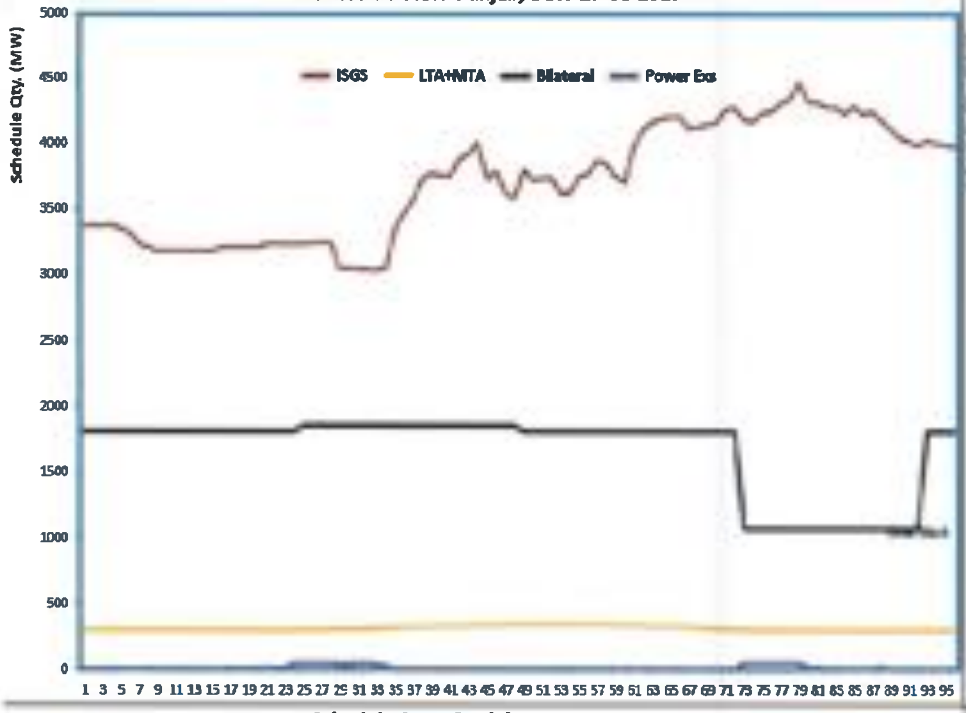

Schedule State-Maharashtra, Date-27-06-2017
ISGS
LTA+MTA
Bilateral
Power Exs
Schedule Qty. (MW)
Time Block


Schedule State-Maharashtra, Date-28-06-2017
ISGS
Bilateral
Power Exs
Schedule Qty. (MW)

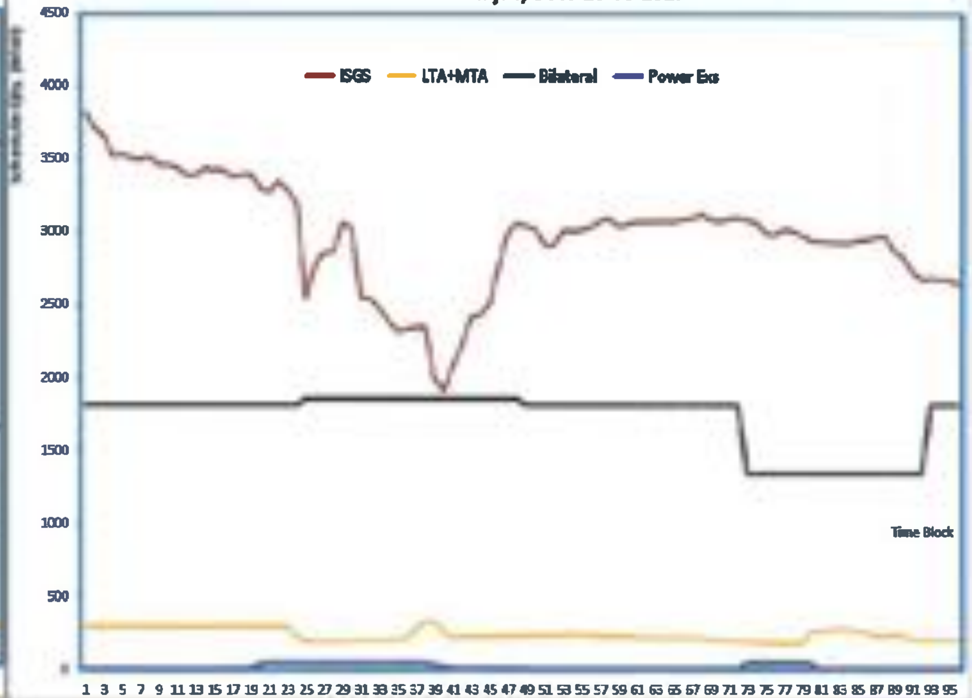

Schedule State-Maharashtra, Date-29-06-2017
ISGS
LTA+MTA
Bilateral
Power Exs
Schedule Qty. (MW)


Schedule State-Maharashtra, Date-30-06-2017
ISGS
Bilateral
Power Exs
Time Block

Schedule State-Punjab, Date-27-06-2017

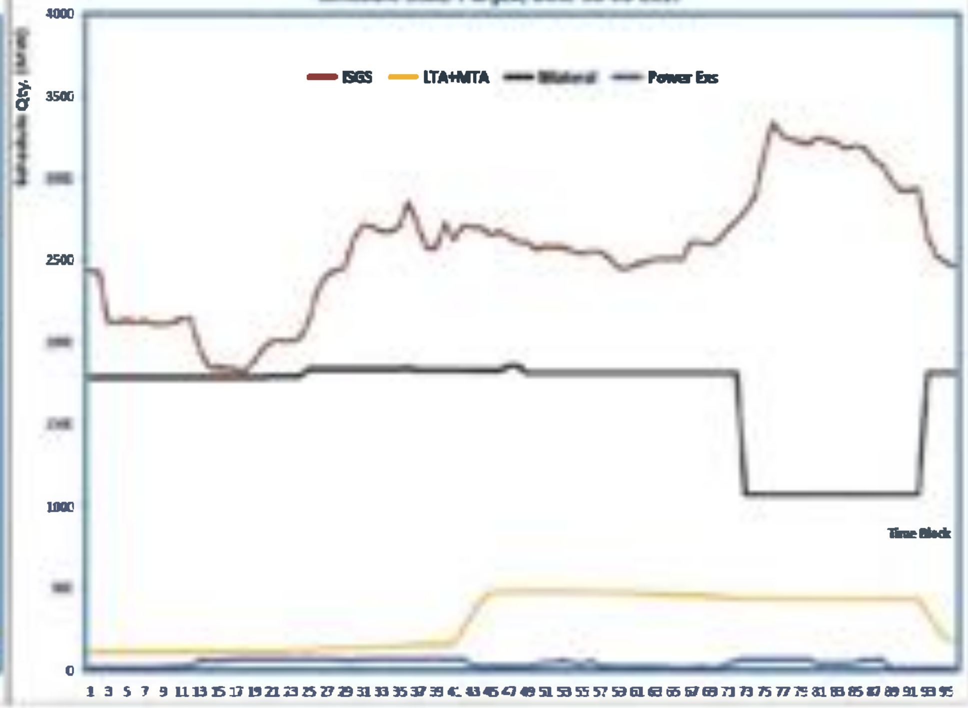


Schedule State-Punjab, Date-28-06-2017

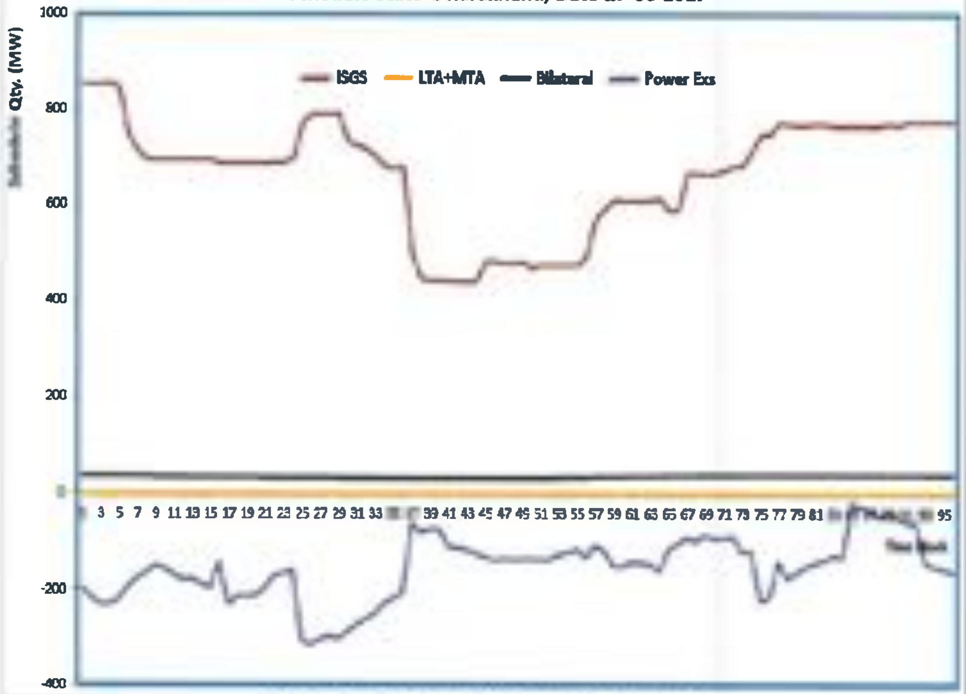


Schedule State-Punjab, Date-29-06-2017

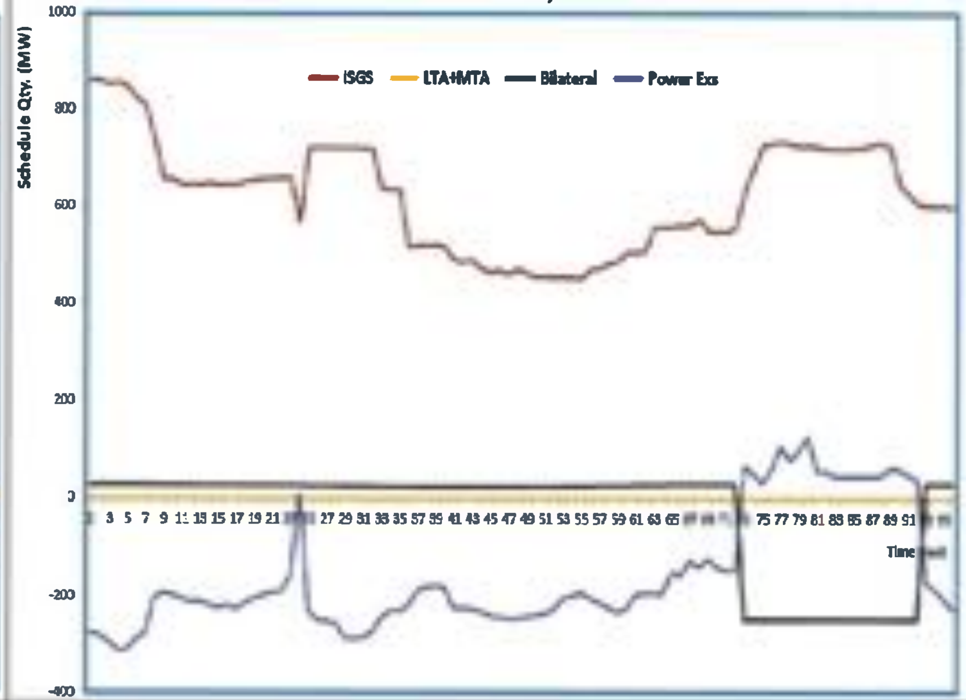
Schedule State-Punjab, Date-30-06-2017



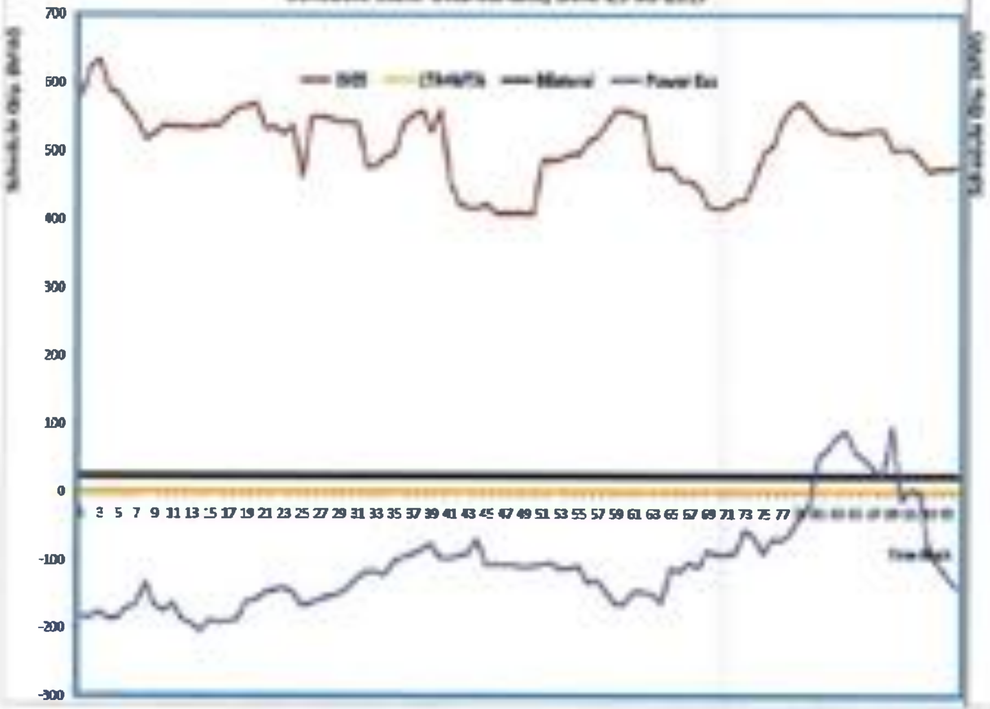
Schedule State-Uttarakhand, Date-27-06-2017



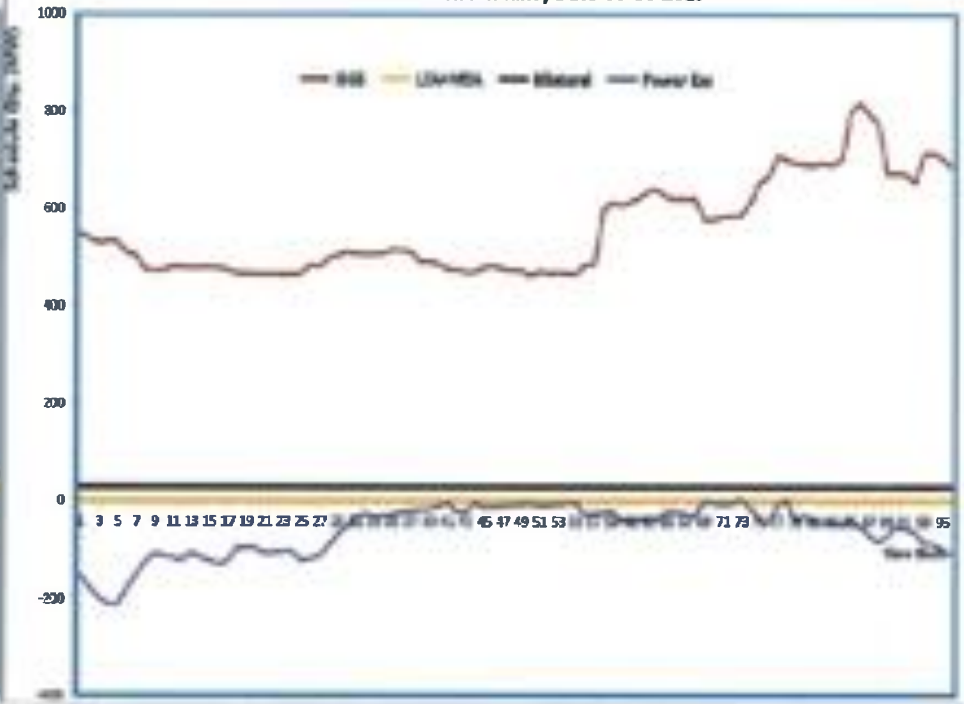
Schedule State-Uttarakhand, Date-28-06-2017



Schedule State-Uttarakhand, Date-29-06-2017

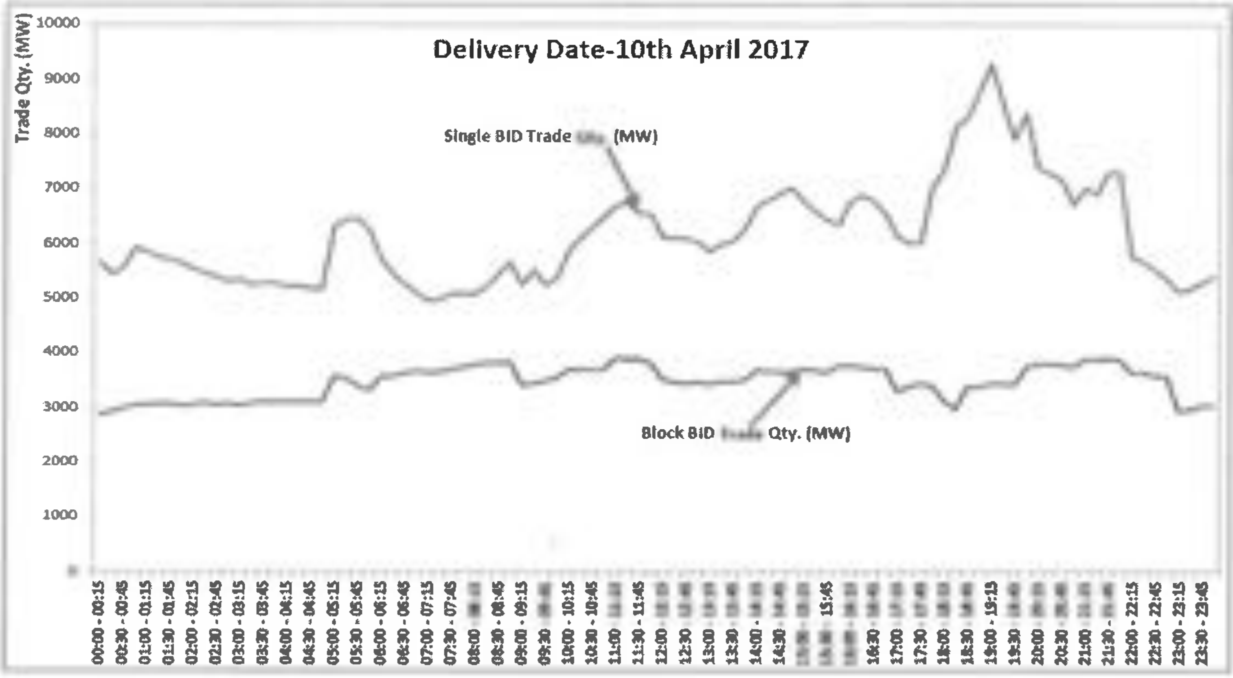


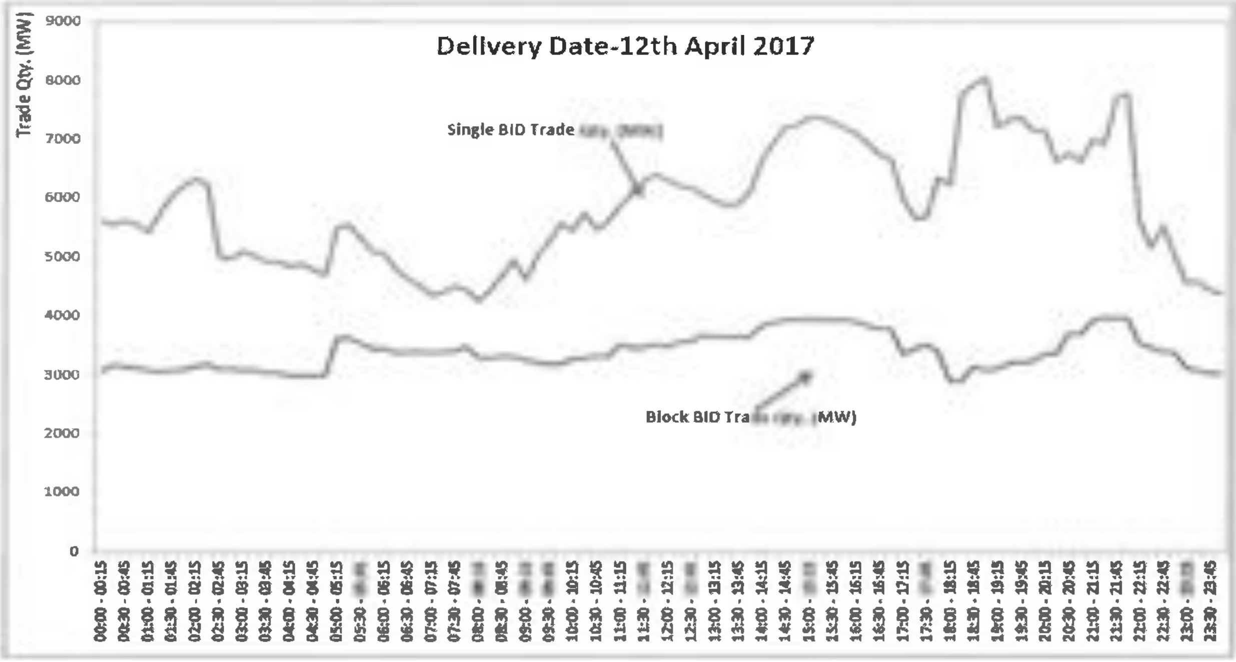
Schedule State-Uttarakhand, Date-30-06-2017



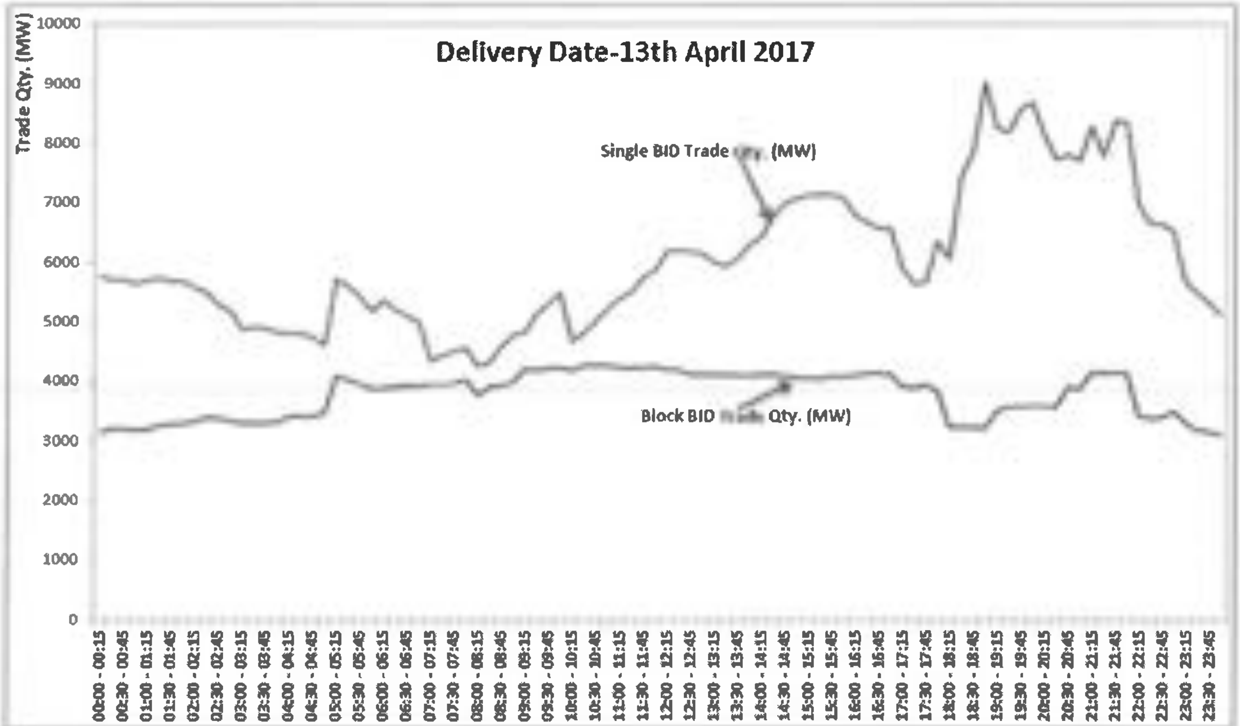
Annexure-IV B

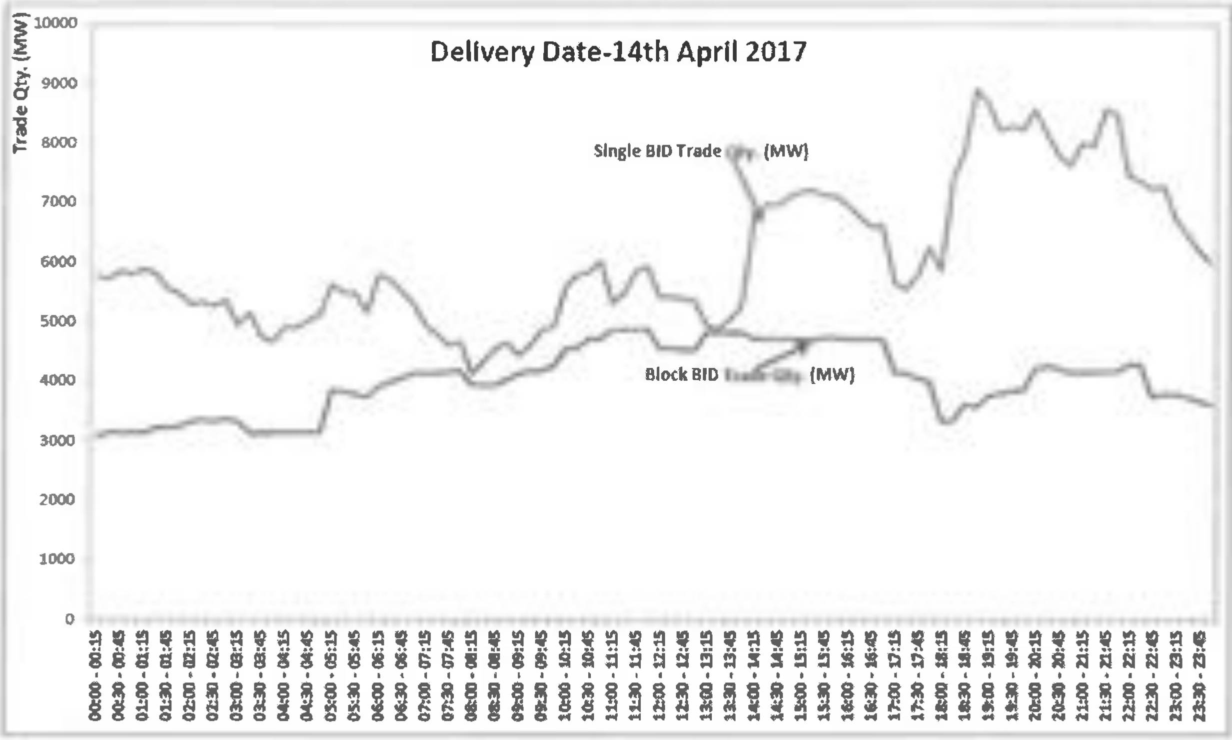
A. 3 Days Status Before Launch of Block Bid> 50 MW

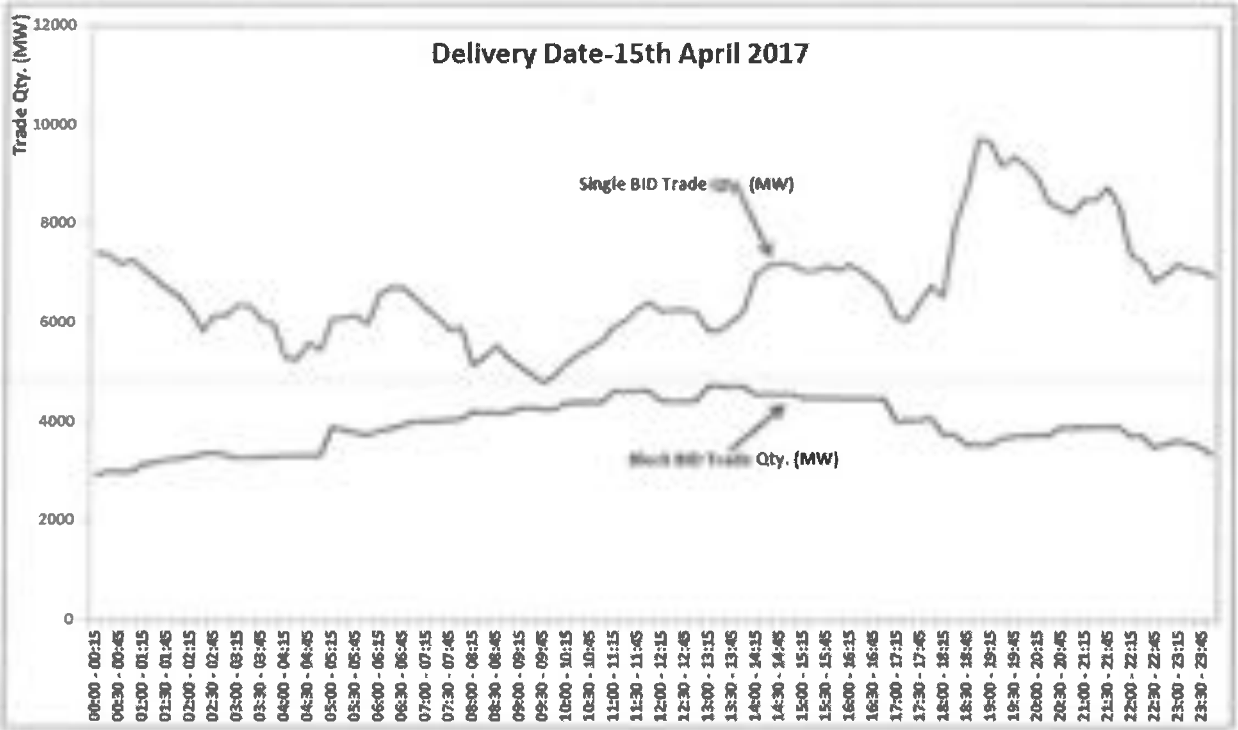




B. **3 Days Status After Launch of Block Bid> 50 MW**




Delivery Date-14th April 2017
Trade Qty. (MW)
Single BID Trade (MW)
Block BID (MW)


Delivery Date-15th April 2017
Trade Qty. (MW)
Single BID Trade (MW)
Qty. (MW)

ANNEXURE 5

Advanced Bid Structures

Dr Rajeev Gajbhiye
Prof S. A. Soman

Department of Electrical Engineering
IIT-Bombay

September 7, 2017

Reason for Introduction of Block Bids

- Encourage participation of generators with high startup and shutdown cost
- Guaranty on volume and operation over consecutive hours allows to bid competitive price
- Consider a generator with marginal cost of 5 per unit and fixed cost of 200, maximum volume of 50
  - Operation over single hour and full volume leads to price of $(200 + 50 \times 5)/50 = 9$
  - Operation over four consecutive hours and full volume leads to price of $(200 + 50 \times 5 \times 4)/(5 \times 4) = 6$

Problems with Block Bids

- Possibility of paradoxically rejection, especially during liquidity crunch
- Reducing volume increases bid price
- Volume rigidity is a problem

Flexible Structures I

- Allow volume flexibility
- Time flexibility can also be explored
- Minimum income criteria for bid clearing

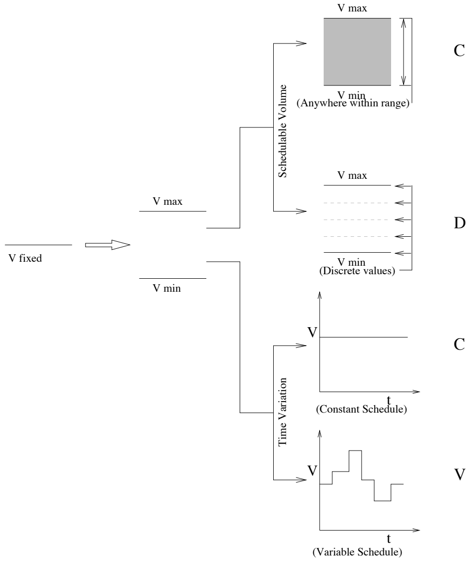


Figure: From fixed volume to flexible range.

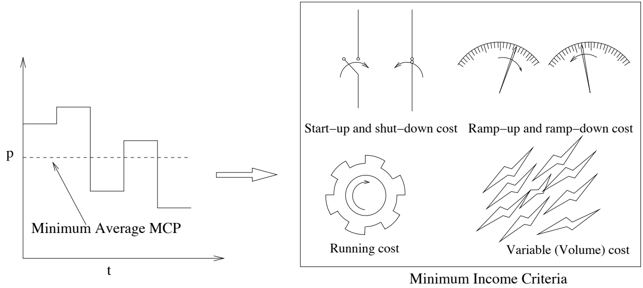


Figure: From minimum average price to minimum income criteria.

MILP Modelling

- Constant Marginal Price
- Stepped Marginal Price with FAK steps
- Stepped Marginal Price with FOK steps

MILP Modelling I

Constant Marginal Price

Specifications:

- Fixed cost to account for startup ($\alpha^{\uparrow}$) and shutdown ($\alpha^{\downarrow}$),
- Fixed running cost (ω), proportional to the time being in service, and,
- Variable cost (β) proportional to amount of power delivered.

MILP Modelling II

Constant Marginal Price

Constant volume operation

- Volume scheduling constraint
  - If a bid is not selected, the scheduled volume $V = 0$,
  - If bid is selected, the $V_{min} \leq V \leq V_{max}$

  This constraint can be modelled as follows:

$$sV_{min} \leq V \leq sV_{max}$$

- Minimum cost recovering constraint
  - If a bid is not selected, there is no cost to be recovered,
  - If a bid is selected with scheduled volume V, the minimum cost to be recovered is

$$\alpha^{\uparrow} + \alpha^{\downarrow} + (h_2 - h_1 + 1)\,\omega + (h_2 - h_1 + 1)\beta V$$

$$V \sum_{h=h_1}^{h_2} \pi_h^p \geq s(\alpha^{\uparrow} + \alpha^{\downarrow}) + s(h_2 - h_1 + 1)\,\omega + (h_2 - h_1 + 1)\beta V$$

MILP Modelling I

Variable Volume Schedule

- $V_h \in \mathcal{R}^+$ as a scheduled volume variable for each time slot $h \in \{h_1, h_1+1, \cdots, h_2\}$
- Slight modification over previous model

$$sV_{min} \leq V_h \leq sV_{max} \quad \forall h \in \{h_1, h_1+1, \cdots, h_2\}$$

$$\sum_{h=h_1}^{h_2} \pi_h^p V_h \geq s(\alpha^{\uparrow} + \alpha^{\downarrow}) + s(h_2 - h_1 + 1)\,\omega + \beta \sum_{h=h_1}^{h_2} V_h$$

MILP Modelling I

Stepped Marginal Cost (FAK Steps)

Specifications:

Fixed Cost			Volume	
Start Up	Shut Down	Running	Minimum	Maximum
$\alpha^{\uparrow}$	$\alpha^{\downarrow}$	ω	V_{min}	V_{max}

Price	β_1	β_2	....	β_m
Volume	V_1^b	V_2^b	....	V_m^b

Also, $\beta_1 < \beta_2 < \ldots < \beta_m$.

MILP Modelling II

Stepped Marginal Cost (FAK Steps)

Constant volume operation

- $V_i \in \mathcal{R}^+$ variable volume scheduled for each price step, i.e, $i \in \{1, 2, \cdots, m\}$.
- $V \in \mathcal{R}^+$ net volume scheduled.
- $s_i \in \mathcal{B}$ selection of i^{th} bid step.
- $s \in \mathcal{B}$ overall selection of bid, whether full or partial.

MILP Modelling III

Stepped Marginal Cost (FAK Steps)

- Volume scheduling constraint
  - Volume range

$$sV_{min} \leq V \leq sV_{max}$$

  - Scheduled volume sum of all steps' volume scheduled

$$V = \sum_{i=1}^{m} V_i$$

  - Step volume range

$$0 \leq V_i \leq s_i V_i^b, \quad \forall i \in \{1, 2, 3, \ldots, m\}$$

  - Eligibility of higher step

$$s_i \leq \frac{V_{i-1}}{V_{i-1}^b}, \quad \forall i \in \{2, 3, \ldots, m\}$$

  - Relation between bid selection and lowest step selection

$$s = s_1$$

MILP Modelling IV

Stepped Marginal Cost (FAK Steps)

- Minimum cost recovery constraint

$$V \sum_{h=h_1}^{h_2} \pi_h^p \geq s(\alpha^{\uparrow} + \alpha^{\downarrow}) + s(h_2 - h_1 + 1)\,\omega + (h_2 - h_1 + 1) \sum_{i=1}^{m} \beta_i V_i$$

MILP Modelling V

Stepped Marginal Cost (FAK Steps)

Variable volume operation

$$sV_{min} \leq V_h \leq sV_{max}$$

$$V_h = \sum_{i=1}^{m} V_i^h$$

$$0 \leq V_i^h \leq s_i^h V_i^b$$

$$s_i^h \leq s_{i-1}^h, \quad \forall i \in \{2, 3, \ldots, m\}$$

$$s = s_1^h$$

$$\sum_{h=h_1}^{h_2} \pi_h^p V_h \geq s(\alpha^{\uparrow} + \alpha^{\downarrow}) + s(h_2 - h_1 + 1)\,\omega + \sum_{h=h_1}^{h_2} \sum_{i=1}^{m} \beta_i V_i^h$$

MILP Modelling I

Stepped Marginal Cost (FOK Steps)

Constant volume operation

- $V_i \in \mathcal{R}^+$ volume variable scheduled for each price step, i.e, $i \in \{1, 2, \cdots, m\}$.
- $V \in \mathcal{R}^+$ net volume scheduled.
- $s_i \in \mathcal{B}$ selection of i^{th} bid step.
- $s \in \mathcal{B}$ overall selection of bid, whether full or partial.
- $\zeta_i \in \mathcal{R}^+$ value obtained from the market through step, i.e, $i \in \{1, 2, \cdots, m\}$.

MILP Modelling II

Stepped Marginal Cost (FOK Steps)

- Volume scheduling constraint
  - Net volume range

$$sV_{min} \leq V \leq sV_{max}$$

  - Scheduled volume sum of individial step's schedule

$$V = \sum_{i=1}^{m} V_i$$

  - Step volume range

$$V_i = s_i V_i^b$$

  - Eligibility of higher steps

$$s_i \leq s_{i-1} \quad \forall i \in \{2, 3, \dots, m\}$$

  - Bid selection implies lowest step being selected

$$s = s_1$$

MILP Modelling III

Stepped Marginal Cost (FOK Steps)

- Minimum cost recovering constraint
  - Value earned

$$0 \leq \zeta_i \leq s_i M$$

$$-(1-s_i)\mathbf{M} \leq \zeta_i - V_i^b \sum_{h=h_1}^{h_2} \pi_h^p \leq (1-s_i)\mathbf{M}$$

  - Minimum income criteria

$$\sum_{i=1}^{m} \zeta_i \geq s(\alpha^{\uparrow} + \alpha^{\downarrow}) + s(h_2 - h_1 + 1)\,\omega + (h_2 - h_1 + 1)\sum_{i=1}^{m} \beta_i V_i$$

MILP Modelling IV

Stepped Marginal Cost (FOK Steps)

Variable volume operation

- $V_i^h \in \mathcal{R}^+$ volume scheduled for each price step and each time slot,
- $V_h \in \mathcal{R}^+$ net volume scheduled, for h^{th} time slot,
- $s_i^h \in \mathcal{B}$ selection of i^{th} bid step,
- $s \in \mathcal{B}$ overall selection of bid, whether full or partial, and,
- $\zeta_i^h \in \mathcal{R}^+$ value obtained for i^{th} step in h^{th} hour.

MILP Modelling V

Stepped Marginal Cost (FOK Steps)

Constraints

$$sV_{min} \leq V_h \leq sV_{max}$$

$$V_h = \sum_{i=1}^{m} V_i^h$$

$$V_i^h = s_i^h V_i^b$$

$$s_i^h \leq s_{i-1}^h, \quad \forall i \in \{2, 3, \ldots, m\}$$

$$s = s_1^h$$

$$0 \leq \zeta_i^h \leq s_i^h M$$

$$-(1 - s_i^h)\mathbf{M} \leq \zeta_i^h - V_i^h \pi_h^p \leq (1 - s_i^h)\mathbf{M}$$

$$\sum_{h=h_1}^{h_2} \sum_{i=1}^{m} \zeta_i^h \geq s(\alpha^{\uparrow} + \alpha^{\downarrow}) + s(h_2 - h_1 + 1)\,\omega + \sum_{h=h_1}^{h_2} \sum_{i=1}^{m} \beta_i V_i^h$$

MILP Modelling I

Accounting for Ramping Cost

Assumption: Ramping cost proportional to change in volume

$$C_{ramp} = \gamma^{\uparrow}(V_h - V_{h-1}) \quad \text{if } V_i \geq V_{i-1}$$
$$C_{ramp} = \gamma^{\downarrow}(V_{h-1} - V_h) \quad \text{if } V_{i-1} \geq V_i$$

MILP Modelling II

Accounting for Ramping Cost

Constant volume operation

- Term $(\gamma^{\uparrow} + \gamma^{\downarrow})V$ has to be added to the expression representing minimum cost to be recovered
- For example, under fixed marginal cost

$$V \sum_{h=h_1}^{h_2} \pi_h^p \geq s(\alpha^{\uparrow} + \alpha^{\downarrow}) + s(h_2 - h_1 + 1)\,\omega + (h_2 - h_1 + 1)\beta V + (\gamma^{\uparrow} + \gamma^{\downarrow})V$$

MILP Modelling III

Accounting for Ramping Cost

Variable volume operation

- Introduce C_h^{ramp} as cost of ramping from time slot $h-1$ to h
- Ramping costs for each transition

$$C_h^{ramp} \geq \gamma^{\uparrow}(V_h - V_{h-1}) \quad \forall h \in \{h_1+1, h_1+2, \cdots, h_2\}$$
$$C_h^{ramp} \geq \gamma^{\downarrow}(V_{h-1} - V_h) \quad \forall h \in \{h_1+1, h_1+1, \cdots, h_2\}$$
$$C_{h_1}^{ramp} = \gamma^{\uparrow}\, V_{h_1}$$
$$C_{h_2+1}^{ramp} = \gamma^{\downarrow}\, V_{h_2}$$

- Add to minimum income expression; in case of fixed marginal cost model

$$\sum_{h=h_1}^{h_2} \pi_h^p V_h \geq s(\alpha^{\uparrow} + \alpha^{\downarrow}) + s(h_2 - h_1 + 1)\,\omega + \beta \sum_{h=h_1}^{h_2} V_h + \sum_{h=h_1}^{h_2+1} C_h^{ramp}$$

MILP Modelling I

Multiple Start up and Shutdown

Variables

- s_h to model switching in each time slot
- $s_h^{\uparrow}$ and $s_h^{\downarrow}$ to model switch transition in that time slot

Detection of switching

- In each time slot h, the generator might be maintaining its previous state or it may switch from off to on or on to off

$$s_h^{\uparrow} + s_h^{\downarrow} \leq 1$$

- Switch transition from off to on

$$s_h^{\uparrow} \geq s_h - s_{h-1}$$

- Switch transition on to off

$$s_h^{\downarrow} \geq s_{h-1} - s_h$$

MILP Modelling II

Multiple Start up and Shutdown

- No switch transition

$$s_h^{\uparrow} + s_h^{\downarrow} \leq s_{h-1} + s_h$$
$$s_h^{\uparrow} + s_h^{\downarrow} \leq 2 - s_{h-1} - s_h$$

- Initial and final switch state is off

$$s_{h_1-1} = s_{h_2+1} = 0$$

MILP Modelling III

Multiple Start up and Shutdown

Contribution to minimum cost

- Replace expression for fixed cost, $s(\alpha^{\uparrow} + \alpha^{\downarrow})$, by

$$\alpha^{\uparrow} \sum_{h=h_1}^{h_2} s_h^{\uparrow} + \alpha^{\downarrow} \sum_{h=h_1}^{h_2} s_h^{\downarrow}$$

- Replace fixed running cost, $s(h_2 - h_1 + 1)\,\omega$, by

$$\omega \sum_{h=h_1}^{h_2} s_h$$

MILP Modelling I

Linear Approximation of Quadratic Term

- Discretize volume with resolution of ΔV
- Volume representation

$$V = S_s V^{min} + \sum_{g=1}^{m} s_g 2^{g-1} \Delta V$$

- Income criteria from first block of V^{min}

$$-(1 - S_s)M \leq C_s^0 - V^{min} \sum_{h=h_1}^{h_2} MCP(h) \leq (1 - S_s)M$$

$$-S_s M \leq C_s^0 \leq S_s M$$

MILP Modelling II

Linear Approximation of Quadratic Term

- Income criteria through each delta block

$$-(1-s_g)M \le C_s^g - (2^{g-1})\Delta V \sum_{h=h_1}^{h_2} MCP(h) \le (1-s_g)M$$

$$-s_g M \le C_s^g \le s_g M$$

- Any of these delta blocks is eligible for selection only if a main block has been selected

$$s_g \le S_s$$

- Net income

$$C_s = \sum_{g=0}^{n} C_s^g$$

Case Studies I

Small Scale

Base Case: Normal Block Bids

	Buy		Sell		Block Sell	
Hr	Price	Volume	Price	Volume	Price	Volume
1	700	100	350	50	300	100
	600	150	380	150		
	550	200	—	—		
2	700	100	200	50		
	600	200	210	150		
	550	200	—	—		

Case Studies II

Small Scale

- The block bid is unable to be cleared,
- Both selling and buying bids clear at 150 volume for both hours,
- MCP for first hour comes out to be 575 and for second it is 600, and,
- Total traded volume is 300 with a net social welfare of 113500.

Case Studies III

Small Scale

Case I: Stepped Block Bid for Flexibility

- $\alpha^{\uparrow} = 20,000$, $\alpha^{\downarrow} = 20,000$
- $\beta = 100$
- Leads to minimum average price of 300
- Let operation possible at volume levels 50 and 100

Results

- Block bid is able to be scheduled for a total of 50 units of volume,
- Buy bid is scheduled to 200 in both hours and hourly selling bids to 150,
- MCP for the first hour comes out to be 475, while for second it is observed to be 600, and,
- Total traded volume in this case is 400 and net social welfare 121000.

Case Studies IV

Small Scale

Case II: Variable Schedule for Block Bid

- Able to sell the complete 100 unit in first hour
- In second hour 50 units is scheduled
- MCPs: 380 and 470
- Social welfare: 135000

Case Studies V

Small Scale

Case II: More Competition

- Hourly seller drops price for hour 1
  - Only one step of price 300 and volume 150
- In hour 2, one more level of bidding: 200 units of volume at a price of 350

Results

- Block bid unable to trade
- Social welfare: 136500
- Traded volume: 350

Case Studies VI

Small Scale

Case III: Block Bid More Competitive

- Marginal price of 50 for first 50 units of volume
- Marginal price remains 100 for delivering 100 units of volume

Results

- Block bid clears 50 units of volume in both hours
- Social welfare: 136500
- Traded volume: 400

Case Studies I

Performance on Large Scale

Test Cases

- Random generation of test cases
- Total number of hourly bid steps between 200 to 10000
- Advanced bids between 20 to 1000
- Advanced bid can have steps from 1 to 10
- Study over 20 cases

Termination Criteria

- Maximum computation time of 1 hour, and,
- Proximity to optimal solution within 0.01%.

Case Studies II

Performance on Large Scale

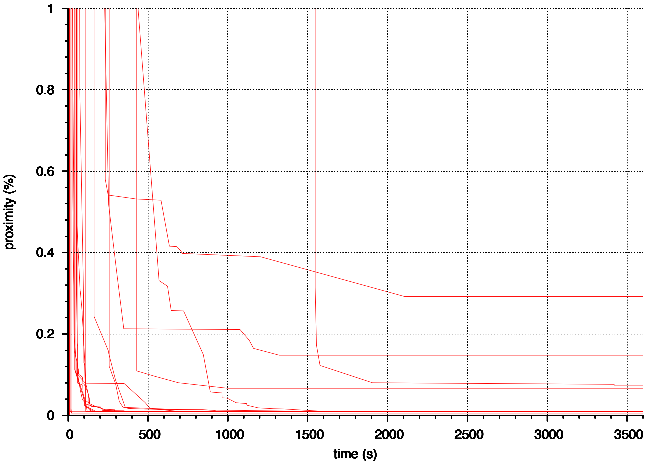


Figure: Convergence profile over various test cases.

Conclusions

- New flexible bid structures proposed as alternative to block bids
- Segregate cost components like startup, shutdown, running, ramping and marginal
- Allows block bidders to be even more competitive and probability of PRB comes down
- Large scale studies demonstrate practical feasibility

Thank You

Introduction to Power Exchange

Dr. Rajeev Gajbhiye
Prof. S. A. Soman

Department of Electrical Engineering
Indian Institute of Technology Bombay

July 13, 2017

Outline

Introduction

- 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.
- 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).

Power Exchange Products

- Day Ahead Market
- Term Ahead Market
- Renewable Energy Certificates Trading

Power Exchange Products

- Day Ahead Market
  - Collective transactions
  - Type of bids: Hourly, Block
  - Inter-regional trading
- Term Ahead Market
- Renewable Energy Certificates Trading

Power Exchange Products

- Day Ahead Market
- Term Ahead Market
  - Bilateral Transactions
  - Regional market
  - Market types
    - Day ahead contingency market: single hourly bids
    - Intra- day market
    - Daily contracts: Base (24 hrs), Night off-peak (8 hrs), day (11 hrs) and Day peak (5 hrs) contracts
    - Weekly contracts: Base (7x24 hrs), Night off-peak (7x8 hrs), day (7x11 hrs) and Day peak (7x5 hrs) contracts
- Renewable Energy Certificates Trading

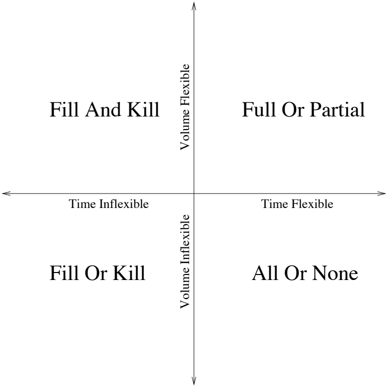
Power Exchange Products

- Day Ahead Market
- Term Ahead Market
- Renewable Energy Certificates Trading
  - Solar and Non-solar certificates
  - Green Attributes of 1MWh of electricity generated by eligible Renewable Generator allowed in CERC (Terms and Conditions for recognition and issuance of Renewable Energy Certificate for Renewable Energy Generation) Regulations, 2010

Power Exchange Products

- Day Ahead Market
- Term Ahead Market
- Renewable Energy Certificates Trading

Bid Order Types



Bid Structures Offered in Market

Hourly Bid

Hourly Bid: Trader has to mention

- Time of deliver, and,
- Maximum amount deliverable/consumable at various price levels (step function)

Properties:

- Selected volume can lie anywhere between 0 to maximum limit
- Form of FAK
- In case of seller, increasing price leads to delivery of more volume.
- In contrast buyer reduces his willingness to consume power with increase in price.
- Example:

Price	50	100	200	300	400
Offer (Actual)	100	150	180	180	200
Offer (Transformed)	100	50	30	0	20

Block Bid: Trader specifies

- Block of time for which volume will be delivered/consumed,
- Fixed volume for trade, and,
- Average limit price

Properties:

- Bid if selected will deliver/consume constant volume for continuously for specified block
- Bid might be under loss in one particular time slot, but may make enough profit to compensate in other time slot
- Form of FOK

Bid Structures Offered in Market

Linked Block Bid

Linked Block Bid Trader specifies

- All specifications as required by block bid, and,
- Block bid on acceptance of which only this bid can be considered for auction.

Bid Structures Offered in Market

Flexible Hourly Bid

Flexible Hourly Bid Trader specifies

- Fixed volume that can be delivered/consumed, and,
- Limit price

Properties:

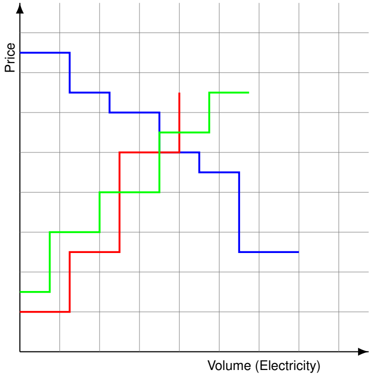
- Bid is considered for schedule in a time slot which has maximum/minimum MCP
- Might be rejected if best MCP over the day doesn't meet requirement of limit price
- Form of All-Or-None, though not purely

Market Clearing

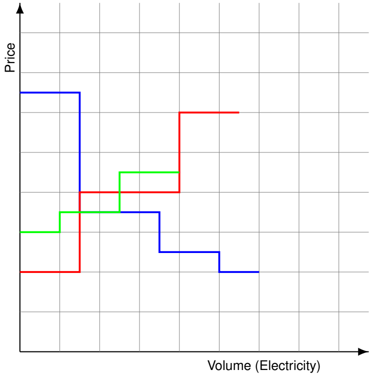
Hourly Bids

- Scheduling for each hour is decoupled of any other time slot
- Equilibrium at the intersection of buyer and seller curves; defines market clearing price (MCP) and market clearing volume (MCV)
  - Arrived schedule ensures that at MCP, each of the traders has maximized its surplus
- Also leads to maximization of social welfare (Consumer Surplus + Supplier Surplus)

Market Equilibrium: Graphical Visualization

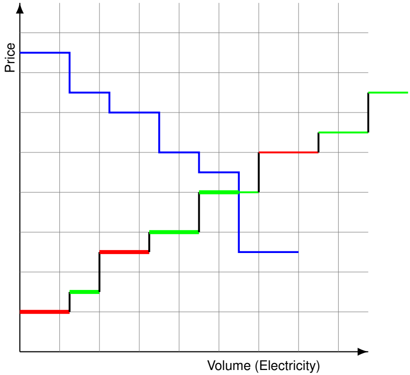


Hour 1

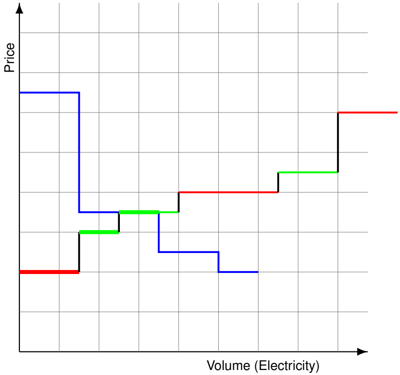


Hour 2

Market Equilibrium: Graphical Visualization

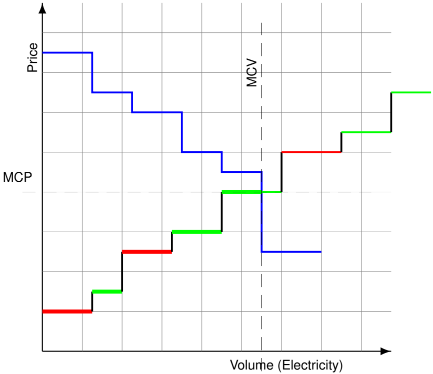


Hour 1

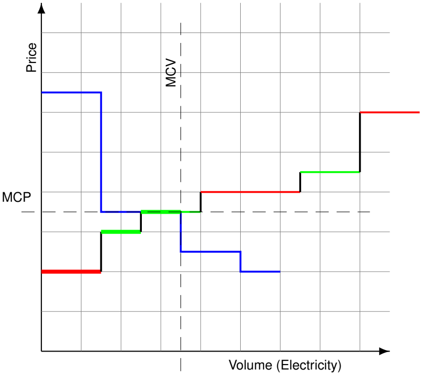


Hour 2

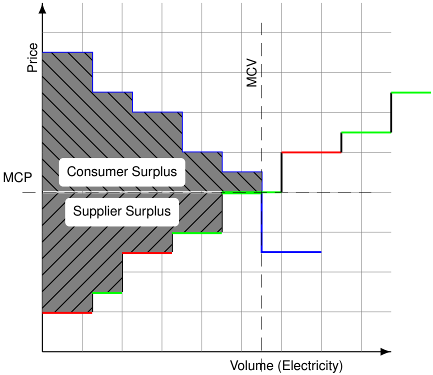
Market Equilibrium: Graphical Visualization



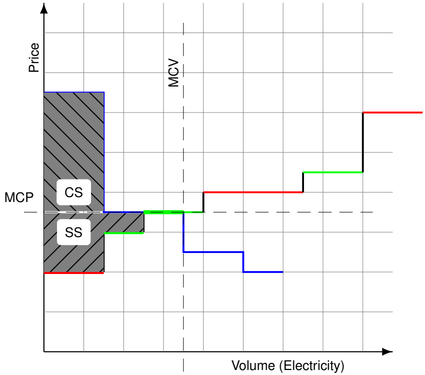
Hour 1



Hour 2

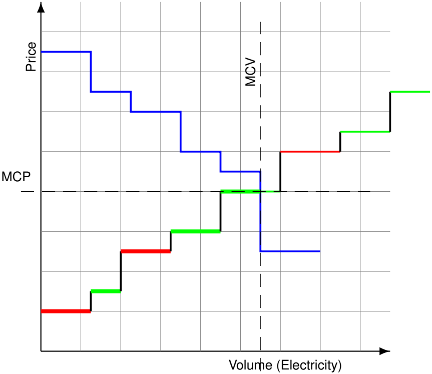

Price
MCV
MCP
Consumer Surplus
Supplier Surplus
Volume (Electricity)

Hour 1

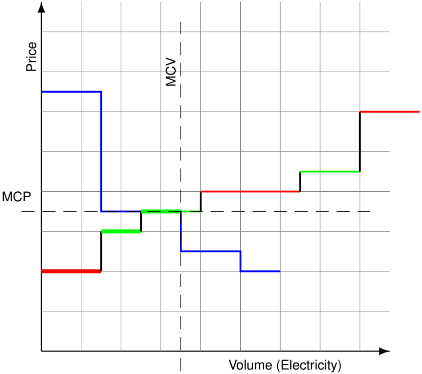

Price
MCV
MCP
CS
SS
Volume (Electricity)

Hour 2

Market Equilibrium: Graphical Visualization

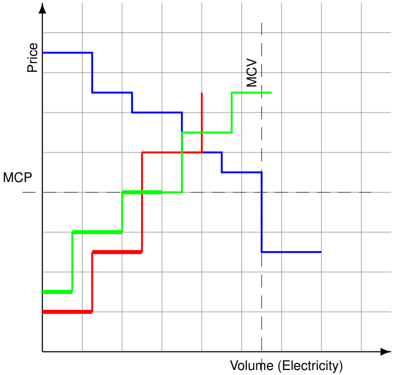


Hour 1

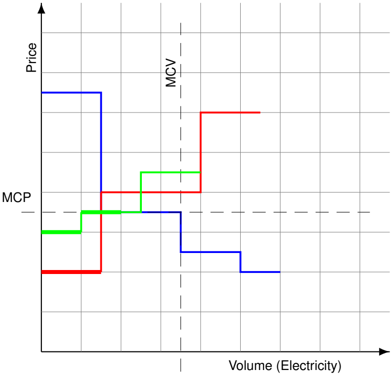


Hour 2

Market Equilibrium: Graphical Visualization

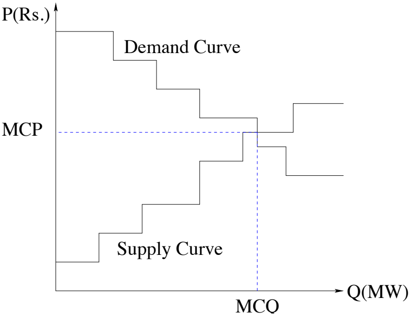


Hour 1

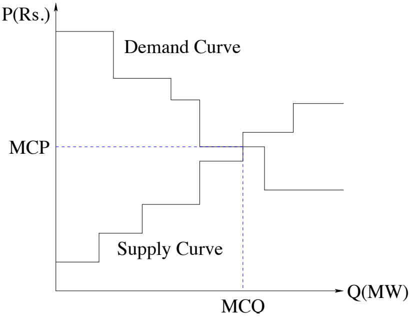


Hour 2

Different Possible Intersections

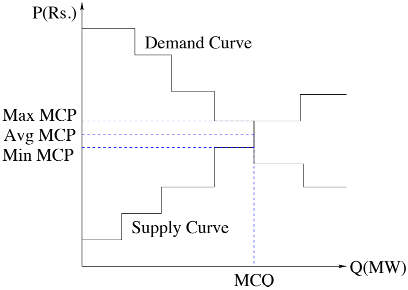


(a) Case 1: Single equilibrium point

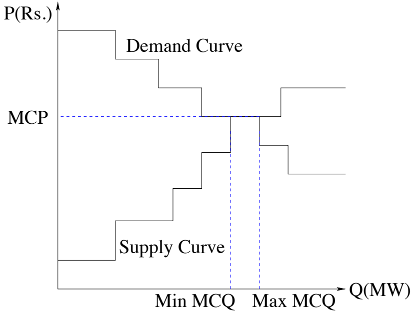


(b) Case 2: Single equilibrium point

Different Possible Intersections (cont.)



(c) Case 3: Multiple MCP



(d) Case 4: Multiple MCQ

Piecewise Linear Curves

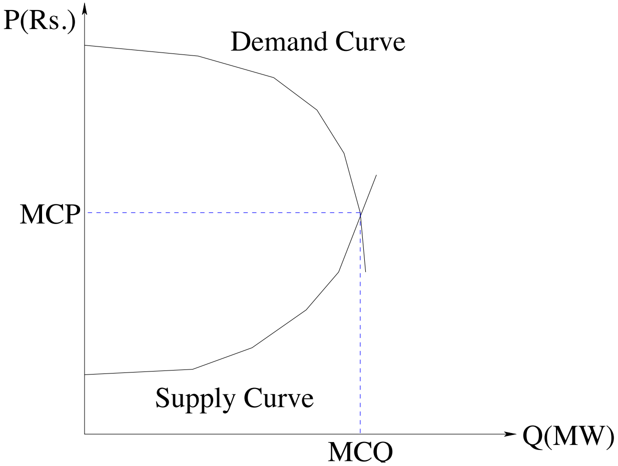
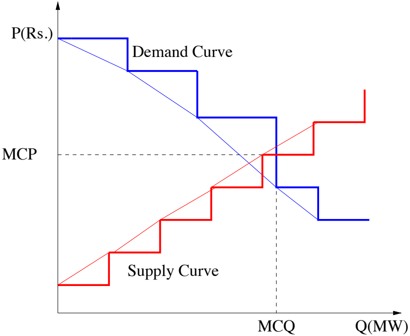
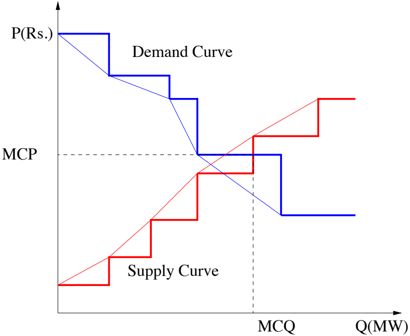


Figure: Piecewise linear curve

Social Welfare in Stepwise and Piecewise Linear Curves

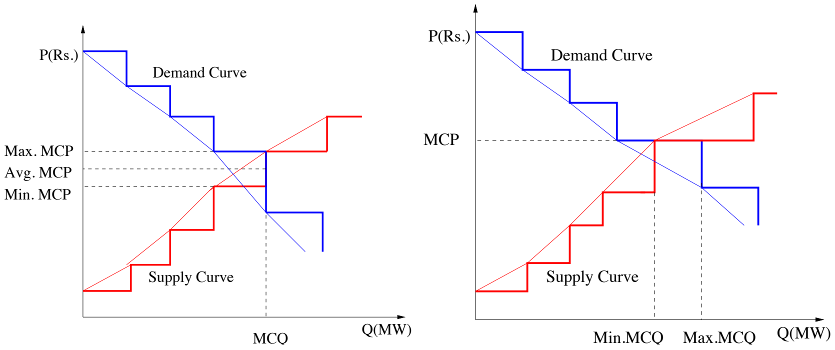


(a) Case1: Single equilibrium point



(b) Case2: Single equilibrium point

Social Welfare in Stepwise and Piecewise Linear Curves (cont.)



(c) Case3: Multiple MCP

(d) Case4: Multiple MCQ

Clearing as Optimization Problem
Hourly Bids

- Each hourly market can be solved independently
- Simple linear programming (LP) framework suffices
- Objective is to maximize social welfare
- Subject to following constraints
  - Any bid to be scheduled within its limit
  - Supply matches demand

Clearing as Optimization Problem (cont.)

Hourly Bids

To formulate mathematically, we first introduce following notations for each j^{th} sell bid from i^{th} supplier

- $\mathbf{V}^{\text{max}}_{\mathbf{s}(\mathbf{i},\mathbf{j})}$ as maximum power that can be supplied
- $\mathbf{p}^{\mathbf{step}}_{\mathbf{s}(\mathbf{i},\mathbf{j})}$ as bid price
- $V^{\text{sch}}_{s(i,j)}$ as power scheduled to be supplied

Similar notations are introduced for demand bids

Finally, we have following LP problem to solve

$$\begin{aligned} \max \quad & \sum_{\langle i,j\rangle \in \mathcal{D}_h^H} V_{b(i,j)}^{\text{sch}} \mathbf{p}_{\mathbf{b(i,j)}}^{\mathbf{step}} - \sum_{\langle i,j\rangle \in \mathcal{S}_h^H} V_{s(i,j)}^{\text{sch}} \mathbf{p}_{\mathbf{s(i,j)}}^{\mathbf{step}} \\ s.t. \quad & 0 \leq V_{s(i,j)}^{\text{sch}} \leq \mathbf{V}_{\mathbf{s(i,j)}}^{\max} \quad \forall \langle \mathrm{i,j} \rangle \in \mathcal{S}_h^H \\ & 0 \leq V_{b(i,j)}^{\text{sch}} \leq \mathbf{V}_{\mathbf{b(i,j)}}^{\max} \quad \forall \langle i,j \rangle \in \mathcal{D}_h^H \\ & \sum_{\langle i,j\rangle \in \mathcal{D}_h^H} V_{b(i,j)}^{\text{sch}} = \sum_{\langle i,j\rangle \in \mathcal{S}_h^H} V_{s(i,j)}^{\text{sch}} \end{aligned}$$

Note: Network is not modeled in the above formulation.

Lagrangian Function for Hourly Bid Matching

$$\begin{aligned}\mathcal{L}(V^{\text{sch}}_{b(i,j)}, V^{\text{sch}}_{s(i,j)}, \lambda_h, \overline{\mu}_h, \underline{\mu}_h) = &- \left(\sum_{\langle i,j\rangle \in \mathcal{D}^H_h} \mathbf{p}^{\mathbf{step}}_{\mathbf{b(i,j)}} V^{\text{sch}}_{b(i,j)} - \sum_{\langle i,j\rangle \in \mathcal{S}^H_h} \mathbf{p}^{\mathbf{step}}_{\mathbf{s(i,j)}} V^{\text{sch}}_{s(i,j)} \right) \\ &+ \lambda_h \left(\sum_{\langle i,j\rangle \in \mathcal{D}^H_h} V^{\text{sch}}_{b(i,j)} - \sum_{\langle i,j\rangle \in \mathcal{S}^H_h} V^{\text{sch}}_{s(i,j)} \right) \\ &+ \overline{\mu}^{b(i,j)}_h (V^{\text{sch}}_{b(i,j)} - \mathbf{V}^{\text{max}}_{\mathbf{b(i,j)}}) - \underline{\mu}^{b(i,j)}_h V^{\text{sch}}_{b(i,j)} \\ &+ \overline{\mu}^{s(i,j)}_h (V^{\text{sch}}_{s(i,j)} - \mathbf{V}^{\text{max}}_{\mathbf{s(i,j)}}) - \underline{\mu}^{s(i,j)}_h V^{\text{sch}}_{s(i,j)}\end{aligned}$$

Lagrangian Function for Hourly Bid Matching

Set gradient of the above Lagrangian function zero

$$\nabla \mathcal{L}(V^{\text{sch}}_{b(i,j)}, V^{\text{sch}}_{s(i,j)}, \lambda_h, \overline{\mu}_h, \underline{\mu}_h) = 0$$

$$\Rightarrow \frac{\partial \mathcal{L}}{\partial V^{\text{sch}}_{b(i,j)}} = -\mathbf{p}^{\mathbf{step}}_{\mathbf{b(i,j)}} + \lambda_h + \overline{\mu}_h^{b(i,j)} - \underline{\mu}_h^{b(i,j)} = 0$$

$$\text{and} \frac{\partial \mathcal{L}}{\partial V^{\text{sch}}_{s(i,j)}} = \mathbf{p}^{\mathbf{step}}_{\mathbf{s(i,j)}} - \lambda_h + \overline{\mu}_h^{s(i,j)} - \underline{\mu}_h^{s(i,j)} = 0$$

- For a bid with no schedule, $\overline{\mu}_h^{b(i,j)} = 0$ and hence, $\lambda_h \geq P_{dj}$
- For a bid with complete schedule, $\underline{\mu}_h^{b(i,j)} = 0$ and hence, $\lambda_h \leq P_{dj}$
- For a bid with partial schedule, $\underline{\mu_j} = \overline{\mu_j} = 0$ and hence, $\lambda_h = P_{dj}$

Lagrangian Function for Hourly Bid Matching

Set gradient of the above Lagrangian function zero

$$\nabla\mathcal{L}(V^{\text{sch}}_{b(i,j)}, V^{\text{sch}}_{s(i,j)}, \lambda_h, \overline{\mu}_h, \underline{\mu}_h) = 0$$

$$\Rightarrow \frac{\partial\mathcal{L}}{\partial V^{\text{sch}}_{b(i,j)}} = -\mathbf{p}^{\textbf{step}}_{\mathbf{b(i,j)}} + \lambda_h + \overline{\mu}_h^{b(i,j)} - \underline{\mu}_h^{b(i,j)} = 0$$

$$\text{and} \frac{\partial\mathcal{L}}{\partial V^{\text{sch}}_{s(i,j)}} = \mathbf{p}^{\textbf{step}}_{\mathbf{s(i,j)}} - \lambda_h + \overline{\mu}_h^{s(i,j)} - \underline{\mu}_h^{s(i,j)} = 0$$

- For a bid with no schedule, $\overline{\mu}_h^{b(i,j)} = 0$ and hence, $\lambda_h \geq P_{dj}$
- For a bid with complete schedule, $\underline{\mu}_h^{b(i,j)} = 0$ and hence, $\lambda_h \leq P_{dj}$
- For a bid with partial schedule, $\underline{\mu_j} = \overline{\mu_j} = 0$ and hence, $\lambda_h = P_{dj}$

λ_h is MCP for h^{th} hour

Market Splitting

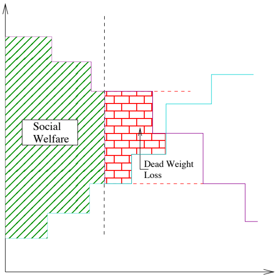


Figure: Social welfare and Dead weight loss in case of inter-regional congestion

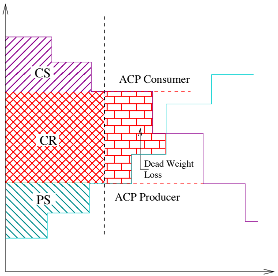


Figure: Congestion Rent

An Example of Market Splitting

Price	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
North												
Demand	7500	6500	6000	4500	4000	3600	3100	2700	2200	1800	1500	1000
Supply	0	0	1000	1800	2000	2600	2800	3000	3200	3200	3300	3400
West												
Demand	8000	7000	6000	5500	4500	4200	3800	3500	3000	2500	2000	1500
Supply	0	0	1200	1500	1800	1900	1900	2000	2100	2100	2400	2400
South												
Demand	3000	2800	2500	2500	2400	2200	2000	1500	1000	500	0	0
Supply	0	1000	1500	1600	1800	2000	2300	2300	2600	2800	2800	3000
East												
Demand	2400	2400	2200	2000	1600	1400	900	500	0	0	0	0
Supply	0	2000	2400	2600	2800	3000	3400	3700	3800	4000	4500	4500
North-East												
Demand	1300	1200	1000	600	400	100	0	0	0	0	0	0
Supply	0	2400	2800	3000	3500	3500	4000	4500	5000	5500	5500	5500

An Example of Market Splitting (cont.)

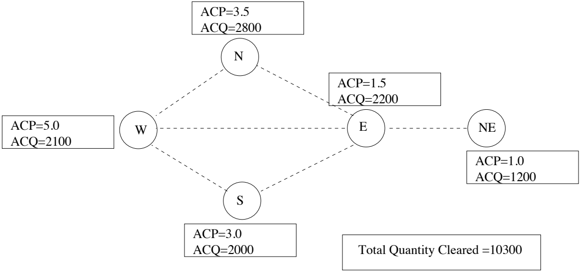


Figure: No inter-connection between zones

An Example of Market Splitting (cont.)

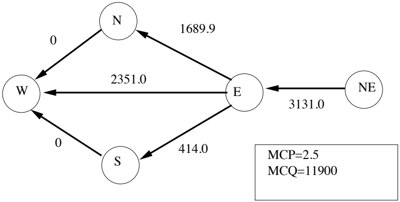


Figure: Flows with no capacity constraints on inter-connections

An Example of Market Splitting (cont.)

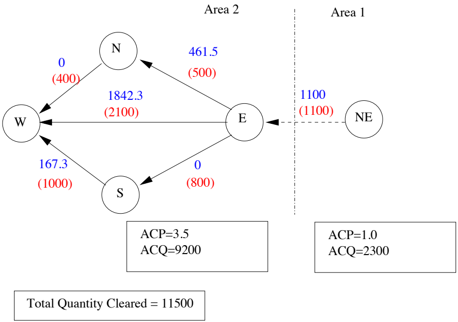


Figure: Market Splitting into two parts

Need of Block Bids

- Encourages participation of generators with high start-up and shut-down cost, typically thermal ones.
- Allows putting competitive price while recovering fixed cost

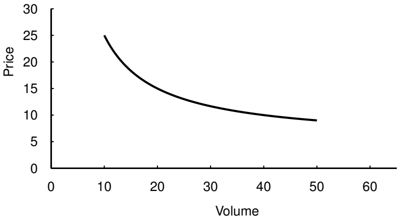
Example

- Consider a generator with cost of 5 per unit of power delivered
- Startup and shutdown cost of 200
- Can schedule maximum of 50 units of volume

Example (cont.)

No Block Bidding Facility:

- Full volume scheduled at least at price 9 to recover sunk cost
- Lower schedule of volume means even higher price



Example (cont.)

Block Bid to the Rescue:

- Bids for 4 contiguous hours
- Fixed cost recovery spread over multiple hours and large volume
- Bidding price becomes more competitive

$$\frac{200 + 4 \times 5 \times 50}{4 \times 50} = 6$$

Problems with Block Bids

- Discrete problem: Schedule full volume or none
- Consequently, scheduling becomes NP-Hard
  - Enumeration is the only known way to solve problem exactly.
- No equilibrium price may exist

Problems with Block Bids

- Discrete problem: Schedule full volume or none
- Consequently, scheduling becomes NP-Hard
  - Enumeration is the only known way to solve problem exactly.
- No equilibrium price may exist

Non Existence of Equilibrium Price: An Example

Suppose following bids/offers are received:

1. Normal bid to buy power up to 100 units of power at price of 7 monetary units (MUs),
2. Normal offer to sell power up to 50 units of power at price of 3.5 MUs,
3. Normal offer to sell power up to 25 units of power at price of 4.0 MUs, and,
4. Block offer to sell 50 units of power at 4.5 MUs,

Non Existence of Equilibrium Price: An Example

Suppose following bids/offers are received:

1. Normal bid to buy power up to 100 units of power at price of 7 monetary units (MUs),
2. Normal offer to sell power up to 50 units of power at price of 3.5 MUs,
3. Normal offer to sell power up to 25 units of power at price of 4.0 MUs, and,
4. Block offer to sell 50 units of power at 4.5 MUs,

MCP > 7 No buyer, while all sellers willing to supply

Non Existence of Equilibrium Price: An Example

Suppose following bids/offers are received:

1. Normal bid to buy power up to 100 units of power at price of 7 monetary units (MUs),
2. Normal offer to sell power up to 50 units of power at price of 3.5 MUs,
3. Normal offer to sell power up to 25 units of power at price of 4.0 MUs, and,
4. Block offer to sell 50 units of power at 4.5 MUs,

$4.5 < \text{MCP} \leq 7$ All offers have to be scheduled

- Total supply of 125
- Maximum possible consumption of 100

Non Existence of Equilibrium Price: An Example

Suppose following bids/offers are received:

1. Normal bid to buy power up to 100 units of power at price of 7 monetary units (MUs),
2. Normal offer to sell power up to 50 units of power at price of 3.5 MUs,
3. Normal offer to sell power up to 25 units of power at price of 4.0 MUs, and,
4. Block offer to sell 50 units of power at 4.5 MUs,

$\text{MCP} = 4.5$ Total demand of 100 to be scheduled, supply can be either 75 or 125

Non Existence of Equilibrium Price: An Example

Suppose following bids/offers are received:

1. Normal bid to buy power up to 100 units of power at price of 7 monetary units (MUs),
2. Normal offer to sell power up to 50 units of power at price of 3.5 MUs,
3. Normal offer to sell power up to 25 units of power at price of 4.0 MUs, and,
4. Block offer to sell 50 units of power at 4.5 MUs,

MCP < 4.5 Buy order for 100 units of power will have to be scheduled, while supply will be below or equal to 75

Non Existence of Equilibrium Price: An Example

Suppose following bids/offers are received:

1. Normal bid to buy power up to 100 units of power at price of 7 monetary units (MUs),
2. Normal offer to sell power up to 50 units of power at price of 3.5 MUs,
3. Normal offer to sell power up to 25 units of power at price of 4.0 MUs, and,
4. Block offer to sell 50 units of power at 4.5 MUs,

Hence, no equilibrium price can be declared.

Introducing Notion of PRB as Solution

- Market has to be cleared
- Some bids will have to be forced out of the market
- Bids rejected even after being competitive in terms of price are termed as *Paradoxically Rejected Bids (PRBs)*
- Which all bids to be rejected?

Introducing Notion of PRB as Solution

- Market has to be cleared
- Some bids will have to be forced out of the market
- Bids rejected even after being competitive in terms of price are termed as *Paradoxically Rejected Bids (PRBs)*
- Which all bids to be rejected?

Example of PRB

We revisit earlier example:

Social welfare maximization: Complete selection of buy bid. Hourly offer and block bid at 50 units each. MCP anywhere between 4.5 to 7. Hourly offer at lower price rejected. Social welfare of 300.

+ No hourly bids as PRBs: Schedule hourly bid at 75 units along with both hourly offers. Traded volume of 75 units and social welfare of 250. MCP at 7 MU.

Example of PRB

We revisit earlier example:

Social welfare maximization: Complete selection of buy bid. Hourly offer and block bid at 50 units each. MCP anywhere between 4.5 to 7. Hourly offer at lower price rejected. Social welfare of 300.

+ No hourly bids as PRBs: Schedule hourly bid at 75 units along with both hourly offers. Traded volume of 75 units and social welfare of 250. MCP at 7 MU.

Example of PRB

We revisit earlier example:

Social welfare maximization: Complete selection of buy bid. Hourly offer and block bid at 50 units each. MCP anywhere between 4.5 to 7. Hourly offer at lower price rejected. Social welfare of 300.

+ No hourly bids as PRBs: Schedule hourly bid at 75 units along with both hourly offers. Traded volume of 75 units and social welfare of 250. MCP at 7 MU.

Example of PRB

We revisit earlier example:

Social welfare maximization: Complete selection of buy bid. Hourly offer and block bid at 50 units each. MCP anywhere between 4.5 to 7. Hourly offer at lower price rejected. Social welfare of 300.

+ No hourly bids as PRBs: Schedule hourly bid at 75 units along with both hourly offers. Traded volume of 75 units and social welfare of 250. MCP at 7 MU.

Example of PRB

We revisit earlier example:

Social welfare maximization: Complete selection of buy bid. Hourly offer and block bid at 50 units each. MCP anywhere between 4.5 to 7. Hourly offer at lower price rejected. Social welfare of 300.

+ No hourly bids as PRBs: Schedule hourly bid at 75 units along with both hourly offers. Traded volume of 75 units and social welfare of 250. MCP at 7 MU.

Example of PRB

We revisit earlier example:

Social welfare maximization: Complete selection of buy bid. Hourly offer and block bid at 50 units each. MCP anywhere between 4.5 to 7. Hourly offer at lower price rejected. Social welfare of 300.

+ No hourly bids as PRBs: Schedule hourly bid at 75 units along with both hourly offers. Traded volume of 75 units and social welfare of 250. MCP at 7 MU.

We revisit earlier example:

Social welfare maximization: Complete selection of buy bid. Hourly offer and block bid at 50 units each. MCP anywhere between 4.5 to 7. Hourly offer at lower price rejected. Social welfare of 300.

+ No hourly bids as PRBs: Schedule hourly bid at 75 units along with both hourly offers. Traded volume of 75 units and social welfare of 250. MCP at 7 MU.

Solution Approach: Enumeration

- Considers all possibilities with block bids and solve scheduling problem for each case
- One with maximum welfare is the solution
- With n block bids, we have 2^n scenarios
- As for example with three block bids we have 8 possibilities: $[0, 0, 0]$, $[0, 0, 1]$, $[0, 1, 0]$, $[0, 1, 1]$, $[1, 0, 0]$, $[1, 0, 1]$, $[1, 1, 0]$ and $[1, 1, 1]$
- For 10 block bids 1024 scenarios
- With 20, we have 1048576 cases
- Clearly Impractical!!

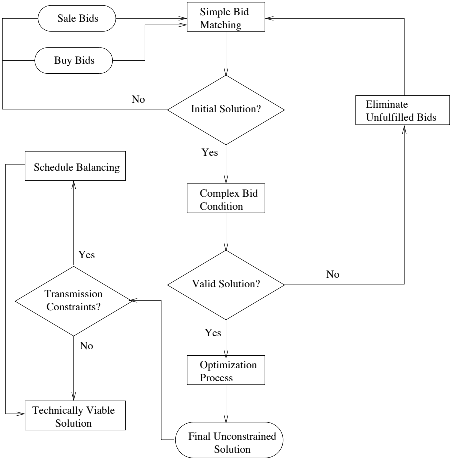
Solution Approach: Enumeration

- Considers all possibilities with block bids and solve scheduling problem for each case
- One with maximum welfare is the solution
- With n block bids, we have 2^n scenarios
- As for example with three block bids we have 8 possibilities: $[0, 0, 0]$, $[0, 0, 1]$, $[0, 1, 0]$, $[0, 1, 1]$, $[1, 0, 0]$, $[1, 0, 1]$, $[1, 1, 0]$ and $[1, 1, 1]$
- For 10 block bids 1024 scenarios
- With 20, we have 1048576 cases
- Clearly Impractical!!

Solution Approach: Heuristic

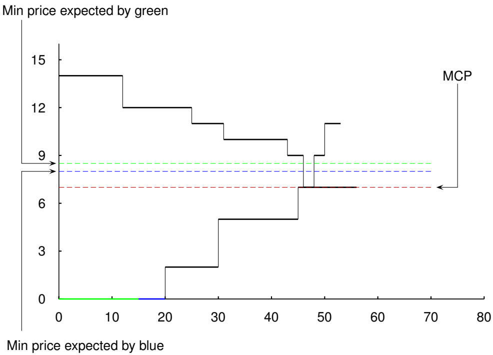
- Follows greedy approach
- Will have either of the following two characteristics
  - Computation time is practically feasible and solution generally not far away from optimal
  - Optimal solution is computed in small time for *most* of the cases; for few cases it may take forever
- Designing good heuristic is a challenge
- Incorporating new condition may lead to development of heuristic from scratch

Example of Heuristic



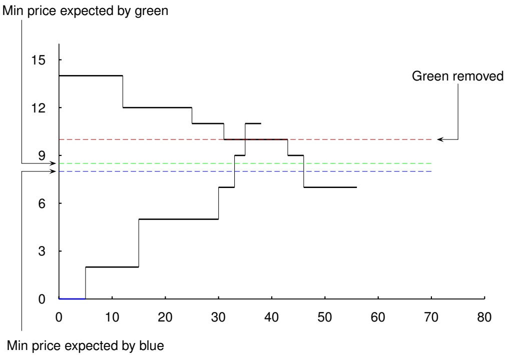
Source: *R. Madlener* and *M. Kaufmann* 'Power exchange spot market trading in Europe: Theoretical consideration and empirical evidence.' Technical report, OSCOGEN, Mar 2002.

How Heuristic May Fail



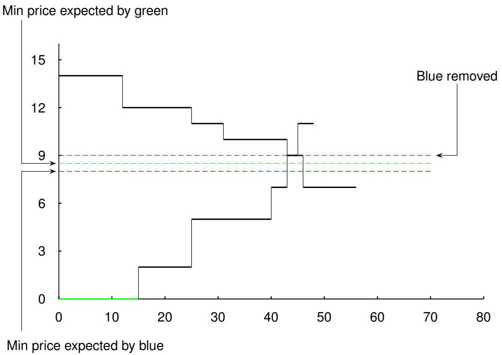
- With block bids placed at zero price, derived MCP shows that green block bid is worst off
- Hence, removed by heuristic and new MCP is computed, which shows blue in profit and thus, heuristic terminates
- However, more efficient solution is the one with green being scheduled

How Heuristic May Fail



- With block bids placed at zero price, derived MCP shows that green block bid is worst off
- Hence, removed by heuristic and new MCP is computed, which shows blue in profit and thus, heuristic terminates
- However, more efficient solution is the one with green being scheduled

How Heuristic May Fail



- With block bids placed at zero price, derived MCP shows that green block bid is worst off
- Hence, removed by heuristic and new MCP is computed, which shows blue in profit and thus, heuristic terminates
- However, more efficient solution is the one with green being scheduled

MILP Approach

- Class of optimization problem with
  - Linear constraints
  - Linear objective
  - Some of the variables integral
- While LP can be solved polynomially, MILP is NP-Hard!!
- Researchers, world wide, have been working on solution techniques on MILP for last few decades
- Consequently, current state of art mature enough to handle few thousand variables for most of the cases
- On mapping scheduling problem to MILP, we can take advantage of these readily available algorithms
- Accounting new bid structures will require adding corresponding mathematical relations
- Network constraints can be very easily modelled

MILP Approach

- Class of optimization problem with
  - Linear constraints
  - Linear objective
  - Some of the variables integral
- While LP can be solved polynomially, MILP is NP-Hard!!
- Researchers, world wide, have been working on solution techniques on MILP for last few decades
- Consequently, current state of art mature enough to handle few thousand variables for most of the cases
- On mapping scheduling problem to MILP, we can take advantage of these readily available algorithms
- Accounting new bid structures will require adding corresponding mathematical relations
- Network constraints can be very easily modelled

Conclusions

- Market clearing mechanism with only hourly bids presented
  - Existence of market equilibrium and its relation with Lagrangian multipliers established
- Resulting complexities due to block bids highlighted
- Notion of paradoxical rejection introduced
- Scheduling techniques in presence of block bids discussed
- MILP framework needed to handle block bids

References

- Yogesh Bichpuriya, S.A.Soman, “Electric Power Exchanges: A Review ” *National Power System Conference* Hyedrabad, Dec. 2010.
- Yogesh Bichpuriya, S. A. Soman, P. R. Apte, “ Design and Testing of Heuristic for Market Splitting in Electric Power Exchange ” *TENCON 2009. IEEE Region 10 Conference* Singapore, Nov. 2009.
- L. Harris, *Trading and Exchanges: Market Microstructure for Practioners.* Oxford University Press, Delhi, 2008.
- M. Maramiroli, M. Tanimoto, Y. Tsukamoto and R. Yokoyama, “Market spilitting algorithm for congestion management in electrcity spot market,” *Proc. 6th Int. Conf. on Power Systems.* Lisbon, Portugal, Sept. 22-24, 2006.
- M. Maramiroli, M. Tanimoto, Y. Tsukamoto and R. Yokoyama, “Market split based congestion management for networks with loops,” *Institute of Electrical Engineers of Japan Trans. PE*, vol. 129, no. 2, pp. 265-271, 2009.

References (cont.)

- L. Meeus, K. Verhaegen and R. Belamns, “Block order restrictions in combinatorial electric energy auctions,” *European Journal of Operational Research.* online, 2008.
- G. Gutirrez, J. Quinonez and G.B. Sheble, “Market clearing price discovery in a single and double-side auction market mechanisms: linear programming solution,” *Power Tech, 2005 IEEE Russia* , June 27-30, 2005.
- T. Sawa, Y. Nakata, M. Tsurugal and S. Sugiyama, “A fast market splitting matching method for the spot electric power market,” *Electrical Engineering in Japan*, vol. 165, no. 4, pp. 21-29, 2008.

Thank You

This is the post-print version of this article: Meeus, L., Verhaegen, K., Belmans, R., 2009. Block order restrictions in combinatorial electric energy auctions. European Journal of Operational Research, 196(3), pp. 1202-1206.

Block Order Restrictions in Combinatorial Electric Energy Auctions

Leonardo Meeus[a,*], Karolien Verhaegen[a], Ronnie Belmans[a]

[a]*Department of Electrical Engineering,*

University of Leuven, Kasteelpark Arenberg 10, 3001 Leuven, Belgium

Abstract

In Europe, the auctions organized by "power exchanges" one day ahead of delivery are multi-unit, double-sided, uniformly priced combinatorial auctions. Generators, retailers, large consumers and traders participate at the demand as well as at the supply side, depending or whether they are short or long in electric energy. Because generators face nonconvex costs, in particular startup costs and minimum run levels, the exchanges allow "block orders" that are all-or-nothing orders of a given amount of electric energy in multiple consecutive hours, while the standard order consists of an amount for a single hour that can be curtailed. All exchanges restrict the size (MWh/h), the type (span in terms of hours) or the number (per participant per day) of blocks that can be introduced. This paper discusses the rationale of block order restrictions. Based on simulations with representative scenarios, it is argued that the restrictions could be relaxed, which some exchanges have already started doing.

Keywords OR in energy, E-commerce, Combinatorial Auctions/bidding, Pricing, Integer programming

1. Introduction

In Europe, the auctions organized by "power exchanges" one day ahead of delivery are an increasingly important part of the wholesale market (Meeus et al., 2005). Although participation is voluntary and the average traded volume is only about 10% of consumption, the hourly auction price is an important reference price for all contract negotiations. Generators, retailers, large consumers and traders increasingly participate at the demand as well as at the supply side, depending or whether they are long or short in electric energy.

The orders that can be introduced at these auctions are for the delivery or off-take of electric energy during an hour of the next day. The exchanges also allow "block orders" that are all-or-nothing orders of a given amount of electric energy in multiple consecutive hours. An auction with block orders can therefore be called a combinatorial auction. Combinatorial auctions have in common that orders can be placed on combinations of heterogeneous

*Corresponding author. Tel.: ++32-(0)16/321722; Fax: ++32-(0)16/321985; E-mail address: leonardo.meeus@esat.kuleuven.be.

items, called packages or bundles, rather than just on individual items. An inspiring and comprehensive work on this topic is the book edited by Cramton, Shoham and Steinberg (2005). Combinatorial auctions have recently been employed in a variety of industries. De Vries and Vohra (2003) provide a comprehensive survey.

The advantage of combinatorial auctions is that participants can more fully express their preferences, such as complementarities between heterogeneous items. In electricity markets, there are complementarities between deliveries of electric energy in consecutive periods, for instance because of start-up costs of power plants. Block orders can indeed be seen as a combination of hourly orders. Blocks allow participants to provide an average price for a combination of hours. On average generators can offer cheaper prices for delivery in multiple consecutive hours as this allows them to spread out the start-up cost.

Both exchanges and participants consider blocks as important. On some exchanges up to 20% of total traded volume consists of block orders. Still, all exchanges restrict the size (MWh/h), the type (span in terms of hours) or the number (per participant per day) of blocks that can be introduced. This paper therefore analyses the rationale of block order restrictions.

Limiting the allowable combinations is known to be effective in reducing computational complexity (Pekec and Rothkopf, 2003; Park and Rothkopf, 2005). This and other reasons to restrict the use of block orders on exchanges are investigated by solving to optimality representative scenarios, based on the historical aggregated order curves of APX, to which sets of block order are added with various degrees of restrictions.

Section 2 explains how the representative scenarios have been constructed. Section 3 introduces the model that is used for the simulations. It therefore also introduces the auction optimization problem with blocks and the pricing approach applied by exchanges to clear their markets. Section 4 then discusses the effect of restrictions, based on the simulation results. Section 5 finally evaluates the restrictions imposed by exchanges.

2. Representative scenarios

The power exchanges with blocks are APX (Netherlands), Belpex (Belgium), Borzen (Slovenia), EEX (Germany), EXAA (Austria), Nord Pool (Norway, Sweden, Denmark and Finland) and Powernext (France). As illustrated in Table 1, the kind of blocks that can be introduced to these exchanges differ substantially.

Table 1: Block order restrictions on APX, Belpex, Powernext and EEX

	Nr block types	Max nr blocks / day / participant	Max size (MWh/h)
APX	354[1]	50	50
Powernext	10	INF[2]	100[3]
EEX	11	6	250

1 All combinations of consecutive periods are allowed
2 Per portfolio it is possible to submit every type once, but participants can submit several portfolios
3 Before 2005 it was 50 MWh

Powernext for instance does not restrict the number of block orders that can be submitted per participant per day, while the size is for instance more restricted on APX (50MWh/h) than on EEX (250MWh/h). On APX, any combination of consecutive hours is allowed so that 354 types of block orders can be traded. Powernext and EEX on the other hand restrict blocks to 10 or 11 types. Table 2

*Corresponding author. Tel.: ++32-(0)16/321722; Fax: ++32-(0)16/321985; E-mail address: leonardo.meeus@esat.kuleuven.be.

illustrates the 10 block types that can be traded on Powernext.

Table 2: Block products on Powernext

Contract name	Time interval
Block Bid 1-4	00.00h – 04.00h
Block Bid 5-8	04.00h – 08.00h
Block Bid 9-12	08.00h – 12.00h
Block Bid 13-16	12.00h – 16.00h
Block Bid 17-20	16.00h -20.00h
Block Bid 21-24	20.00h – 24.00h
Block Bid 1-24	00.00h – 24.00h
Block Bid 9-20	08.00h – 20.00h
Block Bid 1-6	00.00h – 06.00h
Block Bid 1-8	00.00h – 08.00h

The scenarios used in this paper are based on the historical aggregated order curves of the Dutch power exchange APX. Their order curves are publicly available, which is not the case for most other exchanges. The 19 days illustrated in Table 3 have been randomly selected. APX launched their day-ahead auction in 1999 and its liquidity has since steadily increased as can be seen from the table.

Table 3: Days used for scenarios

Date (DD/MM/YY)	Average price (€/MWh)	Maximum price (€/MWh)	Total traded volume (MWh)
15/01/03	32	108	32636
27/03/03	30	41	31240
20/05/03	33	91	32874
04/07/03	33	100	27691
22/11/03	36	96	34102
22/02/04	20	26	34474
19/04/04	29	41	35864
15/06/04	35	70	31357
18/08/04	31	44	35279
21/10/04	32	42	38886
10/12/04	36	75	46350
29/01/05	33	44	50146
10/02/05	36	45	42239
25/03/05	39	60	46373
03/04/05	26	50	40843
07/05/05	32	42	42964
25/05/05	43	80	35119
26/06/05	31	46	47448
20/07/05	45	63	47792

These days are from different years, seasons, week-weekend. The hourly orders are extracted from these curves. Every scenario includes the hourly orders of one of these days. To simulate the effect of adding blocks to these representative days, sets of blocks are generated with various degrees of restrictions as follows:

- To study the effect of a type restriction, in half of all scenarios blocks can be of any type, as on APX, while in the other half, block are restricted to the 10 types found on Powernext (Table 2). Note that the Powernext types have been chosen because they are most restrictive.
- To study the effect of a size restriction, every scenario has a maximum block size between 10 and 300MWh/h. The blocks in a scenario can therefore have different sizes, but all are smaller than the determined scenario size limit. Note that the size limit considered in the analysis is higher than the largest allowed blocks of 250MWh/h on EEX. Blocks larger than 300MWh/h are not considered because such large capacity plants are base load and typically scheduled outside the exchanges.
- To study the effect of an number restriction, the number of blocks in a scenario ranges between 0 and 200. Note that if 200 blocks would be submitted, their share in total traded volume in the scenarios would be larger as it currently is on the exchanges. As mentioned in the introduction,

*Corresponding author. Tel.: ++32-(0)16/321722; Fax: ++32-(0)16/321985; E-mail address: leonardo.meeus@esat.kuleuven.be.

blocks are said to represent up to 20% on some exchanges. Given an average block size of 150MWh/h, 200 blocks correspond to 30000MWh/h. For a block that on average spans 8 hours (1/3 of a day), this corresponds to a total volume of 1000MWh/day, which is up to 35% of the total traded volume on the days used to construct scenarios (Table 3).

Additionally, the following assumptions in line with what can observed on exchanges, have been made:

- Blocks are as likely to be introduced at the demand and supply side
- Blocks are price-setting orders, meaning that their prices are significantly different from zero and close to the market prices. Their price limits have been generated so that they deviate less than 10%, from the average price of the day (Table 3).
- The maximum admissible order price limit (Pmax) is 2500€/MWh, as on APX. Note that this is not intended to be a price cap but rather to protect against human error.

A batch of 200 scenarios has been created in the manner explained above. The results are presented in Section 4. Increasing the batch size to 200 has proved to be sufficient to present results that are not batch specific. The next Section explains how the scenarios are solved to optimality.

3. Auction optimization problem with blocks

Combinatorial auctions are typically difficult to solve optimization problems (Xia et al., 2005). This is also the case for the auction problem with blocks. The all-or-nothing constraint of block orders means that binary variables are necessary to model the auction problem. Models with binary variables for blocks and constrained continuous variables for hourly orders are Mixed Integer Linear Problems (MILP), which are difficult to solve.

With,

- hourly orders characterized by the hour (h) in which they are introduced, whether they are supply (i) or demand (j) and by a price (€/MWh) and quantity (MWh) limit (P_h , Q_h) ;
- block orders characterized by the hours included in the block ($h \in H$), whether they are supply (k) or demand (l) and by an average price (€/MWh) and quantity (MWh/h) limit (P , Q);
- nH the number of hours included in a block;
- block orders having a binary variable to implement the all-or-nothing constraint (b =1 if block is accepted; b =0 otherwise);
- block orders having a quantity limit for every hour to simplify the notation, which is zero for the hours not included in the block ($Q_h = 0$ if $h \notin H$);
- the accepted order quantities (q_{ih} , q_{jh} , q_{kh} , q_{lh}) as the decision variables;

The auction optimization problem with blocks is as follows: maximize total gains from trade (or trade efficiency),

$$Max \sum_h \left(\sum_j q_{jh} P_{jh} + \sum_l q_{lh} P_{lh} - \sum_i q_{ih} P_{ih} - \sum_k q_{kh} P_{kh} \right) \quad (1)$$

subject to market clearing constraints, equalizing demand and supply in every hour:

$$\forall h : \sum_i q_{ih} + \sum_k q_{kh} = \sum_j q_{jh} + \sum_l q_{lh} \quad (2)$$

and the order constraints:

$$q_{ih} \le Q_{ih} \quad (3)$$

$$q_{jh} \le Q_{jh} \quad (4)$$

$$q_{kh} = b_k Q_{kh} \quad (5)$$

*Corresponding author. Tel.: ++32-(0)16/321722; Fax: ++32-(0)16/321985; E-mail address: leonardo.meeus@esat.kuleuven.be.

$$q_{lh} = b_l Q_{lh} \quad (6)$$

Combinatorial auctions are non-convex. This means that linear market clearing prices do not necessarily exist (see for instance Scarf, 1994 and Elmaghraby, 2004). If there are no hourly prices at which demand equals supply, one possibility is to resort to nonlinear pricing (see O'Neill et al., 2005 for a discussion on how shadow prices can be used to implement nonlinear pricing). Nonlinear pricing means that the optimal solution to (1)-(6) in terms of traded volumes (q, MWh) would be settled at hourly prices (p, €/MWh) in combination with a side payment (A, €) which can be different for all orders, i.e. resulting in a "pq + A" settlement.

Exchanges in Europe however have in common that they do not use side payments to clear their day-ahead auction markets (A=0). Instead, they equalize demand and supply at hourly prices by rejecting blocks that should be accepted looking at the hourly prices, i.e. Paradoxically Rejected Blocks (PRB). Note that blocks are however only accepted when they should be and hourly orders are cleared (accepted and rejected) completely in accordance with the hourly prices. To get the optimal solution with the above characteristics, the following constraints including the hourly prices (p_h) need to be added to the auction problem (1)-(6):

First, if a supply block is accepted ($b_k = 1$), the average market price should be at least as high as the price limit of the block, with nH the number of hours included in a block:

$$\forall k : b_k nH_k P_k \leq \sum_{k \in H_k} p_k \quad (7)$$

Equally, if a demand block is accepted ($b_l = 1$), the average market price should not be higher than the price limit of the block, with $P_{\max}$ the maximum admissible price for an order:

$$\forall l : \sum_{l \in H_l} p_h \leq nH_l (P_l + P_{\max} (1 - b_l)) \quad (8)$$

Second, if an hourly supply order or offer is accepted ($b_{ih} = 1$), the hourly price (p_h) needs to be at least as high as the price limit of the offer (P_{ih}), with b_h a binary variable equal to one if the hourly order is accepted:

$$\forall i, h : b_{ih} P_{ih} \leq p_h \quad (9)$$

Equally, if an hourly demand order or bid is accepted ($b_{jh} = 1$), the hourly price (p_h) cannot be higher than the price limit of the bid (P_{jh}):

$$\forall j, h : p_h \leq P_{jh} + P_{\max} (1 - b_{jh}) \quad (10)$$

Third, partially rejected or curtailed hourly orders should set the price. Therefore, if an offer is partially rejected ($b_{ih} = d_{ih} = 1$) or completely ($b_{ih} = d_{ih} = 0$), the hourly price cannot be higher than the price limit of the offer, with d_h a binary variable equal to one if the hourly order is partially rejected:

$$\forall i, h : p_h \leq P_{ih} + P_{\max} (b_{ih} - d_{ih}) \quad (11)$$

Equally, if a bid is partially rejected ($b_{jh} = d_{jh} = 1$) or completely ($b_{jh} = d_{jh} = 0$), the hourly price needs to be at least as high as the price limit of the bid:

$$\forall j, h : P_{jh} - P_{\max} (b_{jh} - d_{jh}) \leq p_h \quad (12)$$

All exchanges impose linear prices, which means that every day they solve the optimization problem (1)-(12). If they would drop constraints (7)-(12), they would increase gains from trade (and avoid PRBs), but trade would have to be settled by using side-payments.

As mentioned earlier, exchanges have however chosen to avoid the complexities of a settlement with side payments. Simplicity can indeed be considered as

*Corresponding author. Tel.: ++32-(0)16/321722; Fax: ++32-(0)16/321985; E-mail address: leonardo.meeus@esat.kuleuven.be.

an important design feature of the exchanges in their role of fine tuning market of which the reference price is more important than the volume they clear directly.

4. Effect of block order restrictions

A batch of 200 scenarios has been solved to optimality according to the MILP model (1)-(12) on a Pentium® IV, using the CPLEX v11.0® solver software called from Matlab® using the Tomlab® interface.

In two scenarios, the optimal solution was not yet found after 2.5 days so that the solver was stopped. For all other scenarios, the solver calculation time is 4 minutes on average. The minimum and maximum calculation time is respectively a few seconds and 3.5 hours. 50% of the scenarios solve in less than one minute and 95% less than 10 minutes. This is typical for the performance of commercial MILP solvers.

The optimal solution to the MILP model (1)-(12) yields 4.15 PRBs per day on average, with a maximum of 27 in a day. In total, there are 829 PRBs for 19619 blocks in these scenarios. Therefore, the likelihood of blocks to be paradoxically rejected is only 4.36%. It is important to note that almost 40% of these PRBs are actually not loosing any money, i.e. their price limit is equal to the average market price, but other blocks loose up to 18€/MWh/h.

In the remainder of this Section, the effects of restricting the use of blocks on calculation time, the number of PRBs and trade efficiency are considered based on the simulation results.

4.1 Calculation time

Pekec and Rothkopf (2003) discuss non-computational approaches to mitigating computational problems in combinatorial auctions. Limiting the combinations participants are allowed to bid is described as an effective way to reduce the computational complexity of combinatorial auctions. Park and Rothkopf (2005) even propose an auction with bidder-determined allowable combinations.

Also in combinatorial electric energy auctions this is true. As discussed in the Section 2, in 50% of the scenarios every combination of consecutive hours is allowed, while in the other 50% of scenarios only have the 10 combinations that are allowed at Powernext. The difference in calculation time between these scenarios is illustrated in Figure 1.

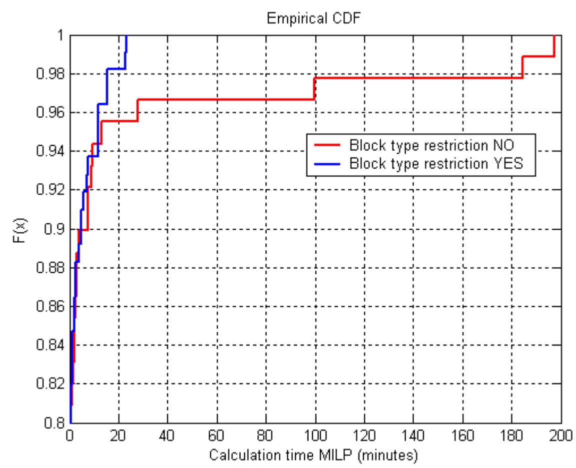


Figure 1: Calculation time MILP model (1)-(12) in minutes with and without a block type restriction

As illustrated in the figure, the group of scenarios in which the allowed combinations or block types are not restricted has more extreme outliers. Indeed, also the two scenarios not indicated in the figure that were stopped after 2.5 days of calculation are scenarios without a type restriction.

Significant coherence between calculation time and the number or size of blocks in the scenarios could not be found. One could expect a correlation between the number of blocks and the solver calculation time, as the number of blocks increases the problem size in terms of binary decision variables, but

*Corresponding author. Tel.: ++32-(0)16/321722; Fax: ++32-(0)16/321985; E-mail address: leonardo.meeus@esat.kuleuven.be.

such a correlation could not be found. The correlation in the batch of 200 scenarios is only 0.041 and not significant. This can be partly explained by the fact that binary variables are also assigned to hourly orders and the number of hourly orders differs more between scenarios than the number of blocks.

Note that if linear prices are not imposed on the clearing, the calculation time significantly reduces to 0.6 seconds on average with a maximum of 1.4 seconds. This clearly indicates that the most significant computational complexity comes from constraints (7)-(12) and the binary variables that need to be assigned to the hourly orders to implement these constraints and therefore not from the number of blocks.

4.2 Paradoxically Rejected Blocks (PRB)

On average 4.36% of the blocks are paradoxically rejected. This indicates that it is not that big of an issue for the auction participants, which has been confirmed by talking to traders. Still, this paragraph will respectively consider whether block type, size and number restrictions are an effective way of reducing the number or likelihood of PRBs.

Table 4 compares the PRBs of the scenarios with and without a type restriction. There is no significant difference in the number of PRBs between these categories of scenarios. The null hypothesis that the means are equal, assuming a normal distribution for both samples and equal standard deviations cannot be rejected for a 5% significance (p-value is 0.1585).

Table 4: Effect block type restriction on PRB

Nr PRB	All types	Powernext types
Mean	3.6	4.5
Standard deviation	3.6	5.2

From the combinatorial nature of blocks, it can be expected that small blocks are less likely to become paradoxically rejected. Indeed, for instance only 1% of blocks smaller than 50MWh/h are paradoxically rejected, which is four time less than the average for blocks. However, as indicated in Table 5, there is no significant correlation between the likelihood of PRB and the maximum block size. Such a correlation would appear if all blocks in the scenarios are taken equal to the maximum block size, but what these results indicate is the presence of large blocks does not increase the likelihood that small blocks are paradoxically rejected.

It can also be expected that the number of PRBs increases with the number of blocks. The results in Table 5 confirm this, but also indicate that the increase is more or less proportional, as there is no significant correlation between the likelihood of PRB and the number of blocks in a scenario.

Table 5: Linear effect size and number of blocks on PRB throughout the whole range of that data

Correlations (linear regression R^2)	Nr blocks	Maximum block size
Nr PRB	0.6407 (41.4%)	0.3053 (9.3%)
Likelihood PRB (Illustrated in Figure 2)	-0.0362 (0.13%)	0.2139 (4.6%)
Likelihood PRB blocks < 50MWH/h	0.103 (1%)	0.181 (2.2%)

*Corresponding author. Tel.: ++32-(0)16/321722; Fax: ++32-(0)16/321985; E-mail address: leonardo.meeus@esat.kuleuven.be.

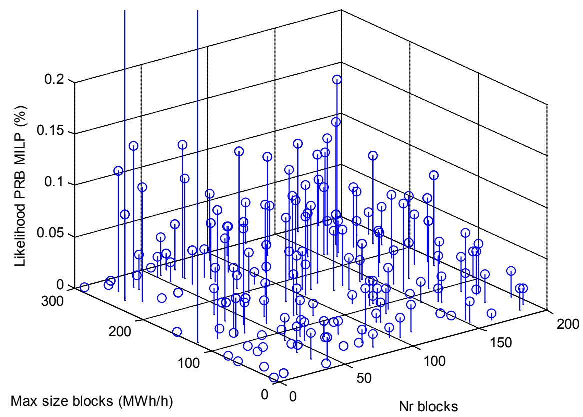


Figure 2: Likelihood PRB in MILP model (1)-(12)

4.3 Trade efficiency

The value of the objective function (1) is largely driven by the hourly orders because there are many price taking hourly orders. This does not mean that power exchanges should simply stop using block orders and thereby avoid the complexity of dealing with them. On the contrary, blocks are important for market parties and represent up to 20% of traded volume on the exchanges.

This does however explain why restricting the number, size or types does not have a statistically significant effect on the total gains from trade. This also explains why imposing linear prices only results in a loss of .0.05% in terms of gains from trade.

Note that the lost value is linked to paradoxically rejected blocks and can therefore be avoided by applying nonlinear pricing. However, this would also mean that side payments would have to be made. Applying the nonlinear pricing approach introduced in O'Neill et al. (2005) to the 200 scenarios, would for instance mean that 317393€ side payments need to be made in total. This is almost 9 times more than the total gains from trade that can be won by making these side payments. Note that only blocks would receive side payments, the average payment being 502€.

5. Evaluation of restrictions

From the previous section can be concluded that a block type restriction is an interesting option to consider. The results indicate that a type restriction has a clear effect on the solver calculation time and reducing this time can be of interest to exchanges that typically have only between 15 and 30 minutes to clear their day-ahead auctions. A type restriction is also not necessarily binding for the auction participants as blocks are mainly introduced for base load, peak load, etc and the allowed combinations typically match these periods.

From the previous section could also be concluded that the number of blocks and their size should not be restricted. The simulations clearly indicate that these restrictions have no significant impact on calculation time, the likelihood of PRB or trade efficiency. Still, it can be explained why all exchanges have such restrictions. One possible explanation is that participants were not used to trade blocks under the linear pricing regime introduced by power exchanges, which has been introduced in this paper and which is very different from the pricing approaches in other combinatorial auctions, so that every PRB is a potential complaint for starting exchanges. Note however that restricting the use of blocks is an artificial way of reducing PRBs. The real solution would be to avoid PRBs by resorting to nonlinear pricing.

It is also sometimes said that the unrestricted use of blocks would increase price volatility. For immature or illiquid markets with a lack of hourly orders, the lumpiness of blocks can indeed be an issue for the formation of prices. The scenarios used in this

*Corresponding author. Tel.: ++32-(0)16/321722; Fax: ++32-(0)16/321985; E-mail address: leonardo.meeus@esat.kuleuven.be.

paper are based on APX from 2003 to 2005, which is more than 4 years after the exchange started in 1999. The results indicate that for mature markets the impact on prices of adding blocks is limited. In other words, there are ways to explain why exchanges have introduced these restrictions, but as these markets have matured it is time for them to omit or at least relax them.

Note that the size restrictions are currently clearly binding for traders. Generation units are easily larger than 50 MW and even larger than 250 MW. Because blocks can be paradoxically rejected, submitting 5 blocks of 50 MWh/h is not the same as submitting a block of 250 MWh/h.

7. Conclusions

The simulation results presented in this paper argue against restricting the use of blocks in the day-ahead auctions organized by exchanges. It is in the benefit of exchanges and auction participants to omit or at least relax these restrictions. Some exchanges have already starting doing that. The French Powernext has for instance doubled the allowed block size from 50 to 100 MWh/h and more recently also allows more combinations of hours in a block order.

The simulations are based on representative scenarios using actual order data from the Dutch exchange APX. Block sets with various degrees of block restrictions are added to these scenarios to study the rationale of these restrictions. The results clearly argue against block size restrictions and also against restrictions on the number of blocks a participant can submit per day. Inline with existing combinatorial auction literature (Pekec and Rothkopf, 2003; Park and Rothkopf, 2005), the results however do confirm that limiting the allowable combinations that can be included in a block reduces the solver calculation time. This could therefore justify a block type restriction.

It has also been explained that order restrictions in general can be justified for starting or illiquid exchanges. For instance the Austrian exchange EXAA introduced blocks in 2003 after one year of operation when the market had somewhat matured. More recently also the Belgian exchange BELPEX started without blocks in 2006, but introduced them after a few months of operation.

Apart from providing guidelines to exchanges on how to deal with blocks, this paper also discusses their particular approach of imposing linear prices in a nonconvex auction. An interesting extension to this work could therefore be to consider this pricing approach for other combinatorial auction settings (see Xia et al. 2004 for an overview of pricing approaches in combinatorial auctions). Specifically towards power exchanges, this work could be extended by considering other combinatorial products. A block in itself is also a restricted product. The auction participants might for instance be interested to combine hours without having to offer the same amount of electric energy in every hour. Note that some exchanges have already started to introduce more flexible combinatorial products and other are looking into this issue.

Acknowledgements

The authors gratefully acknowledge the support and contributions received from APX, Belpex, Elia and Powernext. The authors also thank the anonymous referees and the editor for their comments. The analysis and conclusions are of course the sole responsibility of the authors.

*Corresponding author. Tel.: ++32-(0)16/321722; Fax: ++32-(0)16/321985; E-mail address: leonardo.meeus@esat.kuleuven.be.

References

Cramton P., Y. Shoham and R. Steinberg (eds.) (2006), Combinatorial Auctions, MIT Press, ISBN 0262033429.

De Vries S. and R. V. Vohra (2003), “Combinatorial auctions: a survey,” INFORMS Journal on Computing, vol. 15, no. 3, pp. 284-309.

Elmaghraby W. J., R. O’Neill, M. Rothkopf and W. Stewart, "Pricing and Efficiency in Lumpy Energy Markets," The Electricity Journal, vol. 17, no. 5, June 2004, pp. 54-64.

Meeus L., K. Purchala and R. Belmans (2005), Development of the Internal Electricity Market in Europe, The Electricity Journal, vol. 18 no. 6, pp. 25-35.

O’Neill R. P., P. M. Sotkiewicz, B.F. Hobbs, M.H. Rothkopf and W.R. Jr. Stewart (2005), “Efficient market-clearing prices in markets with nonconvexities,” European Journal of Operational Research, vol. 164, no. 1, pp 269-285.

Park S. and M. H. Rothkopf (2005), “Auctions with bidder-determined allowable combinations,” European Journal of Operational Research, vol. 161, no 2, pp 399-415.

Pekec, A., and M. H. Rothkopf (2003), “Combinatorial Auction Design,” Management Science, vol. 49, no 11, pp1485 - 1503

Scarf H. E. (1994), The Allocation of Resources in the Presence of Indivisibilities, The Journal of Economic Perspectives, vol. 8, no. 4, pp 111-128.

Xia M.., G. J. Koehler and A. B. Whinston (2004), “Pricing combinatorial auctions,” European Journal of Operational Research, vol. 154, no. 1, pp251-270.

Xia M., J. Stallaert and A. B. Whinston (2005), "Solving the combinatorial double auction problem," European Journal of Operational Research, vol 164, no 1, pp 239-251.

*Corresponding author. Tel.: ++32-(0)16/321722; Fax: ++32-(0)16/321985; E-mail address: leonardo.meeus@esat.kuleuven.be.

ARTICLE IN PRESS

Energy ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Market coupling and the importance of price coordination between power exchanges

L. Meeus *, L. Vandezande, S. Cole, R. Belmans

Electrical Engineering Branch, Energy Institute, University of Leuven (KUL), Kasteelpark Arenberg 10, B-3001 Leuven, Belgium

ARTICLE INFO

Article history:
Received 3 July 2007

Keywords:
Pricing
Electric market equilibrium
Operational research
Power system economics
Duality

ABSTRACT

In Europe, market coupling stands for a further integration of wholesale trading arrangements across country borders. More specifically, it refers to the implicit auctioning of cross-border physical transmission rights via the hourly auctions for electric energy organized by power exchanges (PEXs) one day ahead of delivery. It therefore implies that the PEXs can optimize the clearing of their day-ahead auctions. Due to verticals in the aggregated order curves, the optimal solution can be settled at different prices. In order for prices to give correct locational signals for network development, generation and consumption, price coordination between exchanges is necessary. The paper illustrates this issue, its relevance and discusses how to deal with it.

1. Introduction

In Europe, generators self-schedule and they do this by submitting a production program to the network operator. Which and when generators are turned on and run is the result of trading in several types of markets. Trading is mainly bilateral, but in most countries this is supplemented with auction trading organized by power exchanges (PEXs) one day ahead of delivery for every hour of the next day. The auctions are used by market parties to fine tune their portfolios, which for instance means that generators can be on the supply as well as demand side depending on whether they are long or short. The PEXs use simple rules to settle contracts one day ahead of delivery when it is not worth getting into time consuming bilateral negotiations. Additionally, the exchanges act as counter-party for all transactions. The traded volume on the PEXs is typically 10% of consumption.

While wholesale trading within countries is not constrained by the network, it is constrained at the borders where there are structural bottlenecks. The transmission system operators (TSOs) determine transfer capacities (so-called net transfer capacities) independently per border and before trading actually takes place. In other words, before it is known how flows will be distributed over the different interconnections and without taking the interdependencies of a meshed network into account. About 10% of consumption is currently traded across borders in Europe.

As discussed in [1], the European version of a flow gate approach is not the most efficient way of dealing with the scarce network resources. This is not about to change soon, but what is changing is how these capacities are allocated to market parties. Non-market-based allocation methods have largely been abolished and replaced by separate auctions per border. The auctions are organized by the TSOs and are typically for yearly, monthly and daily physical transmission rights.

Arbitrage between the various PEXs is therefore already possible but explicit, requiring the purchase of physical transmission rights on a contract path. Besides being constrained by the available border capacities, arbitrage is also constrained by the time lag between the closing of the different border and PEX auctions and the uncertainty that this brings, especially given the high price volatility. Several empirical studies that compare the prices of border capacity with the price difference between exchanges indeed indicate that arbitrage is currently inefficient (see for instance [2]).

Market coupling refers to the implicit auctioning of physical transmission rights via the hourly auctions organized by PEXs one day ahead of delivery. Nord Pool (Elspot) already does this for several years for the total available capacity on the internal borders of the Scandinavian countries. Since November 2006, the capacity available day-ahead on the internal borders of France, Belgium and the Netherlands that used to be auctioned in a separate market organized by the respective TSOs is now used by the exchanges to optimize the clearing of their day-ahead auctions. This so-called trilateral market coupling (TLC) initiative is expected to be extended to include more countries.

Market coupling implies that exchanges can optimize the clearing of the offers and bids for electric energy submitted to

* Corresponding author. Tel.: +32 16 321722; fax: +32 16 321985.
E-mail addresses: leonardo.meeus@esat.kuleuven.be (L. Meeus), leen.vandezande@esat.kuleuven.be (L. Vandezande), stijn.cole@esat.kuleuven.be (S. Cole), ronnie.belmans@esat.kuleuven.be (R. Belmans).

0360-5442/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.energy.2008.04.013

their day-ahead auctions. As such, total gains from trading are increased. Often quoted benefits are also reduced price volatility and increased liquidity as orders can be matched across borders. Due to verticals in the aggregated order curves, the optimal solution can, however, be settled at different prices. In order for prices to give correct locational signals for network development, generation and consumption, price coordination between exchanges is necessary.

Section 2 introduces the market coupling optimization problem. Section 3 introduces the widely accepted approach to settle trading with network constraints, i.e. locational marginal pricing (LMP). Section 4 then illustrates that locational marginal prices (LMPs) have important properties and that they are not always uniquely determined. Section 5 discusses price coordination between exchanges, including its relevance and how it is being dealt with in the TLC initiative.

2. Market coupling optimization problem

The market coupling optimization problem involves demand and supply orders of different exchanges that need to be matched in order to maximize the total gains from trading. This means that the cheapest supply orders are matched with the most willing to pay demand orders. The only complexity in comparison with a single exchange optimization problem is that these orders come from different exchanges which represent a different network location. The demand and supply volumes traded on the different exchanges do not have to be equal, as long as the traded volumes equalize in total and the resulting flows between locations are feasible given the limited available network capacity.

For the market coupling optimization problem, the topology and capacities of the simplified network that need to be taken into account are given as they are pre-determined by the involved TSOs. Given is also the volumes and prices of the orders that have been submitted. What needs to be determined is which orders are accepted at which hourly price for every exchange. The optimization problem can therefore be formulated as follows:

Maximize the value of demand minus the cost of supply:

$$\operatorname*{Max}_{q}\left(\sum_{z}\left(\sum_{j} q_{jz}P_{jz}-\sum_{i} q_{iz}P_{iz}\right)\right) \tag{1}$$

with P_{jz} is the price limit of demand side order j submitted to exchange z (or introduced at location z), P_{iz} is the price limit of supply side order i submitted to exchange z (or introduced at location z), q_{iz}, q_{jz} is the decision variable representing the accepted volume of the respective orders

Subject to the order constraints (2) and (3), making sure that the accepted volume is not higher than the volume limit of an order:

$$q_{iz}\leqslant Q_{iz} \tag{2}$$

$$q_{jz}\leqslant Q_{jz} \tag{3}$$

With Q_{jz} is the volume limit of demand side order j submitted to exchange z (or introduced at location z), Q_{iz} is the volume limit of supply side order i submitted to exchange z (or introduced at location z).

And subject to DC load flow network constraints (4) and (5), which are a simplification of the actual power flow equations as for instance discussed in [3]. Constraints (4) equalize the net injections with the off-takes at every location. Constraints (5) make sure that the flow is not higher than the available capacity between the locations:

$$\forall z:\sum_{i} q_{iz}-\sum_{x} q_{jz}-\sum_{x} B_{zx}(\theta_z-\theta_x)=0 \tag{4}$$

$$\forall z,x\in Z: B_{zx}(\theta_z-\theta_x)\leqslant Cap_{zx} \tag{5}$$

with B_{zx} is the susceptance of the interconnector between zone z and x, θ_z is the voltage angle, Cap_{zx} is the capacity of the interconnector between z and x.

Note that in practice, the exchanges solve this optimization problem for every hour of the next day and the hours are interdependent because of so-called block orders [4]. For reasons of clarity, abstraction is made of block order in this paper.

3. Price properties

Locational marginal prices (LMPs) are the most obvious choice to settle the optimal solution to the market coupling optimization problem. It basically means that the orders of an exchange are settled at the price that corresponds to the shadow price of its market clearing constraint (4). LMPs have interesting properties. They for instance give efficient locational signals for network development, generation and consumption. LMP is also widely used; especially in the North American markets (see for instance [5]). Although a lot of literature is available discussing the properties of LMPs (see for instance [6]), much less is available on implementation issues of LMP. This paper discusses an implementation issue related to the verticals in the aggregated order curves of the exchanges that is relevant for the European context.

The properties of LMPs can be derived from the optimality conditions of the market coupling optimization problem (1)–(5) as has been done in [7] for the more generalized problem. This leads to the following equations that define the necessary relation between the LMPs and the shadow prices of (5), which correspond to the value of the interconnections:

$$\forall z,x:\sum_{x} B_{zx}[p_z-p_x+\mu_{zx}-\mu_{xz}]=0 \tag{6}$$

with p_z is the LMP, or simply price corresponding to location z. Note that demand and supply orders of a single location or exchange are cleared at the same price. μ_{xz} is the value of the interconnector between x and z, in the direction x–z, which corresponds to the shadow price of (5). Therefore, this price is zero if constraint (5) is non-binding, which is the case when the interconnector is not fully used.

Note that LMPs are not always as intuitive as one might think. Based on simplified examples in non-meshed networks, these prices have sometimes been attributed properties that the approach cannot deliver. For a discussion of common misunderstandings, see for instance [7,8].

4. Freedom in prices

4.1. Price ranges

Consider three exchanges PX1, PX2 and PX3 to which the orders listed in Table 1 are submitted. Fig. 1 illustrates the implied aggregated order curves for the three exchanges separately and jointly. If the exchanges are not coupled they would have cleared a volume of, respectively, 100, 100 and 100 MW h at a price of 10, 25 and 90€/MW h. Total gains from trading in that case would have been 18,500€ ((PX1:) 100 MW h (90–10€/MW h)+(PX2:) 100 MW h (90–25€/MW h)+(PX3:) 100 MW h (90–50€/MW h)). If the exchanges would be coupled without binding network constraints,

Table 1
Demand and supply orders introduced to PX 1 to 3

PX1	PX2	PX3
Demand orders (bids)		
100 MW h@ 90€/MW h	100 MW h@ 90€/MW h	200 MW h@ 90€/MW h
Supply orders (offers)		
300 MW h@ 10€/MW h	175 MW h@ 25€/MW h	100 MW h@ 50€/MW h

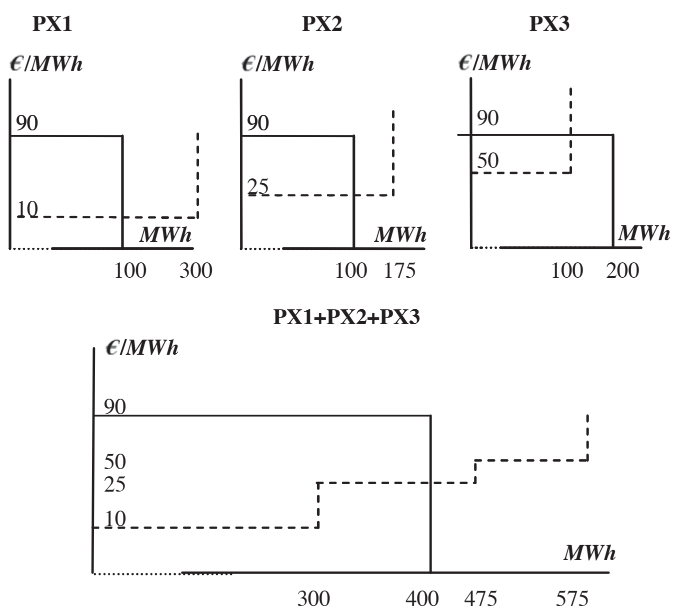


Fig. 1. Aggregated order curves of three PEXs separately and jointly.

they would have cleared a total volume of 400 MW h at a price of 25€/MW h. In comparison with the non-coupled situation, the volume traded in total has increased with 100 MW h and total gains from trading have gone up to 30,500€ (300 MW h (90–10€/MW h)+100 MW h (90–25€/MW h)). The difference, 12,000€, is because at PX3 more demand can be supplied (100 MW h (90–10€/MW h)) and additionally the more expensive supply offer at PX3 can be replaced with the cheaper supply offer introduced at PX1 (100 MW h (50–10€/MW h)).

The optimal solution implies a transfer of 200 MW h from PX1 to PX3, i.e. an injection in the network of 200 MW h at location 1 and a withdrawal of 200 MW h at location 2. Fig. 2 illustrates the possible locational prices and their corresponding export level. Note that these prices reflect the property of LMP that there is a single price per location to settle demand and supply at that location. Take for instance PX1:

- No supplier is offering at a price below 10€/MW h, while at such low prices demand will definitely want to be supplied fully, so that the corresponding import level for prices lower than 10€/MW h is 100 MW h.
- Demand does not want to pay more than 90€/MW h, while at such high prices supply will definitely want to be supplied fully, so that the corresponding export level for prices higher than 90€/MW h is 300 MW h.
- In between 10 and 90€/MW h demand wants to be fully supplied and suppliers want to supply all they offered as they can make a profit, so that the corresponding export level for prices between 10 and 90€/MW h is 200 MW h.
- If the price is 10€/MW h/90€/MW h supply/demand can be curtailed as the orders are marginally accepted at those prices, so that there are several corresponding import/export levels, as illustrated in Fig. 2.

In other words, an export of 200 MW h corresponds to several possible locational prices at PX1. As illustrated in Fig. 2, the same counts for PX3, which we will refer to as locational price ranges. Therefore, the LMP property of having a single price per location alone does not fix the prices in this illustration. Another LMP property is that if there are no binding network constraints, the network does not generate revenue. Fig. 3 illustrates the impact on the network of the transfer between PX1 and PX3. Note that it is assumed that all interconnector susceptances are equal so that 1/3 of the transfer goes via PX2 and 2/3 goes via the direct interconnection. Assuming that there is enough capacity to make this solution feasible, the remaining optimality conditions (6) translate into:

$$2p_1 - p_2 - p_3 = 0 \tag{7}$$

$$-p_1 + 2p_2 - p_3 = 0 \tag{8}$$

$$-p_1 - p_2 + 2p_3 = 0 \tag{9}$$

These equations basically imply that the locational prices have to be equal. Given that the price of PX2 is fixed at 25€/MW h (Fig. 2: there is no locational price range for PX2), this is the price for the three exchanges. In conclusion, an important LMP property is that LMPs are equal if there is no congestion in the network. Furthermore, in this example, there is only one set of prices that satisfies all LMP properties.

4.2. *Alternative sets of LMPs*

If we introduce binding network constraint to the example introduced in the previous section, the optimal solution changes. Fig. 4 illustrates this with a binding capacity constraint between PX1 and PX3. In this network, a transfer between PX2 and PX3 is more interesting than a transfer between PX1 and PX3, because the latter uses more of the scarce network resource (double the amount) which offsets the supply cost advantage PX1 (10€/MW h) has over PX2 (25€/MW h). In this network setting, the optimal solution is to transfer as much as possible between PX2 and PX3 and to use what remains on the interconnector between PX1 and PX3 for a transfer between these exchanges, as illustrated in Fig. 4.

Fig. 5 illustrates that the optimal solution yields two price ranges (PX2: $25<p<90$; PX3: $50<p<90$), but the export level of PX1 implies a price of 10. Given that there is a binding constraint between PX1 and PX3 so that μ_{13} is positive and given that p_1 is 10, (6) translates into:

$$20 - p_2 - p_3 + \mu_{13} = 0 \tag{10}$$

$$-10 + 2p_2 - p_3 = 0 \tag{11}$$

$$-10 - p_2 + 2p_3 - \mu_{13} = 0 \tag{12}$$

Eqs. (10)–(12) is a set of 2 two linear independent equations with three unknowns, meaning that there is some freedom in the prices. Indeed, solving the example in Matlab using the linprog solver yields prices of 10, 41 and 73€/MW h, respectively, for PX1, PX2 and PX3 and solving it with the CPLEX solver yields prices of 10, 30 and 50€/MW h (Table 2). In other words, the example clearly illustrates that prices can differ significantly depending on which software is used to solve the problem. If no additional

Please cite this article as: Meeus L, et al. Market coupling and the importance of price coordination between power exchanges. Energy (2008), doi:10.1016/j.energy.2008.04.013

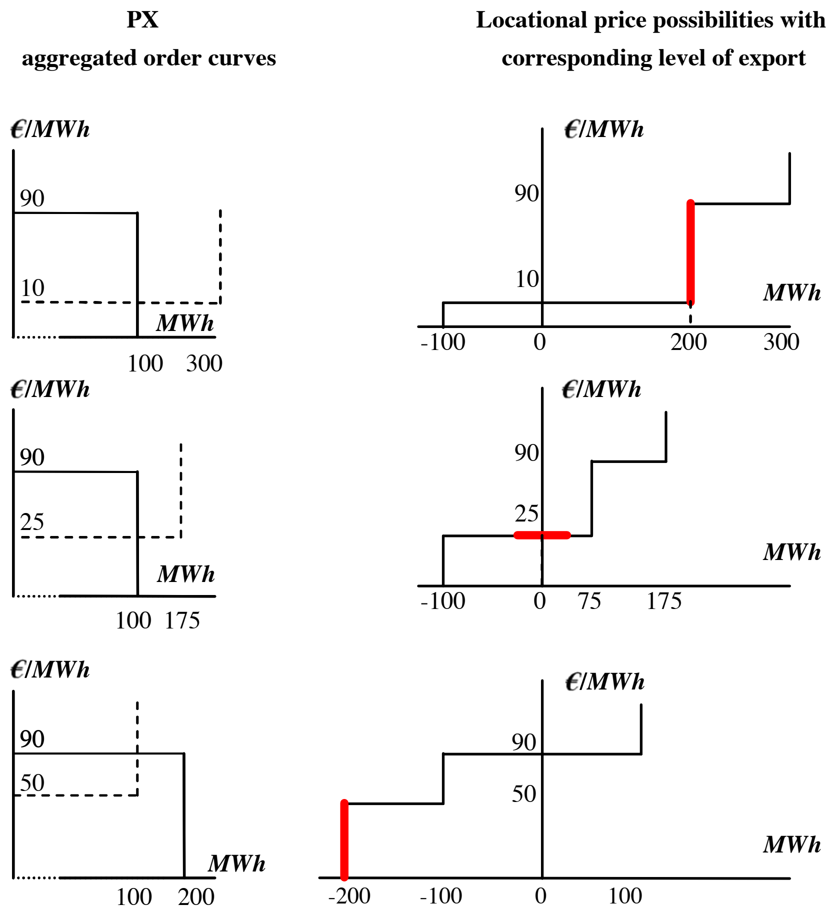


Fig. 2. Locational price ranges corresponding to the optimal solution reported in Fig. 1 as the intersection of aggregated order curves joined for the three exchanges.

method is applied to consciously choose between the alternative sets of LMPs, the solution will depend on the solver software that is used.

5. Price coordination

5.1. Importance of price coordination

Perhaps the simplest way of dealing with price ranges is to allow every exchange to independently choose which price they take of the possible prices that correspond with the optimal export level that comes out of the market coupling problem. The consequence would, however, be that even the most basic LMP property, which is that prices should be equal if there is no congestion, is not necessarily satisfied. Even though the most willing to pay demand would still be matched with the cheapest suppliers, the distribution of gains from trading would be different. In this case, the network could generate congestion rents, giving incentives to further invest in the network, while increasing the network capacity would not improve welfare. In other words, only LMPs give correct locational signals for network development, generation or consumption. Therefore, the best way to coordinate prices is to use the shadow prices of the market clearing constraint, which are the LMPs.

The remaining question is what to do in case there are alternative sets of LMPs. Consider the illustration from the previous section. Table 2 summarizes some of the possibilities to choose from. As indicated in the table, the value of the interconnector between PX1 and PX3 (μ_{13}) is always positive. This is because the interconnector between PX1 and PX3 is congested. The value of a congested interconnector (€/MW h) is equal to the congestion rents (€) divided by the flow over the interconnector (MW h). Congestion rents are the result of transfers between exchanges with different prices. In the illustration, prices in PX1 and PX2 are lower than in PX3 so that transferring energy from PX1 and PX2 to PX3 generates a revenue that is called congestion rent. In general, congestion rents can be expressed in function of the value of the interconnectors μ_{zx}:$z, x \in Z$, but also as a function of the LMPs p_z:$z \in Z$, which is equivalent:

$$\sum_z \sum_x B_{zx}(\theta_z - \theta_x) \cdot \mu_{zx} = \sum_z (\sum_j q_{jz}* - \sum_i q_{iz}*) \cdot p_z \qquad (13)$$

With $q_{iz}*$, $q_{jz}*$ is the optimal traded volumes, resulting from the solving the market coupling problem (1)–(5).

Note from Table 2 that the signal to invest in the network (μ_{13}) can be double as high in the illustration, depending on whether congestion rents are minimized or maximized when choosing between different sets of LMPs. The highest μ_{13} value is actually the negative effect on total gains from trading if the capacity would be reduced with 1 MW, while the lowest μ_{13} value is the positive effect on total gains from trading if the capacity would be increased with 1 MW:

- 1 MW more, is 3/2 MW h more transfer between PX1 and PX3, which would mean replacing 3/2 MW h of supply in PX3 at 50€/MW h with supply from PX1 at 10€/MW h, which is a gain of 60€ (3/2(50–10)).

Please cite this article as: Meeus L, et al. Market coupling and the importance of price coordination between power exchanges. Energy (2008), doi:10.1016/j.energy.2008.04.013

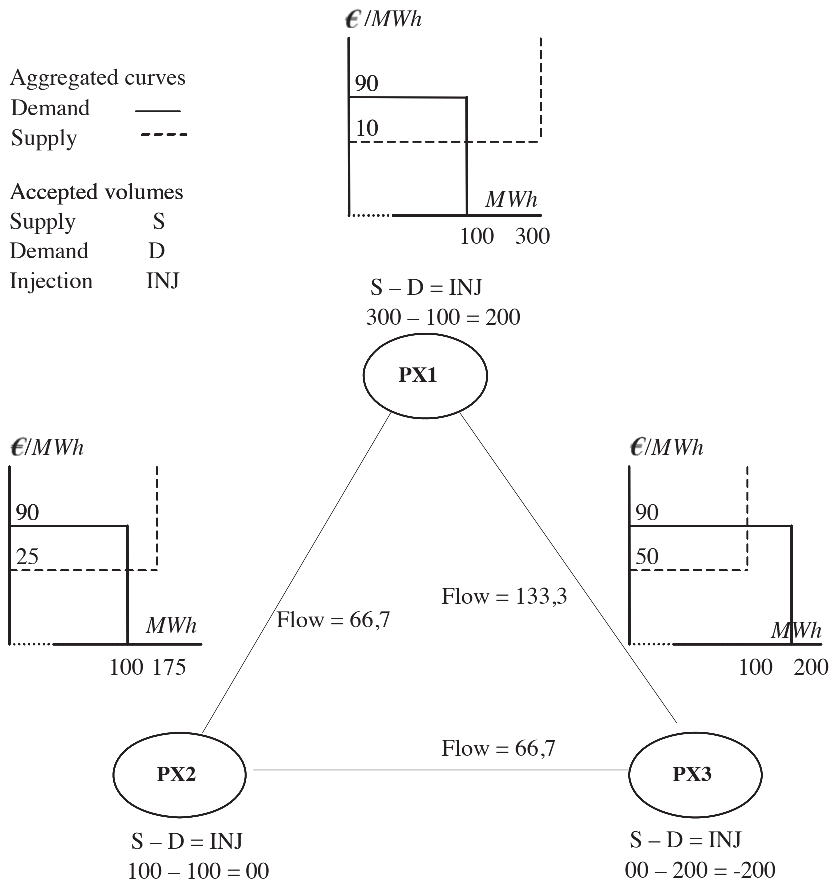


Fig. 3. Impact optimal solution (Fig. 1, intersection of aggregated order curves joined for the three exchanges) on the network.

- 1 MW less, is 3/2 MW h less transfer between PX1 and PX3, which would reduce by 3/2 MW h demand in PX3 with a value 90€/MW h and supply in PX1 at 10€/MW h which is a loss of 120€ (3/2(90–10)).

In principle, the highest and the lowest value are as relevant, but in a European context with scare interconnection capacity between countries, the question is rather which interconnector to further expand than which to maintain. This is one argument in favor of minimizing the congestion rents when choosing between sets of LMPs. Another argument is that one of the main concerns at the moment in Europe is that only a small fraction of the congestion rents is used to invest in the network.

It can therefore be concluded that a good and straightforward way to choose between alternative sets of LMPs is to minimize congestion rents.

5.2. *Minimizing congestion rents*

A general approach to determine LMPs would therefore be to first solve the market coupling problem (1)–(5). Once the optimal traded volumes ($q_{iz}*$, $q_{jz}*$) are known, also the price ranges are known for every exchange. The optimization problem can therefore be formulated as follows:

Minimize congestion rents:

$$\sum_z \left(\sum_j q^*_{jz} - \sum_i q^*_{iz} \right) \cdot p_z \qquad (14)$$

with p_z is the decision variable, representing the price corresponding to location z.

Subject to the price ranges and (6), which are the optimality conditions of the market coupling problem. If applied to the illustration from the previous section, solving this simple linear programming (LP) problem yields prices of 10, 30 and 50€/MW h for PX1, PX2 and PX3 (Table 2). Eqs. (10) or (12) than imply that the value of the interconnection between PX1 and PX3 is 60€/MW h, which is the value that corresponds to 1 MW capacity increase of that interconnection as discussed in the previous subsection. Note that if the market coupling problem has to deal with more constrained interconnectors as in the illustration, this only means that the above LP problem will contain more variables.

5.3. *Relevance of price coordination*

Which price is chosen on a price range is of course only relevant if coupled exchanges are often faced with such price ranges and if they are significant. Fig. 6 illustrates the price ranges on Belpex for the first 2 months of operation. In 30% of the hours observed there is no price range, and in 80% of the hours the price range is smaller than 20€/MW h. This implies that in 20% of the hours the price is larger than 20€/MW h. Note that there are even a few observations with price ranges peaking close to 400€/MW h, even though the figure stops at 160€/MW h. Given that a typical wholesale price is 50€/MW h, this is a very relevant part of the price formation on the PEXs.

Please cite this article as: Meeus L, et al. Market coupling and the importance of price coordination between power exchanges. Energy (2008), doi:10.1016/j.energy.2008.04.013

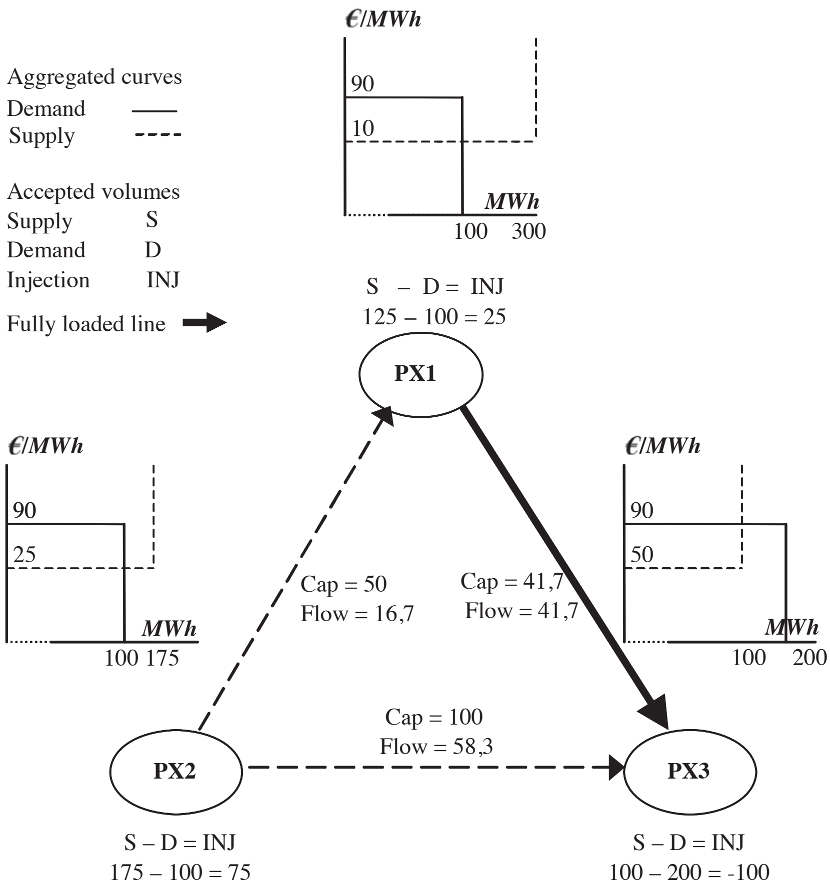


Fig. 4. Introducing price sets.

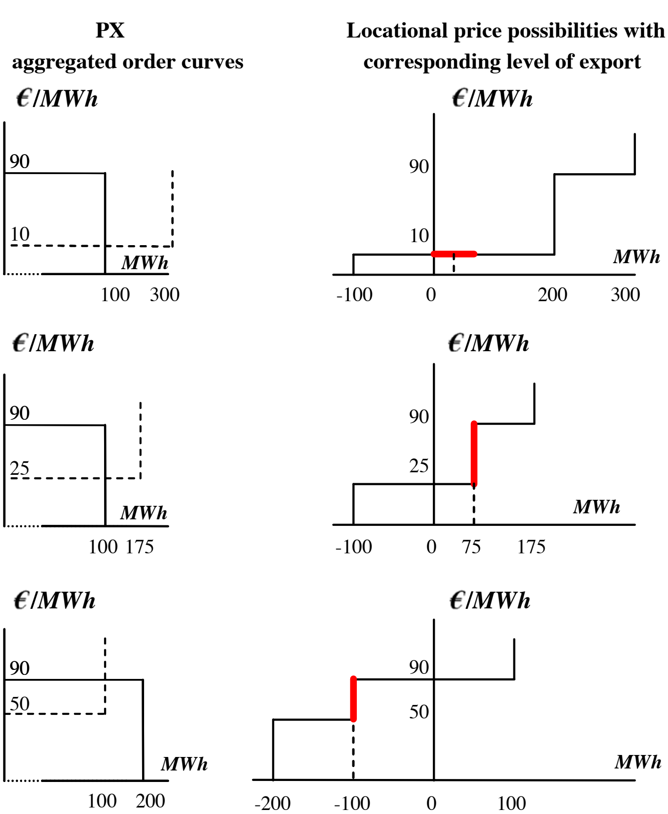


Fig. 5. Locational price ranges for solution in Fig. 4.

Table 2
Demand and supply orders introduced to PX 1 to 3

(€/MW h)	Linprog	CPLEX	Min CR	Max CR
PX1	10	10	10	10
PX2	41	30	30	50
PX3	73	50	50	90
μ_{13}	94	60	60	120

For the moment, the TLC initiative encompasses only France, Belgium and the Netherlands, which are aligned in that order. As the internal borders are not meshed, LMPs have more straightforward properties. For instance, the price of an interconnector is the difference between the location prices a both sides of the interconnector. Additionally the flow always goes from a high price region to the low price region, which is not necessarily the case if the network is meshed.

In [9], the price determination in case of price ranges is explained for TLC. The approach is specifically for three aligned markets. It is based on taking the middle price of an overlap between price ranges, subject to the LMP properties, which are called high level properties of the algorithm. If market coupling is extended to more markets and meshed networks, the approach discussed in this paper could be used, which is to minimize congestion rents, subject to the optimality conditions of the market coupling problem.

6. Conclusions

Market coupling means that exchanges optimize the clearing of the electric energy orders submitted to their day-ahead auctions. In

Please cite this article as: Meeus L, et al. Market coupling and the importance of price coordination between power exchanges. Energy (2008), doi:10.1016/j.energy.2008.04.013

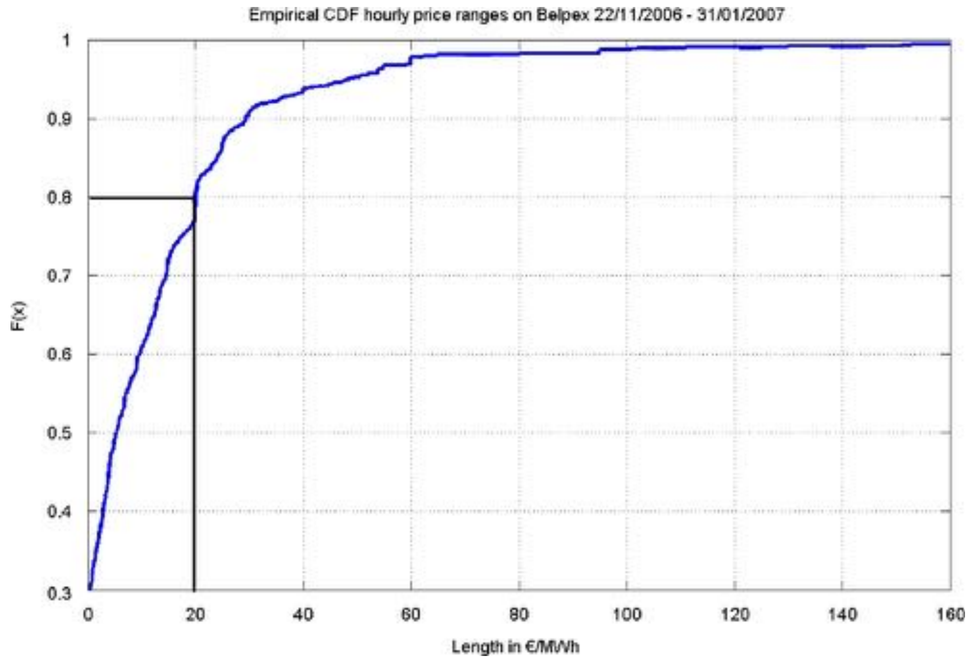


Fig. 6. Observations from Belpex.

doing so, orders introduced at different locations are exchanged to the extent that the available network capacities allow. Prices at these optimal exchange levels can be undetermined on an interval or price range due to the verticals in the aggregated order curves. For a single PEX, a simple rule such as taking the middle price of the possible prices is sufficient. For coupled exchanges, coordination is, however, necessary in order not to distort the locational incentives for network development, generation and consumption. Additionally, it has been discussed that LMPs can be derived from the optimality conditions of the market coupling optimization problem, but that these conditions do not necessarily uniquely determine the prices, in which case it has been discussed that the set of prices needs to be chosen that minimizes congestion revenues.

Acknowledgments

The authors thank the three anonymous referees and the editor for their valuable comments. The analysis and conclusions are of course the sole responsibility of the authors.

References

[1] Ehrenmann A, Smeers Y. Inefficiencies in European congestion management proposals. Util Policies 2005;13(2):135–52.
[2] Purchala K, Meeus L, Belmans R. The analysis of the cross-border capacity allocation in the Benelux region. In: Proceedings of the 40th CIGRE conference, 2004.
[3] Purchala K, Meeus L, Van Dommelen DM, Belmans R. Usefulness of DC power flow for active power flow analysis. IEEE power engineering society general meeting, 2005.
[4] Meeus L. Power exchange auction trading platform design. Leuven KU, PhD dissertation, 2006. See also: 〈http://hdl.handle.net/1979/338〉.
[5] Ott AL. Experience with PJM market operation, system design, and implementation. IEEE Trans Power Systems 2003;18(2).
[6] Stoft S. Power system economics, designing markets for electricity. New York: IEEE Press; 2002.
[7] Wu F, Varaiya P, Spiller P, Oren S. Folk theorems on transmission pricing: proofs and counterexamples. J Regul Econ 1996;10:5–23.
[8] O'Neill RP, Mead D, Malvadkar P. On market clearing prices higher than the highest bid and other almost paranormal phenomena. Electr J 2005;18(2): 19–27.
[9] Belpex. Market rules and procedures (indirect) participation agreement. Appendix 2, TLC algorithm. Belgium, Brussels. See also: 〈http://www.belpex.be/index.php?id=45〉.

Please cite this article as: Meeus L, et al. Market coupling and the importance of price coordination between power exchanges. Energy (2008), doi:10.1016/j.energy.2008.04.013

OSCOGEN

Optimisation of Cogeneration Systems in a Competitive Market Environment

Reinhard Madlener, Markus Kaufmann

Power exchange spot market trading in Europe: theoretical considerations and empirical evidence

OSCOGEN

Deliverable 5.1b

March 2002

Contract No.
ENK5-CT-2000-00094

Project co-funded by the European Community under the 5th Framework Programme (1998-2002)

Contract No.
BBW 00.0627
Project co-funded by the Swiss Federal Agency for Education and Science

Contract No.
CEU-BS-1/2001
Project co-funded by Termoelektrarna toplarna Ljubljana, d.o.o.

Abstract

This paper discusses exchange-based spot market trading of electricity in Western Europe, both from a theoretical and an empirical perspective. The theoretical section contains a selection of references to recent and seminal research in this field of research, and touches upon issues such as the dealing with grid constraints, modelling of bidding systems, bidding strategies, types of auctions, pricing and matching rules, types of spot markets, trading systems, and the main benefits and success factors of power exchanges. In the empirical part, it provides an overview of the main features and the functioning of the major existing (and planned) power exchanges in Europe (i.e. APX, Borzen, EEX, EXAA, GME, Nord Pool, OMEL, Powernext, UKPX, and APX UK). The article ends with a glossary of selected terms that are important in this field of research. The information contained should provide useful for the design of bidding tools that can be used by power-only and combined-heat-and-power (CHP) generating companies for generating bids in a liberalised power market environment.

JEL Classification Nos.: C62, C78, D44, D81, R32;

Keywords: electricity exchange, spot market trading, power pool auctioning, bidding system, CHP, OSCOGEN;

Table of Contents

1 Introduction

Over the last years and in the face of the ongoing liberalisation of the electricity sector in Europe and many other parts of the world, a number of electricity exchanges has been put into operation, and the development is far from completed. The main goal of exchange-based spot markets lies in the facilitation of the trading of short-term standardized products and the promotion of market information, competition, and liquidity. Power exchanges (ideally) also provide other benefits, such as a neutral marketplace, a neutral price reference, easy access, low transaction costs, a safe counterpart, and clearing and settlement service. Besides, spot market prices are an important reference both for over-the-counter (bilateral) trading, and for the trading of forward, future and option contracts.

In this paper, which mainly focuses on some theoretical considerations and a description of the most important exchange-based spot markets for electricity in Western Europe, we discuss various trading systems and related aspects. This will help to better understand how electricity generators can place their bids on the various power market exchanges, and helps in the design of bidding tools for the generation of optimal bids, and in the actual generation of bids, given certain production characteristics and a particular market structure and situation.

The organisation of the paper is as follows: Section 2 contains some theoretical considerations on the functioning and crucial aspects of bidding systems for electricity, and provides an overview on the most important literature in this field. Section 3 then describes the bidding mechanisms of the major (Western) European power exchange markets. Section 4 concludes. At the end of the paper, a glossary with a selection of important terms has been appended.

2 Theoretical Considerations

Competitive power markets are commonly organized around one or more auctions. Particularly, a market maker receives bids from generators and demand estimates or bids from power retailers and/or end-users, from which he/she calculates an optimal dispatch schedule – i.e. the production rule that minimizes the cost of meeting demand, subject to the technical and physical constraints imposed by the grid. Moreover, the price and dispatch schedule found constitutes a reference for other products, such as bilateral contracts, term products, financial contracts, physical options, and the like (Léautier, 2001). In order to enhance market transparency, typically a daily price index is published.

2.1 Bidding System Modelling

In the literature several approaches have been introduced to model the behaviour of generating firms that place bids in the power exchange market. Bolle (1992), Green and Newbery (1992), and Newbery (1998) have modelled the market by means of *supply-function equilibria*, i.e. the bids of a supplier are assumed to be continuously differentiable. In contrast, von der Fehr and Harbord (1993) and Brunekreeft (2001) have modelled the pool market by an *auction approach* that assumes a *step supply function*. The model of Brunekreeft, for example, provides theoretical arguments for several empirical observations. For example it reveals that with a decrease in the number of firms the bids of these firms increase unambiguously. Wolfram (1998) obtains corresponding empirical results.

2.2 Bidding Strategies

The actual bidding strategy chosen by an electricity generator will depend on a multitude of factors, such as market history, auction market rules, etc. The development of an appropriate bidding strategy requires, on the one hand, the simulation of the market and, on the other hand, a dynamic adaptation of the bidding strategy according to the changes in the market.

Supatgiat, Zhang, and Birge (2001) derived optimal bidding strategies for generators as a Nash equilibrium. They proved that in a deterministic demand case a pure strategy equilibrium point always exists. But with stochastic demand it is possible that no such point will result. They also show that the dispatch result may not be socially optimal when each bidder behaves optimally. Wolfram (1998) examined empirically the bidding behaviour in the case of the pool system in England and Wales and found evidence for several manifestations of strategic bidding. For example the mark-up over marginal costs in sale bids rises with the probability that the plant will be used.

2.3 Types of Auctions

A variety of auctions can be thought of to be used as allocation and pricing mechanisms for electric power. Table 1 depicts an example for a classification of auctions. One criterion is the number of bidding sides. If only price bids from one market side – normally the sellers – are accepted, the auction is called *one-sided*. In contrast, a *double-sided* auction uses bids from both the sellers and the buyers of the traded commodity. For the pricing rule there are also two general variants relevant. First, the *uniform pricing* provides the same price for every accepted bid. The price is set according to the price limit of the last accepted bid. Second, the transactions can be priced in a discriminatory manner (*pay-your-bid pricing*), with the price being the limit of the accepted bid in question (see section 2.6 below for details). [1] Auctions also differ in the way bids are handled, i.e. whether they are disclosed to all participants or not (*sealed vs. open auctions*).

Table 1. Classification of auction types (example)

Criteria	Type	
No. of bidding sides:	One-sided	Double-sided
Objective function:	Cost minimisation	Consumer payment minimisation
Pricing rule:	Uniform pricing	Discriminatory (pay-your-bid) pricing
Disclosure of bids:	Open	Sealed

Source: own illustration

In order to find an efficient mechanism various auction types have been studied. For example Hobbs et al. (2000) analysed a Vickrey-Clarke-Groves auction, which is a generalization of the Vickrey auction.[2] A special feature of this auction type is the payment determination, which is a function of the bid price for the amount of power accepted and of the increase in social welfare that results from accepting that bid. This feature motivates honest bidding even by participants with market power. The disadvantage of this type of auction is that it will frequently result in losses for the auctioneer. Elmaghraby and Oren (1999) compared auction structures differentiated according to the way the daily demand is partitioned in separate markets. Another way to classify auctions is according to their demand type. On the one hand, in *vertical auctions*, daily demand is split into hourly or half-hourly markets. *Horizontal auctions*, on the other hand, are characterised by a division of the demand into

[1] See Sheblé (1999): 19-20, 45.

[2] In a Vickrey auction or a second-price sealed-bid auction for an indivisible good, the buyer with the highest bid gets the good at the price corresponding to the second-highest bid.

different types – e.g. base, shoulder and peak demand – that are auctioned sequentially. They concluded that a horizontal auction is more efficient than a vertical auction.

The question of whether to use uniform or discriminatory pricing rules is addressed by Bower and Bunn (2001) and Madrigal and Quintana (2001), among others. In the model of Bower and Bunn the auction results in higher market prices when using the discriminatory pricing rule than with the uniform pricing rule, because of a significant informational advantage of large participants in a discriminatory auction. In contrast, Madrigal and Quintana propose a non-uniform pricing rule to avoid prices far above the competitive level. Denton, Rassenti, and Smith (2001) investigate the performance of an auction mechanism with *sealed bids* and a mechanism with *open displayed tentative market results* until the market is called, respectively. The former mechanism outperforms the latter one in a non-convex environment.[3] With sealed bids attempts to manipulate prices are more costly.

2.4 Dealing With Grid Constraints

Externalities arising from the transmission network can be seen as an 'unusual technical feature' inherent to the power system. Léautier (2001) for example shows that in the presence of transmission constraints power exchange auctions do not necessarily yield *ex post* production-efficient solutions.

Another question is the expansion of the grid. Boyer and Robert (1998) deal with the search for mechanisms to ensure efficient investment in the enlargement of the network. Proposed mechanisms include some form of *access pricing rule* that allows entrants to increase the grid capacity by using the infrastructures of incumbents and tradable transmission congestion contracts that reward investment in grid infrastructure.

2.5 Other Issues

There are various other issues concerning bidding-based trading systems for electricity. For example, the possibility of generators to exercise *market power* attracts considerable attention. Wolak (2000) and Green and Newbery (1992) addressed this issue for Australia and for England and Wales, respectively. Wolak suggested regulating the price by forcing a large enough quantity of hedge contracts on the generators to restrict the exercise of market power.

Geman (2001) discusses some features of *spot and derivatives prices*. Boisseleau (2001) is concerned about *competition* on a power exchange and about *competitiveness* of a power exchange. These two issues cannot be separated, as a minimal level of competition among the participants on an exchange is a condition for the competitiveness of this exchange.

Others analyse the *unit commitment problem*. Dekrajangpetch and Sheblé (1999) state that the *LaGrangian relaxation* based auction methods are biased in favour of the power suppliers.[4] They suggest that the unit commitment should be decentralized in order to allow the market operator to use auction methods that are not based on heuristic rules, like for example interior point linear programming. Madrigal and Quintana (2001) propose a non-uniform pricing scheme to select a schedule if no market equilibrium exists in the unit commitment problem.

[3] Non-convexity in this context refers to the avoidance of fixed cost penalties for generators in the case of operation below the minimum capacity and for wholesale buyers in the case of failure to serve their non-interruptible demand.

[4] Such an auction uses LaGrangian relaxation to find the solution to the unit commitment problem (see also Glossary, p. 28).

2.6 Markets

On a liberalised electricity market, the participants can act on a variety of markets.[5] Traditionally they can trade electricity bilaterally on the over-the-counter market (OTC), where the bulk of transactions is still being settled. Alternatively, in some countries organised markets (i.e. exchanges) have been established. These organised markets typically comprise one or more of the following markets.

2.6.1 Day-ahead market

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 x minutes each. Each bidding firm makes a price bid for every generation unit for the whole day.

Commonly, 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 being traded. 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 organised for a certain number of *standardised blocks* (dominant), or for *flexible blocks* (as has been introduced at the Amsterdam Power Exchange).

2.6.2 Intra-day/Adjustment/Hour-ahead market

Due to the long time span between the settling of contracts on the day-ahead market and physical delivery, exchanges sometimes offer an *intra-day market*, sometimes also referred to as *hour-ahead or adjustment market*. This market closes a few hours before delivery and enables the participants to improve their balance of physical contracts in the short term.

2.6.3 Balancing services/Real-time market

To balance power generation to load at any time during real-time operations, system operators use a balancing or real-time market. After the closure of the spot market, participants can submit bids that specify the prices they require (offer) to increase their generation or decrease their consumption (decrease their generation or increase their consumption) for a specific volume immediately. Such balancing services (also referred to as ancillary services), for which competitive market mechanisms are increasingly sought for, cover the provision of a number of services (e.g. voltage control, frequency response and reactive power support).

Some grid operators in Europe have started to procure the capacities and energy necessary to provide ancillary services from other companies via published auctions. This currently still fragmented market is expected to become increasingly integrated in the near future.[6] Therefore, especially the tertiary- and minute-reserve market could turn into a liquid wholesale market, as there are many power producers who are able to provide those services and to meet the existing substantial needs of both the grid operators and the suppliers in this direction. Furthermore, as there is no need to make additional investments in technical equipment, the market access barrier is small.

CHP plants could basically provide these services, too, given that sufficient capacity is being held in reserve for these purposes when optimising the unit commitment and/or dispatching. The authority responsible for the bidding at the market has – sometimes simultaneously – to find the best bidding strategy for electricity, reserve capacity, heat, and possibly fuel in order to maximize profits.

[5] See Kraus and Turgoose (1999): 64-68.
[6] Personal communication with A. Hofmann/BEWAG; see also www.eon-net.com; www.rwenet.com .

On some markets, the reserve capacity is being cleared only after the clearance of the power market. In those cases it is quite likely that prices are being calculated at the marginal cost, as this is the last possibility to sell the available capacity. On the contrary, this situation seems quite unrealistic, as several power exchanges are in the process of building up intra-day trading markets. Therefore, plant operators will trade on fixed and variable costs in order to make the opportunity profits otherwise realized at the power exchange market.

2.7 Trading System

European exchanges normally provide *bidding-based trading* in contracts for power delivery during a particular hour of the next day (except in England and Wales, where half-hour contracts are traded). The usual trading system is a daily *double-sided auction* for every hour to match transactions at a single price and a fixed point in time. Again the UK is an exception, since trading only takes the form of *continuous trade*.

In either form participants determine, by submitting their bids, how much they are prepared to sell or buy at what prices. Sometimes the possible price values are bounded by a top limit (e.g. EEX in hourly auctions, Powernext). Another special feature to be aware of are limits to price volatility in order to achieve price continuity (e.g. EEX in continuous trading, Borzen). If the potential execution price lies outside these limits, participants are allowed to change their bids in an extended call phase of an auction or an auction is initiated in continuous trading to get a new reference price.

Usually the participants can add several execution conditions to their bids, and they can offer or ask the same quantity of power for a period of consecutive hours called *block bids*. All the submitted bids are collected in a sealed order book, i.e. the participants know only their own bids.

2.7.1 Auction trading

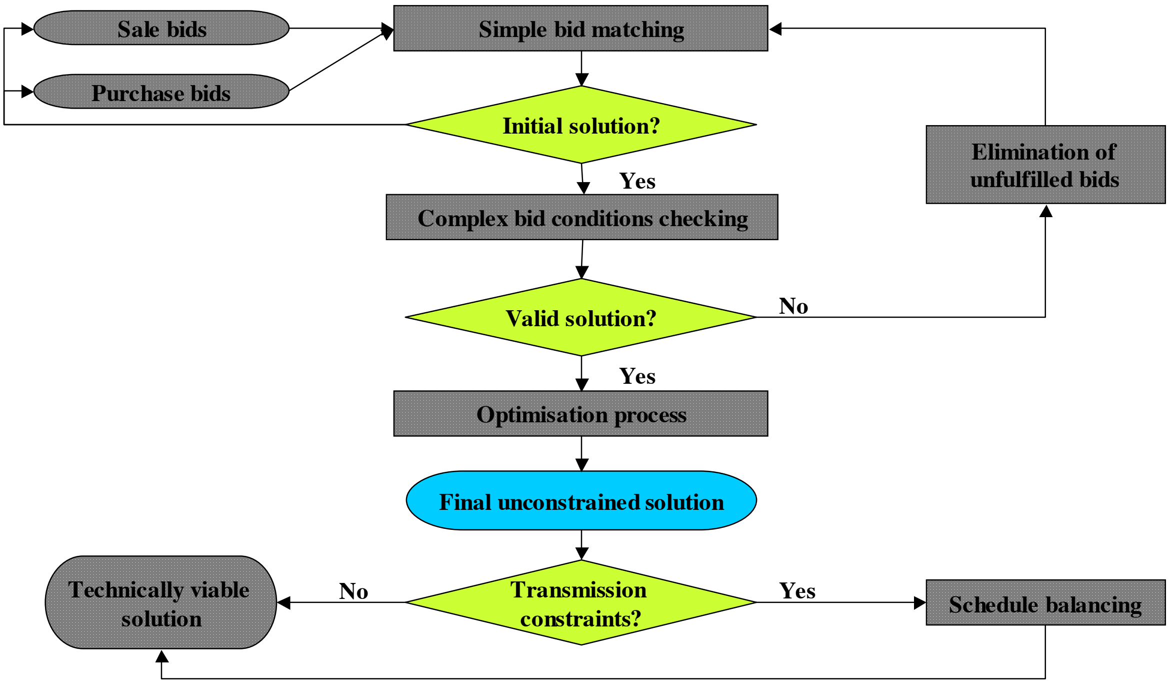
Figure 1 depicts the *basic structure of an auction*. Participants can submit and change their bids until the closure of the call phase. Changed bids get a new time designation, which may be important for the matching of bids (section 2.9). For *price determination* all the bids collected up to the predetermined closure of the call phase are sorted according to the price and aggregated to get a market demand and supply curve for every hour. Some exchanges include the block bids in the aggregation by changing the blocks into price-independent bids for the hours concerned (e.g. APX, EEX in hourly auctions, Nord Pool). Others use continuous trading to settle block contracts (section 2.8.2.).

The simple bid matching ignores any execution conditions or grid capacity constraints and results in an initial market clearing price, or *initial auction price*, for every hour and trade volumes for every bid (see Figure 2). The market clearing price is the price level at the intersection of the aggregated demand and supply curves. If there is no intersection of the two curves, there may be a second round of submitting bids in order to get an auction price or the last calculated market clearing price of the product in question – referred to as the reference price (see sections 2.8 and 2.9 below for more details).

The initial solution has first to be checked against all the *conditions added to the bid*. For block bids, an average of the market clearing prices for the hours included in the bid is calculated. This price has to be equal, or better, than the price limit stated by the participant to satisfy the bid (minimum income (sales) or maximum payment (purchases) condition).

If not all conditions are satisfied the initial solution is not valid. In this case one of the unfulfilled bids is eliminated and the price calculation is run again. This checking process is iterated until all the remaining bids can be fulfilled.

Figure 1. Basic structure of an auction



Source: own illustration

Sometimes the *valid solution* resulting of the bid conditions checking *is optimised* in a next step (such as at APX and OMEL). This process tries to minimise the amount of money that removed bids would earn if they were not removed.

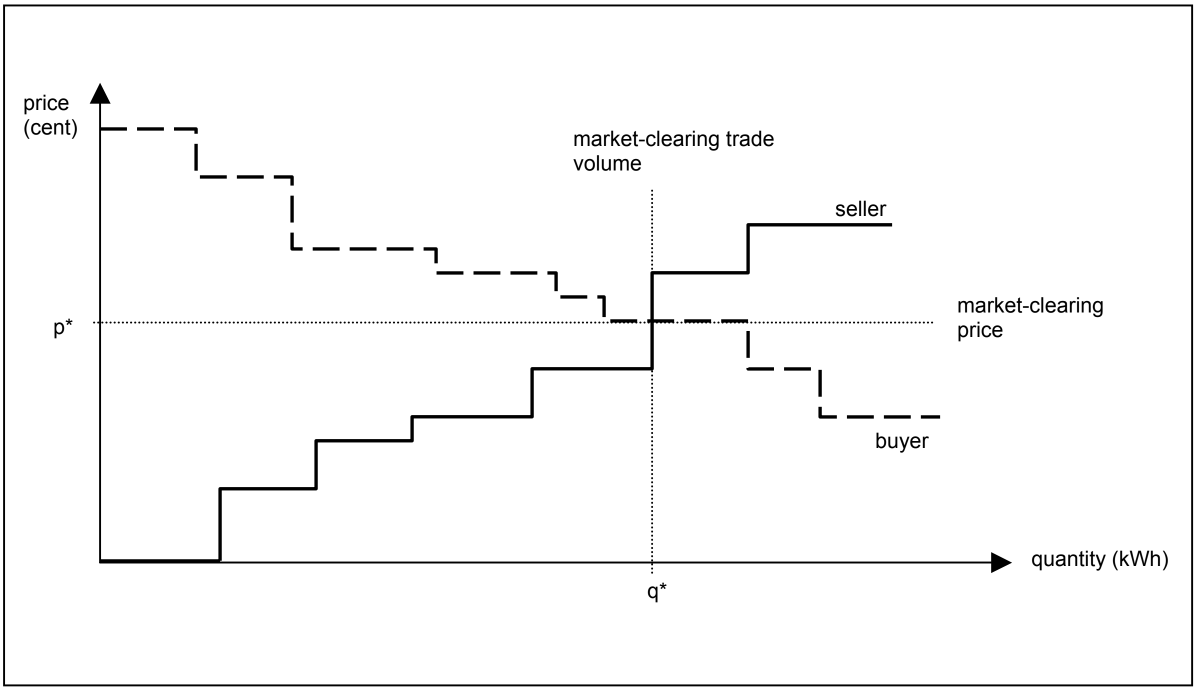
The trade volumes of the matched bids have also to be checked against the transmission grid capacities. If there are *transmission constraints*, the schedules have to be balanced to get a technically viable solution. *Schedule balancing* is done by only adjusting the trade volumes (like at OMEL), by adjusting the trade volumes and re-running the iterative bid matching (like at APX), or by splitting the market in several areas (like at EXAA, EEX, GME, Nord Pool). This takes place either before (APX) or after the optimisation (OMEL) process and results in a technically viable solution.

2.7.2 Continuous trading

Some exchanges provide an alternative trading form to the auction system called *continuous trading*. This form is used to either trade only block contracts (Borzen, EEX) or individual hours and block contracts (UKPX, APX UK).

Continuous trading differs from auctions in the following points. Firstly, participants have access to the order book. Secondly, each incoming bid is immediately checked and matched if possible according to price/time priority. Finally, the contract price is not the same for all transactions as it is determined according to only the concerned bids (pay-your-bid pricing at UKPX, APX UK) or the bid register at the time of the bid matching (Borzen, EEX). At some exchanges (Borzen, EEX) continuous trading is preceded by an opening auction and followed by a closing auction. Both auctions are similar to the auction described before.

Figure 2. Simple bid matching



Source: own illustration

2.8 Pricing Rules

2.8.1 Auction trading

In auctions the most common pricing rule is uniform pricing. The uniform price is the price level at the intersection of the aggregated demand and supply curves and is normally called the *market clearing price*. It provides a maximum trade volume. Because a simple aggregation of the bids results in discrete curves, there may not be a well-defined price solution. Exchanges handle this problem in two different ways. Some use linear interpolation instead of simple aggregation to get linear curves (EEX in hourly auctions, Powernext).[7] Others set up additional rules for price determination in case of multiple price levels at the intersection of the two curves.

Linear interpolation can be used at two different stages. For instance, EEX interpolates between the price values of every single bid, whereas Powernext interpolates between the highest price for which aggregated demand is greater than aggregated supply and the lowest price for which aggregated supply is greater than aggregated demand.

Rules for price determination in case of multiple price limits at the intersection of aggregated demand and supply curve differ also between the various exchanges. At APX the average of the purchase and the sale price limit at the intersection is chosen.[8] OMEL determines the market clearing price as the price of the last accepted sale bid that was accepted to meet the matched demand.[9]

In Austria (EXAA), in contrast, price determination is based on the so-called reference price, defined as the weighted average of the market clearing prices of the same product on the same weekday of the last three weeks:

---

[7] Information results from personal communication with T.Pilgram/LPX and from www.powernext.fr .
[8] See www.apx.nl/main.html .
[9] See www.omel.es .

- If the reference price lies *between the highest and lowest price limit*, the auction price is equivalent to the reference price;
- If the reference price is higher than the *highest price limit*, the auction price is determined according to this limit;
- If the reference price is lower than the *lowest price limit*, the auction price is determined according to this limit.[10]

To minimize the surplus for each price limit in the order book, EEX uses a still more sophisticated rule for the opening and closing auctions in continuous trading, namely one that is based on the surplus: if the surplus of all price limits is on the buy side (*demand surplus*), the auction price is stipulated according to the highest limit; in contrast, if the surplus of all price limits is on the sell side (supply surplus), the auction price is stipulated according to the lowest limit.[11] When there is a supply surplus for one part of the price limits and a demand surplus for another part, or when there is no surplus for any price limit, the reference price as the last price determined for an energy product is taken into account for the stipulation of the market clearing price (i.e. in the same way as at EXAA).

At Borzen the middle value of the possible values is taken as the market clearing price, provided it is equal or greater than the reference price. Otherwise, the reference price is taken for the settlement of the contracts.[12] The reference price is defined as the *market clearing price* achieved in the previous corresponding trading session (previous working day, previous non-working day, national or other holiday). The reference price is also used for the pricing of transactions when only bids without price limit are executable.

2.8.2 Continuous trading

In continuous trading there is no uniform price for all settled contracts. Contracts are either priced at the offered price of the bids in question (APX, UKPX, APX UK), or according to complex rules that take all the bids of the order book at the moment of matching into account.

The following rules apply for price determination in continuous trading at EEX (in addition to price/time priority; Borzen established similar rules):

- if an incoming bid encounters an order book where there are only bids with price limit on the opposite side of the book, the price is determined by the respective highest bid or lowest ask limit in the order book;
- if a bid without price limit is entered into an order book where there are only bids without price limit on the opposite side of the book, this bid is executed at the reference price and to the extent possible;
- in all other cases the incoming bid is executed against the bids without price limit, according to price/time priority, at the reference price or higher (at the highest limit of executable bids) in the event of unexecuted purchase bids, or at the reference price or lower (at the lowest limit of executable bids) in the event of unexecuted sale bids, respectively.

2.9 Matching Rules

2.9.1 Auction trading

In auctions all purchase bids with a price limit higher than the market clearing price and all the sale bids with a price limit lower than the market clearing price are executed. Just as for the case of price

[10] See www.exaa.at .
[11] Information results from personal communication with T. Pilgram/LPX, 4 June 2002.
[12] See www.borzen.si/en/about.htm .

determination the simple aggregation of the bids may not result in well-defined trade volume since supply and demand curves are discrete. Again different solutions to this problem exist.

Linear interpolation as mentioned with regard to price determination is one of these solutions. At EEX, for example, in the hourly auctions for every bid a volume can be assigned to every price. At Powernext, to give another example, the volume assigned to each participant will be calculated by linear interpolation between the two price/quantity combinations of the bid within which the market clearing price falls.

Other exchanges use rules for matching an eventual surplus instead of linear interpolation. In case of a demand (supply) surplus, APX and OMEL for instance distribute the offered (demanded) quantity at the market clearing price proportional to the volume of the purchase (sale) bids at this price limit. Another way is to state a matching priority according to the volume (bigger volumes come first) and/or the time designation of the bids (first come, first serve). This ensures that at maximum one bid is subject to only partial execution (Borzen, EEX in auctions around continuous trading, EXAA).

2.9.2 Continuous trading

Continuous bids are normally matched according to price acceptance of bids of the opposite side. At EEX, to give an example, incoming bids are checked against and matched with the bids in the order book to the possible extent according to price/time priority. Bids with no price limit have precedence over bids with a price limit and sale (purchase) bids with a lower (higher) price limit take precedence over bids with a higher (lower) limit. In the event of bids having the same limit, time applies as the second criterion. In this case, bids that were entered earlier have priority. Unexecuted bids, or parts of bids, are entered into the order book and sorted according to the price/time priority.

2.10 Services Provided and Success Factors of Power Exchanges

In this final subsection, we want to list some of the most important services (benefits) offered by, and the success factors of, power exchange markets.

A power exchange typically offers the following services:

- an automatic and in most cases Internet-based market interface;
- clearing & settlement of deals;
- counterpart risk taking;
- accounting and billing of the spot market and term-market products;
- various information needed, or asked for, by the market participants.

Success factors of an exchange can be measured by:

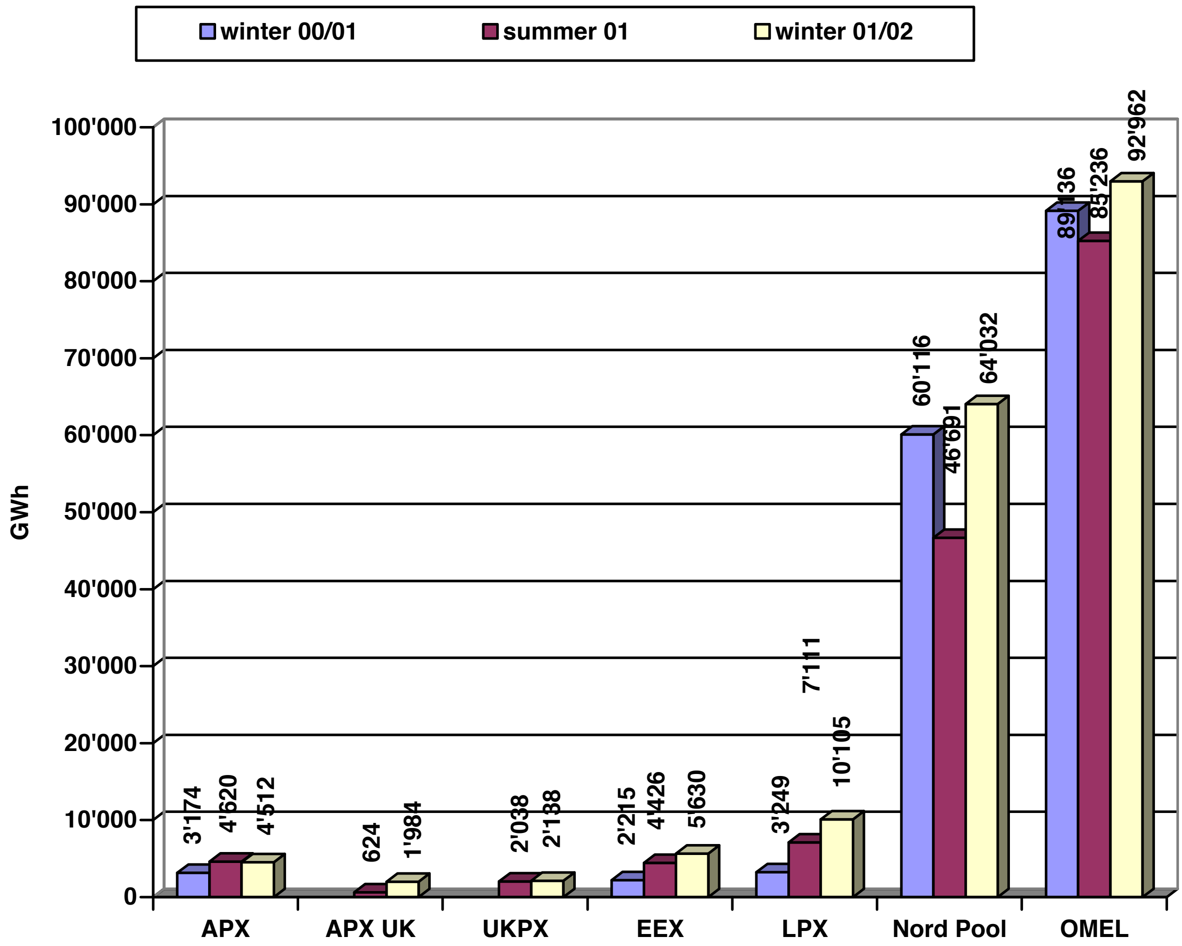
- number of market participants;
- liquidity of the market;
- (regional) growth of the market;
- competitiveness of the fee structure.

3 Empirical Evidence: Market Mechanisms and Bidding Systems at European Power Markets

In this section we provide an overview of the various bidding systems in place, or currently being planned, at the main Western European power markets (in alphabetical order: APX, Borzen, EEX/LPX, EXAA, GME, Nord Pool, OMEL, Powernext, and the triade UKPX/ APX UK/ UK IPE).

As an indication of the relevance of the various exchanges, total volumes traded on the spot market for the exchanges that have been in operation for at least a year are summarized in Figure 3. Particularly, the figures shown depict the turnover for six months (winter: October to March, summer: April to September) on the day-ahead market (except for APX UK and UKPX: hour-ahead market). Note also that the volume traded at OMEL is not directly comparable to the others because it is a mandatory pool.

Figure 3. Spot market volumes on European power exchanges



Source: CEPE, based on a similar illustration by Cap Gemini Ernst & Young (2002)

3.1 APX – Amsterdam Power Exchange (The Netherlands)

The Amsterdam Power Exchange comprises a *daily day-ahead spot market* (since May 1999) and, more recently, an *adjustment market* (since Feb 2001).[13] In 2001, on average some 9% of Dutch net electricity consumption were traded on the APX. By January 2002 altogether 36 international market players (generators, distributors, traders, industrial end-users) have been active on the APX.[14]

[13] See also www.apx.nl/products/main.html .
[14] For another assessment of APX see Boisseleau (2001).

3.1.1 Day-ahead spot market

The day-ahead spot market enables participants to buy and sell electricity for any of the 24 hours of a day one day in advance. Participants can also offer blocks, i.e. the same quantity of power for a period of more than one hour. In contrast to other exchanges, where blocks are usually standardized, APX allows the trading of flexibly definable blocks since October 2001.

APX runs a daily two-side energy auction, where all players can act as buyers or sellers. Bids are made known to APX fully electronically until 10:30 on the day prior to delivery. They express in up to 25 quantity/price pairs how much power (in MWh) a participant wants to buy or sell up to a specific price limit (in Euro, with 2 decimals). Block bids contain two conditions: First, the whole volume has to be accepted by the matching process. Second, the average price over the hours included in the block has to be equal, or better, than the stated price limit (minimum income (sales) or maximum payment (purchases) condition).[15]

3.1.2 Adjustment market

The adjustment market at the APX is designed to correct unexpected supply-demand imbalances which arise during the day because of load or generation variations (short-term position improvements by trading relatively small quantities). It is based on a simple model: *hourly prices/volumes* and *block bids*. The adjustment market facilities provide bid and ask prices (in EUR/MWh) and the latest trade volumes, and allow the avoidance of bilateral contracting (which is usually more cumbersome and costly). Based on continuous trade, transactions are determined by price acceptance (i.e. quote-driven, where demand and supply meet) and are executed immediately whenever possible.

3.2 Borzen (Slovenia)

The daily market at the Borzen power exchange started operation on 3 January 2002. There, supply of and demand for electricity for the next working day, or for a period up to and including the next working day, are matched.[16] Additionally, Borzen provides a week-ahead market for so-called 'preferential dispatch' electricity (see 3.2.2.). The number of participants in April 2002 was 16. The average daily traded volume from January 2002 until April 2002 was 2966 MWh (344 MWh for base-load power, 65 MWh for peak-load power, and 26.5 MWh for hourly power, respectively).

3.2.1 Day-ahead market

At the Borzen daily market, currently four products are traded (3 block contracts in continuous trading sessions, and 24 hourly contracts in an auction):

- *base-load power* (0:00 – 24:00 hours): the basic quantity/lot is 24 MWh;[17]
- *peak-load power* (6:00 – 22:00 hours; working days only): the basic quantity/lot is 16 MWh;
- *off-peak load power* (0:00 – 06:00 hours and 22:00 – 0:00 hours); the basic quantity/lot is 8 MWh;[18]

---

[15] When entering a (sales) block bid, the participant defines a block of consecutive hours, a volume applicable for all hours, and a price. 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 throughout 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 (cf. www.apx.nl/marketresults/aggcurve/disclaimer.html).

[16] www.borzen.si/en_data.htm , additional information results from personal communication with Boris Štraus/ BORZEN

[17] When time changes from winter to summer, 1 lot equals 23 MWh; when time changes from summer to winter, 1 lot equals 25 MWh.

[18] When time changes from winter to summer, 1 lot equals 7 MWh, and when it changes from summer to winter it is equal to 9 MWh.

- *hourly power* (24 hours of one day); the basic quantity/lot is 1 MWh.[19]

There are two types of bids: *market bids* (the participant sets no limit regarding the price) and *limited bids* (the participant sets the acceptable highest purchase and lowest sale price).[20] Volumes are stated in MWh, corresponding to a multiplier of the basic quantity unit (lot) of the product. Prices are stated in SIT[21]/MWh (rounded to the nearest 10 Tolars).

In *auction trading*, the following additional or special conditions for the execution of bids are possible:

- *remaining quantity bids:* this is a special kind of bid made by the market participants after the marginal price has been calculated and the possible remaining unmatched quantity is known; these bids only include the quantity because the remaining quantity is sold at the marginal price.

In *continuous trading*, the following additional or special conditions for the execution of bids are possible:

- *undisclosed quantity bids:* the order book does not reveal the entire quantity of the bid but only part of it; such bids can only be limited bids;
- *"all-or-nothing" bids:* the bids are only executed if the entire quantity of the bid is agreed upon;
- *"stop" limited bids:* the bids are entered in the order book as limited bids only after exceeding, or falling below, a set price;
- *"stop" market bids:* the bids are entered in the order book as market bids only after exceeding, or falling below, a set price.

Trading of hourly contracts is organised as an auction which is divided into several stages: the (a) *pre-trading* stage lasts from 8:00 a.m. until 10:00 a.m., while the subsequent (b) *first-price stage* lasts from 10:00 a.m. until 10:14 a.m. Participants can enter and/or remove their bids during both stages. In the meantime, the market operator publishes data on the best bids. During the first-price stage, the market operator additionally publishes a balanced price for each product separately. When the first-price stage ends, the *market clearing price* is calculated for each product separately. During the (c) *final stage* of the auction, from 10:15 a.m. until 10:30 a.m., the surplus amount is offered; in this stage participants can only purchase any eventual surplus electricity at the calculated marginal price.

Block contracts are settled in continuous trading sessions during from 8:00 a.m. until 10:00 a.m., with a pre-trading stage lasting from 6:00 a.m. until 8:00 a.m. During pre-trading only limited bids without special conditions can be entered and the price and quantity of the sale bid with the lowest price and the purchase bid with the highest price are published. The continuous trading session starts with an opening auction to calculate the price for all transactions concluded on the basis of bids received during pre-trading.

3.2.2 Preferential dispatch trading (week-ahead auction)

In the preferential dispatch trading market, the following products are traded once a week for the following week: (i) *base load* (0:00 – 24:00 hours, Monday – Sunday) and (ii) *peak load* (7:00 – 21:00 hours, Monday – Sunday).

Participants are certain (temporarily) qualified electricity generators nominated by the Slovenian government and generators that use domestic fuel. A qualified generator has, in individual generation

[19] When time changes from winter to summer, trading involves 23 hours of the day, and when it changes from summer to winter it involves 25 hours.

[20] See „Rules of Operation for the Electricity Market" issued by BORZEN Market Power Operator d.o.o. (www.borzen.si/).

[21] SIT = Slovenian Tolar (EUR 1 = SIT 225, USD 1 = SIT 258; approx.).

facilities, to generate electricity with an above-average actually achieved output in the combined generation of electricity and heat, or to use "either waste or renewable energy resources in an economically appropriate way in compliance with environmental regulations". The volume of preferential dispatch electricity is restricted to 15 per cent of the primary energy required to meet the electricity demand of one year according to the Slovenian energy balance sheet.[22]

Trading on the preferential dispatch market is organised as an auction, too. The *pre-trading stage* lasts from 10:30 a.m. until 11:00 a.m. and the *first-price stage* from 11:00 a.m. until 11:30 a.m. Participants may enter and/or remove their bids during both stages. During the first-price stage, the market operator publishes data on the best bids and a balanced price for each product separately. At 11:30 a.m. the calculation of the uniform price starts. When the uniform price is published, the trading for surplus amounts begins and lasts until 12:00 noon. During this stage it is only possible to purchase the eventual surplus amount of electricity at the market clearing price.

3.3 EEX – European Energy Exchange (Germany)

3.3.1 The merger of EEX and LPX

The German power exchanges in Leipzig (LPX) and Frankfurt (EEX), respectively, are currently in a period of transition after the announcement has been made in October 2001 that the two exchanges will be merged after all. The LPX spot market was launched in June 2000 with auction trading for individual hours and block contracts.[23] EEX started operation in August 2000 with a day-head market for individual hour and block contracts settled in auctions and continuous trading, respectively.[24] The number of participants at LPX was around 80 in March 2002. In January 2002, in contrast, 60 participants were admitted to trade at EEX.

The new exchange, named European Electricity Exchange (EEX) and located in Leipzig, will offer its participants trade with already existing products and proven trading systems. More specifically, at the spot market it will offer the *auction market* as well as the *continuous trading*. Trading takes places from Monday to Friday except for pan-German holidays. Therefore traded delivery days are the calendar day following the trading day, all days of the weekend, and pan-German holidays directly after the trading day as well as the trading day directly after weekends and holidays. On Fridays, for example, the products are traded which are actually fulfilled on the following Saturday, Sunday, and Monday.

3.3.2 Auction market

The system of the auction market corresponds more or less to the trading system that hitherto existed at the LPX market.[25] Trading is based on double-sided auctions for every individual hour. Participants can transmit their bids to EEX and can change them via a special Internet software (ElWeb; receipt before 12:00 noon), or by fax (receipt before 11:30 a.m.; backup solution). All bids are collected in a *closed order book* and then used at 12:00 a.m. to calculate the prices.

Individual hour contracts are traded with a minimum of 0.1 MWh (in steps of 0.1 MWh) for day-ahead delivery. Participants at least have to state a volume for the bottom and top price limit defined by EEX and can add 62 price/volume pairs within the price scale. Specifying the same volume for the bottom and top price limit generates independent bids.

Apart from the individual hour contracts, the following blocks are being offered in auction trading:

---

[22] See also Articles 1 and 155 of the Borzen „Rules of Operation for the Electricity Market" (www.borzen.si).
[23] See www.lpx.de/index_e.asp .
[24] See www.eex.de/content/en_index.html .
[25] Personal communication with T. Pilgram/LPX, 4 June 2002.

- 1 – *EEX Night* (0:00 – 6:00 a.m.)
- 2 – *EEX Morning* (6:00 – 10:00 a.m.)
- 3 – *EEX High-Noon* (10:00 – 2:00 p.m.)
- 4 – *EEX Afternoon* (2:00 p.m. – 6:00 p.m.)
- 5 – *EEX Evening* (6:00 p.m. – 12:00 p.m.)
- 6 – *EEX-Rush Hour* (4:00 p.m. – 8:00 p.m.)
- 7 – *Baseload* (0:00 p.m. – 24:00 p.m.)
- 8 – *Peakload* (8:00 a.m. – 8:00 p.m.)
- 9 – *Off Peak 1* (0:00 a.m. – 8:00 a.m.)
- 10 – *Off Peak 2* (8:00 p.m. – 12:00 p.m.)

Participants state the desired volume and price for a block. The maximum size of an individual block bid has been set to 100 MW, and a maximum of six block bids per participant can be sent.

3.3.3 Continuous trading

EEX provides also continuous trading for three block contracts. The system is taken from the former EEX. The products traded continuously are defined as follows:

- *Base-load contracts* have 24 MWh/lot (equivalent to a constant 1 MW delivery over the period midnight – midnight);[26] the quotation is in unit points of EUR/MWh; the minimum price movement is 0.01 point (corresponding to 1 $¢_{EUR}$/MWh);

- *Peak-load contracts* have 12 MWh/lot (equivalent to a constant delivery of 1 MW in the period from 8:00 a.m. to 8:00 p.m.) and are eligible for Monday to Friday; quotation of unit points is in the same way as for base-load contracts (i.e. unit points of EUR/MWh, minimum price movement 0.01 point, corresponding to 1 $¢_{EUR}$/MWh);

- *Weekend base-load contracts* have 24 MWh/lot (equivalent to a constant 1 MW delivery over the period midnight – midnight) and only are eligible for Saturday and Sunday together; the quotation is in unit points of EUR/MWh; the minimum price movement is 0.01 point (corresponding to 1 $¢_{EUR}$/MWh).

Two basic types of bids are permitted for the price determination process: *market orders* (i.e. unlimited bid and ask orders, to be executed at the best possible price) and *limit orders* (i.e. bid and ask orders which have to be executed at the given limit or better). In addition three special order types are provided:

- *Market-to-limit orders* are unlimited bids of which any unexecuted part enters the order book with the same price limit and time stamp as the executed part;
- *Stop orders* are entered into the order book automatically as a market or limit order, as soon as the given stop limit is reached (undercut or exceeded);
- *Iceberg orders* are a number of consecutive orders with the same limit and quantity; only the first order is visible in the order book; when the first order is executed, the second order becomes visible, etc.

Several execution conditions and trading limitations are selectable to specify the bids:

- an *immediate-or-cancel (IOC) order* is an order which is immediately executed either in its entirety or as much as possible. Those parts of an IOC order which are not executed are deleted without being entered into the order book;

[26] When the clock is changed from wintertime to summertime, the lot comprises 23 MWh, and when it is changed again from summertime to wintertime, the lot comprises 25 MWh.

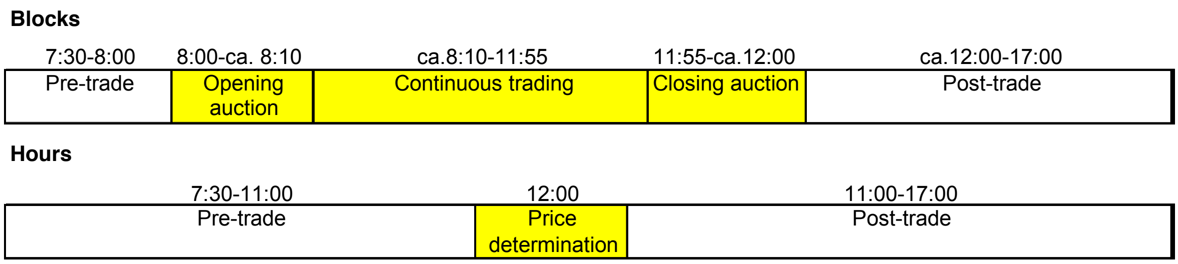
- a *fill-or-kill (FOK) order* is an order which is either executed immediately in its entirety or not at all; if complete execution is not possible immediately, the FOK order is deleted without being entered into the order book
- bids can be restricted to auctions only, to the opening auction only, or to the closing auction only;
- an accept surplus order is an order which is permitted during order book balancing phases only.

Continuous trading starts at 7:30 a.m. with the *pre-trading phase* in which the participants can submit bids and the order book is closed (see also Figure 4). In order to be able to process all orders from the pre-trading phase and to be able to determine an objective reference price at the start of the trading, the trading of blocks begins at 8:00 a.m. with an *opening auction* that includes a *10-minute call phase*, during which participants can enter new orders and change or delete their own existing orders. In order to counteract price manipulation, the call phase has a *random end* within a time period of 30 seconds after which the auction price is calculated. The price is valid for all transactions to be made up to this moment. The auction ends with an *order book balancing phase* when there is any surplus. For a limited time period the surplus is offered at the auction price and can be accepted by entering accept surplus orders.

At the end of the opening auction, all unexecuted or partially executed orders are taken up into *continuous trading* (insofar as traders wish). Continuous trading is followed by a *closing auction* at 11:55 a.m. After a call phase of 5 minutes with a random end within 30 seconds, price determination takes place in a similar manner as in the opening auction. Again price determination may be followed by an order book balancing phase in case if there is any surplus.

The trading day ends with a post-trading phase for the processing of all executed trades.

Figure 4. Phases in continuous trading at EEX



Source: own illustration

3.3.4 Transmission constraints and bid areas

The market is divided into *bid areas* that are defined by EEX.[27] Market participants can only place bids for a bid area if he/she is part of a balance area in the relevant bid area, and all bids received by EEX will be assigned to a particular bid area. In case of transmission constraints individual supply and demand curves are aggregated per bid area resulting in a market clearing price for every bid area. Different prices in the bid areas are adjusted by using price-independent demands and supplies to create power flows from bid areas with low market clearing prices to bid areas with high market clearing prices. If the transmission capacity between the bid areas involved constrains a complete levelling, the bid areas form price areas. Otherwise the market clearing price is the same for all areas and is valid for all trades carried out.

[27] A bid area either consists of one TSO area or several connected TSO areas where the transmission system operators involved have agreed to cooperate concerning activities at the interface to EEX. Normally, the bid areas correspond with the TSO areas, as defined in the Verbändevereinbarung II plus (of 13 Dec 2001; see www.bmwi.de/Homepage/ download/energie/VVStrom.pdf).

3.4 EXAA – Energy Exchange Austria (Austria)

Trading on the day-ahead market of the Energy Exchange Austria (located in Graz, Styria) was launched in March 2002.[28] Currently, only hour contracts are available, but it is planned to provide futures contracts in 2003, and block contracts if the need should arise. It is also envisioned for the future to implement an adjustment market. In the first month of operation of the EXAA, average daily traded volume has been about 2,000 MWh, traded by 13 members of the exchange.

From Monday to Friday, a double-sided auction is carried out.[29] The participants can submit purchase and sale bids anonymously and only via the Internet between 8.00 a.m. and 10.00 a.m. for all 24 hours[30] of the next day. There are three possible types of bids: First, *market orders*, which are price independent, i.e. they are executed at the market clearing price. Second, *step orders*, for which volumes and prices are quoted stepwise. Third, *linear orders*, for which volumes and prices are quoted as a linear interpolation. The minimum size of the order is 1 MWh and the minimum tick size is EUR 0.01. These orders are collected in the sealed order book. The prices for every hour are calculated until 10.15 a.m. and then publicly announced.

Transmission constraints are managed by market splitting. The market area is split into trade zones,[31] and the participants have to assign every bid to one of these trade zones. If there are transmission constraints between trade zones, then a market clearing price can be calculated for every trade zone concerned. To minimize the differences between market clearing prices of the trade zones and of the whole market area, the available transmission capacities are fully exploited to alter aggregated demand or supply in a trade zone and the trade zone price, respectively. If the transmission capacities are not sufficient to equal the prices, different prices are used for executed transactions in the different trade zones.

3.5 GME – Gestore Mercato Elettrico (Italy)

The launch of the Italian power exchange market is scheduled for October 2002. The exchange will eventually provide five markets:

- day-ahead market
- adjustment market
- congestion management market
- reserve market
- balancing market.[32]

In the next two subsections, as the market is not yet in operation, we will restrict our discussion to the planned day-ahead energy market and the adjustment market.

3.5.1 Day-Ahead Energy Market

In the day-ahead market hourly contracts will be traded in daily double-sided auctions one day in advance of delivery. Market participants are allowed to submit multiple sale bids for a single generating unit, or point of interconnection with a foreign country, provided that the prices of the bids do not decrease with increasing quantities. Multiple purchase bids can be submitted for a single point

[28] See www.exaa.at , additional information results from personal communication with C. Kawann/EXAA.
[29] On Fridays, hour contracts for Saturday, Sunday and Monday are traded.
[30] Note that on the day the time changes from winter to summer time, the 3rd hour is not tradable, and on the day the time changes from summer to winter time, the 3rd hour automatically is taken into account twice.
[31] At the moment Austria is divided into three trade zones – the three grids of Austrian Power Grid GmbH, Tiroler Regelzonen AG, and Vorarlberger Kraftwerke-Übertragungsnetz AG –, corresponding to the term "Regelzone" defined in the Austrian Electricity Act (ElWOG 2000).
[32] See www.mercatoelettrico.org .

of withdrawal or of interconnection with a foreign country, provided that these bids are not increasing in price with increasing quantities. Bids from both sides can also be price independent.

If there are transmission constraints, GME will divide the market into two or more zones to be able to select the bids in each zone in accordance to the available grid capacities.

3.5.2 Adjustment market

GME also plans to provide an adjustment market with two sessions. The first will take place after the closure of the day-ahead market, covering all hours of the next day; the second will take place in the morning of the next day, covering all the hours of that day remaining after the closure of the session. Trading will be very similar to the day-ahead market. Hourly contracts are going to be settled in auctions with bids from the supply and the demand side. Quantities can be offered and demanded with or without price limit. In case of transmission constraints, again market splitting will be applied.

3.6 Nord Pool (Norway / Sweden / Finland)

Nord Pool launched its day-ahead market in 1993 and its adjustment market in March 1999.[33] 216 participants were allowed to trade on the spot market in December 2001.

3.6.1 Elspot (day-ahead market)

The Elspot day-ahead power market is a market with physical delivery. The products traded are power *contracts with one hour duration* and *block bids*. The *hourly contracts* cover all 24 hours of the following day. Currently, there are five block periods approved for trading in the day-ahead market:

- Block 1 – 1:00-7:00;
- Block 2 – 8:00-18:00;
- Block 3 – 19:00-24:00;
- Block 4 – 1:00-24:00;
- Block 5 – 8:00-24:00.

Prices at Elspot are determined through auction trade for each delivery hour. Each sale/purchase bid is a sequence of price/volume pairs for each specified hour with a minimum size of 0.1 MWh/h.

Bids are submitted to the marketplace either electronically via Internet, or by fax on special bid forms, before noon (deadline). Purchases are designated as positive numbers, sales as negative numbers.

3.6.2 Elbas (adjustment market)

The adjustment market "Elbas" aims to improve the balance of physical contracts of the participants.[34] The trading products are one-hour physical delivery contracts, which can be traded up to 1 hour before delivery. This market is currently limited to Sweden and Finland, but the inclusion of further Nordic countries is under consideration.

Elbas offers *continuous trading* all around the clock and every day. The trading session for a specific day starts after the publication of the results of Elspot for this day. Bids can be submitted electronically or by phone (helpdesk). Their minimum size is 1 MWh and prices are quoted in Euro with a minimum tick size of 0.1 Euro.

Grid congestion is relieved in two different ways: (a) within Norway and at the interconnections between the Nordic countries by introducing *different market area prices*; and (b) within Sweden, Finland and Denmark by *counter-trade purchases* based on bids from generators. The *system price* in

---

[33] See www.nordpool.no . Nord Pool also runs a balancing market, that is analysed by Skytte (1999).
[34] See www.elbas.net .

the Elspot market is the market clearing price for Elspot power in the absence of grid congestion, calculated once the bids from all participants have been received. The total market is divided into bidding areas, which may become separate price areas if the contractual flow of power between bid areas exceeds the capacity allocated for Elspot contracts by transmission system operators (TSO). In the case of *grid congestion*, two or more area prices are created.

3.7 OMEL - Spanish Power Exchange (Spain)

OMEL provides power trading on a day-ahead and on an hour-ahead market since January 1998.[35] In September 2001 the number of participants was 79.

3.7.1 Daily Day-Ahead Market

Most transactions at the OMEL are carried out on the double-sided day-ahead daily market, where hour contracts for every hour of the day following the auction are traded. The sale bids may be simple, or may include (optional) additional conditions. Simple offers are presented as at most 25 price/volume pairs for each hourly period and production unit. Complex bids, in contrast, also include some or all of the technical or economic conditions shown in Table 2.

Table 2. Technical and economic conditions for complex bids at OMEL

Sale bids	Purchase bids
Simple bids: • upward supply curve	*Unpriced bids:* • rigid demand curves
Complex bids: • indivisibility • minimum income • load gradient • scheduled shutdown	*Priced bids:* • downward demand curve

Source: OMEL

A bid includes the volume stated in MWh and the price stated in Euro/kWh. If a bid shall be submitted not only for one day, it can be set to a default bid which means that the order is automatically put to every day's order book. At OMEL purchase and sale bids are matched that are received before 10:00 a.m.

3.7.2 Intra-Day (Hour-Ahead) Market

Once a technically viable daily schedule has been published, the market operator starts to run several sessions of the hour-ahead market, in which participation is voluntary. The bid structure and the matching processes in the hour-ahead market are similar to those in the day-ahead market – except that the solution will be added to the previous market results and that some complex conditions (e.g. gradients) are applied over the complete schedule (i.e. previous market *and* current hour-ahead result).

The intra-day market currently comprises six daily sessions over time horizons between 9 and 28 hours. Multiple sale and/or purchase bids may be presented for each production/by each purchasing unit. Each bid consists of up to five price/volume pairs for each hour, and may additionally include optional conditions as well (load gradient, minimum income or maximum payment, complete acceptance in the matching process of the first block of the bid, complete acceptance in each hour in

[35] See also www.omel.es . For a more detailed description of the Spanish power exchange see also Gonzalez and Basagoiti (1999).

the matching of the first block of the bid, minimum number of consecutive hours of complete acceptance of the first block of the bid, maximum matched power).

Just like in the day-ahead market, network constraints are not taken into account for the matching process. After the unconstrained hour-ahead market results are obtained, they are sent to the system operator who checks the viability of the transactions. Non-viable transactions are eliminated, taking account of the economic merit orders of the hour-ahead bids, and the schedule is balanced again.

3.8 Powernext (France)

Powernext, launched in November 2001, is an "optional and anonymous organized exchange for the delivery of electricity into the French hub".[36] It offers *standard hourly contracts* negotiable on a daily basis by French generators and foreign players acting on their own behalf. Current number of participants is 18 (April 2002). Transaction liquidity is established by concentrating bids on an auction. In the first six months (November 2001 to April 2002) the turnover accumulated to 515 GWh. There are plans to launch block products, standardised futures contracts, to extend to other hubs, and to introduce bilateral contract clearing via the central counterparty 'Clearnet', used to improve financial security and physical deliveries of power.

Hourly product trading and quotations are undertaken on an Internet-accessible platform. The negotiation system used acts as a centralised order book that calculates and distributes the market clearing price and market clearing volume. Market participants may place their bids from Wednesday of the previous week at 5:00 p.m. until 11:00 a.m. on the auction day. The content of the order book is not disseminated during the pre-auction period. On the auction day at 11:00 a.m., market clearing prices and volumes are determined. The participants then have 15 minutes to raise any potential disputes.

The system, for technical reasons, displays the default price limits in the order form. The bottom limit is currently set at zero Euros and the top limit at EUR 3,000. Within these two limits, members can parameterise up to 62 prices between the top and bottom limits, which leads to a total of 64 price/quantity pairs that can be offered by hour and for the 24 hours of the following day. The minimum price tick is EUR 0.01 per MWh. Quantity must be in whole MWh. Positive (negative) quantities correspond to purchases (sales).

Table 3 provides a summary for the hourly products traded at Powernext, while Figure illustrates the Powernext trading schedule.

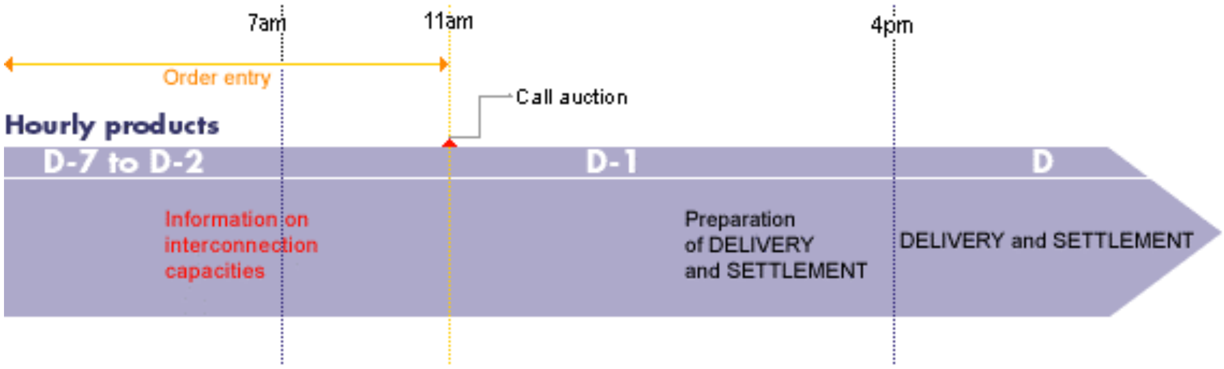
Table 3. Summary of the Powernext hourly products

Characteristic	Description
Product definition	24 separate hour periods throughout the following delivery day (Mon – Sun)
Trading system	ElWeb (Internet interface)
When to place orders	between Wed of the previous week at 5:00 p.m. and 11:00 a.m. on the trading day
Fixing times	11:00 a.m., seven days a week (dispute settlement period: 15 min.)
Minimum volume step	1 MWh
Minimum quotation step	EUR 0.01 / MWh
Quotation method	blind auction by linear interpolation
Order wording	up to 64 price/quantity combinations for the 24 hourly intervals of the following day
Delivery point	French electricity grid (French hub), managed by RTE
Settlement	Market clearing price x volume traded

Source: Powernext

[36] See www.powernext.fr . Note that Powernext transactions can be delivered *at any point* into the French grid.

Figure 5.Trading Schedule at Powernext



Source: Powernext

3.9 UKPX / APX UK / UK IPE (United Kingdom)

In the United Kingdom, despite the early liberalisation of the electricity market in 1990, power exchanges have developed only recently. Until March 2001 a pool-based market existed through which all physical supplies of bulk electricity was traded.[37] This day-ahead market has been running by the National Grid Company (NGC), i.e. the system operator. All generators who wished to have their plant(s) dispatched, had to submit their bids to NGC. NGC constructed a supply curve by stacking the bids in price merit order, and identified the optimal (lowest cost) combination of generation plants that would meet its forecast of demand in each of the 48 half-hourly periods of the next day. It also calculated the uniform price according to the bid price of the most expensive generating set that would have to run in each half–hour. Consumers had also to pay a uniform price, but had no direct involvement in the price setting mechanism except for a few very large power users.

Because of the belief that the pool system allowed to keep market prices well above marginal production costs, the New Electricity Trading Agreement (NETA) was introduced, replacing the pool with a system of voluntary bilateral markets and power exchanges. The new trading system pays generators not in a uniformly but in a discriminatory fashion with their own bid prices. Since the introduction of NETA, three main cleared power exchanges have developed – the UKPX, the APX UK, and the UK IPE. The former two are trading significant volumes of power in the short-term markets, while the latter currently provides futures contracts only, so that it is not going to be discussed any further here.

3.9.1 UKPX

The UK Power Exchange (UKPX) was launched in June 2000. At the beginning of its operation it only provided futures contracts (6-month, 3-month, 4 to 5 weeks, week and day contracts[38]). In March 2001 a round-the-clock spot market went live, where half-hour contracts are traded in lots of 0.5 MWh. They are traded from 10:15 p.m. two days before the flow period in question until 4 hours before delivery. Two new products were introduced in April 2002: block hour and day-ahead contracts, which are tradable all around the clock until 4 hours before delivery. Block hour contracts cover 4 subsequent hours and are listed for trading at 10:15 p.m. three days prior to the flow period in question. Day-ahead contracts are available as base load (constant flow of 1 MW of electricity per hour for the period 11:00 p.m. to 11:00 p.m. next day, daily) and as peak load (constant flow of 1 MW

[37] See Bower, John and Derek Bunn (2001): 568-570.
[38] All these contracts are available as base load (constant flow of 1 MW of electricity per hour for the period 23.00 to 23.00 daily) and as peak load (constant flow of 1 MW of electricity per hour for the period 07.00 to 19.00 for each of the days Monday to Friday). See www.ukpx.com for more details.

of electricity per hour for the period 7:00 a.m. to 7:00 p.m. for each of the days, Monday to Friday). They are listed for trading at 10:15 p.m. two days prior to the flow period in question.

Trades on the UKPX currently account for most of the non-OTC-traded contracts. In April 2002 a total of 44 participants traded at the UKPX.

The price quotation for all contracts is in Pounds Sterling per MWh, with a minimum tick size of £0.01. Spot contracts are traded continuously. Participants submit bid and offer prices, which are posted. Trades are matched continuously where these prices match or are bettered. Pricing follows the pay-your-bid rule, i.e. there is no uniform price for a specific product. Moreover, there are no restrictions to the aggregated trade volume, as transmission constraints are not relevant to this market.

3.9.2 APX UK

The APX UK spot market started in March 2001 and counted 30 participants in November 2001. It provides continuous trading of contracts for physical electricity – so-called *electricity forward agreements* (EFA) - in lots of 1 MW via an anonymous electronic trading platform.[39] APX UK intends to introduce exchange-traded forward products as soon as a market need should arise.

Traded products are 48 half-hour contracts available on a rolling basis, 2-hour and 4-hour blocks, day peak (from 7:00 a.m. to 7:00 p.m.) and day base contracts, balance of week (Monday to Friday, Tuesday to Friday, Wednesday to Friday, and Thursday to Friday) and weekend contracts. The market opens up to 12 days prior to the trading day and closes four hours prior to delivery time. Trading takes the same form as at the UKPX (i.e. continuous trading).

3.9.3 Balancing market

In order to enable NGC (the system operator) to balance the system after gate closure, i.e. after all trades have been centrally notified, a balancing market has been established. Furthermore, *"[p]articipants submit to NGC pairs of offers (to sell power) and bids (to buy power) prior to gate closure. Offers represent the ascending price the participant will require from NGC to provide incremental increases in output (or reduction in demand). Bids represent the diminishing payments a participant is willing to make to NGC in order to reduce the level of generation or increase demand. NGC can call any offer or bid submitted for a particular half-hour, at any point up to real-time, provided that the instruction is in keeping with the plant's dynamic parameters. A generator's accepted bids and offers will be treated as separate contracts and will not cause a balanced generator to go into imbalance (or improve an imbalanced generator's position)."* [40]

4 Summary and Conclusions

In this paper we have addressed both some general theoretical considerations and the actually implemented, or almost implemented, exchange-based spot markets for electricity in Western Europe. The information contained in the paper should provide useful as a starting point for the design of bidding tools that can be used by power-only, and combined-heat-and-power (CHP), generating companies for generating bids to be used in a liberalised market environment. Whereas the literature survey and the overview of important issues with regard to such markets has shown that there are many (and often rather complex) issues that need to be tackled, the empirical part provides an overview of the main features, and the most recent development, of the most important of these markets in Europe to date.

[39] See www.apx.com , additional information results from personal communication with C. Crane/APX
[40] Ibid.

Apart from plant-specific factors, the generation of optimal bids, and bidding strategies, is crucially dependent on the particular market structure, the auction mechanism concerned, and the particular information that can be received. And although it would be useful to obtain and take into account information on the bidding strategies used by competitors (derived, for example, from a model that exploits data on historical market actions), this is information that is generally not easily available, and the modelling issues involved are far from trivial. Besides, the development and evaluation of complete bidding strategies requires both the modelling and the simulation of the market, and a dynamic restructuring of the bidding strategy chosen in reaction to market changes and changes in competitive bidders' behaviour. This, however, is well beyond the scope of the OSCOGEN project for which this report has been produced.

Acknowledgments

We are grateful for comments received from various OSCOGEN team members, in particular from Alfred Hofmann of BEWAG, Berlin, and for funding received from the Swiss Federal Agency for Education and Science (BBW), Berne. The usual caveat applies.

References

Bolle, F. (1992). Supply function equilibria and the danger of tacit collusion. The case of spot markets for electricity. *Energy Economics*, **14**(2) April, 94-102.

Bolle, F. (1997). Necessary conditions for efficient multi-bid auctions. In: Nau, R., Gronn, E., Machina, M., and Bergland, O. (eds.), *Economic and Environmental Risk and Uncertainty: New Models and Methods*. Boston/Dordrecht/London: Kluwer Academic Publishers, 123-143.

Boisseleau, F. (2001). La Bourse de l'electricite des Pay-Bas est-elle competitive? (The Dutch Power Exchange: A Competitive Marketplace?), *Economies et Societies*, **35**(1-2) Jan/Feb, 247-261.

Bower, J. and D. Bunn (2001). Experimental analysis of the efficiency of uniform-price versus discriminatory auctions in the England and Wales electricity market, *Journal of Economic Dynamics & Control*, **25**(3-4): 561-592.

Boyer, M. and J. Robert (1998). Competition and access in electricity markets: ECPR. global price cap, and auctions, in: Zaccour, Georges (ed.), *Deregulation of Electric Utilities. Topics in Regulatory Economics and Policy Series*. Boston/Dordrecht/London: Kluwer Academic Publishers, Ch. 3. Brennan, D. and J. Melanie (1998). Market power in the Australian power market, *Energy Economics*, **20**(2), 121-133.

Brunekreft, G. (2001). A multiple-unit, multiple-period auction in the British electricity spot market, *Energy Economics*, **23**(1): 99-118.

Cap Gemini Ernst & Young (2002). European Markets Deregulation Observatory: First Edition – Summer 2001 data set (www.no.cgey.com/news/archive/2002/0203_Brochure-EEMDO_EN_for-screen.pdf).

Dekrajangpetch, S. and G. B. Sheblé (1999). Bidding information to generate bidding strategies for LaGrangian relaxation-based auctions. *Electric Power Systems Research*, **52**(1): 87-96.

Denton, M. J., S. J. Rassenti, and V. L. Smith (2001). Spot market mechanism design and competitivity issues in electric power, *Journal of Economic Behavior & Organization*, **44**(4): 435-453.

Elmaghraby, W. and S. S. Oren (1999). The Efficiency of Multi-Unit Electricity Auctions, The *Energy Journal*, **20**(4): 89-116.

Geman, H. (2001). Spot and Derivatives Trading in Deregulated European Electricity Markets. *Economies et Societies*, **35**(1-2) Jan/Feb, 263-280.

Gonzalez, J. J. and P. Basagoiti (1999). Spanish Power Exchange Market and Information System. Design concepts, and operating experience (www.econ.iastate.edu/tesfatsi/ sp1epmp.pdf).

Green, R. J. and D. M. Newbery (1992). Competition in the British electricity spot market. *Journal of Political Economy*, **100**(5): 929-953.

Hobbs, B. F., M. H. Rothkopf, L. C. Hyde, and R. P. O'Neill (2000). Evaluation of a Truthful Revelation Auction in the Context of Energy Markets with Nonconcave Benefits, *Journal of Regulatory Economics*, **18**(1): 5-32.

Kraus, Michael and Bob Turgoose (1999). Entwicklungen bei wettbewerblichen Strommärkten. Energiewirtschaftliche Tagesfragen 1999; **49**(1/2): 64-68.

Lawler, K. (2001). Auctions, Auction Theory and Economics, *Economic Issues*, **6**(1) March, 82-86.

Léautier, T. O. (2001). Electricity Auctions, *Journal of Economics & Management Strategy*, **10**(3) Fall: 331-358.

Madrigal, M. and V. H. Quintana (2001). Existence and Determination of Competitive Equilibrium in Unit Commitment Power Pool Auctions: Price Setting and Scheduling Alternatives. *IEEE Transactions and Power Systems*, **16**(3) August, 380-388.

Newbery, D. M. (1998). Competition, contracts and entry in the electricity spot market, *RAND Journal of Economics*, **29**(4): 726-749.

Sheblé, G. (1999). *Computational Auction Mechanisms for Restructured Power Industry Operation*, Boston/Dordrecht/London: Kluwer Academic Publishers.

Skytte, K. (1999). The regulating power market on the Nordic power exchange Nord Pool: an econometric analysis. *Energy Economics*, **21**(4): 295-308.

Supatgiat, C. R. Q. Zhang, and J. R. Birge (2001). Equilibrium Values in a Competitive Power Exchange Market, *Computational Economics*, **17**(1): 93-121.

Von der Fehr, N. H. M. and D. Harbord (1993). Spot market competition in the UK electricity industry. *Economic Journal*, **103**(418): 531-546.

Wolak, F. A. (2000). An Empirical Analysis of the Impact of Hedge Contracts on Bidding Behavior in a Competitive Electricity Market, *International Economic Journal*, **14**(2) Summer, 1-39.

Wolfram, C. D. (1998). Strategic bidding in a multi-unit auction: an empirical analysis of bids to supply electricity in England and Wales. *RAND Journal of Economics*, **29**(4): 703-725.

Links to Power Exchanges Discussed

AUSTRIA:	Energy Exchange Alpen Adria (EXAA) www.exaa.at
FRANCE:	Powernext www.powernext.fr
GERMANY:	European Exchange (EEX) www.eex.de/content/en_index.html
	Leipzig Power Exchange (LPX) www.lpx.de/index_e.asp
ITALY:	Gestore Mercato Elettrico (GME) www.mercatoelettrico.org
NETHERLANDS:	Amsterdam Power Exchange (APX) www.apx.nl/main.html
NORWAY:	Nord Pool www.nordpool.no
SLOVENIA:	Borzen Power Exchange (Borzen) www.borzen.si/en/about.htm
SPAIN:	Spanish Power Exchange (OMEL) www.omel.es,
	www.comel.es/en/reglas_contrato/mreglasconadhesionfr.htm
UNITED KINGDOM:	The UK Power Exchange (UKPX) www.ukpx.com
	Automated Power Exchange UK (APX UK) www.apx.com
	UK International Power Exchange (UK IPE) www.ipemarkets.com

Glossary (Selection of Terms)

- **Balanced offer**

  The term “balanced offer” refers to an offer that is submitted on the adjustment market, which consists of zero-priced supply offers and non-price-dependent demand bids such that the respective quantities are balanced; balanced offers may be submitted by different market participants, provided they refer to the same geographical area.

- **Bidding area**

  Part of the market which usually corresponds to the area of a TSO and may form a separate price area in case of constraints in the transmission from and/or to other bidding areas.

- **Block bid**

  Offer to sell or buy the same quantity of energy for a period of consecutive hours.

- **Discriminatory pricing**

  Discriminatory pricing means that each bidder (generating company) gets paid corresponding to its bid; this is in contrast to uniform pricing where every bidder gets the same price.

- **Heuristic selection**

  In some cases, the dispatcher has to use heuristic selection in order to find a market outcome, so that no ‘fair’ solution may exist.

- **LaGrangian relaxation (LR)**

  LR is an optimisation technique that decomposes the main and usually complex mathematical programming problem into simpler sub-problems that are additively separable by relaxing the hard (e.g. coupling) constraints; each (separately solved) sub-problem is coupled through common LaGrangian multipliers, one for each period; the LaGrangian multipliers at each iteration are updated until a near-optimal solution is found (cf. Dekrajangpetch and Sheblé 1999).

- **Limited bid**

  Offer to sell or buy energy up to a price limit.

- **Lot**

  Basic quantity unit.

- **Market bid**

  Offer to sell or buy energy at the price determined by the exchange.

- **Minimum income condition**

  The minimum income condition assures that a block bid will not be accepted by the matching algorithm if the minimum income requested by the participant is not fulfilled.

- **Multiple-bid auction**

  In a multiple bid auction the market participants submit multiple bids for a single applicable period of time and for a single generating unit by splitting the total quantity of energy offered to the market into multiple bids.

- **Multiple-period auction**

  In a multiple-period auction the participants submit bids for several periods of time separately.

- **Multiple-unit auction**

  In a multiple-unit auction the firms split the total quantity of energy offered into separate bids for each generating unit.

- **Ordinary bid**

  Offer to sell or buy a specified quantity of energy for a single hour.

- **Strategic bidding**

  Strategic bidding refers to the bidding behaviour of individual suppliers that is not solely based on cost considerations, but merely aimed to raise the price above the competitive level (in order to increase profits, or to yield contracts which can otherwise not be obtained).

- **Tacit collusion**

  Tacit collusion occurs when independent market participants exhibit some form of 'cooperative' bidding behaviour, without communication before the actual auction takes place, in order to obtain a better result as compared to a non-cooperative bidding situation.

- **Unconstrained market clearing price**

  Price resulting from the auction trade system of the spot market without considering capacity constraints.

- **Undercutting**

  Undercutting is the submission of a bid for a generating unit that would otherwise be excluded from the dispatch schedule, with a lower price than the equilibrium bid of a competitor, to increase one's output.

New Bid Structures for Power Exchange with Modelling in ILP Framework

Rajeev Gajbhiye, *Student Member, IEEE*, S. A. Soman, *Member, IEEE*

***Abstract*—Block bid were introduced in power exchanges to allow generators with high fixed cost component (start-up and shut-down cost) participate in the market. However, block bid has been designed with very simple structure. Rigid structure in block bid often leads to them being rejected paradoxically. With this factor as motivation, we present new bid structures which retains objective of block bid, but brings in more flexibility, resulting in more liquidity in market.**

***Index Terms*—Power Exchange, Block Bids, Paradoxically Rejected Bids, Integer Linear Programming**

Glossary

$\mathcal{B}$	Set of binaries, i.e. 0 and 1, 3
$\Re$	Set of real numbers, 3
$\Re^+$	Set of positive real numbers including 0, 3
Block Bid	Such bid specify fixed volume that, if cleared, has to be delivered over a certain number of consecutive time slots. It is cleared if average MCP over operation time horizon is more than (or less than for loads) specified price limit., 1
Fill-And-Kill	Under this specification, bid can be accepted partially but it should be scheduled in fixed time slot. Remaining volume is immediately canceled. Abbreviated as *FAK*, 3
Fill-Or-Kill	Bid with this nature have to be either executed in complete volume at a fixed execution time or canceled altogether. Abbreviated as *FOK*, 3
PRB	Paradoxically Rejected Bids. Bid which confirms to the market clearing price but still is forced out of market or rejected., 1

Rajeev Gajbhiye is with the Department of Electrical Engineering, Indian Institute of Technology–Bombay, Mumbai, India (e-mail:rajeev81@ee.iitb.ac.in)

S. A. Soman is with the Department of Electrical Engineering, Indian Institute of Technology-Bombay, Mumbai, India (e-mail:soman@ee.iitb.ac.in)

I. Introduction

Power Exchange (PX), is a platform to trade power in a day ahead market for each time slot, each slot being typically of one hour, thought 15 minutes and half hourly slots are also in practice. It provides a spot market (mainly day-ahead), which like any other market matches demand and supply for each time slot (typically of an hour), while providing a public price index.

One of the simple most market model will consists of buy bids and sell offers for each hour, where each participant submits his demand/supply curve. Any of these orders may then be met completely, partially or rejected altogether. A common market clearing price (MCP) is declared and based upon these price, bid scheduling takes place.

- If a bid is above MCP, it is selected completely.
- If a bid is below MCP, it is rejected altogether.
- If an offer is below MCP, it is selected completely.
- If an offer is above MCP, it is rejected altogether.
- If any of the bid/offer is exactly at MCP, it may be selected, rejected or partially scheduled.

Since, supply and demand should be equal (neglecting losses) to maintain power balance in real time, this MCP will come at intersection of aggregated demand and supply curves.The above mentioned equilibrium also maximizes social welfare.

Various exchanges provides different bidding options to accommodate a wide range of customers. As for example, due to technical constraint (say generator having high start up and shut down cost) participating in decoupled hourly market may be risky, or may have to bid very high, thereby lowering the probability of his bid being selected. To account for such participants and bring more flexibility in the market, PXs have come up with product commonly referred as *block bid* [1], [2]. This kind of bid has three important characteristics:

1) Multi-hour operation,
2) Constant volume operation, and,
3) Selection criteria based upon average MCP.

This means that a block bidder bids for multiple contiguous hours at once, and in case his bid is selected agrees to supply/consume constant power over these consecutive time periods. Also, his bid can be selected based upon average price expected by participant. Thus, player might be making loss in one hour, but may be compensated in next hour and hence, overall be in money. Block bidding also allows participation of those generators, which are technically constrained to produce power for certain number of hours once scheduled. Some exchanges restrict block bidding to pre-defined block periods, called as strips, whereas in other exchanges trader are be allowed to choose his own block.

Incorporation of block bids leads to market clearing problem across various hours being coupled. Thus, simple approach of intersecting supply and demand curve cannot be applied. In fact, exchanges mostly apply heuristics to clear the market [3]. These heuristic approach, however, does not guarantee optimal scheduling. Block bids leads to another complexity, that price signal may not be sufficient to dictate acceptance and rejection of bids while maintaining supply and demand balance. Exchanges handle this problem by forcing certain block bids to be rejected, even when at clearing prices trader qualifies for selection. Such rejected bids are termed as *Paradoxically Rejected Bids (PRBs)* [4].

Both the above mentioned problems, market clearing getting tougher and bids being rejected paradoxically, are due to the inflexibility in block bid structure. While first problem can be handled by developing more sophisticated algorithms, second issue requires evolution of bid structures to account for technical constraint as well as allowing certain degrees of flexibility.

Even if PRB issue is not that critical, with market maturing over the time, exchange have to explore more flexible options [4]. Requirements will be felt to model trader's technical constraints more accurately. In this paper, we take a step forward in this direction and propose few additional bid structures meeting the above mentioned goal. In particular, we address problem of modelling start up, shut down costs and ramping costs along with marginal cost in bid structure itself.

Mixed Integer Linear Programming (MILP) has been widely used in power system problems in last decade[5],[6],[7]. Though solving MILP is theoretically a tough problem, various techniques have been developed which can handle most of the practical problems with ease. Such a framework has been developed in [4] to handle block bids. In this paper, we extend this model to incorporate proposed bid structures.

II. Paradoxically Rejected Bids

To understand PRBs, let us consider a simple example of single hour market clearing problem. Suppose following bids/offers are received:

1) Normal bid to buy power up to 100 units of power at price of 7 monetary units (MUs),
2) Normal offer to sell power up to 50 units of power at price of 3.5 MUs,
3) Normal offer to sell power up to 25 units of power at price of 4.0 MUs, and,
4) Block offer to sell 50 units of power at 4.5 MUs,

Now it can be easily shown that there exists no price which by itself enforces appropriate bid acceptance and rejection. If market clearing price p is declared such that $3.5 < p < 7$, then hourly bids and offers have to be scheduled completely. In such a case, there is imbalance of 25 MUs. Now this imbalance cannot be met by rigid block bid of size 50 units each. If $p = 7$, then buy bid can be scheduled partially or completely, but going by price signal all other sell bids qualify. Similar observation can be made when $p = 3.5$. Thus, price is not enough to determine selected set of bids/offers. Some bids have to be forced to rejection even when they are meeting price criteria.

Allowing social welfare maximization determine appropriate schedule will lead to complete selection of buy bid, hourly offer to deliver 50 units and block bid of 50 units. clearing price can be anywhere 4.5 to 7. Consequently, hourly offer willing to deliver power at lower price of 4 MU is rejected. Net social welfare comes out to be 300.

However, exchanges across the world practice the policy that if price criteria is met by hourly bids, then they should be scheduled, even if it means *meeting* goal of overall social welfare to a *lesser extent* possibly coupled with lower traded volume. Also, bids/offers exactly at market price can be scheduled partially. Hence, honoring above mentioned constraint, solution to our problem will be to schedule hourly bids of 100 units along with both hourly offers, leading to overall traded volume of 75 units and social welfare of 250. Clearing price has to be 7 MU, as buy bid is getting partially scheduled.

Observations, based upon above example, can be summarized as follows:

1) Block bids, due to their rigidity, makes market clearing problem complex, both from computation as well as policy perspective,
2) If only social welfare maximization is the criteria, then more competitive normal bids/offers may have to be rejected (paradoxically) due to rigidity of block bids, and,
3) If policy to accept bids/offers meeting the market clearing price is followed, then social-welfare along with net traded volume may be compromised. Also, certain block bids might be paradoxically rejected.

Looking into above facts, one of our motivation while devising new bid structures would be to mitigate paradoxical effects of block bids, while meeting the objective of introduction such an instrument.

III. Need of Block Bids

Block bid was introduced to encourage generators with high start-up and shut-down cost, typically thermal ones. As for example consider a generator which incurs cost of 5 MU per unit of power delivered. However, in has also to recover start-up and shut-down cost of 200 MU. It can deliver up to 50 units. Now, if this trader has to bid for single hour, no matter how much volume he delivers, minimum cost of 200 has to be recovered anyhow. If he has option of delivering either full 50 units of volume or none, then he has to bid $200 + 5 \times 50 = 450$ for 50 unit of power or 9 MU.

Now let us take a case where trader is allowed to bid for consecutive 4 blocks of hours. Now he has to bid so as to recover $200 + 4 \times 5 \times 50 = 1200$ for 5 hours of supply of 50 units of power. Thus, in this case he is bidding 6 MU, which is more competitive than former. This is because, fixed cost corresponding to start-up and shut-down is distributed over multiple hours. This is precisely the reason that exchanges have incorporated block bids.

In subsequent sections, we develop advanced structures and develop corresponding MILP model. The developed model can be then, easily integrated with the MILP framework developed in [4].

IV. Development of Advanced Bid Structures

We revisit example from section II. If in this case, block bidder had the idea that size of his bid will be too large to be selected and only 25 units will be the market requirement, he would have bid accordingly. He would have quoted for 25 units of power only but at higher price say 6 MU, as fixed cost have to be recovered over small amount of volume. This way, even this bid could have entered the market and make profit.

Nevertheless, deriving such a priori information may be impossible. Hence, a bid structure is required where he can segregate associated fixed cost and volume dependent cost while putting up his quotation and also allowing him to bid for a range of volume and not a fixed quantity.

In essence, rather then specifying fixed volume and minimum average MCP, bidder can specify, volume range and other parameters to derive minimum income to be recovered. This bid structure can be thought of as hybrid of FOK and FAK, where if selected minimum volume has to be at least filled completely and rest can be partially filled and hence, can be given the name *Fill Minimum or Kill (FMOK)*.

Based upon mode of schedule profile, two possible operations can be thought of:

Constant Volume: Under this mode of operation, generator will get volume schedule, within specified limits, which will remain constant throughout the bidding execution period.

Variable Volume: Under this mode of operation, generator can get variable schedule for each time slot but will remain with in allowed range.

Variable scheduling scheme adds another dimension of flexibility. Benefit of this scheme is that bid will not be rejected because in one hour requirement is more, whereas in next low volume has to be met. If volume has to be kept constant then it is possible that normal hourly bids, even being priced higher, may get priority.

While putting up such a bid, trader has to specify following information

1) Start-up cost $\alpha^{\uparrow}$,
2) Shut-down cost $\alpha^{\downarrow}$,
3) Fixed running cost ω, and,
4) Some model to specify marginal cost (volume dependent variable component).

Based upon what model is used to specify marginal cost, we come up with variants which are being discussed now.

Remark 1. *Even though modelling is being carried out from supplier's perspective, similar model can be built for consumer as well.*

A. Constraint Modelling of Proposed Bid Structures

We now develop MILP model, which can be integrated with model proposed in [4], to represent selection criteria on proposed bid structures.

1) Constant Marginal Cost: Under this structure, marginal cost is specified with the help of single parameter β, which is marginal cost for delivering single unit of power. Thus, if V amount of power is delivered, net marginal cost will come out to be βV.

Constant Volume Schedule: For a block bid over a period of h_1 to h_2 under this scheme, let us introduce $V \in \mathcal{R}^+$ as scheduled volume variable and $s \in B$ to represent bid selection.[1] Then, following constraints models financial of the generator

- Volume scheduling constraint
  - If bid is not selected then scheduled volume $V = 0$, and,
  - If bid is selected then $V_{min} \leq V \leq V_{max}$

  This constraint can be modelled as

$$sV_{min} \leq V \leq sV_{max} \tag{1}$$

- Minimum cost recovering constraint
  - If bid is not selected then there is no cost to be recovered, and,
  - If bid is selected with scheduled volume being V, then minimum cost to be recovered is

$$\alpha^{\uparrow} + \alpha^{\downarrow} + (h_2 - h_1 + 1)\omega + (h_2 - h_1 + 1)\beta V$$

  Thus, minimum income criteria can be modelled as,

$$V \sum_{h=h_1}^{h_2} \mathrm{MCP}_h \geq s(\alpha^{\uparrow} + \alpha^{\downarrow}) + s(h_2 - h_1 + 1)\omega + (h_2 - h_1 + 1)\beta V \tag{2}$$

Ineqn 1 models range of power volume that can be scheduled. If bid is not selected ($s = 0$), upper and lower bound both becomes 0, forcing scheduled volume to be 0. On the other hand, if bid is selected ($s = 1$), lower bound becomes V_{min} and upper bound becomes V_{max}.

Ineqn 2 models minimum income criteria. If bid is not selected, both sides of this relation become zero, thereby honoring the above mentioned relation. However, if bid is selected, then net income coming out of declared MCPs should be more than or equal to sum of fixed cost and variable cost. Note that this relation results in non-linearity, quadratic to be more precise. However, this *problematic* quadratic term can be approximated by linear set of relations as discussed in appendix I.

Variable Volume Schedule: For a block bid over a period of h_1 to h_2 under this scheme, let us introduce $V_h \in \mathcal{R}^+$ as scheduled volume variable for each time slot $h \in \{h_1, h_1 + 1, \cdots, h_2\}$ and $s \in B$, to represent bid selection. With slight modification over previous model, we arrive at following model, which allows volume fluctuation across contiguous time slots in single block

$$sV_{min} \leq V_h \leq sV_{max} \quad \forall h \in \{h_1, h_1 + 1, \cdots, h_2\} \tag{3}$$

$$\sum_{h=h_1}^{h_2} \mathrm{MCP}_h V_h \geq s(\alpha^{\uparrow} + \alpha^{\downarrow}) + s(h_2 - h_1 + 1)\omega + \beta \sum_{h=h_1}^{h_2} V_h \tag{4}$$

[1] $s = 0$ implies bid rejection and $s = 1$ implies selection

2) Stepped Marginal Cost (FAK Steps): This bid structure is generalization of the one discussed above. In this scheme bidder can give his fixed cost along with minimum and maximum volume between which he can deliver, if his bid is selected. In addition, to this he can give price per unit volume at various levels of volumes. If variable price is independent of volume delivered, we arrive back to the earlier model. Such a scheme has been demonstrated in table below. Volumes tabulated here are incremental.

Fixed Cost			Volume	
Start Up	Shut Down	Running	Minimum	Maximum
$\alpha^{\uparrow}$	$\alpha^{\downarrow}$	ω	V_{min}	V_{max}

Price	β_1	β_2	....	β_m
Volume	V_1^b	V_2^b	....	V_m^b

Constant Volume Schedule: For a block bid over a period of h_1 to h_2 under this scheme, let us introduce

- $V_i \in \mathcal{R}^+$ volume variable scheduled for each price step, i.e, $i \in \{1, 2, \cdots, m\}$.
- $V \in \mathcal{R}^+$ to represent net volume scheduled.
- $s_i \in \mathcal{B}$ to represent selection of i^{th} bid step.
- $s \in \mathcal{B}$ to model overall selection of bid, whether full or partial.

Then, following constraints model financial requirements of the generator

- Volume scheduling constraint
  - If bid is not selected then scheduled volume $V = 0$ and if selected then $V_{min} \le V \le V_{max}$. Following relation captures this criteria,

$$sV_{min} \le V \le sV_{max} \tag{5}$$

  - Scheduled volume will be sum of volume scheduled from each step

$$V = \sum_{i=1}^{m} V_i, \quad \forall i \in \{1, 2, 3, \ldots, m\} \tag{6}$$

  - Corresponding to each step, scheduled volume will lie between 0 and maximum limit of the step V_i^b, provided that this step is selected. If a step is not selected, then this mini-schedule will be 0.

$$0 \le V_i \le s_i V_i^b, \quad \forall i \in \{2, 3, \ldots, m\} \tag{7}$$

  - Higher order step can be considered for selection, if previous order step has been filled completely

$$s_i \le \frac{V_{i-1}}{V_{i-1}^b}, \quad \forall i \in \{2, 3, \ldots, m\} \tag{8}$$

  - If bid is selected, then lowest step should have been selected.

$$s = s_1 \tag{9}$$

- Minimum cost recovering constraint
  - If a bid is not selected then there is no cost to be recovered, and,
  - If a bid is selected with scheduled volume being V, then minimum cost to be recovered is sum of fixed cost, fixed running cost and cost arising out of marginal price and volume delivered. Marginal cost (Γ) is calculated as follows

$$\Gamma = \beta \sum_{i=1}^{m} V_i$$

where, β marginal price of last volume step being selected, which implies β is variable and hence, expression for Γ is not being modelled linearly. To represent this cost component we develop following linear model:

$$\begin{aligned} -\left(1-(s_i - s_{i+1})\right) M &\le \Gamma - \beta_i \sum_{i=1}^{m} V_i \\ &\le \left(1-(s_i - s_{i+1})\right) M \\ &\forall i = 1, 2, m-1 \end{aligned} \tag{10}$$

$$-\left(1 - s_m\right) M \le \Gamma - \beta_m \sum_{i=1}^{m} V_i \le \left(1 - s_m\right) M \tag{11}$$

$$-M \sum_{i=1}^{m} s_i \le \Gamma \le M \sum_{i=1}^{m} s_i \tag{12}$$

To understand the effect of above model, let us assume that step $k < m$ is selected. In such a scenario $s_1 = s_2 = \cdots = s_k = 1$ and $s_{k+1} = s_{k+2} = \cdots = s_m = 0$. Now, from eqn 10 for $l < k$, $s_l = s_{l+1}$. Therefore, $s_l - s_{l+1} = 0$ and hence, lower and upper bound on $\Gamma - \beta_l \sum_{i=1}^{m} V_i$ comes out to be $-M$ and M, and hence this constraint becomes ineffective. However, for $l = k$, we have $s_k - s_{k+1} = 1$ and hence, both lower and upper bound on $\Gamma - \beta_k \sum_{i=1}^{m} V_i$ comes out to be 0 and hence, $\Gamma = \beta_k \sum_{i=1}^{m} V_i$ is enforced. If all the steps are selected, then only eqn 11 will be effective to enforce $\Gamma = \beta_m \sum_{i=1}^{m} V_i$. Eqn 12 ensures that if none of the step is selected, then Γ is forced to take the value of 0.

Thus, we can model minimum income criteria as follows:

$$\begin{aligned} V \sum_{h=h_1}^{h_2} \mathrm{MCP}_h \ge\, & s(\alpha^{\uparrow} + \alpha^{\downarrow}) + s(h_2 - h_1 + 1)\omega \\ & + (h_2 - h_1 + 1)\Gamma \end{aligned} \tag{13}$$

Variable Volume Schedule: Under this mode of operation, we have to make slight adjustment and introduce volume, step-volume and step selection variables for each time slot $h \in \{h_1, h_1 + 1 \cdots, h_2\}$. Following similar steps as while modelling constant volume schedule model, we will arrive at following set of relations:

$$sV_{min} \leq V_h \leq sV_{max} \tag{14}$$

$$V_h = \sum_{i=1}^{m} V_i^h \tag{15}$$

$$0 \leq V_i^h \leq s_i^h V_i^h \tag{16}$$

$$s_i^h \leq s_{i-1}^h, \quad \forall i \in \{2,3,\ldots,m\} \tag{17}$$

$$s = s_1^h \tag{18}$$

$$\sum_{h=h_1}^{h_2} \mathrm{MCP}_h V_h \geq s(\alpha^\uparrow + \alpha^\downarrow) + s(h_2 - h_1 + 1)\omega \quad + \sum_{h=h_1}^{h_2} \Gamma_h \tag{19}$$

where, marginal cost pertaining to h^{th} hour (Γ_h) is derived as discussed earlier

(20)

3) Stepped Marginal Cost (FOK Steps): Bid structure is very much similar to earlier discussed model with the difference that each step is *indivisible*. This type of specification will benefit those generators, which can change volume only in steps.

Constant Volume Schedule: For a block bid over a period of h_1 to h_2 under this scheme, let us introduce

- $V_i \in \mathcal{R}^+$ volume variable scheduled for each price step, i.e, $i \in \{1, 2, \cdots, m\}$.
- $V \in \mathcal{R}^+$ to represent net volume scheduled.
- $s_i \in B$ to represent selection of i^{th} bid step.
- $s \in B$ to model overall selection of bid, whether full or partial.
- $\zeta_i \in \mathcal{R}^+$ variable to model value obtained from market through step, i.e, $i \in \{1, 2, \cdots, m\}$.

Then following constraints models finance of the generator

- Volume scheduling constraint
  - If bid is not selected then scheduled volume $V = 0$ and if selected then $V_{min} \leq V \leq V_{max}$. Following relation captures this criteria,

$$sV_{min} \leq V \leq sV_{max} \tag{21}$$

  - Scheduled volume will be sum of volume scheduled from each step

$$V = \sum_{i=1}^{m} V_i, \quad \forall i \in \{1, 2, \ldots, m\} \tag{22}$$

  - Each step volume if not selected will result in volume to be delivered to be 0, otherwise full volume will be scheduled. Thus,

$$V_i = s_i V_i^* \tag{23}$$

  - Higher order step can be considered for selection, if previous order step has been filled

$$s_i \leq s_{i-1} \quad \forall i \in \{2, 3, \ldots, m\} \tag{24}$$

  - If bid is selected, then lowest step should have been selected.

$$s = s_1 \tag{25}$$

- Minimum cost recovering constraint
  - If bid step is not selected then there is no corresponding value earned, i.e. $\zeta_i = 0$ but if it is selected then since full step will be scheduled, value earned will be product of corresponding volume with sum of MCPs from h_1 to h_2. Above mentioned constraint is modelled as follows

$$0 \leq \zeta_i \leq s_i M \tag{26}$$

$$-(1 - s_i)M \leq \zeta_i - V_i^* \sum_{h=h_1}^{h_2} \mathrm{MCP}_h \leq (1 - s_i)M \tag{27}$$

  - Minimum cost to be recovered comes out to be 0 if bid is not selected, else it is sum of start up, shut down, fixed running cost and volume delivery cost arising out of marginal cost. Hence,

$$\sum_{i=1}^{m} \zeta_i \geq s(\alpha^\uparrow + \alpha^\downarrow) + s(h_2 - h_1 + 1)\omega + (h_2 - h_1 + 1)\Gamma \tag{28}$$

Variable Volume Schedule: For a block bid over a period of h_1 to h_2 under this scheme, let us introduce

- $V_i^h \in \mathcal{R}^+$ volume variable scheduled for each price step and each time slot
- $V_h \in \mathcal{R}^+$ to represent net volume scheduled, for h^{th} time slot
- $s_i^h \in B$ to represent selection of i^{th} bid step.
- $s \in B$ to model overall selection of bid, whether full or partial.
- $\zeta_i^h \in \mathcal{R}^+$ variable to model value obtained for i^{th} step in h^{th} hour

Following similar steps as in constant volume schedule, we will arrive at following formulation

$$sV_{min} \leq V_h \leq sV_{max} \tag{29}$$

$$V_h = \sum_{i=1}^{m} V_i^h \tag{30}$$

$$V_i^h = s_i^h V_i^h \tag{31}$$

$$s_i^h \leq s_{i-1}^h, \quad \forall i \in \{2, 3, \ldots, m\} \tag{32}$$

$$s = s_1^h \tag{33}$$

$$0 \leq \zeta_i^h \leq s_i^h M \tag{34}$$

$$-(1 - s_i^h)M \leq \zeta_i^h - V_i^h \mathrm{MCP}_h \leq (1 - s_i^h)M \tag{35}$$

$$\sum_{h=h_1}^{h_2} \sum_{i=1}^{m} \zeta_i^h \geq s(\alpha^\uparrow + \alpha^\downarrow) + s(h_2 - h_1 + 1)\omega + \sum_{h=h_1}^{h_2} \Gamma_h \tag{36}$$

B. Modelling of Term Contributing to Social Welfare

For all the structure discussed, right hand term of inequations modelling minimum income criteria will form the contribution term towards social welfare with negative sign. For example for the structure with constant marginal cost and constant volume, discussed in section IV-A.1, following term will be added to social welfare:

$$-\left(s(\alpha^{\uparrow}+\alpha^{\downarrow})+s(h_2-h_1+1)\omega+(h_2-h_1+1)\beta V\right)$$

C. Modelling Ramping Cost

Whenever, generator has to ramp (up or down) to shift from one volume level to another, some fuel might be wasted and hence cost needs to be recovered. Till now we have not accounted for this cost component. However, this factor cannot be ignored particularly in bid structure allowing volume to vary from one hour to another. We will assume that ramping cost (up and down) is proportional to change in volume schedule. Thus,

$$C^{ramp}=\gamma^{\uparrow}(V_h-V_{h-1}) \quad \text{if } V_t>=V_{t-1}, \text{ i.e. ramping up}$$
$$C^{ramp}=\gamma^{\downarrow}(V_{h-1}-V_h) \quad \text{if } V_{t-1}>=V_t, \text{ i.e. ramping down}$$

Here, $\gamma^{\uparrow}$ is ramping up cost by per unit volume, and $\gamma^{\downarrow}$ is cost for ramping down by per unit of volume.

Constant Volume Schedule: Under constant volume operation, if ramping cost has to be modelled, only change will be over the right hand term on minimum income criteria. More precisely, term $(\gamma^{\uparrow}+\gamma^{\downarrow})V$ has to be added to the expression representing minimum cost to be recovered (minimum income). As for example eqn 2, modelling minimum cost to be recovered under fixed marginal cost mechanism, will be modified as

$$V\sum_{h=h_1}^{h_2}\mathrm{MCP}_h \geq s(\alpha^{\uparrow}+\alpha^{\downarrow})+s(h_2-h_1+1)\omega + (h_2-h_1+1)\beta V+(\gamma^{\uparrow}+\gamma^{\downarrow})V \quad (37)$$

Remark 2. *Because of the objective to maximize social-welfare, each of C_h^{ramp} will be pushed down as much as possible, and hence, will attain tighter of the bounds.*

Variable Volume Schedule: Irrespective of whether model is fixed and variable or fixed and marginal, modelling ramp is same. Let us define, variable C_h^{ramp}, as cost of ramping from time slot $h-1$ to h. Thus, considering bid for a period of h_2 to h_1, following condition holds,

$$C_h^{ramp} \geq \gamma^{\uparrow}(V_h-V_{h-1}) \quad \forall h\in\{h_1+1,h_1+2,\cdots,h_2\} \quad (38)$$

$$C_h^{ramp} \geq \gamma^{\downarrow}(V_{h-1}-V_h) \quad \forall h\in\{h_1+1,h_1+1,\cdots,h_2\} \quad (39)$$

$$C_{h_1}^{ramp}=\gamma^{\uparrow}V_{h_1} \quad (40)$$

$$C_{h_2+1}^{ramp}=\gamma^{\uparrow}V_{h_2} \quad (41)$$

If $V_h>V_{h-1}$, eqn 38 gives tighter bound on C_h^{ramp}, whereas eqn 39 gives same for the case of $V_{h-1}>V_h$. Now add this variable to minimum income expression. Hence, for the case of fixed and marginal cost structure, corresponding expression (eqn 4) will be modified as

$$\sum_{h=h_1}^{h_2}\mathrm{MCP}_h V_h \geq s(\alpha^{\uparrow}+\alpha^{\downarrow})+s(h_2-h_1+1)\omega + \beta\sum_{h=h_1}^{h_2}V_h+\sum_{h=h_1}^{h_2+1}C_h^{ramp} \quad (42)$$

Similar relation follows for other models as well.

TABLE II
BASE CASE SAMPLE DATA

	Buy		Sell		Block Sell	
Hr	Price	Volume	Price	Volume	Price	Volume
1	700	100	150	50	300	100
	600	150	180	150		
	550	200	—	—		
2	700	100	200	50		
	600	200	210	150		
	550	200	—	—		

V. CASE STUDIES

A. Base Case: Normal Block Bids

Table II lists out data received for 2 hour market. On performing bid matching, it is observed that

1) Block bid is unable to clear,
2) Both sell and buy bid clears to 150 of volume for both the hours,
3) MCP for first hour comes out to be 575 and for second it is 600, and,
4) Total traded volume is 300 with net social welfare of 113500.

B. Case I: Stepped Block Bid for Flexibility

Let us assume that block bid came with a figure of 300 for 100 unit volume by the fact that its start up and shut down cost are both 20,000, and marginal cost of 100 when delivering volume of 100. Hence, for two hour operation, it has total cost of $(20,000+20,000)+2\times(100\times100)=600,000$. Hence, it requires average MCP of $\frac{600,000}{2\times100}=300$. However, suppose it can operate at two voltage levels of, one being 50 and other being 100. If this trader bid in this format (using stepped bid option), then bid matching process results in following observation:

1) Block bid is able to schedule total of 50 units of volume,
2) Buy bid schedules to 200 in both the hours and sell bid to 150,
3) MCP for first hour comes out to be 475, while for second it is observed to be 600, and,
4) Total traded volume in this case is 400 and net social welfare is 121000.

C. Case II: Variable Schedule for Block Bid

In this case we allow block bid to change its scheduled between both the hours. In this case it is observed that block bid is able to trade more in first hour where it is able to sell complete 100 unit of volume. MCPs comes out to be 380 and 470 with social welfare now being 135000.

D. Case II: More Competition

In this case seller (hourly) drops his price for hour 1. He bids price of 300 for total volume of 150. In hour 2, he introduced one more level of bidding, where he is willing to trade for 200 unit of volume, provided he gets price of 350.

Under this condition, block bid is unable to make any trade. Though, social welfare has increased to 136500 (due to low price by seller), traded volume comes down to 350.

E. Case III: Block Bid More Competitive

In response to above competition, block bidder observes that he can sustain with marginal price of 50 for first 50 unit of volume. However, if it is asked to deliver 100 unit of volume, its marginal price remains 100.

In this case block bids clears 50 unit of volume in both the hours, with social welfare being same at 136500, but with traded volume being 400.

VI. Conclusions

In this paper, we have developed new bid structures as alternative to block bids. Central notion behind each of these structure is ability to specify various cost components, namely, start-up, shut-down, ramping, running and volume dependent variable price. Possibility of block bid varying its volume is also explored and modelled in the structure. Case studies demonstrates that such a structure allows block bidder to come up with more competitive price. Also number of block bids being rejected paradoxically decreases. It is expected that incorporation of proposed block bid structures will lead to more volumes being scheduled. However, more thorough investigation is required to establish any such relation.

References

[1] [Online]. Available: http://www.nordpoolspot.com/glossary
[2] [Online]. Available: http://www.nordpoolspot.com/trading/The_Elspot_market/159/Bid_types/
[3] R. Madlener and M. Kaufmann, "Power exchange spot market trading in europe: Theoritical considerations and empirical evidence," Oscogen, March 2002. [Online]. Available: http://www.oscogen.ethz.ch/reports/
[4] L. Meeus, K. Verhaegen, and R. Belmans, "Block order restrictions in combinatorial electric energy auctions," *European Journal of Operational Research*, vol. Online, 2008.
[5] R. Romero, A. Monticelli, A. Garcia, and S. Haffner, "Test systems and mathematical models for transmission network expansion planning," in *IEE proceedings generation, transmission and distribution*, vol. 149, no. 1, Jan. 2002.
[6] R. K. Gajbhiye, A. De, and S. A. Soman, "Computation of optimal break point set of relays: An integer linear programming approach," *IEEE Transactions on Power Delivery*, vol. 22, no. 4, pp. 2087–2098, Oct. 2007.
[7] D. Dua, S. D. Dhambare, R. K. Gajbhiye, and S. A. Soman, "Optimal multistage scheduling of pmu placement: An ilp approach," *IEEE Transactions on Power Delivery*, vol. 23, no. 4, pp. 1812–1820, Oct. 2008.

Appendix I
Linearizing Quadratic Term in Minimum Income Expression

In expressions modelling minimum income constraint, we have encountered terms like $V\sum_k \mathrm{MCP}_k$ or $\sum_k V_k \mathrm{MCP}_k$. Since, both volume and MCP terms are variable, they cannot be used directly in ILP model. Hence, we develop linear approximation of the same. We will present this exercise for $V\,\mathrm{MCP}$. V can be appropriately replaced by V_k or kept V. Similarly, MCP by $\sum_k$ MCP of MCP_k. Let us assume that V can be varied between V^{min} to V^{max} with a resolution of ΔV. Let $V^{max} - V^{min} = n\Delta V$, where n is an integer. Define integer m, such that $m = \lfloor \log_2 n/2 \rfloor + 1$. Hence, any value between V^{min} and V^{max} can be represented by following expression,

$$V = S_s V^{min} + \sum_{g=1}^{m} s_g 2^{g-1} \Delta V$$

where, s_g represents m switches to be selected appropriately, and S_s is block selection switch.

- Income criteria from first block of V^{min}

$$-(1-S_s)M \le C_s^0 - V^{min} \sum_{k=k1}^{k2} MCP(k) \le (1-S_s)M$$

$$-S_s M \le C_s^0 \le S_s M$$

- Income criteria through each delta block

$$-(1-s_g)M \le C_s^g - (2^g-1)\Delta V \sum_{k=k1}^{k2} MCP(k) \le (1-s_g)M$$

$$-s_g M \le C_s^g \le s_g M$$

- Any of this delta block is eligible for selection only if main block has been selected

$$s_g \le S_s$$

- Net income

$$C_s = \sum_{g=0}^{n} C_s^g$$

Thus, in expression modelling minimum income, right hand term ($V\sum_k \mathrm{MCP}_k$ or $\sum_k V_k \mathrm{MCP}_k$), can be replaced by C_s.

Rajeev Kumar Gajbhiye (S'05) is currently working towards Ph.D. degree in Department of Electrical Engineering at Indian Institute of Technology-Bombay, Mumbai, India. His research interests and activities include large scale power system analysis, electricity markets, application of optimization techniques and power system protection.

S. A. Soman (M'97) is a Professor in Department of Electrical Engineering, Indian Institute of Technology-Bombay, Mumbai, India. He has authored a book titled "Computational Methods for Large Power System Analysis: An Object Oriented Approach", published by Kluwer Academic in 2001. His research interests and activities include large scale power system analysis, deregulation and power system protection.

Facilitating Emission Trade within Power Exchange: Development of Conceptual Platform

Rajeev Gajbhiye, *Student Member, IEEE*, S. A. Soman, *Member, IEEE*

***Abstract*— Electricity sector is one of the major contributor of emission. Hence, any policy which restricts emission level will have significant impact on its functioning. As a consequence, electricity traders will have to actively participate in emission market. What it means is that electricity traders will have to trade in two separate markets, namely power and emission (or carbon). However, to be able to derive maximum benefit, trader should be able to accurately forecast prices in either of the markets. Alternatively, we propose a new scheme where emission trading is facilitated within power exchange (PX). This not only provides single trading platform for the traders but also ensures that maximum benefit is achieved for individually as well as collectively by utilizing available carbon credits optimally.**

***Index Terms*— Power Exchange, Carbon Trading, Social Welfare Maximization, Market Equilibrium**

I. Introduction

KYOTO protocol established caps on the maximum quantity of greenhouse gas emission permitted for Annex I developed and developing countries [1, pg 35]. Internal quotas are set by these countries on emissions as a result of local business and other organizations, generally termed as 'operators'. Each operator is allocated carbon credits, where each credit gives the owner the right to emit one metric ton of CO_2E. The GWP (Global Warming Potential) factors are used to convert each of the five gases (like methane, for example) that are not CO_2 into tonnes of CO_2 equivalent (CO_2E), which is the standard of trading. Those who have unutilized quotas can sell the same to those who feel the need of additional allowances. Such trading occurs privately or in the open market [1]. In fact, such trading can also occur between two nations. In effect, this mechanism provides an incentive for adoption of green technologies as doing so will bring down emission level and hence, spare allowance can be sold in market to generate additional revenue.

Electricity sector is a major contributor towards emission and hence, such a policy restricting emission level will have major impact on it. This, in turn, means that electricity traders will have to participate actively in emission market. In fact, electricity market by itself may provide considerable volume in carbon trade.

Under emission constrained environment, electricity traders have to take the cost of emission into account while putting up bids/offers. Sometime it may be even profitable to sell owned allowances. An electricity seller may like to sell carbon credits due to one of the following reasons:

Rajeev Gajbhiye (e-mail:rajeev81@ee.iitb.ac.in) and S. A. Soman (email:soman@ee.iitb.ac.in) are with the Department of Electrical Engineering, Indian Institute of Technology Bombay, Mumbai, India

1) Generating capability being not enough to exhaust allocated credits i.e. surplus carbon credits,
2) Inability to get adequate amount of schedule due to low demand or being costlier generation, and,
3) Price of selling credits being more favourable than price of selling electricity using these credits.

Similarly, one may like to purchase carbon credit if one feels that purchasing additional credits enable scheduling units, which otherwise could not have been. Moreover, profit acquired out of these additional schedules is more than what have been spent on purchasing credits.

Currently, separate markets exist for power and carbon trading. As a result, trader has to put up his offers in power market judiciously. It has to take possible price, at which trader may be able to purchase additional carbon credits, in consideration. Therefore, trader should be able to forecast price on either of the market accurately. Situation can become more complex for block bidders/offers, who even after knowing the price may not be certain whether they will get schedule or not.[1] In contrast, in our work we propose to couple power and carbon markets which will make such accurate forecasting need almost redundant. Trader has to only worry about how corresponding generation capability is valued or what utility one can associate with energy consumption. Proposed market mechanism by itself will take care of allotting appropriate credits to the traders at optimal price. This results, as demonstrated by case studies, in better utilization of emission allowances.

Some work have been reported on coupling emission constraints with unit commitment. In [2], authors have applied Lagrangian-relaxation-based algorithm, wherein emission is considered as a second objective function with a weighting factor. This approach, actually tries to minimize net emission rather than limiting it to a predefined value. Similar technique have been applied in [3], but here certain limit is imposed on net emission. In [4], authors have used simulated annealing to solve unit commitment problem, while the emission constraints are taken into consideration by counting the cost of purchasing additional emission allowances in the case that the total system emissions exceed a predefined maximum limit. This approach tries to find an optimal trade-off between the total cost of the system and the enforcement of the emission constraint. An iterative methodology has been proposed in [5] which accounts for network constraints as well. In all these cases, emission constraint is imposed globally and hence, no trading of carbon credits takes place. The work in [6] has formulated this problem as an instance of mixed integer non-

[1]Block bids may be rejected paradoxically.

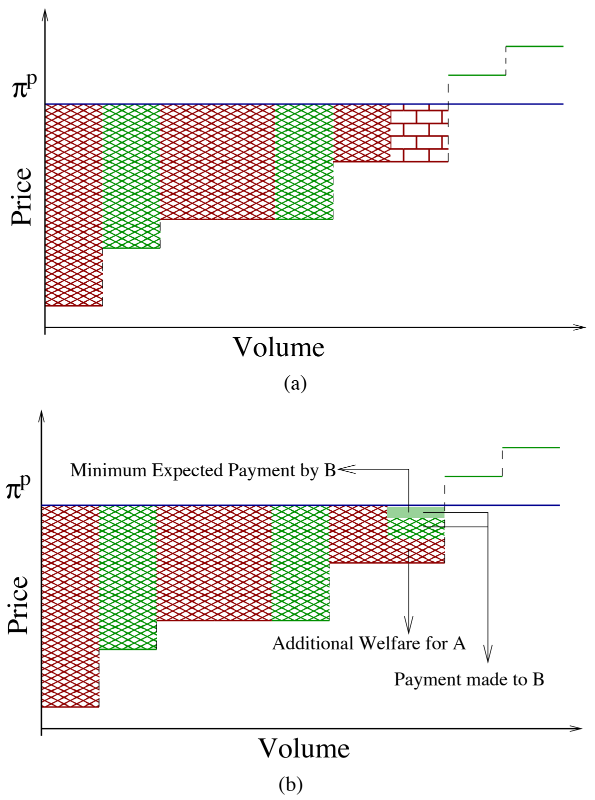


Fig. 1. Effect of emission constraint on Scheduling and Social Welfare

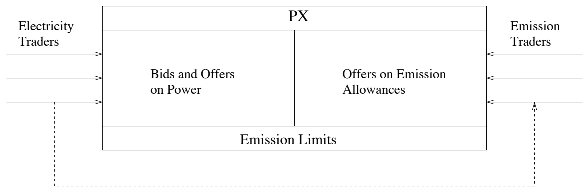


Fig. 2. Conceptual Illustration of Emission Trading within Power Exchange

linear programming problem. Here, authors have accounted the possibility that a trader can buy/sell deficit/surplus emission allowances in separate emission market.

As far as our investigation indicate, there is no prior work reported, which has attempted to couple such a constraint within power exchange. Moreover, this work differs in the sense that while emission constraint is honoured globally, each trader also have certain limits to be obeyed. However, this limit, can be either increased/decreased by buying/selling carbon credits from/to other traders.

We begin with a motivation example in section II to bring out the benefit of facilitating trading power and carbon credits under single platform. Thereafter, we develop conceptual understanding on the market behavior within the proposed mechanism and also extend the definition of social welfare and equilibrium prices in section III. Results are presented in section IV to bring out the distinction when compared with normal market after which paper is concluded in section V.

II. Motivation Example

Fig 1 represents a simplified scenario. There is one demand bid with single step, whereas on supply side two traders, say trader A (shown in red color) and trader B (represented by green color). Both sellers have put up offers in multistep. In absence of emission constraint all red steps are cleared whereas two steps in green goes out of the market.

Now suppose that generators possessed by trader A pollutes high. Consequently, he may have to curtail his generation to a lower schedule even though his price is well below market price. As a result he looses part of surplus, marked in brick pattern in figure 1(a). Now since, trader B has enough spare carbon credits, either due to lack of schedule or due to less polluting units, some of his credits may be transferred to trader A. However, this transfer is possible provided minimum sell price expected by trader B ensures that trader A makes additional profit over restricted schedule.

To develop clearer understanding, let us suppose to generate 1 MWh of energy (or 1 MW of power for 1 hour), A's generator emits k units of pollutants. Let us assume that market price for electricity and emission trading comes out to be π^p and π^e respectively. Let unscheduled step have bid price of p. Also, trader B might have lower limit on sell value of carbon credits, say p^l. On scheduling this step, trader A will earn surplus of $\pi^p - p$ per unit of volume. However, trader has to also spend $k\pi^e$ for each unit of additional volume being scheduled. Now, transfer of credit is acceptable to trader A if incremental expenditure (on purchasing credits) is less than incremental surplus. Hence, if there exists π^e such that, $p^l \leq \pi^e$ and $\pi^p - p \geq k\pi^e$, transfer of credits can take place.

Figure 1(b) captures the effect of credit transfer. As shown in the figure, trader A is able to schedule complete volume at this last step as well. However, he loses certain surplus due to expenditure incurred on paying trader B to buy additional credits.

III. Proposed Mechanism

In [6], authors have modelled emission sales and purchase from separate spot market in optimal unit commitment. Generators in addition to cost curve also submit estimate on emission allowances price for buy and sell at which, if required, trader can obtain additional credits or sell spare ones. The objective of this model is to minimize net generation cost, which accounts for cost curve, start-up costs and costs associated with buying and selling emission allowances.

This model can be easily applied to PXs' scheduling framework as well, though with few additional/modified constraints. However, in proposed scheme, we follow different methodology. We capture possibility of emission trade among electricity traders as a part of PX activity. Under this mechanism, traders, in addition to their price-volume relation, declares emission limits that they are willing to utilize over the whole day. They also declare minimum price at which they will be willing to sell spare allowances. This model even permits pure emission seller to participate in the market. Whether to allow such participation or not is left to PX's discretion. Figure 2 captures the concept of proposed mechanism.

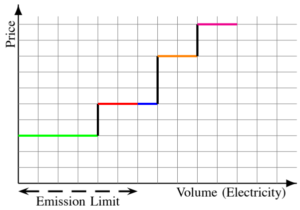
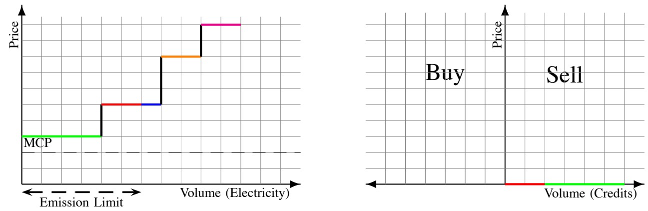


Fig. 3. Example Aggregated Supply Curve



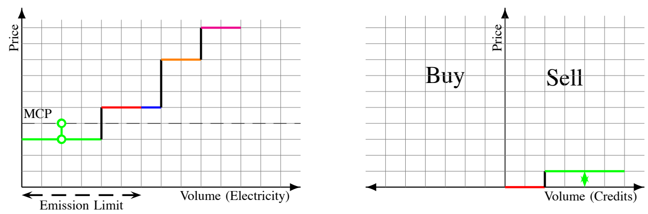
(a) (b)

Fig. 4. Effect on Emission Utility with MCP below first step

A. Inferred Emission Utility on the Basis of Power Market Clearing Prices

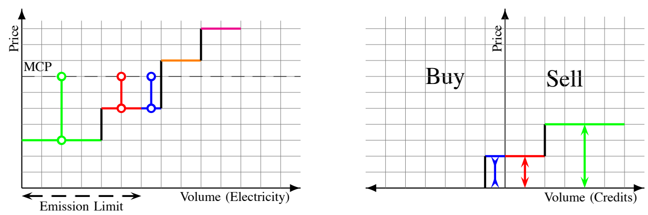
In this section, conceptual understanding is developed on the relation between clearing prices in power market and utility of emission credits. More precisely, through simple example, it is demonstrated that *significance/importance* that trader will associate with emission rights will have direct correlation with prices at which power market clears. In short, it is established that if lower prices are prevalent in power market, then appetite for carbon credits diminishes, whereas with higher price priority will reverse.

Figure 3 represents an example supply offer curve from a trader. Also, marked is the limit on generation capability due to limit on emission allowances held by him. We assume that emission factor remains same irrespective of amount of power being delivered. We also make simplified assumption that emission allowances by itself has no value for the trader, which means, if he is unable to utilize the credits, he is willing to sell them for free. This restriction can be easily relaxed as explained in remark 1.



(a) (b)

Fig. 5. Effect on Emission Utility with MCP between first and second step



(a) (b)

Fig. 6. Effect on Emission Utility with MCP between second and third step. Inward arrows indicates price should be less than limit for corresponding trade to be acceptable while outward arrows represents greater price.

We now consider MCP at various levels and its impact on utility that is perceived out of emission credits.

MCP below first step:
Since, trader cannot schedule any amount of power, he can put all his credits for emission trade with price zero as shown in fig 4(b).

MCP between first and second step:
Under this scenario, second step cannot be scheduled at all and hence, corresponding allowances can be put up as offer with zero limit price. Trader will prefer scheduling first step, unless emission price is so high that revenue earned there is more than the surplus gained in power market. Consequently, he can put up offer for this part of emission allowances at an appropriate price. Thus, if emission constant is k, offer price is p and MCP is π_h^p, then trader will put up an offer on credits with limit price of $\frac{\pi_h^p - p}{k}$ as shown in fig 5(b).

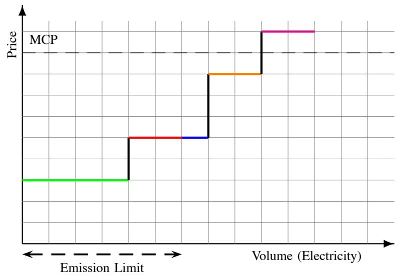
MCP between second and third step:
In this case, trader can schedule both first and second step profitably. However, second step can be scheduled partially due to emission constraint. As in earlier case, trader can derive offer prices on emission credits corresponding to both these steps. Additionally, he will like to schedule remaining part of second step provided he can acquire additional credits at cost less than the surplus which trader will gain through corresponding trade in power market. Thus, trader can put up appropriate bid for emission purchase as indicated in fig 6(b). In similar vein, curve on emission trade can be derived for other MCPs.

Remark 1. *In the example worked out above, we assumed that emission allowance by itself has no value for trader. However, if trader associates certain minimum value, then it can be accounted by simply shifting the curve by that value while selling.*

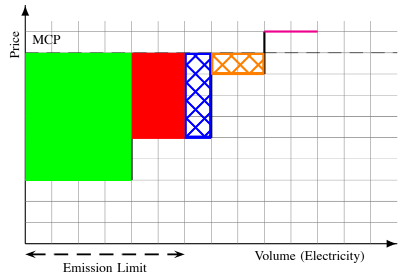
B. Relation of Surplus Maximization Strategy with Clearing Prices on Power and Emission Trading

It was observed that different MCPs in power market leads to different perception on emission allowance utility from a trader's perspective. Next, using this relation, we develop understanding on the strategy that should be adopted by a trader so as to maximize his surplus for a given set of prices on both power and emission.

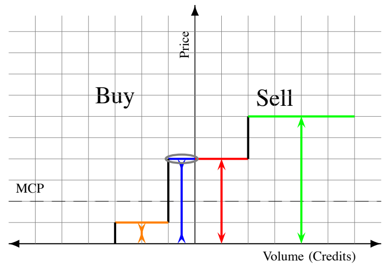
In fig 7(a), the example discussed earlier (fig 3) is revisited, where MCP in power market lies between third and fourth offer step. Consequently, trader could have scheduled each of the first three steps due to positive surplus gained in each of them. However, constraint on emission means that generation has to be backed down resulting in clearing of first step and partially second step. This is indicated in fig 7(b), where surplus possible within available credits are marked in solid colors while surplus lost is marked in cross-hatched pattern.



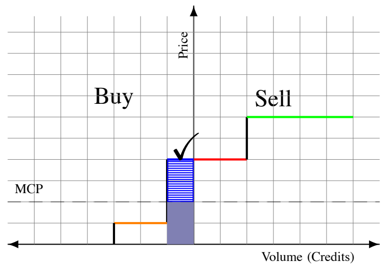
(a) Example offer curve from a trader with corresponding emission limit. MCP is also marked.



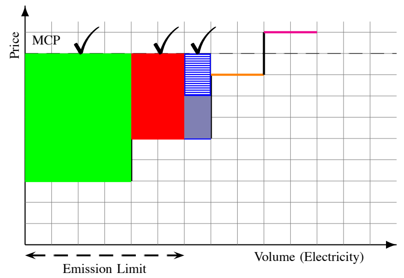
(b) Solid blocks are surplus that can be gained within available emission limits and cross-hatched indicates that which can be gained if additional credits are available



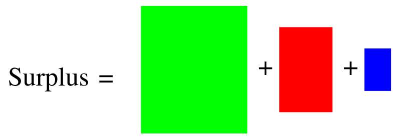
(c) Emission trading curve, with MCP in emission market is as marked. At this MCP, buying credits corresponding to blue step is profitable for the trader.



(d) Semi-filled block is the cost incurred by trader and solid block is the surplus gained in addition to green and red.

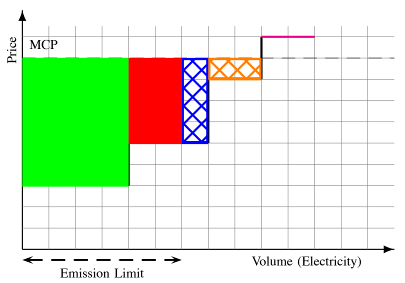


(e) Along with red and green steps, blue steps can be scheduled due to additional credits procured from emission market. However, orange step cannot be scheduled as emission price is not that favourable.

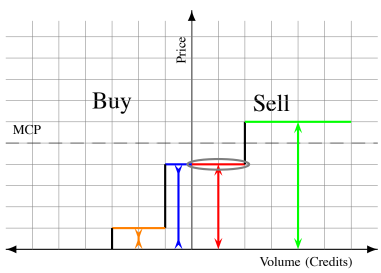


(f) Net surplus after accounting trade in both the markets.

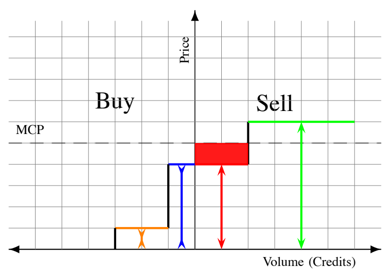
Fig. 7. Maximizing trader's surplus considering prices both in power and emission market: Low price in emission market



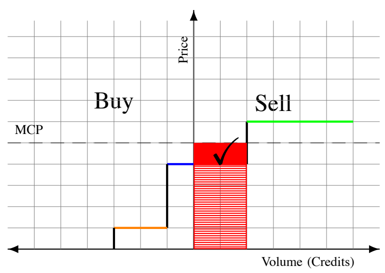
(a) At given MCP, trader can schedule first two steps profitably and next two steps if emission credits can be procured in appropriate price.



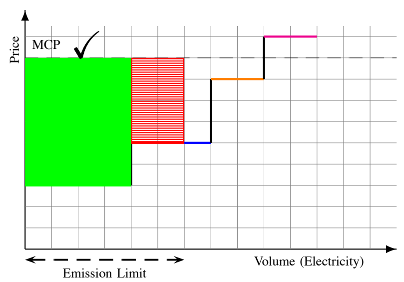
(b) Emission curve inferred in response to MCP in power market. Selling credits corresponding to second step is observed to be more profitable due to higher emission price.



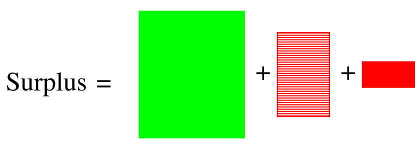
(c) Spare credits that can be generated after backing of second generation step. The red rectangular block is additional surplus on selling these credits as compared to what could be gained by scheduling second step and consuming them.



(d) Surplus made out of backing generation and selling corresponding credits.



(e) Only first step is scheduled, second step is backed down.



(f) Net surplus after accounting trade in both the markets.

Fig. 8. Maximizing trader's surplus considering prices both in power and emission market: High price in emission market

If this MCP was known a-priori, supplier would have put emission trading curve as shown in fig 7(c). In this curve, left part represents bids on emission purchase and right component models offers on sale. If trader can procure small amount of additional credits, he will be able to schedule part of blue step. However, for such a trade to be possible, price on emission should be less than incremental surplus gained for each unit of credits. Hence, he comes with the corresponding price for the same and also amount of volume which he can purchase (which is limited by maximum volume in blue part). Next is third step which has even less amount of surplus and hence leads to lower value being associated with credits as shown in figure.

It is also possible that trader could back down his generator provided prices on emission is more than incremental surplus gained out of the step being backed down. Thus, two such steps forms the part of emission sell curve. Now, as shown in fig 7(c), if emission price turns out to be on lower side say somewhere in between first and second step of buy part of curve, trader will naturally purchase credits which will enable him to schedule blue part of generation completely as indicated in fig 7(e).

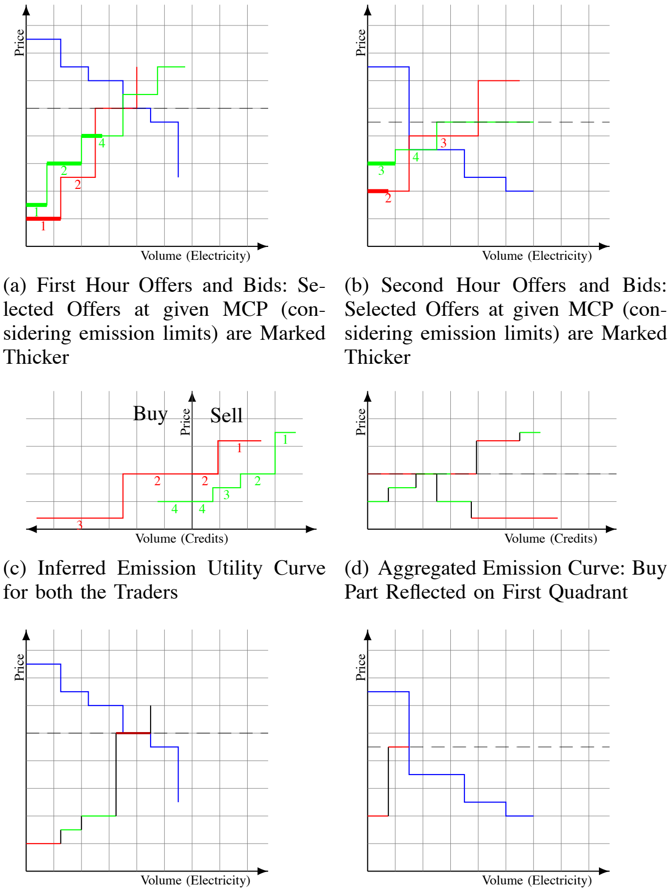
Net surplus, as indicated in fig 7(f), now has blue component which is combined effect of power and emission trading. As it is observed, part of surplus gained in power market is now paid to procure required credits.

Now let us consider same example but with higher price on emission trading as shown in fig 8(b). As it can be observed, maximum benefit for trader will be in selling all the credits associated with scheduling of red part of offer. Doing so gives him additional surplus over what he was able to obtain by scheduling same part of generation. This additional benefit is marked as solid red coloured rectangle in fig 8(c). Net surplus, thus made out of overall trading is shown in fig 8(f). The middle component in this figure is the surplus that trader would have acquired if he had not backed down. Third component is additional benefit that trader gains by trading generated spare credits in market.

Remark 2. *In the proposed framework, the value of emission credits is derived from offer values and MCP in the electricity market. This leads to formation of a* sub-market *on emission, where sellers only provide minimum expected price on selling. Actual offers (sell) and bids (buy) on emission are implicitly modelled as function of electricity offers and corresponding MCP. A simultaneous solution of two markets leads to equilibrium scenario while maximizing social welfare which has component from both electricity as well as emission trading.*

C. Market Equilibrium

In a market, *equilibrium* is said to exist if at the given MCP none of the traders have any incentive to move away from allocated schedule. These price(s) are referred as *equilibrium price(s)*. We extend this concept to the proposed scheme as follows:
"A given set of prices and schedules on power and emission trading is said to establish market equilibrium, if at these MCPs (on both electricity and emission) one can come up with



(a) First Hour Offers and Bids: Selected Offers at given MCP (considering emission limits) are Marked Thicker

(b) Second Hour Offers and Bids: Selected Offers at given MCP (considering emission limits) are Marked Thicker

(c) Inferred Emission Utility Curve for both the Traders

(d) Aggregated Emission Curve: Buy Part Reflected on First Quadrant

(e) Adjusted Offer Curves for First Hour after Accounting for Emission Trade

(f) Adjusted Offer Curves for Second Hour after Accounting for Emission Trade

Fig. 9. Fictitious two hour market to demonstrate equilibrium with embedded emission trading mechanism

schedule as well as emission trade (along with corresponding price), maintaining supply-demand balance on both power and emission, to which none of the trader has any objection."

Figure 9 demonstrates this concept. In this example, a fictitious two hour market is considered with one consumer (in blue) and two suppliers (in red and green respectively referred as A and B). A has emission limit of 10 $MTCO_2E$ with emission factor being 1.25 $MTCO_2E/MWh$, while B can pollute up to 15 $MTCO_2E$, with his generators leading to 1 $MTCO_2E$ of emission for each MWh of energy generated. Each grid in the figure represents 4 MW of power (and hence 4 MWh of energy over 1 hour) on x-axis and 4 MU (MU stands of appropriate monetary unit) for price on y-axis On solving this problem, equilibrium prices are found to be 20 MU/MW for first hour and 18 MU/MW for second. We now explain how these prices lead to equilibrium. Provided prices are known, both the traders will schedule so as to maximize profit while honouring individual emission limits. This scheduled is indicated by thicker line-segments in fig 9(a) and 9(b). Note that as emission limit is across the entire scheduling period (in this case 2 hours), steps from both the hours will be ranked based upon their difference from corresponding MCP

TABLE I

TEST CASE CONSISTING OF 3 SELLERS AND 1 BUYER

	Offers/Bids as Strings of (Price,Volume)		Emission		
	Hour 1	Hour 2	L	F	V
S1	(2,7) (5,5) (10,8)	(6,6) (10,6)	12	0.8	3
S2	(2,13) (5,8) (7,8) (9.15)	(2,6) (8,6) (10,5) (12,3)	15	1.25	2
S3	(9,10) (11,15)	(4,2) (10,6) (15,6)	20	0.25	1
B1	(20,10) (18,7) (15,7) (10,14) (5,12)	(20,10) (15,8) (10,8) (5,4)	–	–	–

L=Limit; F=Factor; V=Value

(MCP – Offered Price); highest difference means first rank. Steps are then selected in this order till limit is exhausted or no more step is left. This ranking is marked in the figure itself. Hence, emission utility curve can be inferred on behalf of both the traders as shown in left part of fig 9(c), which is then aggregated (as shown in fig 9(d)). The intersection of buy and sell curve leads to clearing price of 8 MU/MTCO_2E and traded volume to be anywhere between 7 to 10 MTCO_2E, with buyer being A. As one will like to maximize the traded volume, we choose 10 MTCO_2E. Consequently, B has to back-down 10 MWh of generation and A has freedom to deliver 8 MWh of energy more over the period of two hour in any combination. Naturally, B will back-down that part of generation which brings him least surplus whereas A schedules those bringing him most surplus. Eliminating unscheduled part of generation curve and accounting for emission purchase on portion of A's curve representing additional schedule (due to emission trade), aggregated curves are plotted for each hour in fig 9(e) and 9(f). As it is observed, resulting intersection exactly at the MCPs assumed earlier. Repeating same exercise for other set of MCPs (say 24 MU/MW and 16 MU/MW), one can observe that final intersection will occur at some other price levels and hence non-equilibrium state.

IV. Results

We consider a simple test case with three sellers (S1, S2 and S3) and single buyer (B1) as shown in table I. Emission factor is assumed to be constant for each of the seller. S2 has cheapest offer and is also most polluting, whereas S3 is costliest but cleanest source of power supply. S1 lies in between the two in terms of both offered electricity price as well as pollution.

Three cases are considered; in *first* case emission limits are ignored while *second* one enforces emission limits but no trading whereas *third* case permits emission trading among participants. Table II summarizes overall results. As it is observed from this table, Case-I results in highest social welfare, which is on the line of expectations. However, resulting schedules means that S1 has to cover deficit of 2.4 units of emission credits while in case of S2 it is 32.5 units whereas S3, being unable to clear enough volume due to costlier generator(s), is left with 18 units of spare credits. Case-II, due to individual emission restrictions, means that generation has to be curtailed significantly by S1 and S2. This, in turn, allows S3 to inject more power, though not much. Consequently, net welfare reduces significantly. While S1 and S2, as expected, are found to exhaust emission credits, S3 is left with spare 15.5 units. Case-III, due to embedded emission trading, allows S1 and S2 to purchase appropriate amount of credits from S3. Social welfare as well as traded volume is boosted as compared to Case-II, but remains lower than Case-I. Emission credits are exhausted completely.

TABLE II

RESULTS ON TEST CASE IN TABLE I

			Case I	Case II	Case III
MCP	Hour 1		7	10	9.6875
	Hour 2		10	10	10.6875
Traded Volume	Hour 1	S1	12	11	12
		S2	26	6	17.1
		S3	0	10	8.9
		B1	38	27	38
	Hour 2	S1	6	4	6
		S2	12	6	6
		S3	8	8	6
		B1	26	18	18
Total Electricity Volume Traded			64	45	56
$\frac{E_{gen}}{E_{lim}+E_{buy}-E_{sell}}$		S1	$\frac{14.4}{12+0-0}$	$\frac{12}{12+0-0}$	$\frac{14.4}{12+2.4-0}$
		S2	$\frac{47.5}{15+0-0}$	$\frac{15}{15+0-0}$	$\frac{28.875}{15+13.875-0}$
		S3	$\frac{2}{20+0-0}$	$\frac{4.5}{20+0-0}$	$\frac{3.725}{20+0-16.275}$
Total Emission Credits Traded			–	–	16.275
Emission Price			–	–	3.75
Social Welfare			673	545	619.125

E_{gen} is generated emission while E_{lim} represents emission limits originally held. E_{buy} and E_{sell} respectively are emission rights purchased and sold.

V. Conclusions

This paper has developed concepts on embedding emission trader within participants in PX while carrying out power scheduling and providing single platform for power as well as carbon trading. Examples presented have demonstrated as how trader's perception towards the utility of emission credits changes with variation in electricity prices. Also, equilibrium prices have new dimension as now equilibrium has also to be established with respect to emission trading. Since emission limits are to be honoured across scheduling period, these prices are dependent, even while considering only hourly bids. Thus, this work has constructed a foundation for detailed mathematical model which captures traders' behaviour under proposed mechanism, so as to develop tool for computing optimal schedule.

References

[1] G. Singh, *Understanding Carbon Credits*. New Delhi: Aditya Books Pvt Ltd, 2009.

[2] S. Kuloor, G. S. Hope, and O. P. Malik, "Environmentally constrained unit commitment," *Generation, Transmission and Distribution, IEE Proceedings*, vol. 139, no. 2, pp. 122–128, Mar. 1992.

[3] T. Gjengedal, "Emission constrained unit-commitment," *IEEE Transactions on Energy Conversion*, vol. 11, no. 1, pp. 132–138, Mar. 1996.

[4] D. N. Simopoulos, Y. S. Giannakopoulos, S. D. Kavatza, and C. D. Vournas, "Effect of emission constraints on short-term unit commitment," in *Electrotechnical Conference, 2006. MELECON 2006. IEEE Mediterranean*, May 2006, pp. 973–977.

[5] I. J. Raglend and N. P. Padhy, "Solutions to practical unit commitment problems with operational, power flow and environmental constraints," in *Power Engineering Society General Meeting, 2006. IEEE*, 2006.

[6] I. Kockar, "Unit commitment for combined pool/bilateral markets with emissions trading," in *Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE*, July 2008, pp. 1–9.

Annex - II

INFORMATION

Five minute settlement

Implementation of five minute settlement

The AEMC has made a rule to align operational dispatch and financial settlement at five minutes. This will reduce the time interval for financial settlement in the national electricity market from 30 minutes to five minutes. The rule has a transition period of three years and seven months.

This information sheet provides high level information on what stakeholders need to do to be ready for five minute settlement.

Implementation of five minute settlement

Five minute settlement will commence on Thursday, 1 July 2021, noting that the transitional provisions of the final rule will commence on 19 December 2017.

From 1 July 2021, the following processes will occur on a 5 minute basis:

- Bidding and offering into the National Electricity Market
- Settlement
- Intervention pricing
- Calculation of trading amounts
- Calculation of the cumulative price threshold

Therefore implementing five minute settlement will require:

- reviewing and where necessary updating existing contract terms and conditions
- upgrading metering to provide five minute granularity data (where required)
- upgrading IT systems to store and process five minute granularity data

The Australian Energy Market Operator (AEMO) will govern and oversee the implementation of five minute settlement. The AEMC acknowledges the breadth and depth of implementation required and therefore recommends that market participants begin transitioning to five minute settlement without delay in consultation with AEMO.

Table 1 (attached) indicates the main actions that stakeholders are expected to take in the lead up to the commencement date and beyond.

Table 2 (attached) sets out the treatment of different meter types, both current and under five minute settlement.

Background

Sun Metals Corporation Pty Ltd submitted a rule change request to reduce the time interval for settlement in the wholesale electricity market from 30 minutes to five minutes.

The AEMC has made a rule, which is a more preferable rule, to align operational dispatch and financial settlement at five minutes. More information about why the rule change was made and the details of the final rule can be found in the accompanying information sheet and final rule determination.

For information contact:

AEMC Executive General Manager, **Kris Funston** (02) 8296 7811
AEMC Senior Adviser, **Ben Noone** (02) 8296 7852
AEMC Senior Adviser, **Emily Brodie** (02) 8296 7818

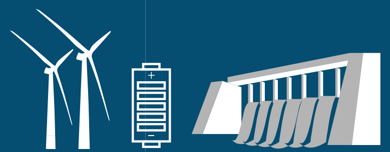
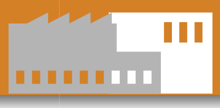
Media: Communication Director, **Prudence Anderson** 0404 821 935 or (02) 8296 7817

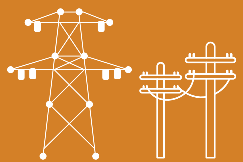
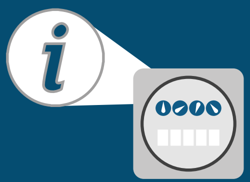
28 November 2017

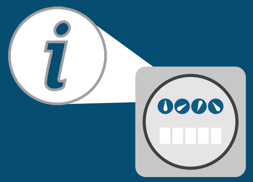
AUSTRALIAN ENERGY MARKET COMMISSION LEVEL 6, 201 ELIZABETH STREET SYDNEY NSW 2000
T: 02 8296 7800 E: AEMC@AEMC.GOV.AU W: WWW.AEMC.GOV.AU

Table 1: Indicative stakeholder actions to implement five minute settlement

Stakeholder	During the transition period	From 1 July 2021
Australian Energy Market Operator (AEMO)	**Procedures** **By 1 December 2019**, consult and amend its relevant procedures, methodologies and guidelines. **By 1 December 2019**, consult and publish a procedure setting out the requirements for applying for an exemption from complying with the data storage requirements for types 1, 2 and 3 metering installations and type 4 metering installations at a transmission network connection point or distribution network connection point where the relevant financially responsible Market Participant is a Market Generator or Small Generation Aggregator installed prior to 1 July 2021. **IT systems to be changed** Where necessary, upgrade/make changes to the following IT systems: ♦ Settlement ♦ Trading ♦ Billing ♦ Reporting ♦ Data collection and storage ♦ Structure of Electricity Market Management System (EMMS) data model tables ♦ B2B e-hub Consider providing a test environment for market participants.	Publish a **30 minute price** (calculated in the same way that the current spot price is calculated) for a regional reference node for each 30 minute period in addition to publishing the five minute spot price for each regional reference node. Publish the **pre-dispatch schedule** in two resolutions: one for a 30 minute period, and one for a five minute period. The five minute period will only be in relation to the 60 minute period before the time that the relevant pre-dispatch schedule is published. Projected Assessment of System Adequacy (**PASA**) processes to continue preparing and publishing information for each 30 minute period. **Exemptions** AEMO can exempt a Metering Provider from complying with the data storage requirements for types 1, 2 and 3 metering installations, and type 4 metering installations at a transmission network connection point or distribution network connection point where the relevant financially responsible Market Participant is a Market Generator or Small Generation Aggregator, installed prior to 1 July 2021 where it is reasonably satisfied that the Metering Provider will be able to otherwise meet the requirements of Chapter 7 of the National Electricity Rules (NER). AEMO is unable to grant an exemption for type 4 metering installations at all other connection points.

Stakeholder	During the transition period	From 1 July 2021
Australian Energy Regulator (AER) 	***By 1 December 2019***, consult and amend its relevant documents.	AER to amend late rebidding procedures and guidelines to amend late rebidding period from 15 minutes to 30 minutes before the start of each five minute trading interval. AER to apply the $5,000/MWh price threshold to the average spot price over rolling 30 minute periods rather than to a trading interval when preparing reports on high price events.
Information Exchange Committee (IEC) 	***By 1 July 2019***, consult and recommend to AEMO any changes to the B2B procedures.	
Generators, small generation aggregators 	Where necessary, update internal procedures and documents. Review and if necessary update existing contracts terms and conditions. Where necessary, upgrade/make changes to the following IT systems: ♦ Settlement ♦ Risk management ♦ Trading ♦ Reporting ♦ Data collection and storage	Submit five minute granularity offers into the National Electricity Market (NEM).
Large consumers (market load) 	Where necessary, update internal procedures and documents. Review and if necessary, update existing contracts terms and conditions. Where necessary, upgrade/make changes to the following IT systems: ♦ Settlement ♦ Risk management ♦ Trading ♦ Reporting ♦ Data collection and storage	Submit five minute granularity bids into the NEM.

Stakeholder	During the transition period	From 1 July 2021
Retailers 	Where necessary, update internal procedures and documents. Review and if necessary update existing contracts terms and conditions Where necessary, upgrade/make changes to the following IT systems: ♦ Settlement ♦ Risk management ♦ Trading ♦ Reporting ♦ Data collection and storage	Retailers can develop and offer new products and services, using five minute data to value dynamic generation and demand response for small and large consumers.
Networks 	Where necessary, update internal procedures and document Where necessary, upgrade/make changes to the following IT systems: ♦ Settlement ♦ Billing ♦ Reporting ♦ Data collection and storage ♦ Network planning system	With respect to billing for distribution services, calculate charges for distribution services from either metering data or settlements ready data for type 4 metering installations. ***From 1 July 2021***, ensure that type 7 unmetered loads are calculated on a five minute basis.
Metering coordinators 	***By 1 July 2021***, upgrade types 1, 2 and 3 metering installations to be capable of recording and providing five minute data. ***By 1 July 2021***, upgrade type 4 metering installations at a transmission network connection point or distribution network connection point, where the relevant financially responsible Market Participant is a Market Generator or Small Generation Aggregator, to be capable of recording and providing five minute data. *(continued over page)*	***By 1 December 2022*** at the latest, ensure that all new and replacement type 4 and type 5 metering installations installed from 1 December 2018 record and provide five minute data. ***By 1 December 2022*** at the latest, ensure that all new and replacement type 4A metering installations installed from 1 December 2019 record and provide five minute data.

Stakeholder	During the transition period	From 1 July 2021
Metering coordinators (continued) 	***From 1 December 2018 to the commencement date***, ensure that all new and replacement metering installations (other than type 4A metering installations) are capable of recording and providing five minute. ***From 1 December 2019 to the commencement date***, ensure that all new and replacement type 4A metering installations are capable of recording and providing five minute data. Where necessary, upgrade/make changes to the following IT systems: ♦ Settlement ♦ Reporting ♦ Data collection and storage ♦ Meter data management system ♦ B2B e-hub	
Metering data providers 	Where necessary upgrade/make changes to the following IT systems: ♦ Reporting ♦ Data collection and storage ♦ Meter data management system ♦ B2B e-hub	***By 1 July 2021***, ensure that type 1, 2 and 3 metering installations record and provide five minute data. ***By 1 July 2021***, ensure that any type 4 metering installations at a transmission network connection point or distribution network connection point, where the relevant financially responsible Market Participant is a Market Generator or Small Generation Aggregator, record and provide five minute data. ***By 1 December 2022 at the latest***, ensure that all new and replacement type 4 and type 5 meters installed from 1 December 2018 record and provide five minute data. ***By 1 December 2022 at the latest***, ensure that all new and replacement type 4A meters installed from 1 December 2019 record and provide five minute data. ***By 1 July 2021***, ensure that type 7 unmetered loads are calculated on a five minute basis.

Stakeholder	During the transition period	From 1 July 2021
Small consumers		Consider whether to access a range of new consumer products and services using five minute interval data.
Financial services (ASX, brokers, etc.)	Where necessary, update internal procedures and documents Review and if necessary update existing contracts terms and conditions Where necessary, upgrade/make changes to the following IT systems: ♦ Settlement ♦ Risk management ♦ Trading ♦ Reporting ♦ Data collection and storage	Consider offering new products and services based on five minute interval data.

Table 2: Treatment of meters under five minute settlement

Meter type	Treatment under 30 minute settlement	Treatment of existing meters under five minute settlement	Treatment of new and replacement meters under five minute settlement
Type 1-3	30 minute data collected and used for settlement	5 minute data collected and used for settlement from 1 July 2021	5 minute data collected and used for settlement from 1 July 2021
Type 4 meters*	30 minute data collected and used for settlement	5 minute data collected and used for settlement from 1 July 2021	5 minute data collected and used for settlement from 1 July 2021
Other type 4	30 minute data collected and used for settlement	30 minute data collected and profiled to 5 minutes using NSLP for settlement from 1 July 2021	Meters installed after 1 December 2018 must provide 5 minute data from 1 December 2022 at the latest
Type 4A	30 minute data collected and used for settlement	30 minute data collected and profiled to 5 minutes using NSLP for settlement from 1 July 2021	Meters installed after 1 December 2019 must provide 5 minute data from 1 December 2022 at the latest
Type 5	30 minute data collected and used for settlement	30 minute data collected and profiled to 5 minutes using NSLP for settlement from 1 July 2021	Meters installed after 1 December 2018 must provide 5 minute data from 1 December 2022 at the latest
Type 6	Data collected quarterly and profiled to a 30 minute basis for settlement	Data collected quarterly and profiled to 5 minute intervals using NSLP for settlement from 1 July 2021	No new type 6 meters are expected to be installed
Type 7	Unmetered loads calculated on 30 minute basis	Unmetered loads calculated on a 5 minute basis from 1 July 2021	Unmetered loads calculated on a 5 minute basis from 1 July 2021

* Type 4 meters at a transmission network connection point or distribution network connection point where the relevant financially responsible market participant is a Market Generator or Small Generation Aggregator