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Modern Commitment and Dispatch in the Balancing Market

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1. Introduction

The operation of the power system in the market environment requires a new approach to methodologies on system operation in particular on commitment and dispatch of power generating units. The approach to commitment and dispatch is frequently driven by the security of the system operation and in many cases transmission system operators stick with routine procedures modified to market conditions. In some cases, the development of balancing market rules is constrained by the existing operation procedures and software used.

The introduction of the common European electricity market creates a need for the modification of two crucial elements of the balancing market operation: commitment and dispatch of the generating units, and congestion management. This chapter describes the universal approach to commitment and dispatch in the balancing market. The methodologies have been successfully implemented in the Polish electricity market in 2001 and after nearly four years in operation have demonstrated many advantages. The experience shows that after some modification the method proposed can be easily implemented in any electricity market structure. It can used as a uniform approach allowing for consistent market operation procedures.

2. Historical background

When the electricity market structure was approved in 1999 in Poland, there was pressure to quickly implement the electricity market [1]. The Power Exchange was established in June 2000 however the balancing market was not ready for operation until September 2001.

The balancing market operation required new computer software which would be able to prepare commitment and dispatch using balancing bids submitted by generating units, taking into account the network constraints and the technical characteristics of over 100 generating units.

Two systems: LPD and GMOS were designed and constructed in 2000 for a day ahead balancing market. However, their implementation had to wait for the development of telecommunication infrastructure. The balancing market started its operation with new systems for commitment and dispatch on 1st September 2001. It has been working successfully ever since.

The power operation planning is based on two systems. The first one Linear Programming Dispatch is the software for linear-binary optimization based on the balancing bids submitted by generating units. The second one GMOS is the data base for the network constraints represented by nodal constraints.

The operation of the balancing market includes several stages [2]. First, it verifies the consistency of contract positions and the bids submitted. Secondly, using the balancing bids and information about technical constraints, the TSO computes commitment and dispatch of generating units. The calculation results in the one-hour interval generation schedule for Day N. However, one-hour intervals used for energy trading are too large for generating unit control, due to large variations in daily electricity demand. The TSO recalculates the one-hour interval schedule to a 15-minute interval schedule in order to provide adequate control signals. It is assumed that the average values of four 15-minute signals, in a given hour, are equal to the energy in this hour set by the one-hour interval generation schedule, [3].

The linear-binary programming has been applied to solve the commitment and dispatch problems, [4]. The LP engine XPRESS provided by the Dash Associates Limited was implemented to find the minimum of the objective function subjected to network constraints.

There are some similarities between the Polish balancing market and the NETA, but the solutions implemented in the Polish balancing market are simpler, allowing for a transparent balancing mechanism with less complicated procedures. In contrast to the NETA which employs power bids with linear approximation for final notifications, the Polish balancing market uses energy for bids, commitment and dispatch. This makes the Polish balancing market more consistent with the energy trade.

3. Structure of the electricity market

The Polish electricity market with a total annual production of about 153TWh operates as a bilateral market with the Power Exchange, which is an independent party and the Balancing Market managed by the Transmission System Operator (TSO). Currently the TSO name is PSE-Operator.

When the electricity market was introduced there were 33 distribution companies and 16 large power stations supplying over 80% of electrical energy. Over 100 generating units, with generating capacity over 100MW, are centrally dispatched by TSO. They are called Centrally Dispatch Generating Units (CDGU) and are obliged to be equipped with second and minute reserve. The CDGU units have to submit the balancing bids to the day ahead balancing market and follow the instruction from the TSO on electricity volume generated .

Fig. 1 depicts the structure of the Polish electricity market. Power Producers (PP) enter bilateral contracts with Distribution Companies (DisCo) and some large industrial users – not shown on this figure. The bilateral trade of various forms covers over 95% of the electricity in the wholesale market including electrical energy in long term contracts, which is traded with the involvement of PSE SA and Minimum Energy Take (MET) imposed on distributors. The Power Exchange turnover is about 2% and the balancing market volume turnover comprises of about 2% of the total electricity produced.

Participants in the wholesale market have to send Information on Energy Sold (IoES) and Information on Energy Purchased (IoEP) to the TSO. The same obligation is imposed on the Power Exchange and energy trades. The information on energy sold and purchased has to relate to each generating unit in one hour intervals for one day ahead. Power generating units also have to submit balancing bids for each generating unit in one hour intervals. Balancing bids from energy users and distributors are not allowed in this stage of the market development.

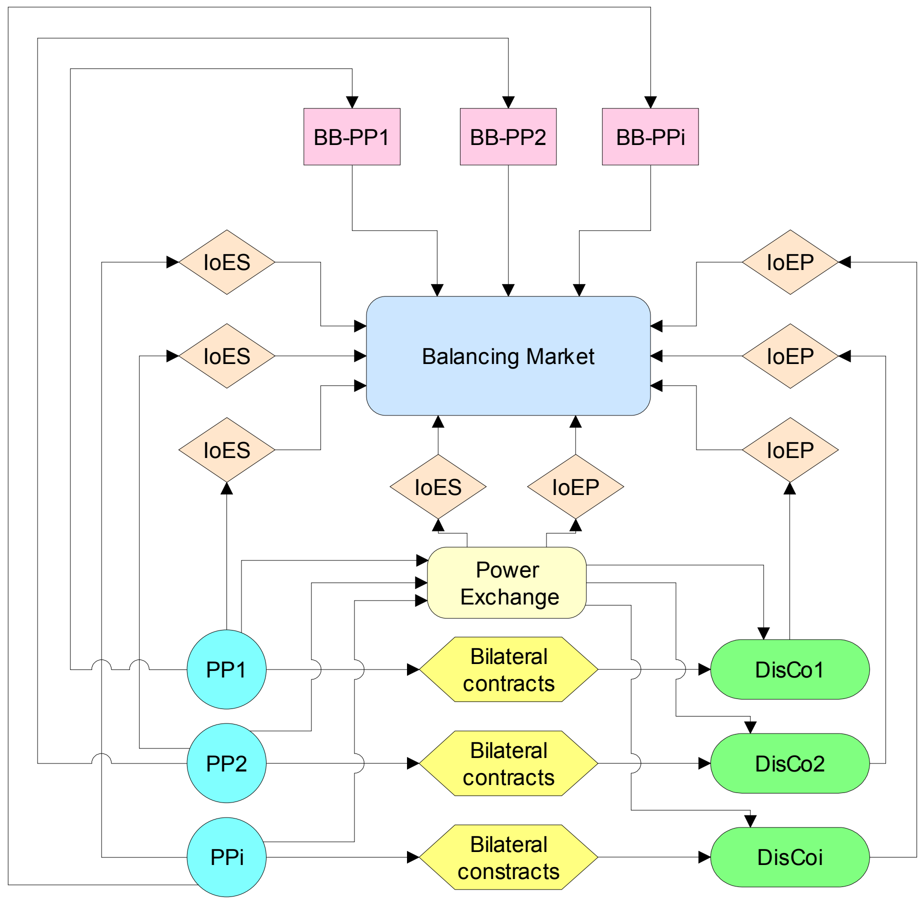

Fig. 1 Structure of a day ahead balancing market

4. Energy assigned to generating units

The TSO forced the obligation to assign the energy traded to each generating unit. The reason behind this solution are the long term contracts between power stations and PSE SA, which is the parent company of PSE-Operator. Long term contracts relate to the individual generating units. The information on energy sold from each generating unit facilitates the settlement of long term contracts, which is carried out outside of the balancing market. However such allocation of the energy sold has several drawbacks.

Electrical energy is traded between power stations and distributors or other energy users as legal entities, so there is no need to specify which generating unit is used to produce electricity as this product has uniform physical features. The TSO does not also need to know which generating unit is assigned to which specific trade party in the purchase contracts when several generating units are connected to a network node. From the network operation point of view the amount of energy injected in a specific node, and a number of working and standby units is sufficient information.

Before the introduction of the balancing market some power stations had installed local optimization software to assign power production to the most efficient unit, preserving volume of energy flowing to the network node on the prescribed level. These power stations were forced by these market rules to shut down their local optimization.

Electricity trade in the Power Exchange is carried out by clearing supply and demand bids submitted by power companies as legal entities and members of the Power Exchange. The balancing market rules, which require an energy purchase party to be assigned to each generating unit, forced several operation cycles in Power Exchange. First the clearing price is calculated using bids submitted by the Power Exchange participants and the information on the volume traded is sent back to power producers. Secondly power producers assign the electricity sold in Power Exchange transactions to individual generating units and transmit this information to the Power Exchange, which passes the information obtained to TSO.

Moreover, such balancing market rules allow for market gaming by power producers. From the information received from TSO power station traders know the nodal constraints required to preserve some level of power production as well as the number of operating units in a network node. They can easily foresee which generating units have to operate due to network constraints. It allows them to assign the energy traded to power generating units which are not required for secure network operation, not assigning energy to the generating units necessary for network operation.

TSO is forced to purchase energy from some generating units and reduce the amount of energy offered by other generating units, which are not necessary for the network operation. This switching of energy between generating units brings extra income to power stations despite the price cap on energy purchase forced by the network condition.

The future solution should aim at splitting system operation from energy trade. In such a case, the balancing market participants will only provide the information on energy sold as legal entities. The TSO should be able to assign power generating units based on network constraints without the need for a trade off between particular generating units. Another solution is to impose on power producers the requirement to provide generating programs complying with all network constraints. This is more difficult to implement in a weak transmission network with many constraints.

5. Demand for electrical energy

The total demand for electric power in Poland reaches over 23000MW. However demand covered by CDGU is smaller. It varies from about 8000MW during low night demand – demand valley – to near 20000MW during maximum demand period – demand peak. Fig. 2 shows the demand to be covered by CDGU in September computed as average values in hours of the days along a 30 day period.

The energy volume in the balancing market is small, reaching about 5000-6000MWh per day. Fig. 3 shows average values calculated for specific hours of the day in two weeks in March 2005.

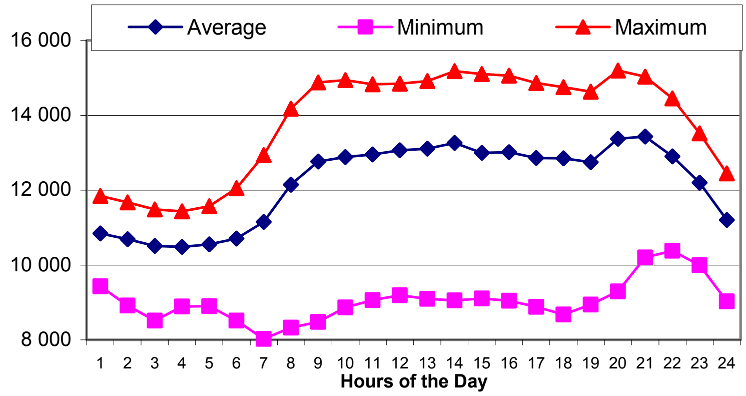

Fig. 2 Demand for electrical energy to cover by CDGU.

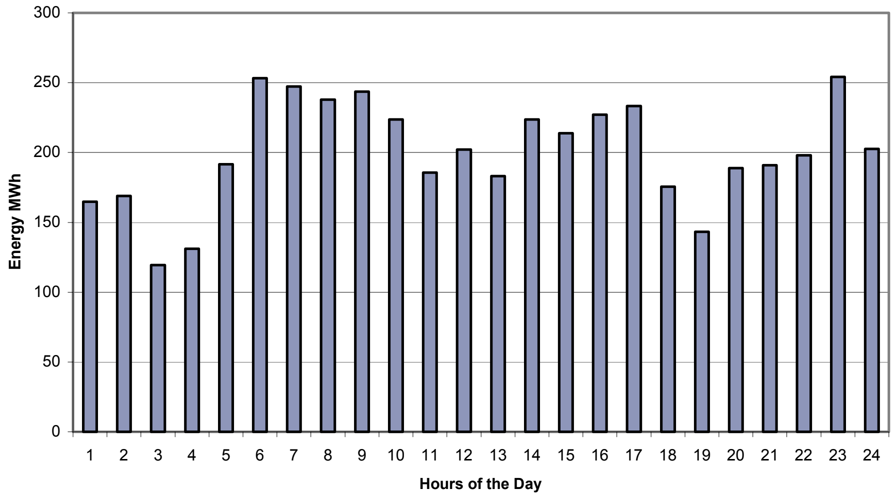

Fig. 3 Energy volume in the balancing market in March 2005.

The demand for electrical energy to be covered by CDGU is calculated by the TSO as the difference between the total demand forecasted, international flows, the production in cogeneration, industrial facilities, small hydro power stations and energy used for water pumping as well as the energy produced by large pumping water power stations – Fig. 4.

The largest portion of energy production outside the large thermal power station relates to cogeneration. Large cogeneration facilities produces nearly 20TWh electrical energy which counts for about 15% of the total domestic electricity production. The largest share of cogeneration appears in spring when co-generating facilities are fully loaded and the total demand is decreasing. This creates danger for secure network operation. It happens that during the demand valley when the total demand is low, the demand to be covered by CDGU is small due to high production from cogeneration. It happens that production required by network constraints is larger than the portion of demand to be covered by CDGU.

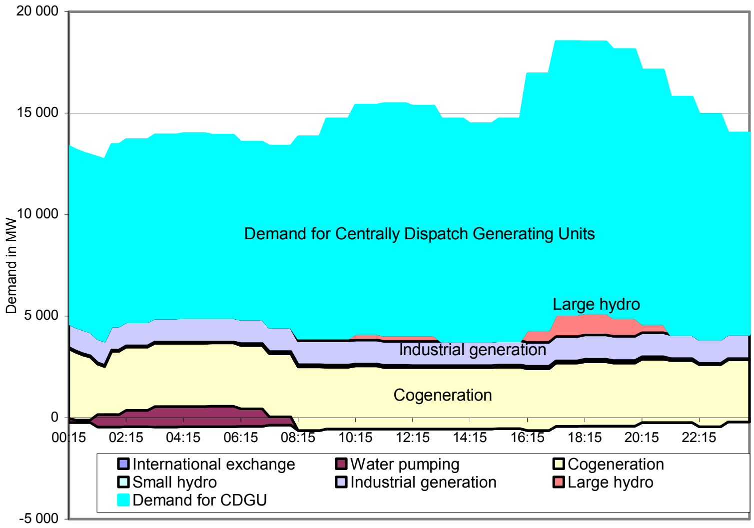

Fig. 4 Calculation of demand for CDGU

6. Market schedule

As the balancing market operates as a day ahead market, in a day before energy delivery (Day N-1), market participants submit information on energy, which they purchased or they sold and submit balancing bids of power generating units. In the beginning of the balancing market operation, the TSO closed the gate at 10:00 am. After one year of operation the gate closure was shifted to 11:00 am.

The Power Exchange closes the gate at 8:00am and finalizes energy trade by 9:00. This allows the market participants 2 hours to adjust information on energy traded and prepare balancing bids – Fig. 5

The information on the energy traded and balancing bids submitted to TSO before 11:00 is verified until 13:00 – 14:00, when the commitment and dispatch computation has to be processed. It requires about 1-2 hour to prepare and verify the commitment and dispatch for a day ahead in one hour intervals. The next step is the completion, before 18:00, the 15 minute schedule in which dispatch in one hour intervals is split into 15 minute periods.

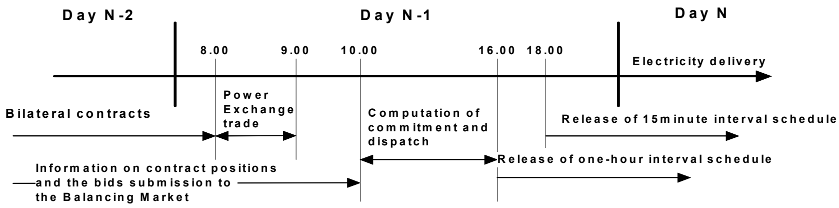

Fig. 5 The schedule of the Polish electricity market

7. Information on bilateral and power exchange transactions

After receiving the information on the energy traded TSO starts the procedure of the data verification. The principles of the balancing market operation require that the data submitted should be consistent and the volume of energy sold should be equal to the volume of energy purchased.

Despite the support of computer software in the data preparation it happens that the data submitted is not consistent. In such cases the TSO has to proceed with the verification procedures. When a mistake is clearly visible, the TSO can ask a balancing market participant to correct and submit the information again. However in most case it is difficult to contact participants pointing out the errors made. TSO has to adjust the information provided to achieve the balance between energy sold and energy purchased.

The adjustment procedures arrange balancing market participants into priority levels. The highest level is assigned to the Power Exchange as its contract position is always closed ie. the energy sold is equal to the energy purchased. The second level is given to power producers as they are limited by technical constraints. The third level is assigned to energy buyers. The verification procedure starts from the information submitted by the Power Exchange (PX) assuming that such information is correct. If any of the market participants' information on his trade in the power exchange transaction is not consistent with the date from the PX his energy volume traded is adjusted to the volume submitted by the PX. The next step involves the information submitted by power producers. If the information from distributors on the energy purchased is not consistent with the power producers' data, the volumes submitted by distributors are adjusted to the values provided by power producers.

Currently power traders have to have closed contract positions so the verification of their information is carried out in the same way as the information from the PX.

Table 1. Information on energy traded submitted by a power producers for one of his generating units for one hour for a day ahead.

Contract partner	DisCo 1	DisCo 2	Energy Trader A	Energy Trader B	Power Exchange	Sum = Contract position
Energy in MWh	30	65	100	50	20	265

Table 2. Information on energy traded submitted by a power buyers for one hour for a day ahead.

Contract partner	Generating Unit X1	Generating Unit X2	Generating Unit X3	Energy Trader B	Power Exchange	Sum = Contract position
Energy in MWh	100	150	120	70	30	470

8. Balancing bid

Balancing bids are provided by power producers for each of their generating units for every hour one day ahead. The balancing bid has a very complex structure allowing for the accommodation of various information – Table 3.

- There are 10 bands providing power producers with a large scope of flexibility to accommodate the energy traded and additional energy offered for production.
- The bands are split into two categories: “R” bands accommodate the energy sold in various bilateral contracts and power exchange transactions, “P” bands allow for the allocation of energy offered to the TSO for production.
- The sum of energy allocated in “R” bands is equal to the volume of the energy traded i.e to the contract position.
- Energy in balancing bids is displayed as net and gross values. It allows power producers to determine the volume of energy required for the operation of the power generating units. This duality is the results of the difference between operational procedures and trade. The commitment and dispatch is carried out using gross energy production while energy trade uses net energy i.e energy injected into the transmission system.
- Prices in bands noted “R” indicate how much a power producer is ready to accept from the TSO when his production is reduced below his contract position.
- Prices in bands noted “P” indicate how much a power producer is ready to accept from TSO for additional power production above his contract position
- The energy volume in the first band must be equal to the minimum power generated by the bid submitting unit. When this generating unit provides second or minute reserve or both, the energy volume in the first band must include Psec+ and Pmin+ values – Fig. 7.
- The sum of energy in all bands cannot be larger than Pmax. If a generating unit provides second or minute reserve or both, the energy in the balancing bid should be reduced, taking into account the values of Psec- and Pmin-

- Price in the band proceeding must be larger by at least in 0,01PLN than the price in the preceding band. This allows for a uniform increase of bid prices.
- The minimum energy offered in any band is 1 MWh
- The last band (numbered as 10) is reserved for the price of the energy produced by a starting up unit. Such energy must have a price assigned. The use of one band in the balancing bid for energy of a starting up unit creates a convenient channel to gain such information from power producers.
- Minimum price is 70PLN/MWh, while the maximum price is equal to 1500PLN/MWh.

Table 3 shows an example of a balancing bid. The electricity traded in the form of bilateral contracts and power exchange transactions is equal to 370MWh = 300 + 40 + 30. This energy is allocated in three “R” bands. The gross production relating to the energy sold accounts for 396MWh = 312 + 42 + 33. The additional energy production offered to the TSO is equal 95MWh = 40 + 15 + 10 + 10 + 10 +10 and is allocated in six “P” bands. The last band price equal to 1449PLN/MWh indicates the energy produced by starting-up generating unit.

The structure of balancing bids allows a large degree of flexibility for power producers. They can split the energy contracted into several “R” bands with various energy amounts and prices. This reduces the risk of being entirely excluded from the schedule when the TSO cannot realize the contract positions declared. Power producers can also offer additional amounts of energy to the TSO if it requires more generation to balance energy demand.

TABLE 3 - Example of a balancing bid submitted for a given generating unit

Band	1	2	3	4	5	6	7	8	9	10
Price (PLN/MWh)	70	75	80	100	105	110	120	130	150	1499
Energy net (MWh)	300	40	30	40	15	10	10	10	10	1
Energy gross (MWh)	312	42	33	42	16	11	11	11	11	1
Band category	R	R	R	P	P	P	P	P	P	P

9. Modelling balancing bid

Balancing bids submitted by power stations in the form of tables which have a graphical representation as a step function – Fig. 6. The approximation of such a function by a high order polynomial is not acceptable by market participants as the approximation error would affect their income from the balancing market trade. Moreover the use of high order polynomial would involve the implementation of optimization procedures which are able to cope with high order nonlinearity. Such procedures provide only local minima dependent on the algorithm starting point.

The algorithm used for commitment and dispatch should compute the global minimum independently on a calculation starting point. This can be achieved by the implementation of Linear Programming. However the representation of the minimum power of a generating unit in the first band and the condition that a unit can not be dispatched below this level leads to the application of binary representation for the first band.

The balancing bid is modeled in the following way:

- The energy in the first band is modeled as a binary value multiplied by energy denoted as $E_{1,j,k}$, where “1” relates to the band number, “j” denotes a generating unit and “k” is the hour of the day for which the bid is submitted.
- The energy in the second band is modeled as a real variable and can take any value within constraints $0 \leq E_2 < E_{2,j,k}$.
- The energy in other bands is modeled in a similar way as in band 2 i.e. $0 \leq E_i < E_{i,j,k}$

Such an approach increases the number of variables as any balancing bid submitted by a generating unit is modeled by 10 variables. However the modelling is very simple and allows the application of linear constraints. When over 100 generating units are dispatched for a day ahead the optimization problem includes over 24000 variables = 100 generating units x 10 variables x 24 hours.

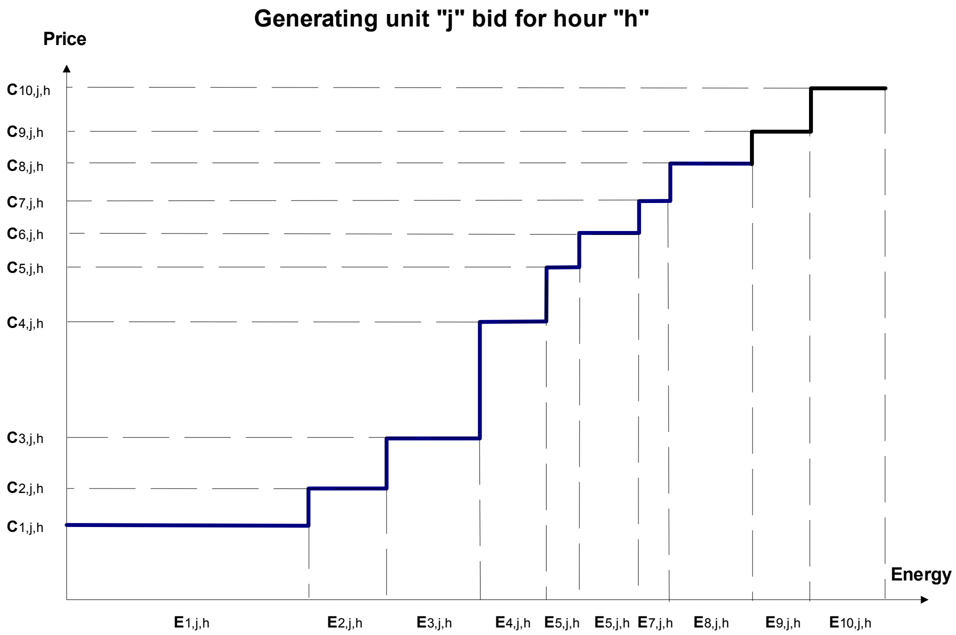

Fig. 6 Graphical representation of a balancing bid

10. Second and minute reserves

Planning power generation for a day ahead the TSO has to ensure an adequate level of second and minute reserve. The value of second reserve for each TSO is determined by UCTE requirements. The value of secondary reserve is set by the TSO to about 400MW.

The TSO buys second and minute reserve once a year in a tendering procedure. There are two components to this Ancillary Service: a stand-by component and a working component. The latter is paid to all power station contracted. They have to preserve the equipment ready for services. Two days before energy generation the TSO sends the information to power stations on how much second and minute reserve will be required. The power stations are obliged to accommodate the second and minute reserve in balancing bids.

When a generating unit is to provide both services the energy allocated in the first band should be equal to minimum power increased by two components i.e $E_1 = (P_{\min} + P_{\sec-} + P_{\min-}) * 1hour$ - Fig. 7. If a generating unit does not provide second and minute reserve the energy in the first band should be equal to the minimum power i.e $E_1 = P_{\min} * 1hour$. Similarly the sum of energy offered in a balancing bid when a generating unit provides both services should exclude power required for second and minute reserve i.e $E = \sum_{i=1}^{10} E_i \le (P_{\max} - P_{\sec+} - P_{\min+}) * 1hour$ - Fig. 7. If a generating unit does not provide any services the sum of energy offered in a balancing bid can reach maximum power $E = \sum_{i=1}^{10} E_i \le P_{\max} * 1hour$.

This very simple system of implementation of second and minute reserve in the balancing bid was implemented as a compromise between the short time given for the software development and the flexibility of reserve optimization. However, the methodology used is able to include the second and minute reserve in the optimization process carried out by LPD.

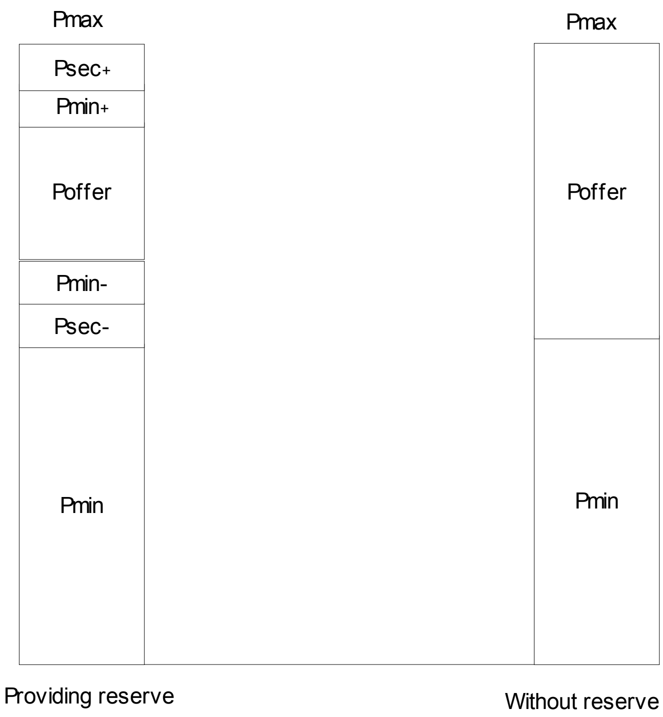

Fig. 7. Including reserve in balancing bid

11. Modelling start-up characteristics

There are three characteristics used in commitment and dispatch of generating units representing the start-up processes from three states: hot, warm and cold. Each characteristic is represented by four points determining the power generated after the given time period. The last point represents minimum power offered in balancing bid. Because the value of this power depends on second and minute reserve served the modelling of start-up characteristics should take into account these Ancillary Services provided by a generating units – Fig 8.

There are three possible combinations of Ancillary Services relating to second and minute reserve:

- Unit does not provide second and minute reserve
- Unit provides only second reserve
- Unit provides only minute reserve
- Unit provides both second and minute reserve.

The combination of possible Ancillary Services and three thermal states leads to twelve start-up characteristic to be used in modelling generating units.

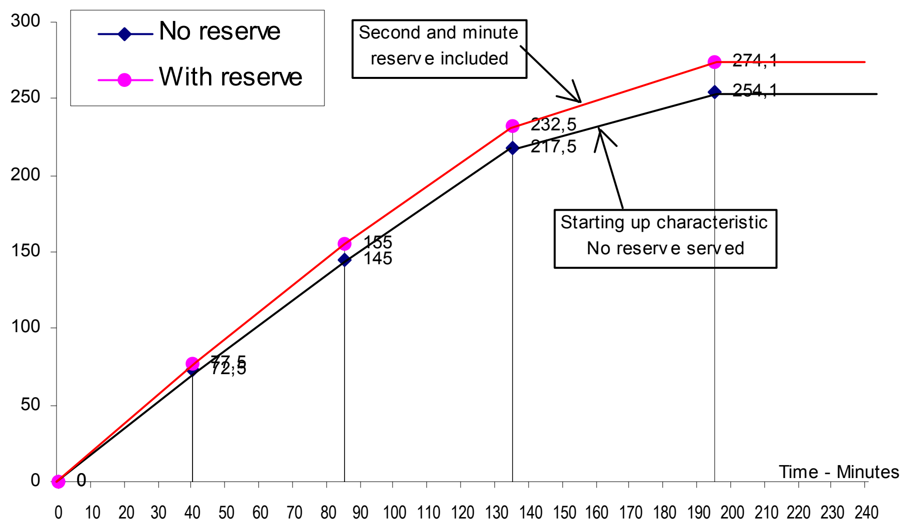

Fig. 8 Start-up characteristics of a generating units.

Another problem to solve is the allocation of star-up intervals determined in minutes into one hour intervals in commitment and dispatch in a day ahead market. If it is assumed that a generating unit begins its start-up process in the first minute of a one hour interval the process would be completed somewhere in the middle of the one hour period. In an example shown in Fig. 9. the start-up process is completed after 195 minutes, just 15 minutes after the beginning of Hour 4. If such solution is implemented the energy generated in Hour 4 should be split into the start-up energy (E4a) and the energy generated after completion of start-up (E4b).

To avoid such problems the modelling of starts-up assumes the each start-up characteristic is shifted to the end of the one hour dispatch interval – Fig. 10. This results in the competition of any start-up process in the last minute of a one hour interval.

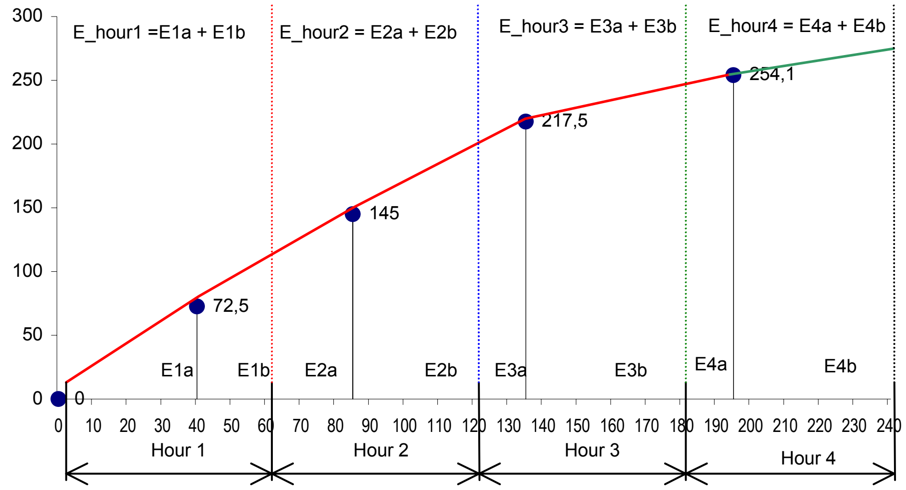

Fig. 9 Start-up periods and one hour dispatch intervals

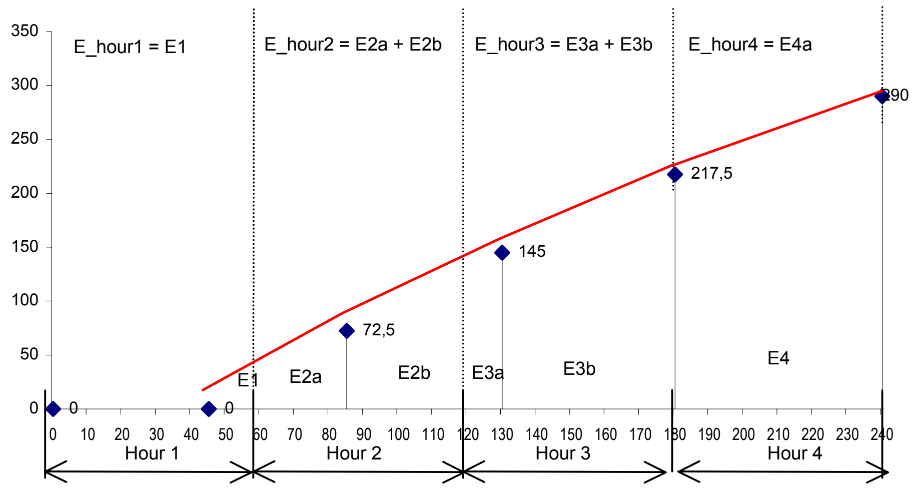

Fig. 10 Allocation of start-up characteristic in one hour intervals.

12. Energy trade in balancing bids

The balancing market rules tie up the energy trade with individual generating units forcing the power producers to allocate the energy traded into generating units and include this information in a balancing bid. Before submitting a balancing bid to the TSO a power producer has to allocate the energy traded and the additional energy that can be produced into a balancing bid. Fig 11 shows an example of such allocation.

Four bilateral contracts and the Power Exchange transaction have been allocated to one generating unit. The sum of contracts and the transaction allocated sets the contract position of this generating unit. There is also the additional energy that can be produced by this unit. The energy traded and energy possible for production has to be accommodated into a balancing bid with ten bands and several constraints.

In this example a power station trader has decided to assign three “R” bands to energy resulting from the contract position. In the first band he has allocated energy relating to the minimum power. The rest of energy traded is split into two ”R” bands.

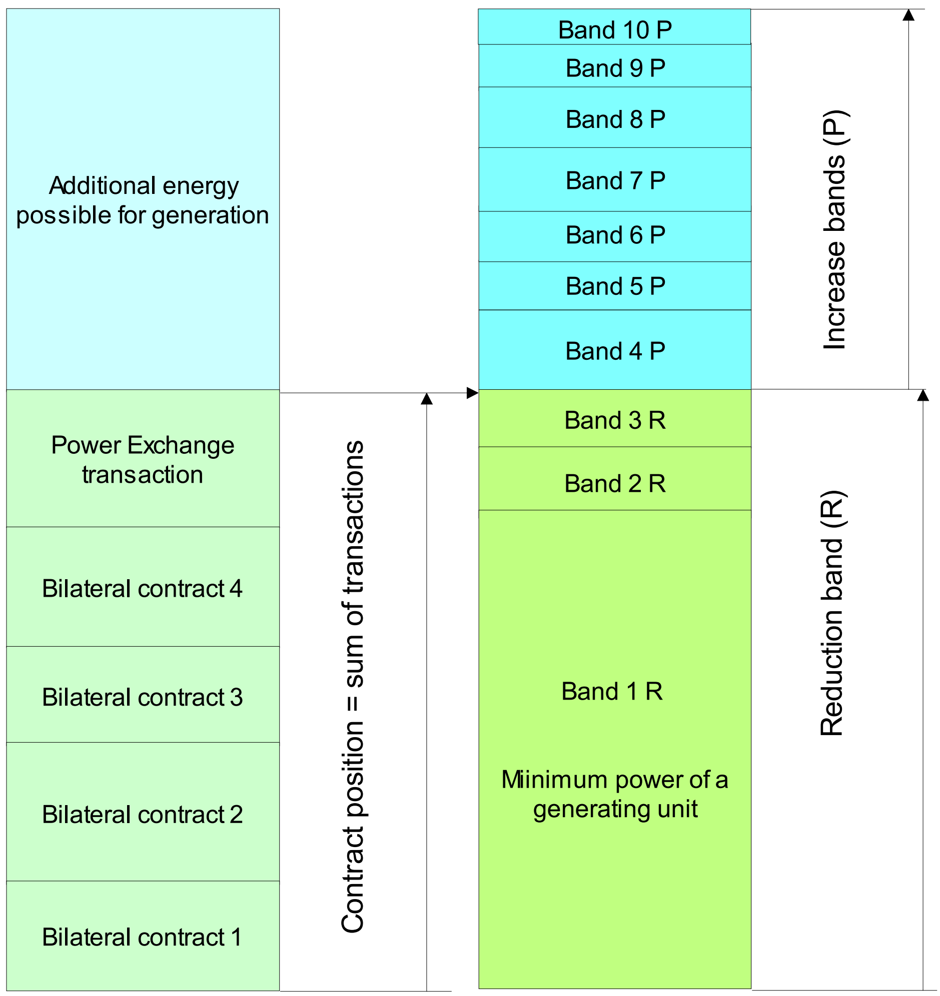

Fig. 11 Relation between energy traded and a balancing bid

The additional energy offered to the balancing market is split into several "P" bands denoted from 4 to 10, taking into account that the price in band no 10 is used to valuate energy produced during a start-up process

13. Objective function

The objective function is formulated as the sum of the products of the bid prices and the energy in the balancing bids. This embraces nine bands. The last band is used to bid on the start-up price. This price is not paid to generators; however, it is used in commitment and dispatch computations. Setting the tenth band as the start-up price allows for the flexibility of balancing bids as a bid provider can express his willingness to be committed by setting a low start-up price.
The objective function has the following form (1).

$$F_{objective} = \min\left\{\sum_{h=1}^{Hk}\sum_{j=1}^{N_j}\sum_{i=1}^{9} c_{h,j,i} * E_{h,j,i} + c_{h,j,10} * E_{h,j}^{start\_up}\right\} \tag{1}$$

where: $E_{h,j,i}$ - dispatch in hour „h", generating unit „j", energy from band „i"; $c_{h,j,i}$ - bid price in hour „h", generating unit „j", in band „i"; $E_{h,j}^{start\_up}$ - start-up energy in hour "h", generating unit "j" resulting from one of three starting unit characteristics; N - number of generating units which have submitted the bids; Hk - time horizon equal to 24 hours.

14. Including reserve

The information on the required level of primary and secondary reserve is distributed to market participants by the TSO two days before energy generation. The contracts for Ancillary Services bind generating units to include power relating to primary and secondary reserve directly to a balancing bid.

A tertiary reserve (hour reserve) is included into the algorithm as a constraint. This means that the difference between the energy offered by all committed units and the energy dispatched in all committed units should be larger than the assumed level of the tertiary reserve.

$$\sum_{j=1}^{N_j}\sum_{i=1_j}^{m} E_{h,j,i} - \sum_{j=1}^{N_j}\sum_{i=m=1_j}^{9} E_{h,j,i} \geq P_{Tertiary}^{reserve}(h) * t \quad \text{for } h = 1....24 \tag{2}$$

The spinning reserve allowing for the reduction of energy generation is set up in a similar way. The assumed system allows for the setting of tertiary reserve values to increase the electricity production and to decrease it for each hour of a day ahead.

15. Input and output data

The module LPD receives the information on network constraints from the module called GMOS in the form of linear constraints. Additionally it receives the load forecast for each hour of a day ahead. The operator sets up the level of tertiary reserve and supplies the balancing bids submitted by power stations – Fig. 12.

The computations are carried out four times:

- For the load forecasted to prepare the basic commitment and dispatch
- For the load lower than forecasted, usually about 2000MW
- For the load higher than forecasted, usually about 2000MW
- For the merit order of balancing bids without constraints.

The differences between the basic dispatch for the load forecasted and dispatch for lower and higher load allows the preparation of priority lists of uploading generating units and downloading these units when the real demand for the electricity is different than forecasted. Each priority list is split into two parts. The first one relates to the increase or decrease of the energy generating using the spinning reserve. The second one contains the units that should be started up when demand increases or shut down when demand decreases. The priority lists are sent together with the dispatch to power stations.

Each computation of commitment and dispatch takes about 2,5-3 minutes.

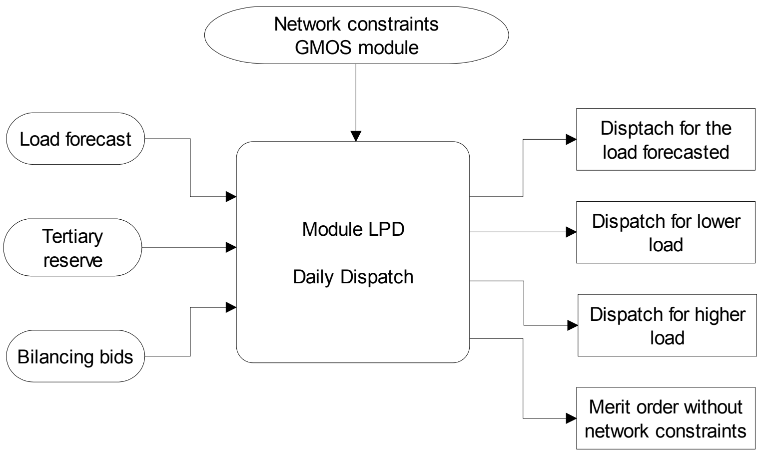

Fig. 12 Input and output module for LPD program

16. Evaluation of commitment

Despite the high reliability of the module computing commitment and dispatch the operation procedure contains the evaluation by experts as the basic element of planning for a day ahead market. There are over 100 generating units submitting balancing bids and about 70-80 generating units are dispatched every day.

To facilitate the evaluation procedure a special evaluation sheet has been designed – Fig. 13. The evaluation table contains 25 columns representing 24 hours of a day ahead and the last hour of the day before noted as 24 in brackets. The names of generating units are located in table rows. The system of notation is as follows. If a table cell is filled up with three dashes it means that a generating unit operates in a given hour. If a cell is empty a unit does not operate in a given hour. When a cell contains three asterisks this means that a unit is starting up. In the example shown in Fig. 13 the united noted BEL 2-01 (unit no 1 in Belchatow power station connected to 220kV) starts up in hours 13, 14 i 15 and generates electricity during the rest of this day. The unit noted BEL 2-02 operates along 24 hours, while the unit noted BEL 4-09 does not operate in a given day.

The evaluation tables allow the graphical representation of the commitment for about 100 generating units using only 2 pages in A4 format. The evaluation takes place after the first run of computation. If for any reason the commitment is not accepted by a dispatcher he can introduce additional constraints and carry out the computation again.

#Power station: Bełchatów

#Unit name	<24>	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
BEL 2-01														***	***	***	---	---	---	---	---	---	---	---	---
BEL 2-02	----	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
BEL 2-03	----	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
BEL 2-04	----	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
BEL 2-05	----	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		
BEL 4-06					***	***	***	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
BEL 4-07						***	***	***	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
BEL 4-08	----	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
BEL 4-09																									
BEL 4-10	----	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
BEL 4-11	----	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
BEL 4-12	----	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

Fig. 13 Commitment evaluation table.

17. Hourly commitment and dispatch

The results of the calculation of commitment and dispatch of generating units in a day ahead balancing market are shown in Fig. 14 for one selected power station. As seen two generating units start up and are shut down during one day.

The electrical energy in the Polish power system is generated mostly by thermal power stations. The demand for second and minute reserve limits tertiary spinning reserve. Large changes in demand during night hours (demand valley) and demand peaks force the system operator to start up and shut down several generating units every day.

To limit the number of starting up units during the day and during any hour the LPD module is equipped with additional constraints allowing a dispatcher to set up a number of starts up for a day and during one hour. However this requires a flexible approach as the introduction of a small number of starting up units often leads to unsolvable optimization problem and the LPD module cannot generate the commitment and dispatch.

The second tool with which a dispatcher is equipped is the reduction of the number of starting up units by a penalty function. A dispatcher has three buttons noted Number of Starts up: “Small”, Medium” and “Large”. The selection of any button results in the assigning the prescribed penalty function leading to the increase of the cost of energy generated during start up. The advantage of this tool is that it does not create over-constrained problem as the previous one.

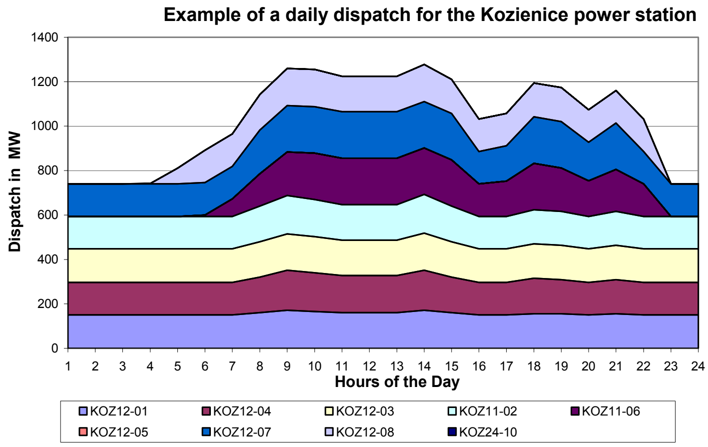

Fig. 14 Example of unit commitment and dispatch for one of the Polish power station.

18. Spinning reserve

The level of spinning reserve represents the possibility to adjust the generation to the load using the units operating. The minimum level of spinning reserve is set up by a dispatcher who is in charge of the LPD module. The real value of spinning reserve depends on the balancing bids and the energy planned for generation.

An example of the spinning reserve values in hours of a day ahead is shown in Fig. 15. It is seen that negative spinning reserve is very small during night hours. This results from the network and security constraints required a specific number of generating units to be operated in order to keep voltage levels and ensure reliability criteria. To satisfy network constraints the LPD module reduces load on generating units to preserve the required minimum number of units to stay in operation. Fig. 16 shows the range in which the generation can be adjusted using spinning reserve.

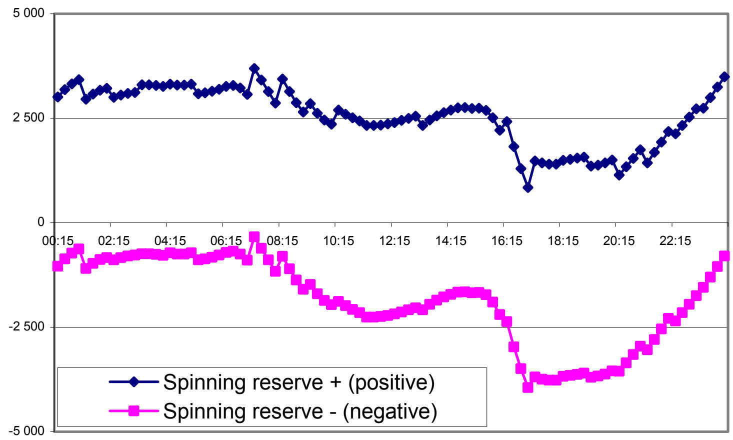

Fig. 15 Spinning reserve in hours of the day.

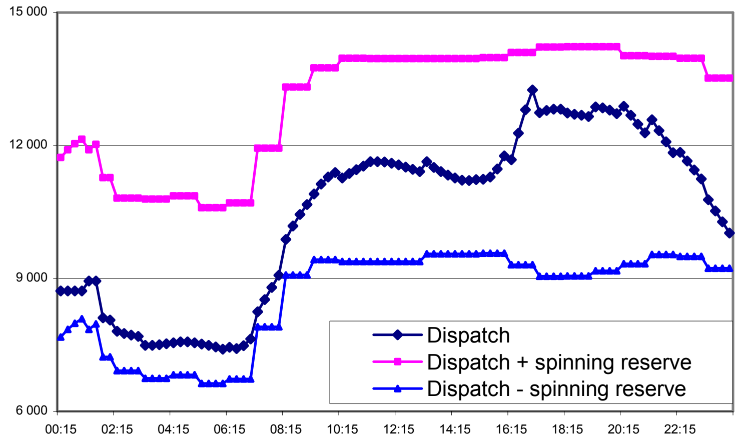

Fig. 16 Dispatch and spinning reserve in hours of the day.

19. Settlement in balancing market

The balancing bids submitted by power stations can be arranged in merit order demonstrating the allocation of the energy sold in “R” bands and the additional energy offered for generation in “P” bands – Fig. 17. When it happens that the total demand (D) in the balancing market is equal to the energy traded as bilateral contracts and power exchange transactions the TSO does not need to undertake any action and the demand is entirely balanced by energy trade.

If the total demand is larger than the energy traded in various forms the TSO has to purchase some amount of energy from the producers using “P” bands from balancing bids – Fig. 18. In such case “P” bands can be split into to groups: bands “P1” from which energy is bought by TSO and bands “P2” in which energy is offered, but not needed to balance demand.

The TSO buys electrical energy from Power Producers (PP) and sells this energy to Distribution Companies (DisCo). Purchasing the energy the TSO pays the prices proposed by PP in bands of balancing bids (pay-as-bid). Selling energy to DisCos the TSO uses weighted average prices. Such a system allows the TSO to stay in a neutral position to the balancing transactions.

There was a vigorous discussion before the introduction of the balancing market as to what price should be applied to power producers. Despite many experts preferring marginal pricing, in the end a “pay-as-bid” system was selected for as some expected to achieve lower prices in the balancing market transactions.

When the demand for electricity is smaller that the total energy traded – Fig. 19 – the TSO has to buy the excess of energy from DisCos and sells it back to power producers. Power producers pay prices offered in “R” bands of balancing bids while DisCos receive the weighted average price. In this case the TSO also stays neutral to balancing market transactions.

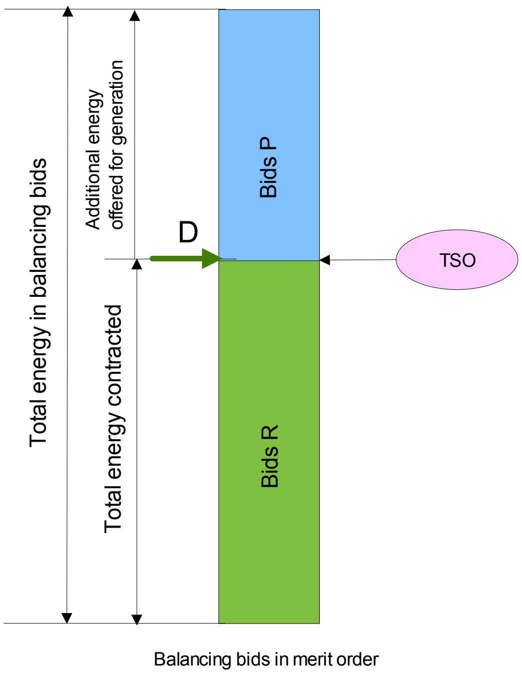

Fig. 17 Allocation of energy – demand (D) balanced by energy trade.

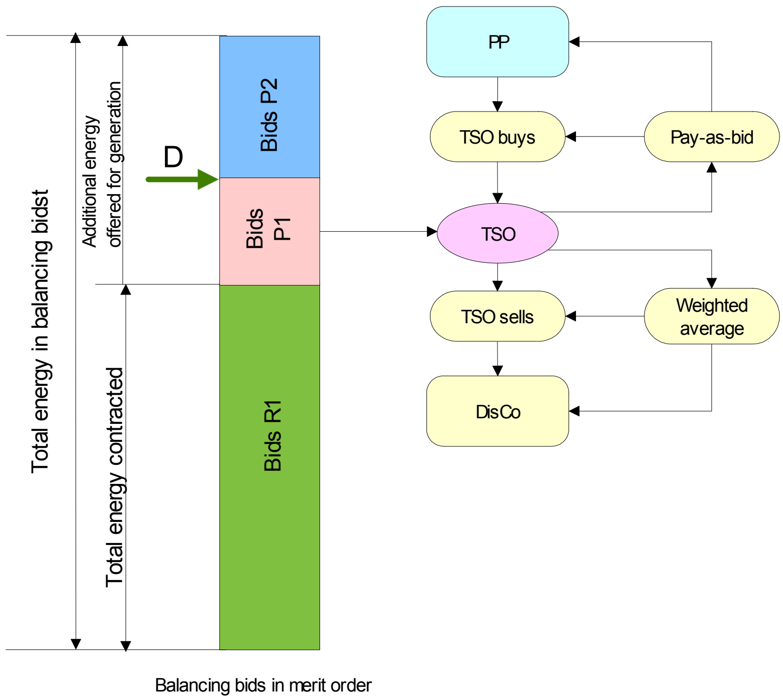

Fig. 18 Allocation of energy – demand (D) larger than the energy traded.

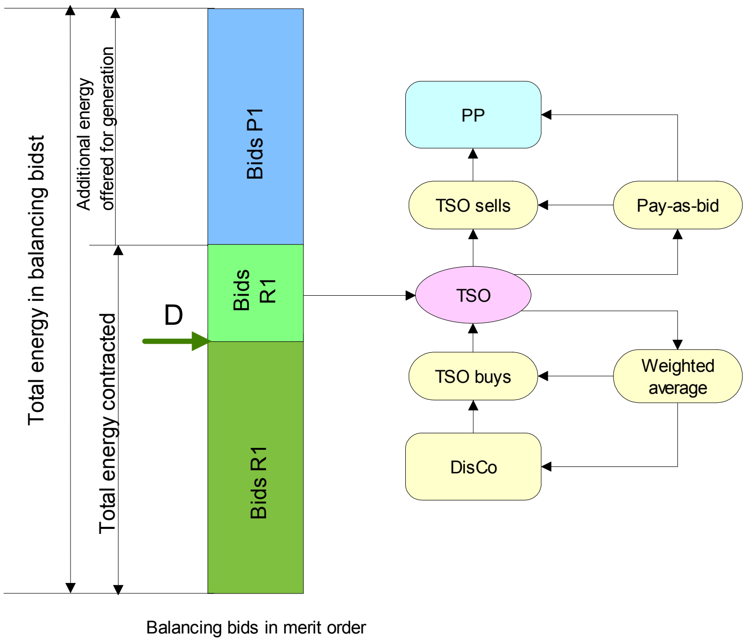

Fig. 19 Allocation of energy – demand (D) smaller than the energy traded.

Fig. 20 Summarizes transactions in the balancing market. When demand is smaller (D1) than the total energy contracted (over contracting) the TSO buys energy from DisCo and sells it back to power producers. When the demand is larger than the energy contracted (D2) TSO buys energy from power producers (PP) and sells to DisCos.

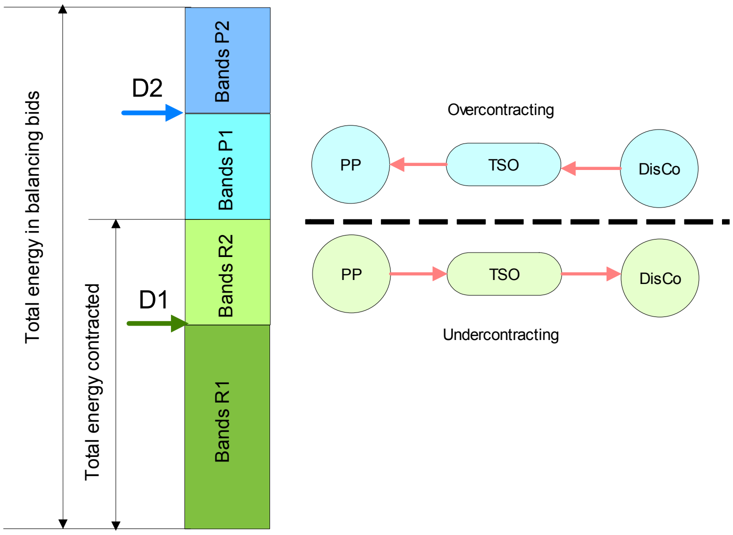

Fig. 20 Payments in the balancing market

20. Network constraints

There are several categories of network constraints used in the dispatch algorithm. These constraints are located in a special module called GMOS [5].

The examples of constraint description are given in Fig. 21 and Fig. 22. The first constraint relates to start up of two generating units noted LZA21-01 and LZA21-02. It indicates that only one unit of these two (LE 1) can start at a given time. The constraint is valid from the first hour (*START 1*) to the end of the day (*END 24*).

Fig. 22 shows the constraint on a minimum number of units in a given node. From the six units of Belchatow power station in this node at least four of them (GE 4) must be dispatched. The constraint is valid for the entire day.

OGR RMAX:LZA2
[LZA21-01] J 1
[LZA21-02] J 1
LE 1
START 1 END 24
Fig. 21 Constraint on simultaneous start

OGR SMINJ:BEL# 1
[BEL 4-06] J 1
[BEL 4-07] J 1
[BEL 4-08] J 1
[BEL 4-09] J 1
[BEL 4-10] J 1
[BEL 4-11] J 1
[BEL 4-12] J 1
GE 4
START 1 END 24
Fig. 22 Constraint on minimum number of units in a given node

21. Cost of network constraints

The presence of the network constraints requires the dispatch of some generating units even if they have not sold electric energy. The dispatch of these units causes that other units which have contracted their energy cannot generate. In such case the TSO purchases energy from some units using "P" bands and sells this energy to other units using "R" bands. These transactions can happen despite demand being in balance with the entire energy contracted.

Fig. 23 illustrates settlement when network constraints do not allow dispatch due to the merit order. The demand (D) is in balance with the energy contracted so there is no need for the balancing transactions, however some transactions are required to handle network constraints. Balancing bids can be arranged into two main categories due to "R" and "P" bands. Each category is split into two groups.

The group denoted "Bands P1" represent generating units which have not sold energy but they have to operate due to the network constraints. Electrical energy from Bands P1 has to be purchased by TSO. To preserve balance between demand and energy generated TSO has to sell the energy purchased to other generating units, which have sold energy but their production have to be reduced “Bids R2”.

The volume of energy in Bands P1 and energy in Bands R2 is the same, however the prices are different. The TSO buys energy from “P” bands in which prices are normally higher than prices in “R” bands. Power producers are able to foresee which power units have to be scheduled due to network constraints and do not allocate energy to such units. Moreover knowing that the TSO has to buy energy from specific units power producers would assign very high prices to such generating units. To reduce the cost of network constraint management the TSO has introduced a cap price for the energy purchased as forced generation.

Despite the price cap which is calculated as the average price in all transactions in the electrical market in the previous year and published by the Energy Regulatory Authority, the difference between prices counts for about 60PLN/MWh what is approximately equal to 14Euro/MWh – Fig. 23. The cost of network constraints is covered by the transmission tariff.

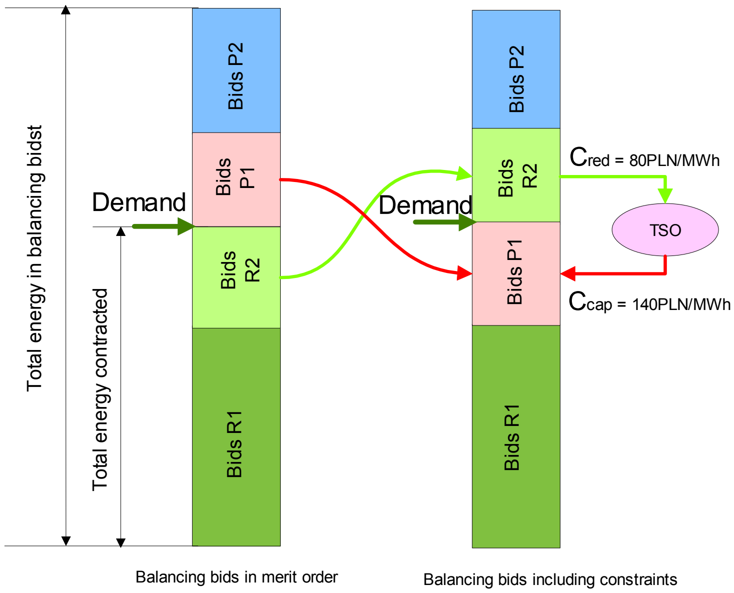

Fig. 23. Management of the network constraints.

22. Imbalance prices

To reduce the cost of network constraints in 2002 the TSO introduced special prices for distribution companies. In 2003 these prices were applied to generating units when they do not follow the schedule for any reason including outages.

The introduction of special prices resulted in are three categories of prices in the Polish balancing market:

- Price of balancing without technical constraints. It is the base price (CRO), in practice not used in settlement. This price is calculated as a weighted average from the bands of balancing bids without taking into account technical constraints – merit order. In the case when the sum of all contracts is smaller than the total demand, the TSO buys electrical energy from the bands noted “P”, in which additional production is offered, and calculates the balancing price (CRO) as the weighted average from the ”P” bands accepted. When the sum of all contracts is larger than the total demand, the TSO sells back the excess of electric energy to producers using the bands noted “R”, in which the producers express their willingness to reduce production and the balancing price (CRO) is calculated as the average from the “R” bands accepted.
- Energy selling price - (CROs). The basic price is subject to the increase calculated with the use of “P” bands in balancing bids and to network constraints. The price (CROs) applies to the energy which a user has to purchase from the TSO when his contract does not cover the entire demand.
- Energy buying price. This price (CROz) is calculated with the use of “R” bands in balancing bids and taking into account network constraints. The price (CROz) applies to the energy, which a user has to sell back to the TSO when he has contracted more energy than his current demand.

An example of the imbalance prices CROs and CROz are shown in Fig. 24. The figure shows that in many hours of the day the Distribution Companies have to pay for imbalances two times more than the cost of balancing energy when only merit order would apply. The average price in contracts for electric energy in Poland was about 31Euro/MWh in year 2003.

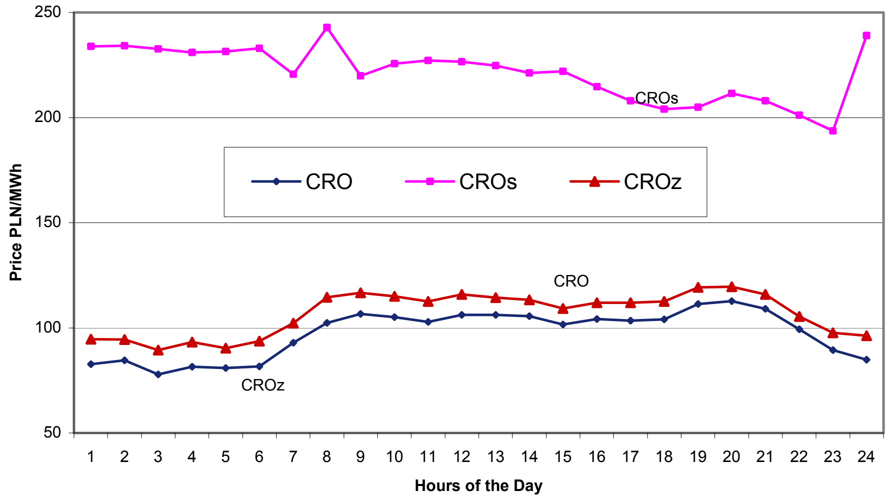

Fig. 24 Values of three prices in the Polish balancing market

Paying such imbalance prices in the balancing market the Distribution Companies have imposed the same rules for imbalances in the distribution systems transferring the same imbalance prices onto the generation and users connected to distribution systems. Such large costs for imbalances reduce the development of the Distributed Generation and users who want to buy energy in a free market.

Distribution companies facing large energy prices when they have to purchase additional energy in the balancing market aim at over contracting, purchasing more energy then they need. In the case of over contracting they are also subject to penalties, however the penalties are significantly lower in the case of over contracting than in the case of under contracting – Fig. 24.

The system of prices introduced by the TSO leads to permanent over contracting in the balancing market. An example of the difference between demand and the amount of energy contracted by distribution companies is shown in Fig. 25.

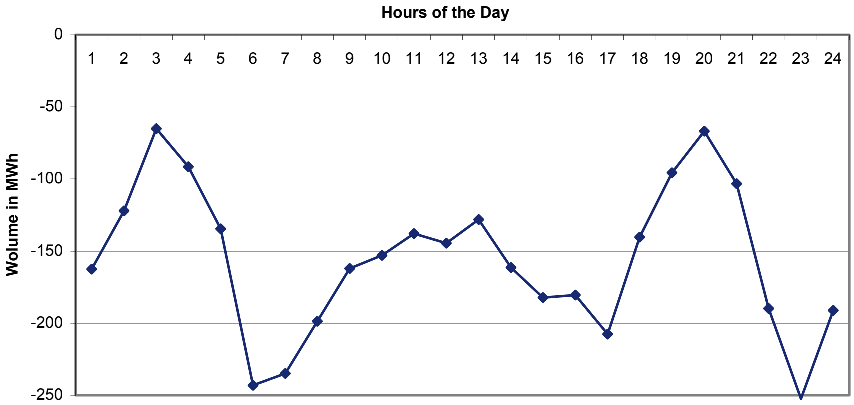

Fig. 25 Difference between demand and the energy contracted.

23. Conclusions

Despite some drawbacks resulting from the presence of long term contracts covering about 50% of electrical energy produced in Poland and the manipulation of balancing market rules to achieve more income to balance high cost of network constraint management, the Polish balancing market was introduced in a very short time taking into account a lack of IT technologies before the market introduction.

The biggest achievement is the design and implementation of the two modules: for commitment and dispatch (LPD) and for network constraints representation (GMOS). The implementation of binary-linear programming has resulted in effective software for commitment and dispatch allowing for simple implementation of these methodologies to various technical and trade market conditions. Both modules LPD and GMOS started their operation on 1st September 2001 and after near four years in operation have shown many advantages.

The experience from the implementation of these methodologies for commitment and dispatch of power generating units in the Polish balancing market can be used for the unification of operational procedures in the common European electricity market.

The authors were responsible for design and implementation of the LPD and GMOS modules for commitment and dispatch in the balancing market.

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