TRADING ANCILLARY SERVICES FOR FREQUENCY REGULATION IN COMPETITIVE ELECTRICITY MARKETS

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With the introduction of the electricity market the system operators as well as the market operators are facing more and more unpredictable challenges. As a completive for the Day Ahead Market, the Balancing Market is meant to perform a more market oriented frequency regulation by using a merit order for real-time dispatch of the generators, particularly for the secondary regulation as well as for the tertiary regulation. Due to the social implications of the electricity market, the market mechanism should be designed so that to avoid market speculations of some participants and to obtain the smallest price possible of energy and ancillary services while maintaining a necessary active power reserve to ensure a certain level of the network security. Based on the actual expected changes in the generation sector of the Romanian power systems as well as the implementation of a possible regional market, the authors will propose some suggestions for the balancing market mechanism to maximize the reserves available for frequency regulation and to minimize the cost of the regulation energy. A comparison between actual implemented mechanism and the proposed mechanism will be performed.

Keywords: ancillary services, balancing market, system security.

1. Introduction

The power systems restructuring and the introduction of electricity markets involved lots of studies concerning the market design and appropriate mechanisms able to stimulate the competition among participants in the sense of economic efficiency increase.

Ancillary services are used to maintain the power system security and to ensure an appropriate level of the quality of the power supplied to consumers. In particular, the frequency regulation assumes that a certain active power reserve should be maintained available all the time so that the balance between generation and consumption be performed from moment to moment, and also a power reserve should be available for the system operator to cope with the most severe contingency. Generally, the *reserve* can be defined as that generation capacity, active power, which can be utilized on a certain period of time for a purpose other then of supplying consumers with electrical energy.

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2. Electricity Markets in Romania

2.1. The structure of electricity market

The electricity market has been introduced in Romania in 2002, and in 2005 it undergone reorganization in order to increase the competitiveness by introducing specific markets for ancillary services as well for real-time balancing. The electrical energy is traded by three types of arrangements. The long-term contracts are traded through regulated contracts or by public auction within the Bilateral Contracts Centralized Market (BCCM), while the short-term arrangements are performed on a daily market called Day Ahead Market (DAM). The DAM’s clearing price is given by the intersection point between the selling offers curve and buying offers curve. DAM is a purely economic market since its mechanism does not take into account any technical restriction. On the ancillary services market (ASM), organized monthly or at two-week, power capacities are contracted, while the Balancing Market (BM), for real-time dispatch, is organized on daily auctions. BCCM and DAM are administrated by the market operator, OPCOM, while ASM and BM are administrated by the TSO, Transelectrica.

DAM and BM are organized in a sequential manner. Therefore, a producer can offer secondary regulation reserve or tertiary reserve for downward regulation only if he owns contracts for electrical energy by any commercial arrangement, that is its units are synchronized with electrical network in the involved dispatch interval. Figure 1 shows the development in time of the Day Ahead Market and Balancing Market.

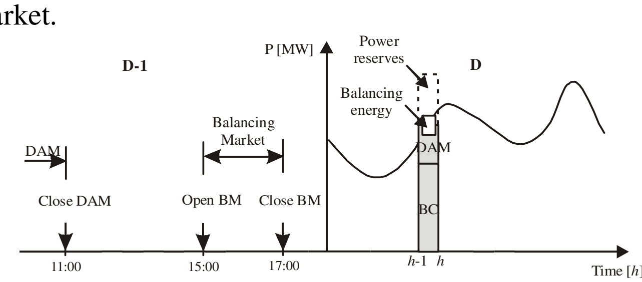

Fig. 1. Development in time of DAM and BM.

2.2. Literature survey

In paper [1] the authors make an analysis regarding the competitiveness of ancillary services procurement, and also debate the problem of energy trading efficiency to ensure the system reliability by generation-consumption balance. The work makes a connection between energy and spinning reserve by means of a coefficient set to stimulate participants to offer spinning reserves at a competitive price. A real-time coordination of all markets is proposed in [2], where the objective is to minimize the cost of electrical energy together with the power reserves taking also into consideration the possibility of curtailing bilateral contracts. Another approach can be seen in paper [3] in which a method for competitive procurement of capacity-based ancillary services is proposed. Priority degrees are assigned to various types of power reserve corresponding to the frequency regulation levels, and the auctions are organized in descending order of priority, offering the possibility, if less costly, to use high priority reserve instead of lower priority reserves.

2.3. Frequency regulation related issues

In Romania the frequency regulation is performed on three levels [4, 5]: primary, secondary and tertiary. The *primary regulation* is performed in an automatically and decentralized manner, by governors actions, that must act in maximum 30 seconds from an imbalance occurrence, and the mobilized power must be sustained for at least 15 minutes. The existence of this type of regulation represents an obligatory condition for connection to the electrical network, so the providers are not financially remunerated for this service. The *secondary regulation* is performed in an automatically and coordinated manner by those units, connected to the central regulator, that can mobilize the called power in maximum 15 minute, and that must be maintained as long as the system operator require. The secondary regulation reserve is used to recover the primary regulation reserve and to correct the mismatch power on the interconnection lines. The third regulation level is the tertiary one, which is performed manually and consists of two types: rapid tertiary, used to recover the secondary reserve – having a time reaction of maximum 15 minutes – and slow tertiary, used to correct imbalances of longer period from the scheduled program.

2.4. Balancing market issues

Figure 2 suggests the way in which the available balancing reserves of the generating units are determined in Romania.

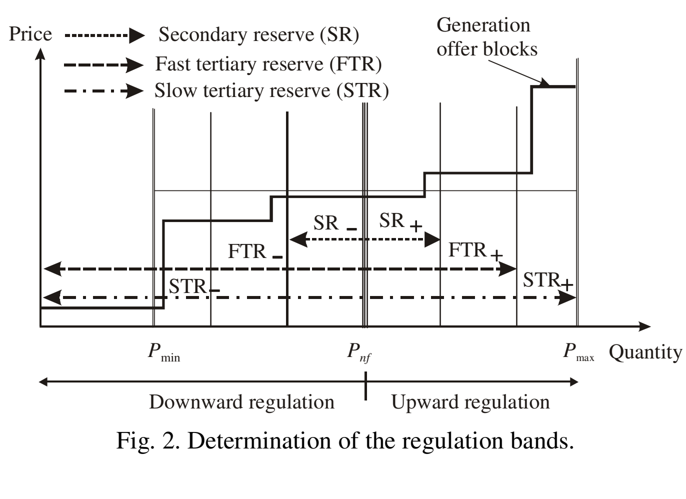

Fig. 2. Determination of the regulation bands.

The generating units qualified to provide ancillary services are dispatched based on the merit order, which is established on intervals. These units may submit on the balancing market, for each of the 24 hourly (dispatching) intervals, up to 10 quantity-price blocks arranged in ascending order of the price, for which the sum of the offered quantities are equal to their available power. For every qualified unit, the regulation offers are determined by selecting those parts of the quantity-price blocks situated in the secondary or tertiary band according to the mechanisms implemented in the balancing market platform.

3. Mathematical Model

Procurement of secondary reserve

Currently, the secondary regulation band represents a symmetrical domain around the notified power, that is twice the semi-band for power increase. Therefore, the objective function is formulated as:

$$\min\left\{\sum_{i=1}^{N_{SR}} \Delta\rho_{i,k}(h)\cdot c_{i,k}(h)\right\}$$

Considering the price difference $\Delta\rho$ between corresponding upward and downward regulation blocks encourage submitting flat price for all regulation blocks since the units are called for both regulation directions.

The secondary regulation semi-band accepted on the balancing market for the generating unit *i*, in the dispatching interval *h* is given by the expression:

$$b_i(h) = \sum_k c_{i,k}(h), \quad i = 1, ..., N_{SR}$$

In other words, the secondary regulation band accepted for the generating unit *i* is: $SRB_i(h) = 2\cdot b_i(h)$

The sum of all capacities offered by all generating units is:

$$B_{SR}(h) = \sum_{i=1}^{N_{SR}} b_i(h)$$

which has to be equal to at least the secondary reserve necessary into the system, $r_{SR}(h)$, that is: $B_{SR}(h) \geq r_{SR}(h)$

mentioning that $r_{SR}(h)$ is independent of price.

The secondary regulation reserve available of the unit *i* is determined in the following manner:

If $P_{nf,i} > \frac{1}{2}\cdot(P_{g,i}^{av} - P_{g,i}^{\min}) + P_{g,i}^{\min}$

Then *SRB* will be restricted by the upper limit and is calculated by expression:

$$SRB_i(h) = 2\cdot\min\left\{15\cdot R_i^{UP}, P_{g,i}^{av} - P_{nf,i}\right\}$$

If $P_{nf,i} < \frac{1}{2} \cdot (P_{g,i}^{av} - P_{g,i}^{\min}) + P_{g,i}^{\min}$

Then *SRB* will be restricted by the lower limit and is calculated by expression:

$$SRB_i(h) = 2 \cdot \min\left\{15 \cdot R_i^{DOWN}, P_{nf,i} - P_{g,i}^{\min}\right\}$$

In the expression of $SRB_i(h)$, 15 represent the time, in minutes, in which a generating unit must react to provide the secondary reserve.

The secondary band of a generating unit that will be selected for the merit order represents the minimum between the available reserves on all dispatching intervals. Taking into consideration the mechanism of the secondary frequency regulation, a unit can participate to this process only if, for the concerned dispatching interval, $P_{nf,i} \geq P_{g.i}^{\min}$, which allows to the unit to remain in operation.

In Romania the secondary reserve is paid at the balancing market clearing price (uniform price), which is the same for all participants, being the price of the most expensive accepted offer. Therefore, for any power increase in the secondary regulation, the producers will be remunerated at the BM clearing price. On the other hand, in the case of power reduction, the producers will be remunerated at a value that defines the opportunity cost due to this restriction to sell electrical energy, determined as the difference between the DAM clearing price and the BM clearing price.

The algorithm for secondary reserve procurement is the following [7]:

Step 1. Establish the secondary regulation band available for each participating generating unit;

Step 2. Identify the quantity-price blocks from the domain corresponding for upward regulation and for downward regulation, respectively;

Step 3. The prices of the blocks from the downward regulation domain are multiplied by (-1), and the obtained semi-band is overlapped in mirror over the semi-band corresponding to the upward regulation domain. The prices of the two semi-bands are added, following to identify the new quantity-price blocks under the form $\Delta c - \Delta\rho$;

Step 4. Collect the new blocks from all generating units and arrange them in ascending order of the price difference $\Delta\rho$;

Step 5. Select the block offers with the smallest $\Delta\rho$ until the required available reserved is met;

Step 6. Calculate the market clearing price $\xi(h)$ as the highest price of the initial blocks from the accepted bands.

Analyzing the above described mechanism it can be said that, the more loaded is a unit, with P_{nf} closer to P_g^{av}, or more unloaded, with P_{nf} closer to $P_g^{\min}$, the tight the secondary band will be. For this reason, in draught periods, when the available power of the HPPs is much reduced, or in rainy periods, when the units are loaded towards the maximum capacity, also in order to avoid floods, the available secondary regulation band would reduce too much.

In order to maximize the secondary regulation band we propose that the procurement and the dispatch of the secondary reserves be considered separately for power increase and for power decrease, respectively. This rule would operate appropriately and would stimulate competition if the HPPs would pertain to different consortia.

Procurement of tertiary reserve

The tertiary regulation reserve is of two types: synchronized (spinning) and non-synchronized. The synchronized power represents the reserve of a generating unit in operation (synchronized with the network) remained unloaded. In this category are included the qualified units for rapid tertiary regulation as well as the generating units qualified for slow tertiary units. The particularity of these regulation reserves types is that they are mobilized manually when called by the system operator.

In the case in which a generating unit has been already selected for secondary regulation, then the tertiary regulation reserve would be the unused reserve, for upward as well for downward regulation. As UCTE [8] also defines, if is not obligatory that the tertiary reserves for the two directions be equal.

– for power increase, the rapid tertiary reserve is determined by:

$$FTR_i^{+}(h) = \min\left\{time \times R_i^{UP}, P_{g,i}^{av}(h) - P_{nf,i}(h) - b_i(h)\right\}$$

where *time* represents the time period required for the tertiary reserve to be loaded;

– for power decrease, the rapid tertiary reserve is determined by:

$$FTR_i^{-}(h) = \min\left\{time \times R_i^{DOWN}, P_{nf,i}(h) - b_i^{-}(h) - P_{g,i}^{\min} \cdot \alpha\right\}$$

where: α=0, if the unit has the capability to start up to the next dispatching interval; otherwise α=1. The start-up time of the HPPs is very low so that we will not consider it in our study.

4. Case Study

Let us consider 5 producers, of different characteristics, but with similar startup and shutdown times, but different ramp-up and ramp-down rates to simulate a competitive environment on the balancing market.

The reserves procurement does not consider network constraints since the real time consumption could be different from schedules. For this reason we consider only the producers performances and their strategy regarding the market participation.

For simplification, consider that all producers offer up to 5 quantity-price blocks. Table I gives the offers MW-m.u./MWh for the considered case, where m.u. designates monetary units. The sum of the reserves offered in the quantity-price blocks by each generating unit *i* is equal to the available power P_g^{av}. The technical characteristics of the producers are given in Table II.

Table I

Generation offers for power reserves

Gen.		Offers				
		1	**2**	**3**	**4**	**5**
A	MW	100	90	70	60	80
	m.u./MWh	81	102	119	169	211
B	MW	110	50	90	80	70
	m.u./MWh	69	109	128	163	221
C	MW	80	60	70	50	40
	m.u./MWh	61	82	122	138	176
D	MW	90	80	50	70	50
	m.u./MWh	84	92	99	112	123
E	MW	200	80	100	120	160
	m.u./MWh	92	101	109	152	164

Table II

Generators characteristics

Gen.	$P_g^{\min}$	P_{nf}	P_g^{av}	R^{UP}	R^{DOWN}
	MW	MW	MW	MW/ min	MW/ min
A	75	255	400	40	50
B	70	240	400	50	60
C	40	240	300	60	80
D	15	165	340	100	120
E	90	391	660	50	80

Assume a secondary band necessary for the system, for the dispatching interval in question, of $r_{SR}(h)$=340 MW, and $r_{RTR}(h)$=500 MW for fast tertiary reserve, respectively.

Procuring balancing reserves considering a symmetrical band for secondary reserve

Applying the actual procedure for selecting and establishing the merit order for the secondary reserve obtain the available secondary reserves and the accepted reserves given in Tables III and IV, respectively.

Table III

Available secondary reserves

Gen.	A	B	C	D	E
MW	145	160	60	150	269

Table IV

Accepted semi-bands

Gen.	A	B	C	D	E
MW	5	36	20	100	11

We find that the BM clearing price for secondary reserve is 163 m.u., it corresponding to unit B, while the secondary reserve (semi-band) available for upward regulation is 784 MW.

Subtracting the reserves accepted for secondary regulation, the rapid tertiary reserves for upward and downward regulation are obtained. These are presented in Tables V and VI, respectively.

Table V

Accepted tertiary reserves for upward regulation

Gen.	D	D	E	B	E	A	C	A
MW	25	50	98	51	160	60	40	16
u.m.	112	123	152	163	164	169	176	211

Table VI

Accepted tertiary reserve for downward regulation

Gen.	E	D	B	C	A	E	B
MW	11	30	80	30	65	100	34
u.m.	152	138	128	122	119	109	109

Since the tertiary reserve, when called by the system operator, is paid on a pay-as-bid basis, the price is a matter of real-time procedure. The system operator could optimize the secondary and the tertiary reserves in real time in order to maintain appropriate security level for the power system.

Procuring secondary reserve separately for upward and downward regulation

If the secondary reserves would be procured by auctions performed separately for upward and downward regulation, it results an available power for upward regulation of 1001 MW, which is greater than in the previous mechanism.

The upward and downward secondary reserves accepted are presented in Tables VII and VIII.

Table VII

Accepted secondary bands for upward regulation

Gen.	A	D
MW	5	170

*Table VII*I

Accepted bands for downward regulation

Gen.	E	C	B	C	A	E	…
MW	11	30	80	70	65	100	…
m.u./MW	152	138	128	122	119	109	…

In this case we find that the clearing price for secondary reserve for upward regulation is 123 m.u./MW, which is much lower than in the previous case.

For downward regulation Table VIII gives the quantity-price blocks, arranged in descending order of the price. The financial remuneration should be optimized in the sense to minimize the costs.

We may observe that the clearing price is lower than the actual case, but due to the lower notified power and the low price offered by producer D the reserves are un-uniformly distributed among participants. But, this procedure would stimulate competition among participants and stimulate them to offer lower prices.

5. Conclusions

In this paper an analysis between the actual mechanism implemented in the balancing market in Romania and some new proposals were performed.

For system security reasons, when large amount of power generation is tripped, it is advisable that the primary and secondary power reserves be as uniformly as possible distributed among all qualified generating units, since more generating units can load the necessary reserve in a period smaller than a period that a reduced number of units need. Considering this aspect, the proposed solution could lead to undesired situations if the market is immature or the participants are not experienced, but the clearing price could decrease very much. On the other hand, this solution stimulates the producers to offer lower prices, which leads to higher competitiveness. However, actually, the secondary reserve in Romania is often provided by very few hydro-units since they are owned by one company, although more units are available to provide this service.

Knowing that the power plants offering regulation reserves are involved in imbalances occurred due to their consumers, with which they have bilateral contracts, it is unfair to leave some participants to benefit from the technical constraints of the power systems, so appropriate legislative rules should be established.

Nomenclature

$P_{g,i}^{av}$ – available generation capacity of the unit i, in MW;

$P_{g,i}^{\min}$ – minimum technical power of the unit i, in MW;

R_i^{UP} – ramp-up rate of unit i, in MW/min;

R_i^{DOWN} – ramp-down rate of unit i, in MW/min;

$P_{nf,i}(h)$ – notified power of unit i, in the dispatching interval h, consisting of power contracts accepted on the BCCM, DAM and/or regulated contracts, in MW;

$SRB_i(h)$ – available secondary regulation band of unit i, in the dispatching interval h, in MW;

$FTR_i^{+}(h)$ – available rapid tertiary reserve for upward regulation of unit i, in the dispatching interval h, in MW;

$FTR_i^{-}(h)$ – available rapid tertiary reserve for downward regulation of unit i, in the dispatching interval h, in MW;

$B_{SR}(h)$ – sum of all offered capacities by all units for secondary regulation, for dispatching interval, in MW;

$\xi(h)$ – market clearing price for secondary regulation, in m.u./MW;

$r_{SR}(h)$ – power reserve necessary for secondary frequency regulation in the system, in MW;

$r_{RTR}(h)$ – power reserve necessary for fast tertiary reserve in the system, in MW;

$c_{i,k}(h)$ – power quantity corresponding of a new block k, of the unit i, from the dispatching interval h, in MW;

$\rho_{i,j}(h)$ – price offered by unit i in the quantity-price block k, in the dispatching interval h, in m.u./MW;

$b_i(h)$ – secondary regulation semi-band accepted on the balancing market for the generating unit i, in the dispatching interval h, in MW;

$\Delta\rho_{i,k}(h)$ – price difference of the power quantity $c_{i,k}(h)$, from the upward block k, corresponding to an identified downward block, of the unit i, from the dispatching interval h, in m.u..

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