Proactive Planning and Activation of Manual Reserves in Sequentially Cleared Balancing Markets

Martin Håberg, Gerard Doorman
Department of Electric Power Engineering
Norwegian University of Science and Technology
Trondheim, Norway
martin.haberg@ntnu.no
gerard.doorman@statnett.no

***Abstract*—As a part of the integration of European balancing markets, new products and platforms will improve the possibilities for Transmission System Operators (TSOs) for exchange of balancing energy and netting of imbalances between areas. Proactive TSOs using early activation of manual reserves will have the opportunity to use combination of different products to cover their expected imbalance. These products will be cleared sequentially on separate market platforms, and at different lead times. This paper describes the situation faced by a TSO when determining its need for balancing energy from different reserve products. It also proposes an opportunity-cost based valuation strategy to optimize the volumes obtained in the different markets, thereby minimizing balancing costs.**

***Index Terms*—optimal scheduling, power generation dispatch, power system economics, power system modeling**

NOMENCLATURE

Indices

a	Area
b	Balancing energy offer
i	Price step in initial balancing energy need
k	Price step in residual balancing energy need

Parameters

$\overline{F}_{na}$	Upper limit on flow between areas n and a
$\overline{Y}_{ak}$	Volume of price step k in area a
$\underline{F}_{na}$	Lower limit on flow between areas n and a
C_b	Price of balancing energy offer b
D_{ak}	Willingness to pay for price step k in area a
E_{ab}	Price of balancing energy offer b in expected future supply
G^*_a	Expected imbalance volume for area a
$H_{m,na}$	Power Transfer Distribution factor of injection in area m on interconnection between areas n and a

Sets

A	Set of areas
B	Set of available offers
I_a	Set of price steps in initial balancing energy need in area a
K_a	Set of price steps in residual balancing energy need in area a

Variables

f_{na}	Flow from area n to area a
x_b	Delivery from balancing energy offer b
y_{ak}	Balancing energy need volume accepted in clearing for bid price step k in area a

Specifiers

$\downarrow$	Downward direction
$\uparrow$	Upward direction

I. INTRODUCTION

European power markets are changing. Through the recently developed new Network Codes, ENTSO-E (European Network of Transmission System Operators for Electricity) are harmonizing the rules and regulations for European power systems and markets. For balancing markets, the Guideline on Electricity Balancing [1] aims at more efficient use of balancing resources through stronger integration of balancing markets.

To facilitate exchange of balancing energy between areas, new Standard Products will be introduced in the years ahead. The activation and exchange of these products will be coordinated on pan-European platforms in which the inter-area netting of imbalances and activation of balancing energy offers will be optimized.

Some European TSOs rely on early activation of manual reserves as a means to cover an expected future imbalance [2]. Such a proactive strategy may be used for economic optimization [3], or to maintain operating margins in systems with limited availability of fast resources, in particular automatic reserves. Systems with frequent internal congestion may also need to make balancing decisions well ahead in time. A TSO using a proactive balancing strategy needs to determine its expected *future* need for balancing energy, and given sufficient lead time, several alternative products may be considered. These products will be activated on different platforms and at different points in time, complicating the TSO decisions on how much balancing energy should be obtained in the different markets.

This paper describes and discusses the situation faced by a TSO when determining what to submit to a common platform as its need for balancing energy from a given product. The paper provides an overview of key products and processes involved, and models how TSO needs and balancing energy offers can be cleared in the platform. A method for calculating the residual balancing energy need based on the expected future supply of alternative products is explained in some detail.

The proposed method is principle extendable to include imbalance forecast uncertainty and any number of balancing products. For this paper, the descriptions and explanations focus on the context of a TSO aiming to proactively cover the expected imbalance in each of its areas through netting and activation of balancing energy offers in the European platforms for replacement reserves (RR) and manual frequency restoration reserves (mFRR) with scheduled activation. The analyses assume marginal pricing and consider decisions on redispatch and availability of balancing energy offers to be made in an external process. Nonetheless, a handful of particularly complicating issues not directly addressed by the proposed method, are also discussed toward the end of this paper.

II. Background

As mentioned in the previous section, the Guideline on Electricity Balancing [1] requires the establishment of Standard Products and common platforms for the exchange of balancing energy. TSOs are to submit their needs for balancing energy and available offers to an Activation Optimization Function, which will find an optimal solution in terms of netting of needs and activation of balancing energy offers using a Common Merit Order (CMO) list.

These design characteristics are partly rooted in the research work done for more than a decade on design of integrated markets for cross-border exchange of balancing energy (cf. [4]–[7]). While some design choices have been made through [1], there are still several issues to be resolved as part of the development of procedures and platforms for balancing energy exchange.

The TERRE (*Trans European Replacement Reserves Exchange*) pilot project [8] has described a design proposal for cross-border exchange of replacement reserves. The design is built around a common platform performing a one-stage clearing of the *imbalance needs* and available balancing energy offers submitted by TSOs. TSOs are allowed to submit elastic imbalance needs to the platform, thereby representing the possibility of covering parts of the imbalance using other means than the TERRE platform, such as mFRR, aFRR or specific products.

The Standard Product for RR to be used for cross-border exchange is also based on a TERRE proposal. This product will be cleared for a delivery period of one hour, while in the future, the platform expects also to allow 15-minute duration periods. The European RR clearing and activation requests must be finished at least 30 minutes before delivery, as this is the activation time allowed by the product.

The TERRE platform design has also served as a starting point for the recently launched development of a design proposal for a common mFRR platform in the ongoing MARI (*Manually Activated Reserves Initiative*) project [9].

European TSOs have not traditionally been bidding for balancing energy in sequential international markets, and literature regarding this specific bidding problem appears nonexistent. However, related electricity market bidding problems have been studied for more than a decade, in particular regarding power producer bidding problems. This also includes bidding in sequential markets, as studied by [10]–[12] and notably [13], who propose a model for coordinated bidding in two sequential markets using multi-stage stochastic programming.

Still, there are considerable differences between producer and TSO bidding problems. While power producers bidding in multiple markets seek to maximize their expected profit, TSOs wish to minimize their expected balancing energy costs. The producer bidding problem also typically includes complexities arising from technical constraints and considerable uncertainty with regard to activation volumes and prices in the balancing energy activation market. The TSO bidding situation is different in that the technical constraints are external to the problem and that products cleared in different markets can to be overlapping to a large degree.

III. Proactive Balancing Model

A. Balancing Processes and Products

Proactive balancing is usually performed through early activation of manual products, although proactive use of aFRR could also be possible using a modified control signal. Most European TSOs procure mFRR, some also procure RR, and while a few years from now, standard products for both reserve purposes will be exchanged on European markets, TSOs also have the opportunity to use specific products for these purposes. Such products which will not be exchanged on European platforms, but can still act as partial substitutes.

The Standard Product for exchange of RR is expected to be modelled on the TERRE product, thus it will be cleared about 35 minutes before each hour for hourly delivery blocks. The mFRR Standard Product expected to be introduced on for scheduled exchange on an European platform will likely have a 15-minute delivery period corresponding the imbalance settlement periods (ISPs), and allow a full activation time of up to 15 minutes. Thus there will be time available between RR and mFRR clearings for delivery in the same period.

The model presented here will assume the context of a proactive balancing process concerned with activation of balancing energy from two Standard Products, cleared sequentially on the European platforms for RR and for scheduled mFRR. The products can be imagined as having the characteristics mentioned above. In principle, specific or automatic products could be included using a similar methodology.

B. Roles and Interactions

The model assumes a structure in which the TSO submits its need for balancing energy for the given product to a common platform, together with a list of available bids within its own area. The platform also has information on remaining Available Transfer Capacities (ATCs), and will identify the minimum cost set of balancing energy offers that will satisfy TSO needs and keep inter-area flows within their limits, taking into account the possibility of netting opposite needs.

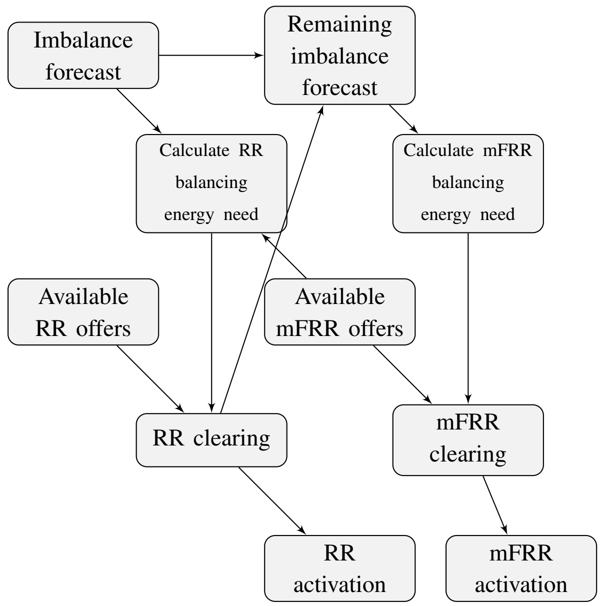

Fig. 1. Proactive electricity balancing optimization considering RR and mFRR product

The platform will then notify TSOs about their activation instructions and accepted volumes, before the TSOs request the activation of the selected balancing energy offers from Balancing Service Providers (BSPs) in their own areas.

C. Proactive Balancing Decisions by the TSO

The main balancing actions by the TSO will be to determine the imbalance need for each manual reserve product and activate the offers selected by the platform optimization, as described in in Figure 1. From this viewpoint, all other actions will be external, including decisions made on which bids should be made unavailable to the platform.

Before submitting the price-volume pairs, the TSO must assess its willingness to pay for different amounts of balancing energy before the platform clearing of each manual product. Before clearing of the next product, the imbalance forecast will be adjusted by taking into account accepted volumes of earlier products.

D. Clearing of Scheduled Standard Products

The following generic mathematical model may represent a common-platform clearing of any scheduled standard product. It assumes that TSOs submit their balancing energy need bids for each area a as price-volume pairs $(D_{ak}, \overline{Y}_{ak})$, each pair comprising one price step k of the bid curve. TSOs also submit a list B_a of price-volume pairs $(C_b, \overline{X}_b)$ representing available offers in area a to be included in the clearing for the given product.

The objective of the clearing in (1) is to maximize the social welfare, found as the difference between, on the one side, cleared volumes for upward balancing energy need bids $y_{ak}, k \in K_a^{\uparrow}$, and downwards offers $x_b, b \in B^{\downarrow}$, and downward balancing energy need bids $y_{ak}, k \in K_a^{\downarrow}$ and upward offers $x_b, b \in B^{\uparrow}$ on the other. The energy balance in (2) requires accepted bids y_{ak} in area a to equal the sum of locally activated offers and additional flow f_{na} into a following the platform clearing. The flow constraint (3) calculates this flow change between areas (n, a) based on the cleared net positions in each area m and the PTDF matrix $H_{m,na}$. Eqs. (4)-(6) set capacity limits on flow, bid price steps and offers.

$$\max \sum_{a \in A} \left(\sum_{k \in K_a^{\uparrow}} D_{ak} y_{ak} - \sum_{k \in K_a^{\downarrow}} D_{ak} y_{ak} \right) + \sum_{b \in B^{\downarrow}} C_b x_b - \sum_{b \in B^{\uparrow}} C_b x_b \tag{1}$$

$$\sum_{k \in K_a^{\uparrow}} y_{ak} - \sum_{k \in K_a^{\downarrow}} y_{ak} - \sum_{b \in B_a^{\uparrow}} x_b + \sum_{b \in B_a^{\downarrow}} x_b + \sum_{n \neq a} f_{na} = 0, a \in A \tag{2}$$

$$f_{na} - \sum_{m \in A} H_{m,na} \left(\sum_{k \in K_a^{\uparrow}} y_{ak} - \sum_{k \in K_a^{\downarrow}} y_{ak} - \sum_{b \in B_a^{\uparrow}} x_b + \sum_{b \in B_a^{\downarrow}} x_b \right) = 0, \quad a, n \in A, n \neq a \tag{3}$$

$$\underline{F}_{na} \leq f_{na} \leq \overline{F}_{na}, \qquad a, n \in A, \ n \neq a \tag{4}$$

$$0 \leq y_{ak} \leq \overline{Y}_{ak}, \qquad a \in A, \quad k \in K_a \tag{5}$$

$$0 \leq x_b \leq X_b, \qquad b \in B \tag{6}$$

E. Determining the Imbalance Need

The TSO needs to determine, in advance of each clearing, the need for balancing energy to be submitted to the platform for the given product.

A simple way of determining the need for balancing energy from a given product would be to create a single price-volume pair $(D_{ai}, \overline{Y}_{ai})$, $i = 1$, setting the willingness to pay D_{ai} to a high value $P^{\max}$ for the entire volume $\overline{Y}_{ai}$, which is set equal to the expected (remaining) imbalance G_a^*. For the last sequential market clearing considered, no alternative products will be available at a later stage, and the TSO can in forward the simple inelastic balancing energy need as explained above.

When alternative products are available in future clearings, this inelastic approach will lead to inefficient utilization of resources, but can still serve as a starting point for valuation of balancing energy from an early product. To optimize between products cleared at different points in time, the TSO should adjust its willingness to pay based on the prices of expected future supply of balancing energy offers from alternative products, resulting in an elastic residual balancing energy need. Figure 2 shows an example of an inelastic initial balancing energy need profile and an expected supply curve for available mFRR.

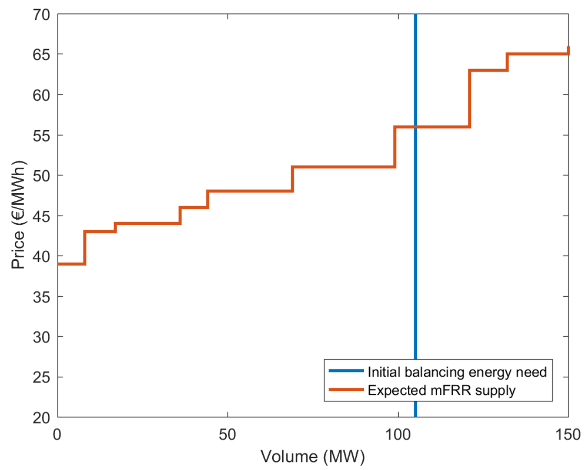

Fig. 2. Example of initial (firm) balancing energy need for RR and expected future supply of mFRR

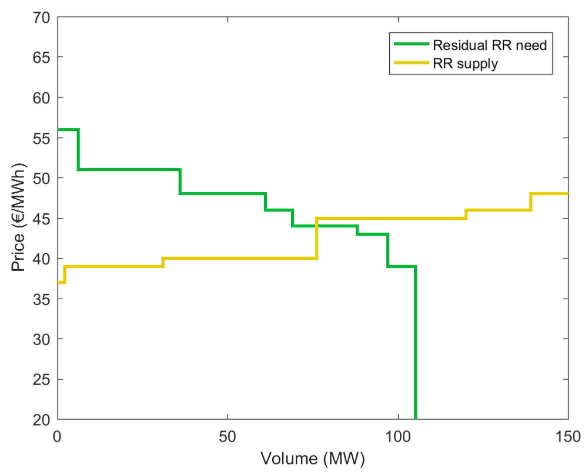

Fig. 3. Example of residual balancing energy need for RR and clearing against available offers in market clearing for RR

A list of price-volume pairs $(D_{ak}, \overline{Y}_{ak})$ comprising the residual balancing energy need can be calculated through vertically subtracting the expected future supply $(E_{ab}, \overline{Z}_{ab}), b \in B_a$ of alternative products. The vertical subtraction procedure is shown in Procedure 1. For the example in Fig. 2, vertically subtracting the expected mFRR supply from the initial balancing energy need gives the residual RR need curve in Fig. 3, which also shows an example of a clearing against available RR offers.

For the RR and mFRR example, first, the direction of the imbalance G_a^* in area a will determine whether a list $K_a^{\uparrow}$ or $K_a^{\downarrow}$ is to be created. Here, an initial balancing need with only one step $I_a = \{1\}$ with $D_{a1} = P^{\text{max/min}}$ (upper or lower price cap) and $\overline{Y}_{a1} = G_a^*$, can be used as a starting point for the RR need profile. Also, the offers $(E_{ab}, \overline{Z}_{ab})$ in the list B_a representing the expected future supply of mFRR in area a during the same period. The resulting elastic bid curve $(D_{ak}, \overline{Y}_{ak}), k \in K_a$ is

Procedure 1 Vertical subtraction for calculating residual balancing energy need

Input: $(D_{ai}, \overline{Y}_{ai}), i \in I_a, \quad (E_{ab}, \overline{Z}_{ab}), b \in B_a$
Output: $(D_{ak}, \overline{Y}_{ak}), k \in K_a,$
  $g \leftarrow G_a*$
  $b, k, i \leftarrow 1$
  while $g > 0$ **do**
    if $E_{ab} < D_{ai}$ **then**
      $D_{ak} \leftarrow E_{ab}$
      $g \leftarrow g - \min\{\overline{Z}_{ab}, g\}$
      $b \leftarrow b + 1$
    else
      $D_{ak} \leftarrow D_{ai}$
      $g \leftarrow g - \min\{\overline{Y}_{ai}, g\}$
      $i \leftarrow i + 1$
    end if
    $K_a \leftarrow K_a, k$
    $k \leftarrow k + 1$
  end while

the residual RR need that will be submitted to the platform clearing.

If more alternative products are to be considered, they can be taken into account by using the residual bid curve as the initial balancing energy need and performing more vertical subtractions with other offer lists.

IV. Complicating Issues

While the generic principles of the proactive balancing model hold, there would be several factors influencing the outcomes of a real-life implementation. While not addressing these issues specifically, this section explains and suggests approaches for analysis in further research.

A. Proactive Product Mix

The TSO must consider carefully which alternative products to represent when constructing a balancing energy need bid for submission to the platform. While in principle any balancing product can be included, there may reasons not to do so, based on operational policies. While aFRR is the balancing energy backbone in some systems, others use it only to cover short-term fluctuations or not at all. Although possible, it is also not advisable to represent the cost of delivering balancing energy from FCR, as such use would conflict its intended purpose.

B. Imbalance Variations

For one-hour RR products, there can be considerable variation in the imbalance during the delivery period. Two main possibilities arise for determining a starting point for the balancing energy need. The first is to calculate the average expected imbalance over the delivery hour, while the second is to select the volume of the the 15-minute sub-period with the lowest expected average imbalance, as proposed by the TERRE project [8]. While the latter will likely give less simultaneous counter-activations and potentially lower balancing energy costs, the first approach makes sense in a control perspective, as it maintains margins for faster products in both directions. Also, if offers from alternative products are competitive, it is unlikely that the entire expected average will be delivered by RR.

C. Uncertainty in Imbalance Forecast

Under the assumption of a perfect imbalance forecast, different balancing products will have the same quality given sufficient lead time. The uncertainty in the imbalance forecast should, however, be expected to be substantial when looking up to almost two hours ahead. Shorter, faster, and more flexible products are better suited to adapt to changes in the imbalance situation, thus they can be considered more valuable. The methodology in Procedure 1 does not address forecast uncertainty, but could easily be extended into a two-stage stochastic program to find an optimal initial target G^*_a for a range of imbalance scenarios.

D. Limited information on Expected Future Supply

The expected supply curves being subtracted should ideally give a correct representation of the marginal cost of using alternative products. In reality, the true marginal costs are unknown, as they depend on exogenous current and future offer prices and imbalance needs in other areas, as well as potential congestion and possibilities for netting.

When representing the expected future supply of balancing energy from alternative products by the list of locally available offers, no information on offers, needs and flows in other areas is used. For products that can be exchanged, this is, however, a considerable simplification, as the willingness to pay for balancing energy would clearly be influenced when expecting e.g. an abundance of low-priced offers for alternative products in neighbouring markets. Groups of TSOs could coordinate their needs and offers in advance to obtain a better expected future supply representation, but it would still be incomplete. Another possibility is for the platform to also collect the latest information on offers of different products, and include competition from these products in the market clearing.

E. Offer Characteristics

Some products and markets allow BSPs to format offers as indivisible (block) offers, exclusive offers or multi-part offers. While TERRE state that such offer formats can be processed by the CMO in the clearing [8], such offers will, when regarding alternative products, also complicate and obscure the representation of the expected future supply of balancing energy.

V. Conclusion

The introduction of common platforms for clearing of manual balancing energy products enable more efficient use of balancing resources, as it provides TSOs with opportunities of exchanging balancing energy offers and netting imbalances between areas. Although cleared sequentially, these markets will partially overlap under a proactive balancing strategy, thus TSOs can minimize expected balancing costs by optimizing the volumes obtained in each of the markets.

As the decisions on balancing energy needs from different products are submitted at different points in time, this paper proposes cross-product optimization through an opportunity-cost based bidding strategy. The method uses information from an imbalance forecast and a representation of the expected future supply of alternative products to calculate an elastic balancing energy need for each product.

The method can be extended to include any number of products, and imbalance forecast uncertainty can be taken into account using a stochastic formulation. Still, unresolved complexities remain in building realistic representations of expected future supply of alternative products.

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