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GB-Flex: Automated and Distributed Decision-Making in Energy Balancing Groups

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Introduction

Balancing Groups (BGs) are Distribution System Operators (DSO) that balance energy production and consumption — possibly aggregated if small. Larger consumers/producers could be considered separated entities in a BG, although these are mostly DSOs. To generalize the discussion, we refer to them as *sub-balance groups*(SBGs).

Each BG performs day-ahead forecasting and announces it to the Transmission System Operators (TSOs) – who rely on it to adjust energy production and expects BGs to follow the plan as close as possible. If BGs deviate, the TSOs penalize them. Likewise, with intraday (more accurate) markets and local flexibility, SBGs could – but do not do it – react to minimize the penalties [1]. Small SBGs do not have trading departments and cannot foresee deviations nor take necessary actions.

This paper briefly summarizes the possible strategies and shows the feasibility and profits of automatizing the BGs.

To systematically reduce transaction costs, the decision-making for balancing (i.e., contracting) and their implementation (i.e., contract fulfillment) need to be automated. Prompt reactions and correcting measures can lead to more effective balancing. Despite singular deviations/fines are small quantities, they can add up to avoidable expensive costs.

Background and State of the Art

In the electricity market, it is imperative to punctually equilibrate supply and demand. TSOs are provided balanced forecasts of feed-ins and withdrawals. However, SBGs can take a strategic position by participating in a local energy trading market. Local energy balancing follows the real-time balancing in European electricity markets. The dual-price system is applied in Switzerland, where the TSO will set the costs/penalties for positive/negative deviation for each settlement period [2].

We share some methodological approaches (e.g., the distributed nature and automated negotiation approaches) with existing research. For example, Wu et al. [3] validate their pricing strategies via simulations, and Hayes et al. [4] propose a co-simulation including P2P energy platforms and energy distribution networks. Other approaches adopt statistical learning algorithms (e.g., reinforcement learning and Q-learning) and game theory, enabling agents to trade autonomously and derive long-term profit-making policies(e.g., see [5, 6]). Approaches using aggregators often try to bring together smaller entities (e.g., on the household level, and allow them to provide their services to the energy market levels [7]). Similarly, they valorize flexibility. However, they typically ignore the existing and, in practice, established form of balancing groups. Our approach relies on existing structures in the energy balancing and enables them to act more dynamically and integrate more partners.

Decision-making approaches for balancing groups

Centralized decision-making: the BG centralizes all the partners, enabling optimization. It requires data centralization (often impossible), and it is implemented either by the BG itself or by the given SBG(s) following the BG's indications to adjust their schedules. In turn, it distributes the financial efforts/benefits among the partners. The advantages of this approach are possible optimization, risk-sharing, and limited balancing concerns. However, technical and organizational challenges (i.e., implementation/scaling) carry disadvantages, including explicit management of trust, transparency, and privacy, and practical difficulties in data integration.
Decentralized decision-making: Single actors (DSOs) make autonomous decisions and are responsible for their balancing (not viable w.r.t. the current regulative framework). Indeed, the concept of balancing groups has been introduced to avoid such a decentralized solution [2]. The (theoretically) full decentralization entails advantages including actors' autonomy and no need for data integration. Nevertheless, it is discouraged by significant disadvantages such as the absence of risk-sharing (everyone is exposed to the risk), every actor needs to invest in balancing efforts (more effort per partner), possible increase of the costs, and not technologically viable.
Hybrid solution: It combines the previously mentioned approaches and valorizes optimization and risk-sharing, with only a limited amount of actors needing to set up resources for balancing. It would still maintain actors' autonomy, reduce the need for data integration, and reduce the sharing of sensitive information with competitors. Besides the hybrid approach, neither of the extreme approaches can be unconditionally recommended for future balancing solutions.

The GB-Flex Simulator

The GB-Flex simulator enables the definition, simulation, and evaluation of several BGs/SBGs strategies leveraging both synthetic and real-world data[1] to mimic today's SBGs (including independent DSOs). Therefore, leveraging the multi-agent paradigm, autonomous agents can make decisions on their behalf and represent their interests. Hereafter, we refer to agents/actors interchangeably as synonymous with SBGs. Several nuances (i.e., politically-driven decisions and local markets' flexibility) have been not considered, given the lack of characterizing data and the difficulty of clearly quantifying their relevance in simulated environments. Despite this simplification, the study results are not necessarily jeopardized. Nevertheless, we rely only on the available data to ensure plausibility and grounding of the results.

We implemented the following strategies: **Do nothing -** SBGs do nothing to prevent penalties (current real-world scenario and baseline for penalties). **Competitive -** SBGs deal with only the outside market. If the forecasts are short, an

[1] 96-intervals day-basis data acquired from 02/2021 to 08/2021 by Valais BG.

SBG can minimize its final share of penalties. If they are long, selling would avoid paying penalties. **Cooperative -** SBGs exchange energy with each other exclusively. If the forecast is long, they try to sell to those short (preventing penalties in the BG). **Opportunistic -** SBGs aim to optimize their profits while preventing penalties for the whole BG. If a surplus cannot be placed within the BG, it is sold to the outside market (partially or entirely). The simulator comprises a web front-end to configure the scenario, set the inputs, and visualize the results, and a back-end enacting BG, SBGs, and their behaviors. The configurable inputs are load/generate data-sets, scenarios, market prices, energy market prices, penalties, buying/selling strategies, and related boundaries. The simulation clock triggers a check of the intraday forecast every 15 *simulated* minutes. GB-Flex includes 3 types of agents: *BG*, *SBG* and External market (EM). The main aim of all SBGs is to get their delta (the difference between their day-ahead and their intraday forecast) to zero – thus avoiding penalties – according to the strategy (unless it is *do nothing*).

Results

To enact BGs and SBGs' strategies and dynamics, we used six months of real-world data (Feb 21-Jul 21) from three main actors (*FMV*, *INERA*, and *OIKEN*) of the BG-Valais. Clearly, six months do not cover the full seasonality of the market. Nevertheless, the selected period suffices for the purpose and avoids strong summer/winter biases. This period tends to genera a surplus in the region, implying over-production. However, conversely to the current exposure to penalties, some strategies proved the benefits of buying/selling energy on the intraday market. We reasonably assume that the intraday energy markets have enough liquidity. In particular, we assume that all bits (buying/selling) an agent places at the market are accepted for the given price. Given the BG's size, this seems a reasonable simplification w.r.t. the traded volume in the energy markets. In theory, all penalties can be avoided if the market price is below the penalty imposed by the TSO. Hence, this assumption always holds because the penalty is related to energy price.

We assumed that the intraday forecasts represent the ground *truth*. This is, in practice, not fully correct and thus also limits the effectiveness of the proposed methods. However, intraday forecasts represent the best information available before execution time — thus, to act on. As mentioned above, current real-world approaches do not employ corrective measures (*do nothing* strategy), the worst possible solution for every entity within the BG. Computing the results for the BG, we speculate on the possible behaviors of some companies.

The potential impact of implementing an active balancing strategy rather than the *doing nothing* approach is confirmed by the several simulations. The SBGs took the initiative to place a surplus or to look for the missing amount of energy. Most of the time, demands and offers among the SBGs have shown to only partially satisfy each other. Nevertheless, seeking the EM has always allowed avoiding penalties (in some cases of 8'326 CHF **in a day**) and possibly generating profits. Our experiments investigate both scenarios with *aligned* strategies (i.e., all actors follow the same strategy) and *mixed* strategies (i.e., the actors have different strategies within the same run). Mixed strategies are particularly interesting to assess situations where single SGBs decide (for whatever reasons) to deviate from a commonly agreed strategy within the entire BG. This allows for each SBG, as well as for the overall BG, to consider strategization and incentivization for desired outcomes. Thus, our hypothesis **"hybrid solutions can be significantly beneficial to the BG, similarly to centralized solutions"** is supported by all empirical evidence we could observe for this balancing group over a period of six months of operational data. Thereby, the need for centralization fades, sparing the actors from its related drawbacks.

Conclusions

This paper investigated the needs, requirements, and constraints of automated decision-making for BG. Hybrid approaches overperformed the unpracticable purely (de)centralized solutions in competitive, cooperative, and opportunistic settings.

Summarizing, the further development of hybrid automated solutions for balancing BGs is a promising direction. They allow for economically efficient and technically feasible implementation, offer a reasonable foundation for further technological and organizational developments, and provide scalability and transferability to other BGs. Moreover, we recommend developing a solution actualizing the GB-Flex simulator in the real world to investigate further the agent-based approach's potential in more realistic settings. Finally, the developed simulator could be refined to ease its usability for non-experts. Such a system is envisioned as an aid for the SBGs in defining and evaluating their strategies ahead of their deployment.

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Availability of data and materials

Detailed material can be found in the project report
`https://www.aramis.admin.ch/Dokument.aspx?DocumentID=68395`.

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