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MASTER THESIS
Optimization of Energy Storage Participation Across Arbitrage and Balancing Markets: A Case Study of Belgium

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Abstract

The accelerating deployment of intermittent renewable energy sources such as solar and wind has introduced significant challenges in maintaining grid stability and efficient electricity market operations. One of the key problems is the **temporal misalignment between electricity generation and consumption**, which creates both technical imbalances in the power system and economic inefficiencies in electricity markets. Battery Energy Storage Systems (BESS) offer a promising solution by providing flexibility, however, their **profitability remains uncertain** due to volatile market conditions, complex participation rules, and degradation costs. Furthermore, most existing approaches focus on single-market participation, overlooking the full economic potential of BESS in multi-market settings.

This thesis addresses that gap by developing a **multi-market optimization model** tailored for BESS operating in Belgium, where storage operators can simultaneously access arbitrage (Day-Ahead and Imbalance) and ancillary service markets (FCR, aFRR and Imbalance). The proposed model is implemented in Pyomo using mixed-integer linear programming and captures operational constraints, efficiency losses, and degradation effects under multiple cycling scenarios. It operates at 15-minute resolution and dynamically allocates capacity across markets to maximize total revenue.

Market data from Elia covering the year 2024 was used to simulate real-world operation, while data after Belgium's integration into the PICASSO platform was excluded due to fundamental changes in aFRR pricing and structure. The analysis reveals that a coordinated multi-market strategy improves profitability over isolated market participation, with ancillary services providing stable revenue and arbitrage exploiting price volatility. Seasonal and temporal revenue patterns were analyzed, showing clear complementarities between markets.

Overall, the results demonstrate that optimizing across energy and balancing markets is a financially and technically sound approach for storage operators. The proposed framework enables better resource allocation, enhances system efficiency, and supports the economic viability of BESS under realistic operational and regulatory conditions in Belgium.