UNIVERSITY OF BRESCIA

PhD Program
in
TECHNOLOGY FOR HEALTH

Models and algorithms for optimizing battery charging cycles to stabilize the renewable energy electricity market

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Background

The increasing adoption of renewable energy sources such as solar and wind presents both opportunities and challenges for modern electricity markets. While these sources contribute to a cleaner and more sustainable energy mix, their intermittent nature creates difficulties in balancing supply and demand. Battery Energy Storage Systems (BESS) have emerged as a promising solution to address these challenges by storing excess energy for later use, stabilizing grid operations, and participating in energy arbitrage to optimize market efficiency. However, leveraging BESS in a dynamic market requires sophisticated optimization models and predictive tools. The integration of Machine Learning (ML) techniques into traditional optimization frameworks can unlock new potentials for real-time decision-making, enhancing economic viability and operational efficiency.

Objectives

This project aims to develop a comprehensive methodology for optimizing the use of BESS in renewable energy markets. A key objective is to analyze the dynamics of renewable energy markets, with a particular focus on Italy's regulatory framework and market mechanisms. The project will also involve the design and adaptation of Mixed-Integer Linear Programming (MILP) models, specifically tailored to the operation of BESS in these markets. Additionally, the integration of ML techniques will be explored to enhance predictive analytics and improve computational efficiency through meta-heuristic optimization. Finally, the methodologies will be validated by evaluating their performance using both historical and simulated data, with an emphasis on key metrics such as operational cost, computational time, and profitability.

Methodologies

The project begins with a comprehensive literature review to establish a foundational understanding of energy markets, BESS, and relevant ML techniques. This will provide insights into existing methodologies and identify gaps in current research. Next, MILP models will be developed and adapted from literature, incorporating specific constraints and objectives related to the operation of batteries in renewable energy markets. Solution development will include the implementation of exact solution methods such as branch-and-cut algorithms, as well as the creation of heuristic and meta-heuristic approaches. One of the key methods will be the kernel search, enhanced with ML-based variable selection, to improve both efficiency and solution quality. The models will be backtested using historical energy data, and the performance of the exact and heuristic approaches will be compared using metrics such as efficiency, renewable energy utilization rate, and economic outcomes.

Expected Results and Impact

This research is expected to produce a robust, scalable optimization framework that successfully integrates BESS into renewable energy markets. It will deliver a hybrid methodology that combines MILP and ML techniques, leading to improvements in computational efficiency and operational performance. The research will also provide practical insights into the economic benefits and challenges associated with deploying BESS for market arbitrage and grid stabilization. Additionally, a detailed comparative analysis of exact and heuristic solution methods will be conducted, offering recommendations for their application in real-world scenarios.