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Multi-objective placement and sizing of battery energy storage systems for stackable services

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Abstract-

Battery energy storage systems (BESS) support the flexibility of the energy transition through their ability to store and deliver energy when required. However, the high initial investment remains challenging for stakeholders with revenue recovery requirements. To address this, the provision of ancillary services has become a necessity. This study proposes a multi-objective approach that considers financial, technical, and operational aspects to determine the optimal placement and sizing of BESS to provide ancillary services, either individually or as stackable services. Power-quality indicators are used to assess the impact of BESS on the voltage variability at the nodes and the unbalance across the three-phase lines of the distribution system. The proposed approach utilizes a brute-force algorithm to explore a search space defined by commercially available BESS sizes and distribution system placements. This strategy generates a set of non-dominated optimal solutions based on Pareto optimality. A clustering-based approach using -means++ is proposed to systematically select representative solutions from the Pareto front. The model is validated on the basis of the frequency-regulation market structure of the Pennsylvania–New Jersey–Maryland Interconnection. A real 240-node distribution system is used for evaluation using OpenDSS with Python. The results indicate service-dependent optimal sizing, with the 3000 kWh/750 kW BESS as the most frequent Pareto-optimal size, while optimal placement consistently concentrates around nodes 2016, 2017, and 2018, near the most unbalanced three-phase lines, for both individual and stackable services. This pattern suggests that, across the analyzed services, Pareto-optimal placements tend to be located near unbalanced areas of the distribution system.

Index Terms- Battery energy storage systems; Frequency regulation; Multi-objective optimization; Pareto optimality; Peak-shaving; Stackable services

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