

A data-driven framework for estimating energy flexibility in renewable energy integrated microgrids

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Abstract

The massive penetration of renewable energy resources into microgrids introduces significant fluctuations and operational challenges, requiring accurate quantification of energy flexibility management. Conventional energy flexibility estimations often rely on parametric assumptions, depending on explicit resource modeling, and fail in the case of multi-node microgrid systems under changing environmental conditions [1]. To overcome these difficulties, this paper proposes a data-driven framework for accurate energy flexibility estimation in renewable energy-rich microgrids. The proposed framework consists of two identical layers [2]. In the first layer, it integrates unsupervised clustering methods to classify historical energy consumption, variable weather conditions, and grid network anomalies. In the second layer, a machine learning (ML) regression map identifies nonlinear spatio-temporal relationships, which explicitly measures the energy flexibility of various assets in the microgrid such as solar PV, wind energy, battery energy storage, and automatically controlled loads [3]. This framework supports microgrids as an integrated data-driven resource, estimating real-time energy capacity and timescales without any internal device parameters [4]. The proposed methods are validated by using empirical smart meter, ground meteorological, and grid constraint datasets from a microgrid in Bangladesh. The results illustrate that it effectively identifies energy flexibility patterns, improves demand-side energy allocation, and provides accurate flexibility estimation. The proposed framework offers highly salary and robust tools for predictive demand management for smart microgrids and community-based energy systems.

Keywords: data-driven framework, energy flexibility estimation, microgrids energy management, renewable integration, machine learning.

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