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SIMULATION-DRIVEN RELIABILITY-AWARE OPERATION OF ACTIVE DISTRIBUTION SYSTEMS

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ABSTRACT

We embed decision- and context-dependent reliability directly into short-term operational decisions for active distribution systems, using simulation for empirical evaluation. Component failure probabilities are learned from operating conditions and ambient temperature using logistic models estimated with Bayesian sampling; rare-event scarcity is handled through weighted bootstrapping. These reliability models are then coupled with an AC power flow representation and solved by a sequential convex approach that iteratively linearizes the expected cost of energy not served. Relative to a cost-only dispatch, the reliability aware controller shifts battery and demand schedules, reduces currents on critical lines, and cuts expected unserved energy cost by more than 20% with a modest increase in operating cost.

1 INTRODUCTION

Distribution system dependability is shaped by operating decisions and context (e.g., temperature). We study how simulation and data-driven reliability models can be embedded in day-ahead operations so that standard economic objectives are co-optimized with risk of service loss. Our main contribution includes:

1. a simulation-driven pipeline that, when real world data are scarce, estimates rare event, decision- and context-dependent component failure probabilities conditioned on operational states and ambient conditions.
2. an operations model that minimizes operating cost plus expected cost of energy not served (EENS).
3. a sequential convex programming workflow tailored to the resulting nonconvex, reliability-aware objective.

2 MODELING AND SIMULATION FRAMEWORK

2.1 Power and reliability co-modeling

We model a radial active distribution grid using the AC DistFlow formulation with controllable distribued energy resources and enforce standard voltage, thermal, and capacity limits (Choobineh et al. 2016). We augment the objective with EENS, where the probability that a bus is de-energized depends on its own condition and the condition of upstream lines, under an independence assumption for component failures.

2.2 Data-driven failure models

For each component, the interval failure probability is modeled by a logistic function of operating stress and ambient temperature. Parameters are estimated by Hamiltonian Monte Carlo, with weighted bootstrapping to mitigate rare-event scarcity and preserve realistic failure frequencies.

2.3 Solution approach

The EENS term makes the objecitve nonconvex. We therefore apply sequential convex programming, iteratively linearizing the reliability term around the current operating point and adding regularization to control step size. The process starts from a cost-only dispatch and iterates until convergence.

3 RESULTS

The reliability-aware model converges under 50 iterations. It reduces EENS cost by 22.6% relative to the cost-only dispatch, with a 12.6% increase in operating cost, depicted in Figure 1. Batteries charge during low-load hours and discharge during high-load, high-temperature hours; demand response activates at peaks, depicted in Figure 1 (Zhang and Mieth 2025). Figure 2 compares DER active power dispatch, expressed as percent utilization of the maximum power limit, for the model that account for reliability (Figure 2a) and the model that do not (Figure 2b) (Zhang and Mieth 2025).

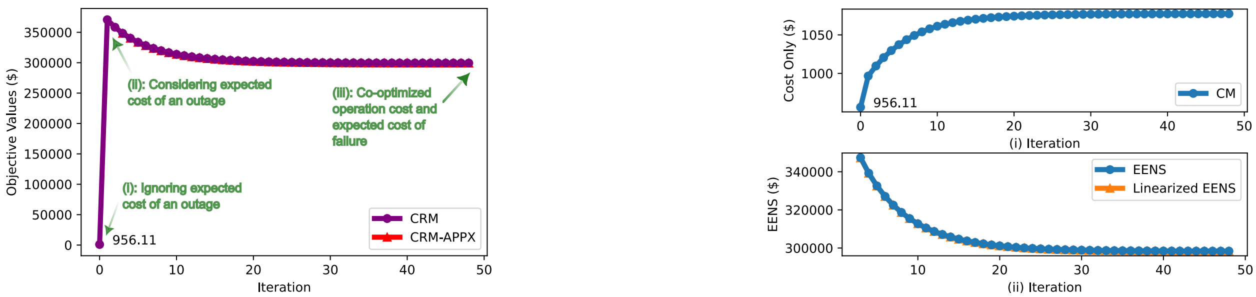
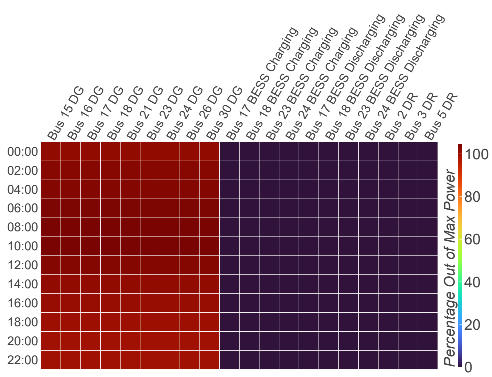
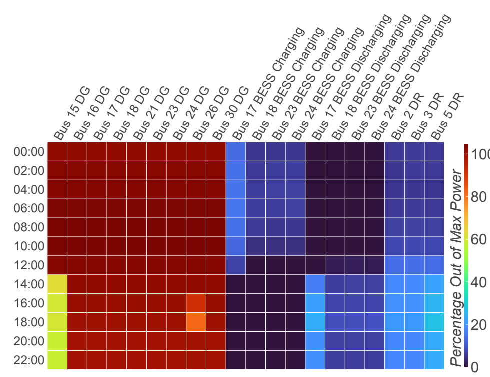


Figure 1: Objective values for reliability incorporated model.



(a) Cost-only



(b) Reliability incorporated model

Figure 2: DER active power dispatch in percent utilization of maximum power limit.

ACKNOWLEDGMENTS

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