Maximizing clean energy in power networks: an approach to find the limits of integrating intermittent sources

Noé Bertramo, Gabriel Duguey

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Problem Description

As the transition toward renewable energy accelerates, power networks face increasing demands to integrate decentralized, intermittent sources like wind and solar. Originally designed for centralized and reliable fossil-fuel generators, networks now need to accommodate for these sources. Despite the promise of reducing emissions and improving resilience, their integration poses major challenges in maintaining grid stability and assuring demand is met.

The crucial question in power grid integration is thus: how much renewable generation can the grid reliably integrate before breaking? Optimizing the maximum level of distributed energy resources (DERs) that a power network can accommodate without compromising performance or requiring upgrades, known as *hosting capacity*, will be our objective. This quantity is influenced by electrical constraints on busses and lines and varies based on factors like network layout and load characteristics.

Traditional methods for computing hosting capacity rely on simulating DER impacts in discrete scenarios until operational limits are reached. These computationally intensive methods overlook uncertainties in load and generation patterns and can miss optimal solutions. We thus propose an optimization-based approach, starting with a simplified model to determine DER integration capacity under key constraints, adding robustness and sensitivity analysis on critical parameters thus offering a clearer picture of how capacity responds to changes in grid conditions and DER configurations.

Ultimately, this project aims to offer insights for grid planners on effectively and robustly scaling DER integration under load uncertainty.

Data

This study uses the IEEE 33-bus radial distribution test system, widely used in the literature, which includes:

- **Network Data:** Information on buses and branches, conductances, resistances, reactances and susceptances, voltage constraints, flow limits and exchange limits with upstream transmission grid.
- **Load Data:** Uncertainty interval of load profiles.

Methods

We formulate an optimization problem to maximize DER capacity subject to:

- **Power Flow Constraints:** we use a linearized AC power flow model to improve computation efficiency.
  - **Power Balance**: we must assure power balance of each bus, for active and reactive power.
  - **Power flow equations**: we will linearize AC power flow equations at each line between busses.
  - **Limits**: voltage limits at each bus and flow limit at each line (active/reactive).
  - **Interconnection**: interconnection constraint with incoming power from the transmission grid.
- **Uncertainty Modeling:** We will create a robust model by incorporating uncertainties in load demand and DER generation.

The model maximizes the total generation (the aforementioned *hosting capacity*) while accounting for uncertainty by implementing the worst-cast scenario (robust optimization):

$$\max \min_{U} \sum_{m \in B} P_m^G$$

Due to page constraints, the equations have not been written here but will be included in the final report.

Expected Results

The proposed method aims to:

- **Propose** an easily scalable model able to identify optimal DER sizes and placements in a given grid to maximize hosting capacity
- **Demonstrate** computational efficiency relative to currently used discrete methods
- **Analyze** limiting factors such as voltage constraints for future network expansion projects

Practical Implications

The findings are expected to assist grid operators and policymakers in several ways:

- **Grid Planning:** Facilitate decision-making on infrastructure upgrades for better DER integration.
- **Policy Development:** Inform DER connection policies and potential grid reinforcements.
- **Increased Renewable Adoption:** Support higher renewable penetration without compromising grid reliability.

This optimization approach could also extend to capacity expansion planning, identifying grid bottlenecks, and facilitating evaluations of various long-term scenarios efficiently.