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Autonomous Microgrid Design Using Classifier-Guided Sampling

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Introduction

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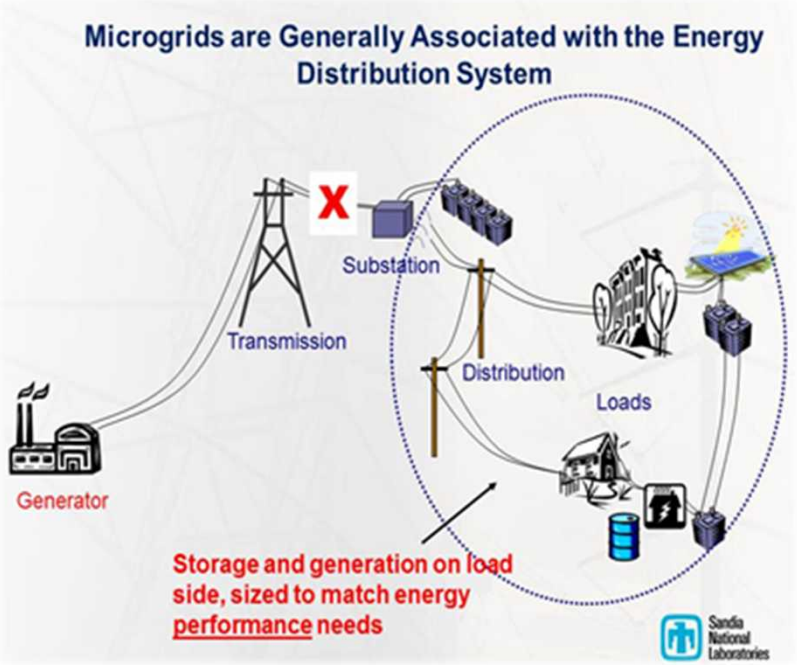
What is a Microgrid?

- Microgrids are an organized collection of distributed energy resources (DER) and controls that can operate autonomously (independent of a bulk power grid) when necessary to provide electrical power.



- They support resiliency, security, efficiency, local control, and increased access to renewable resources.

- Microgrids can provide reliable power during emergency conditions in which the bulk utility power is unavailable and be leveraged for economic value during normal operations.

Motivation

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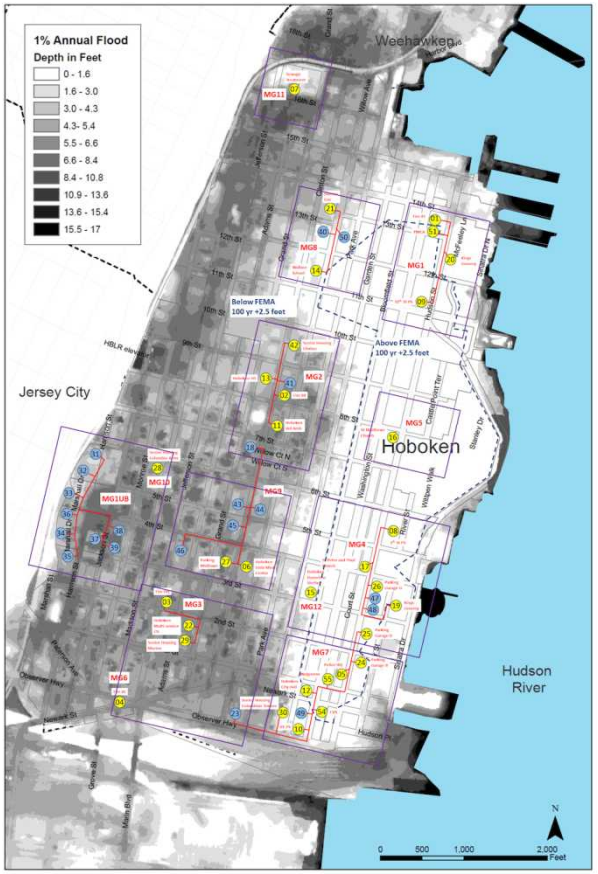
Hoboken, NJ as an Example:

- In October 2012, Hurricane Sandy flooded much of Hoboken, NJ resulting in sustained power outages for many residents and critical infrastructure (hospitals, government buildings, municipal assets, etc.).

- Maintaining electrical power to critical infrastructure in Hoboken would have reduced the risk to lives and enabled a faster recovery.



Analytical Rigor in the Design Process:

- Haphazard microgrid design can create many problems around maintenance, safety, power quality/stability, and central dispatch control.

Hoboken Microgrid Design Optimization

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Optimization Problem Setup

- Objective
  - Minimize average load not served (LNS) in kWh per hour of outage
    - Can exclude buildings and infrastructure that aren't critical
    - Can't ignore uncertainty relating to loads, outage frequency/duration, generator reliability, and distribution infrastructure
- Constraint
  - Total installation cost must not exceed $8 million.
- Design variables
  - Do/Don't install each natural gas generator in 55 critical buildings (131 choices)
  - Do/Don't connect each of 13 sub-grids of building clusters (22 choices)

Approach

- Model and simulate the candidate microgrid designs using the Performance and Reliability Model (PRM)
- Identify optimal configurations with Classifier-Guided Sampling (CGS)

The Microgrid Performance & Reliability Model (PRM)

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- A simulation code that is used to statistically quantify the performance and reliability of a microgrid operating in islanded mode.
- Computes fuel efficiency, fuel usage, renewables penetration and usage, renewable spillage, dispatch statistics, and other operational characteristics of the system and its assets as well as frequency and magnitude of load lost and energy availability at various levels of aggregation over the microgrid.
- Originally developed in support of the Smart Power Infrastructure Demonstration for Energy Reliability & Security (SPIDERS) program.
- Serves as a key component of Sandia's Microgrid Design Tool software.

Classifier-Guided Sampling

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- Classifier-guided sampling (CGS) is a novel search and optimization method that is capable of solving **discrete/discontinuous optimization problems**
- CGS uses a **Bayesian classifier** to drive the search towards regions of the design space that are likely contain high-performance solutions with relatively few objective function evaluations
- CGS may outperform other approaches
  - Metaheuristic techniques (Genetic Algorithms, Simulated Annealing, Tabu Search, etc.)
    - May require numerous function evaluations
  - Metamodel-based optimization (a.k.a. surrogate-based)
    - Limited to continuous objective functions

Bayesian Classifiers

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- Consider a *K* category (class) problem
- c_k is class *k* where *k* = 1,2,…*K*
- **x** is an unevaluated design vector (test point)

Bayes Formula:

$$P(c_k \mid \mathbf{x}) = \frac{P(\mathbf{x} \mid c_k) P(c_k)}{\sum_{k=1}^{K} P(\mathbf{x} \mid c_k) P(c_k)}$$

Probability that **x** belongs to class *k*

Classifier: **x** belongs to the class *k* with the highest posterior probability ($P(c_k \mid \mathbf{x})$)

Classifier-Guided Sampling Algorithm

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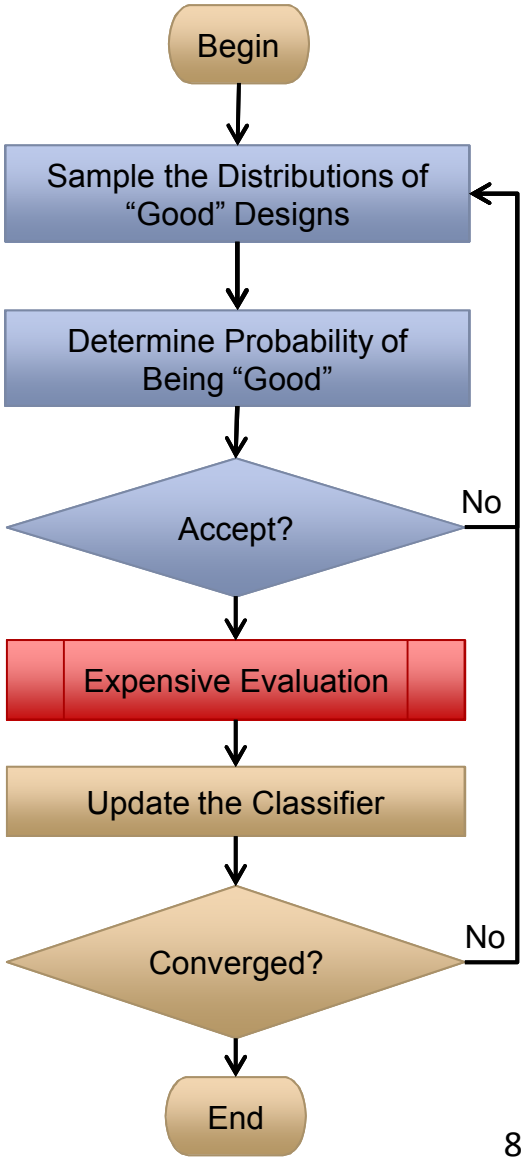
Bayes Formula:

$$P\left(c_{Good} \mid \mathbf{x}\right) = \frac{P\left(\mathbf{x} \mid c_{Good}\right) P\left(c_{Good}\right)}{\sum_{k=1}^{K} P\left(\mathbf{x} \mid c_k\right) P\left(c_k\right)}$$



Key Characteristics of CGS:

- **New candidate solutions are generated by sampling the probability distributions that form the classifier.**
- **The classifier output (probability that a candidate is "Good") is used to determine whether it is worthwhile to spend time evaluating a new candidate point.**
- **The classifier is trained by assigning the top *N* designs a classification of "Good" and assigning all others a classification of "Bad".**

Design Optimization Parameters

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PRM Simulation

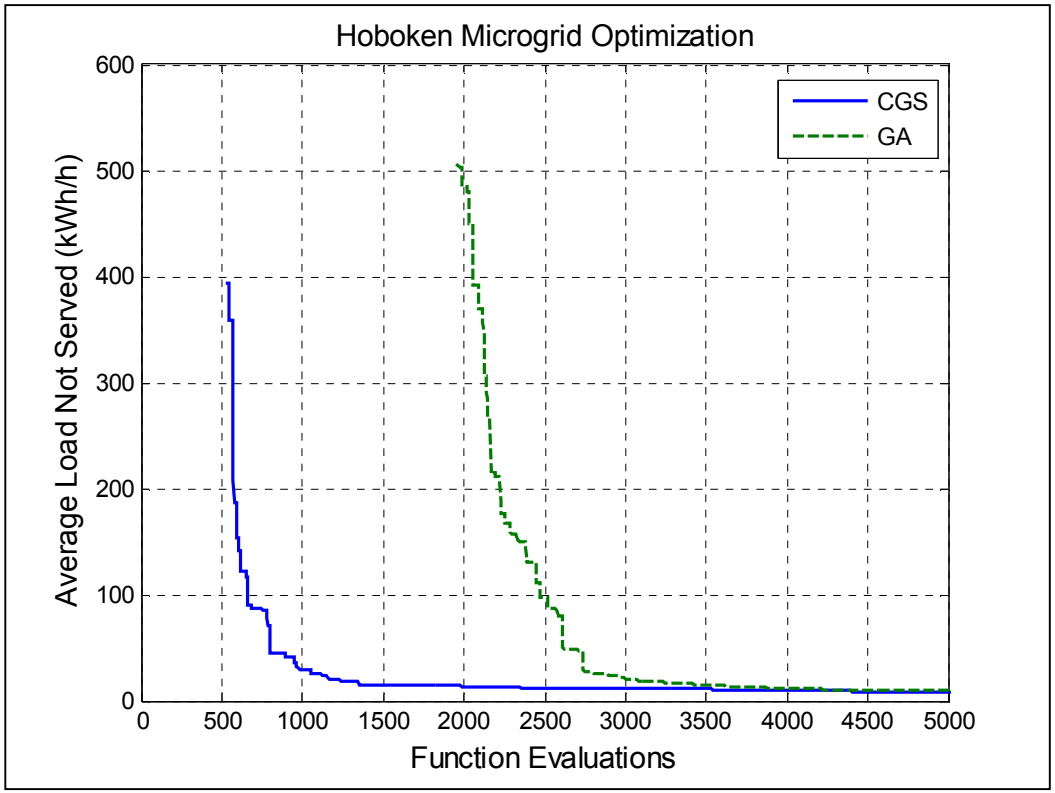
- The PRM is used to simulate an operation period of 100,000 years, with an outage lasting an average of 7 day occurring every 100 years
- Hourly load data is used for each of the 55 critical buildings

Optimization

- CGS and Genetic Algorithm (GA) both used for comparison and validation purposes
- Termination criteria of 10,000 PRM simulations
- Each optimization method is run 5 times and average results computed
- Constraint handled by always preferring a feasible design to an infeasible design, and by preferring a less infeasible design to a more infeasible one
- Repeat evaluations of the same design are precluded

Optimization Results

- Given 5,000 PRM simulations, CGS and GA both identify a design with 5.06 kWh/h of LNS (0.05% of estimated peak load)
- CGS requires roughly 1,400 fewer evaluations to identify feasible solutions
- Generators
  - 34 of 131 possible generators are installed
  - More small generators are generally preferred to fewer large generators
- Building Cluster Connections
  - 5 of 22 candidate building cluster connections are installed
  - The cost to connect the sub-grids is outweighed by the benefit of matching installed capacity to estimated loads



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Questions