



Flexible Design and Operation of a Smart Charging Microgrid

Annette G. Skowronska (TARDEC, OU)

Vijitashwa Pandey (OAKLAND UNIVERSITY)

Zissimos P. Mourelatos (OAKLAND UNIVERSITY)

David Gorsich, Matt Castanier (TARDEC)

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Introduction

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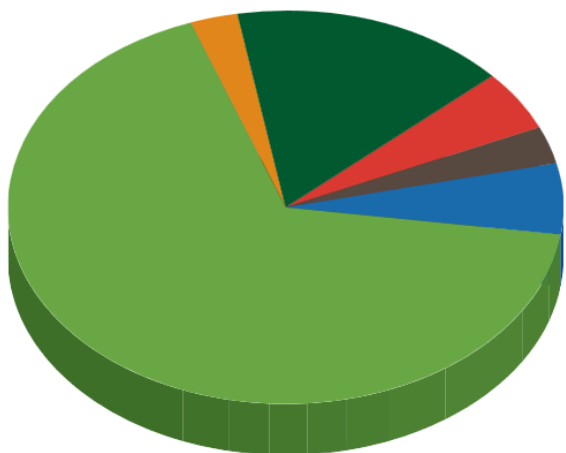


Wheeler
Army Airfield
Installation
in Hawaii

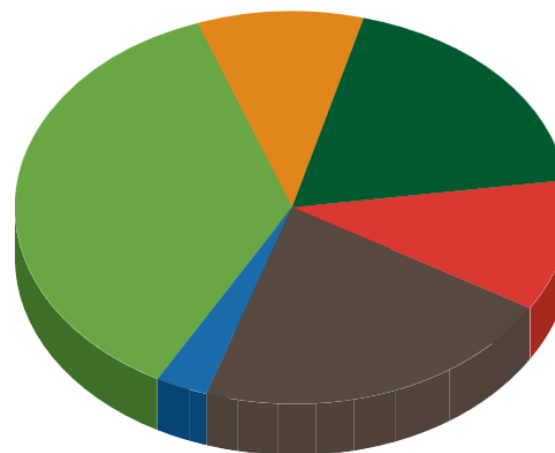
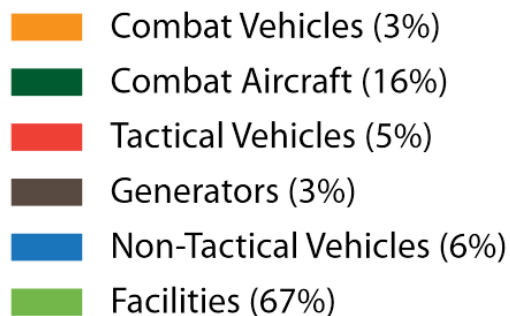
Presentation Outline

- Motivation 
- Designing a Reliable Microgrid
- Repairable Systems
- Microgrid and V2G Overview
- Case Study
- Optimization Problem and Results
- Conclusions and Future Work

Reliability and Cost Efficiency Contributors



Peacetime



Contingency Operations



Microgrid as a Flexible System

- A microgrid is a **reparable system** that needs to accommodate varying operating conditions.
 - A deterministic design tends to be **not feasible**
 - Robust design can still become **suboptimal** as operating conditions change
 - A flexible design accommodates changes in operating conditions and is preferred
- Design of a microgrid involves **multiple conflicting objectives** such as: reliability, cost and planning horizon.
- To calculate these long-term metrics the **computational effort** becomes excessive.
- This work aims at **flexible design** that simultaneously attacks the computational effort.



Microgrid and V2G Design Problem

Determine **optimal** microgrid **architecture** (number, size, and type of energy sources including hybrid vehicles) and **source dispatching**

initial plus inventory

to **minimize** acquisition and operation **cost**

fuel, repairs for readiness (e.g.MFFP)

and **maximize performance** (reliable service of a time-dependent and uncertain load), considering maintainability, repair strategy, inventory, reset, and energy storage.

Incorporate **flexible approach** to microgrid design that **"learns"** from its behavior (loads and sources) and responds accordingly.



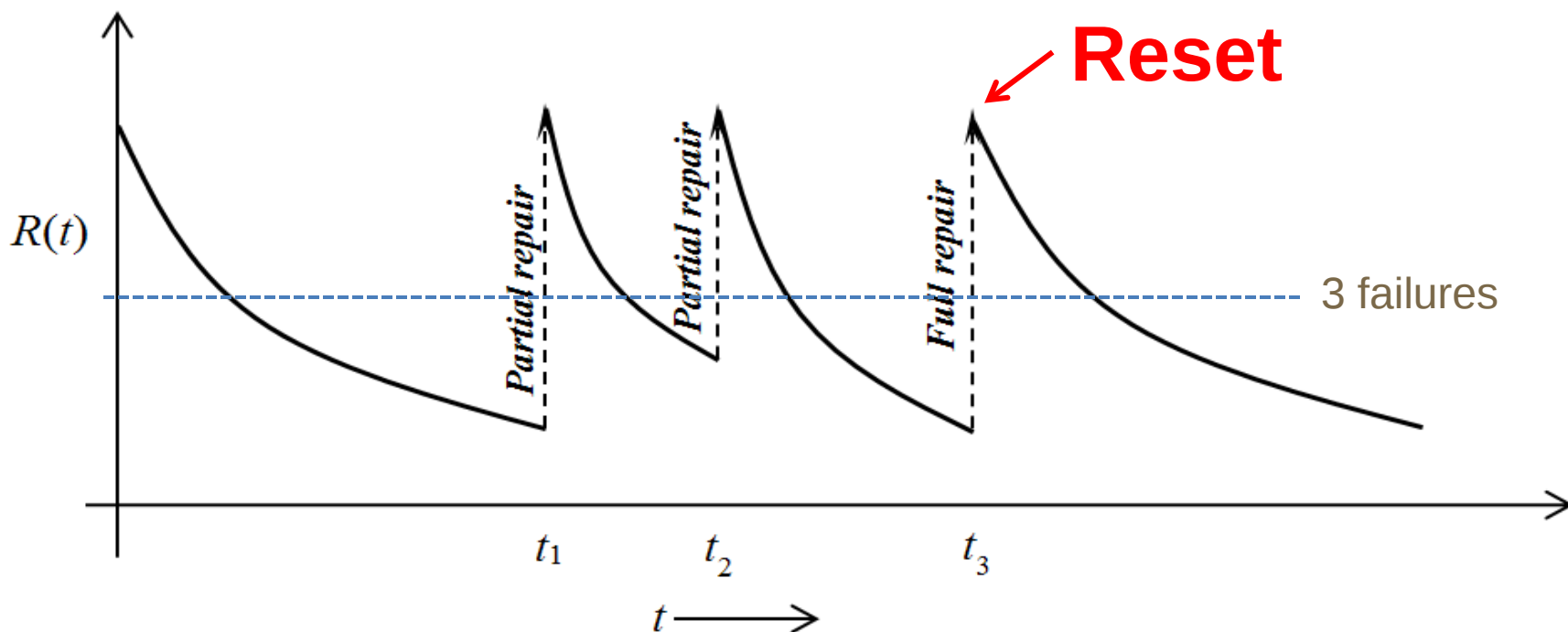
What is a Reliable Microgrid?

- Failure is the inability of the microgrid to meet load requirements.
 - Load exceeds **maximum capacity** of energy sources with **no component failures** (load shedding is required).
 - Load exceeds **available capacity** of energy sources **due to component failures**.
- Failures are expected because of the **stochasticity** regardless of how well the loads are modeled.
- Microgrid is treated as a **repairable system**.

Repairable and Non-repairable Systems

Reliability of a **non-repairable** system is the probability that a system has not failed at any time before the time of interest.

What is the reliability of a **repairable** system?

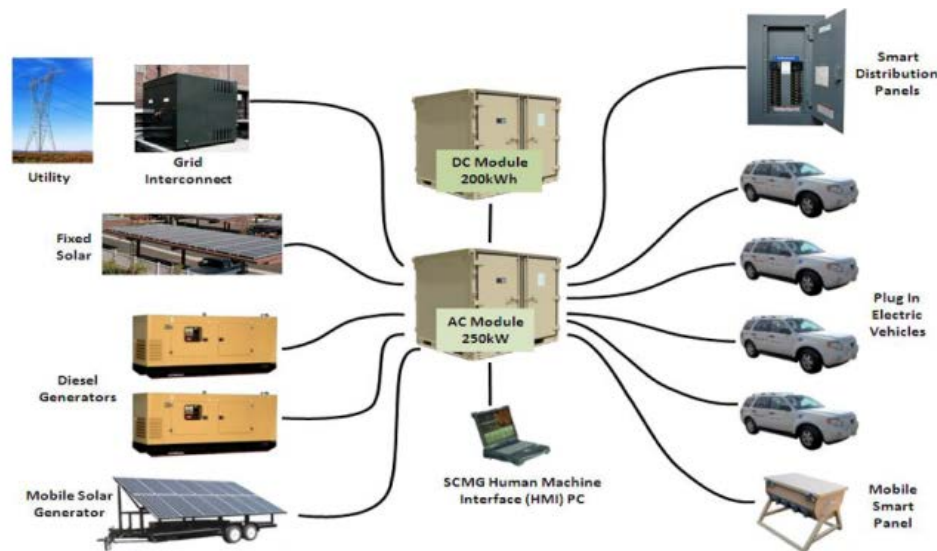


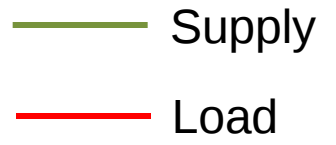
Metrics for Repairable Systems

- In **classical reliability** theory:
 - MTBF, which only reports **the mean of the time to failure distribution**, is used.
 - Availability may be **misleading** if system can be repaired quickly.
- We propose a **set of metrics** useful in capturing different aspects of performance of a repairable system and then select a minimal set (e.g. cost, MFFP, number of failures).
- A small set of metrics can be used to represent system performance using a **Pareto front** so that the best design can be chosen.

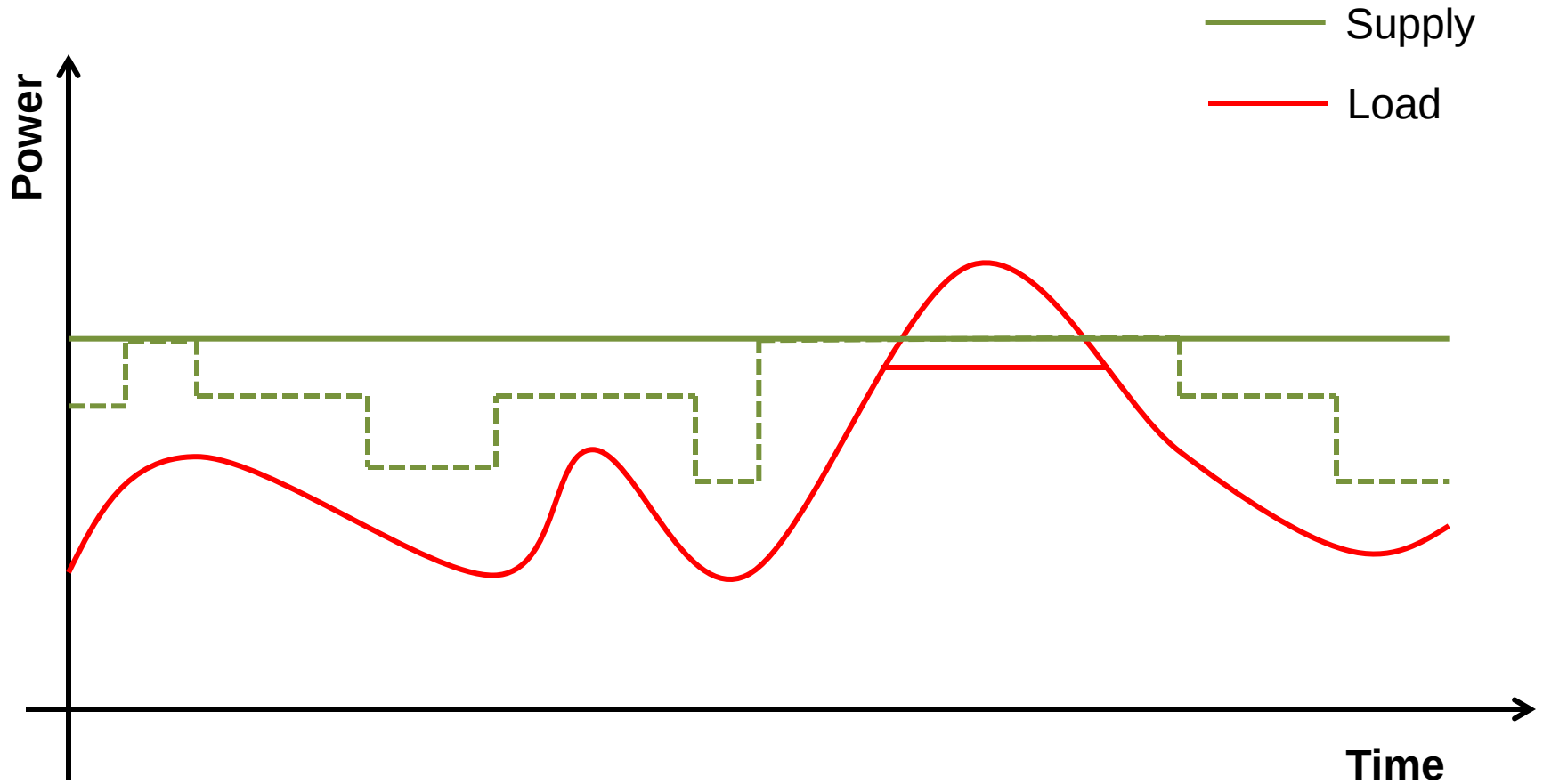
Microgrid and V2G Overview

- Integrates power from multiple sources without loss of power quality
 - 2 x Solar PV (50 kW)
 - 2 x Diesel generators (200 kW)
 - Hybrid vehicles EV batteries (60 kWh @ max discharge rate of 10kW)
- Capable of peak-shaving and load-shedding if required
- Islanded
- Provides power to variable loads
 - Building loads
 - Other miscellaneous loads

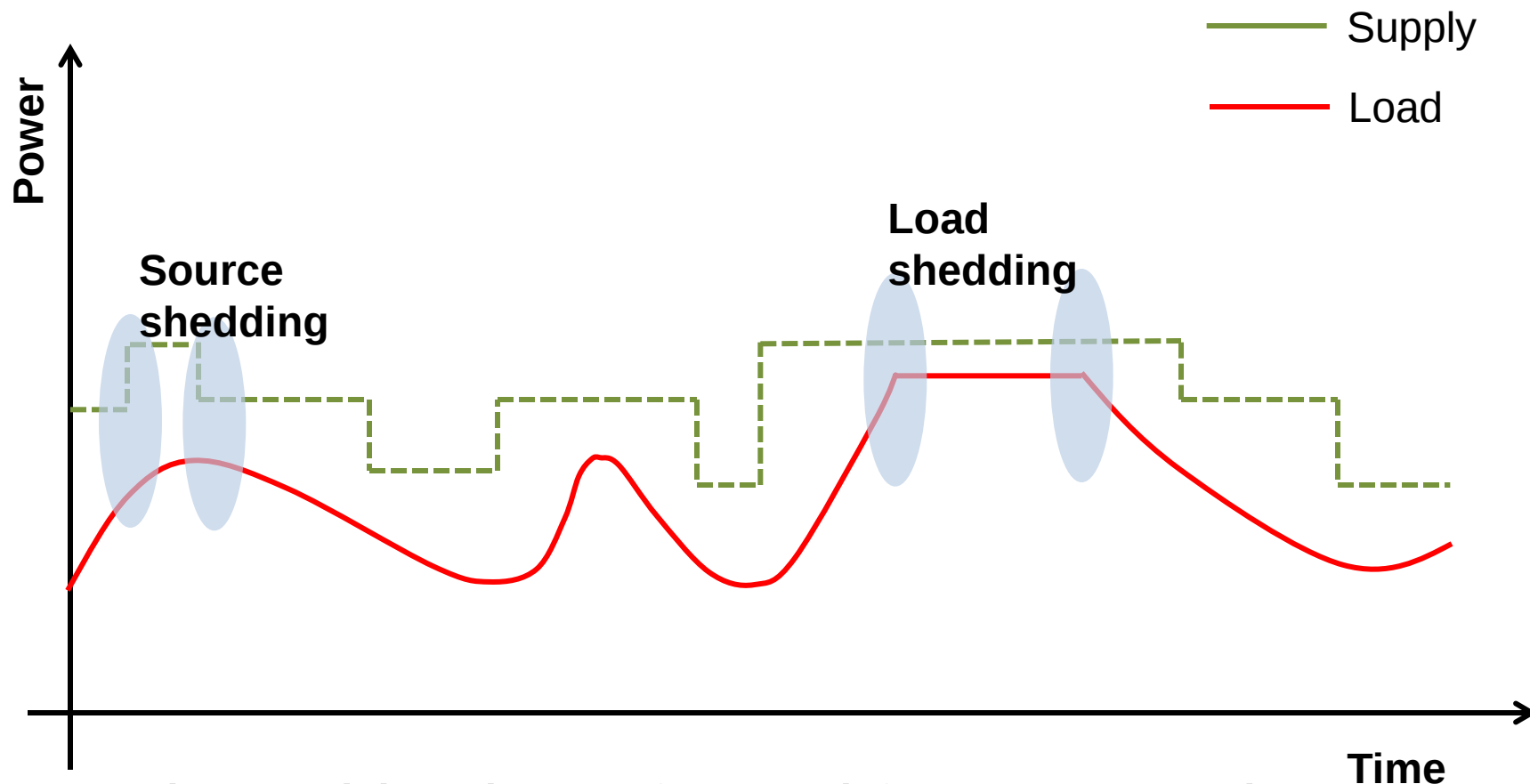




Load and Source Dispatching

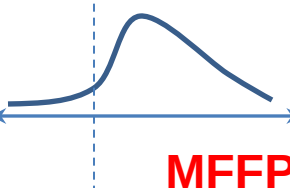


Load and Source Dispatching



Dispatching is performed for **1 year** using
1-hour increment

Optimization Problem



MFFP with 80% probability

$$\underset{\mathbf{x}}{\text{Min}} \{ -T_{0.8}, N_f, C \}$$

←

Number of failures

←

Cost

NSGA-II Algorithm

where: $\mathbf{x} = \{ \underbrace{S_{ls}, S_{so}, S_{lo}, S_{ss}}_{\text{Ruled-based set points (decision variables)}}, n_{gen}, n_{contacts} \}^T$

$T_{0.8} = F_{T_{working}}^{-1}(0.2)$

$C = C_{initial} + C_{repair} + C_{running}$

subject to:

$g_1(\mathbf{x}): P = 8760,$ ← **Planning horizon**

$g_2(\mathbf{x}): p_{gen} = 0.25, \quad g_3(\mathbf{x}): \eta_{repair} = 0.1$

$n_{gen}, n_{contacts} \in N$

$S_{ls}, S_{so}, S_{lo}, S_{ss}, \in [0, 100]$

Issues with Classical Approach

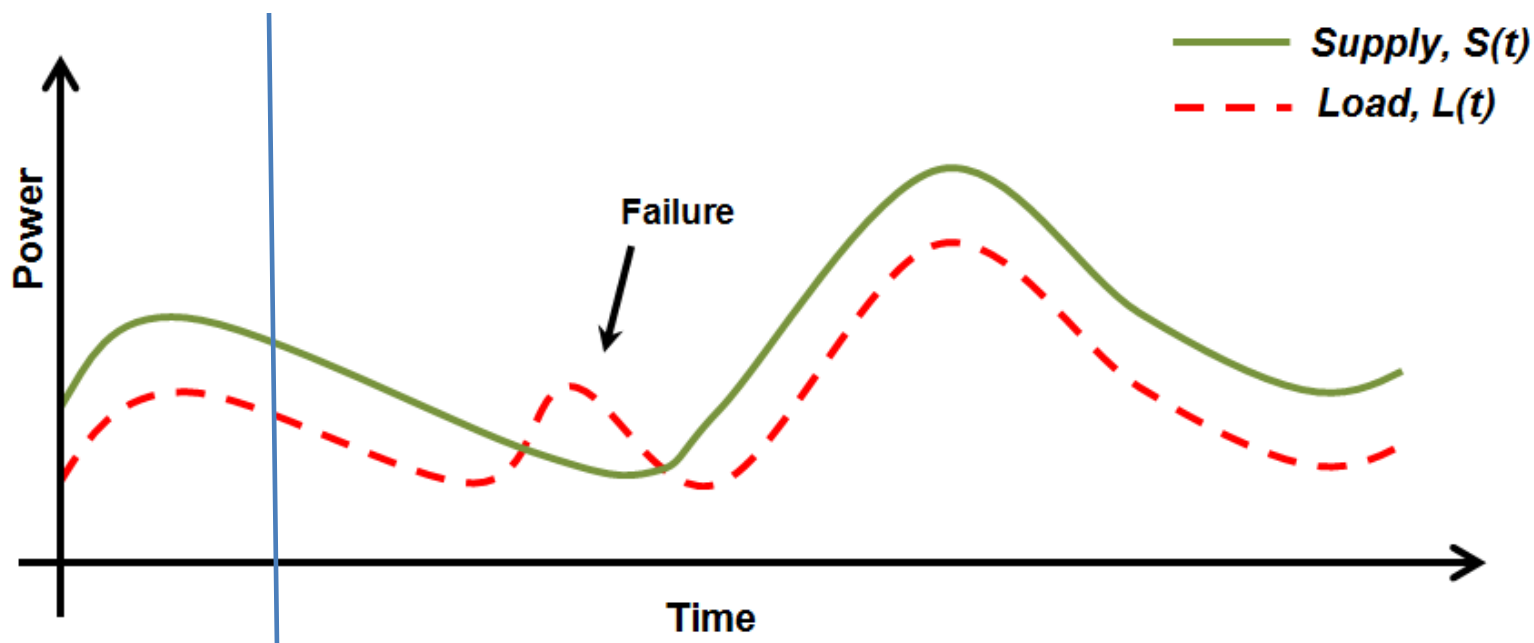
- **Incorrect extrapolations:** Unless done properly, what is learned in a short simulation time **may not be applicable to the entire planning horizon.**
- **Coarse time scales:** Many **transient effects** are not captured properly because they happen within seconds. The flip-side is that fine time scale simulations are **computationally prohibitive.**
- **Uncertainty:** **The effect of uncertainty cannot be fully captured.** For example, we may encounter a chance failure and assume that the microgrid is unreliable or alternatively by luck, we may not see any failure in a short period even if the microgrid is unreliable.

Flexible Microgrid

- We are envisioning a **flexible approach** to microgrid design that **“learns”** from its behavior (loads and sources) and responds accordingly.
- Load follows a stochastic process and in response so does the supply.
- Failures are expected because of the stochasticity regardless of how well the loads are modeled.
- The dynamic microgrid system **must be simulated with a very short time interval for months at a time** in order to fully characterize its operation. This is computationally impractical.
- **Our methodology proposes to “learn” the characteristics of the load profile $L(t)$ and the resulting supply profile $S(t)$, as enacted by an intelligent power management protocol.**

Flexible Microgrid

- The correlation between $L(t)$ and $S(t)$ is also determined.
- A short period of a few days can be used to “learn” the process.
- The quantified stochastic behavior of $L(t)$ and $S(t)$ is used to extrapolate for the system performance metrics at later times.



Current Research – Flexible Microgrid

- AR* time series models the load and source processes

$$L(t_i) = 150 + 100 \sin\left(\frac{2\pi t}{24}\right) + 50(0.0345\varepsilon_{i-1} + 0.1552\varepsilon_{i-2} + 0.2069\varepsilon_{i-3} + 0.2586\varepsilon_{i-4} + 0.3448\varepsilon_i)$$

- Source can be modeled in two ways:

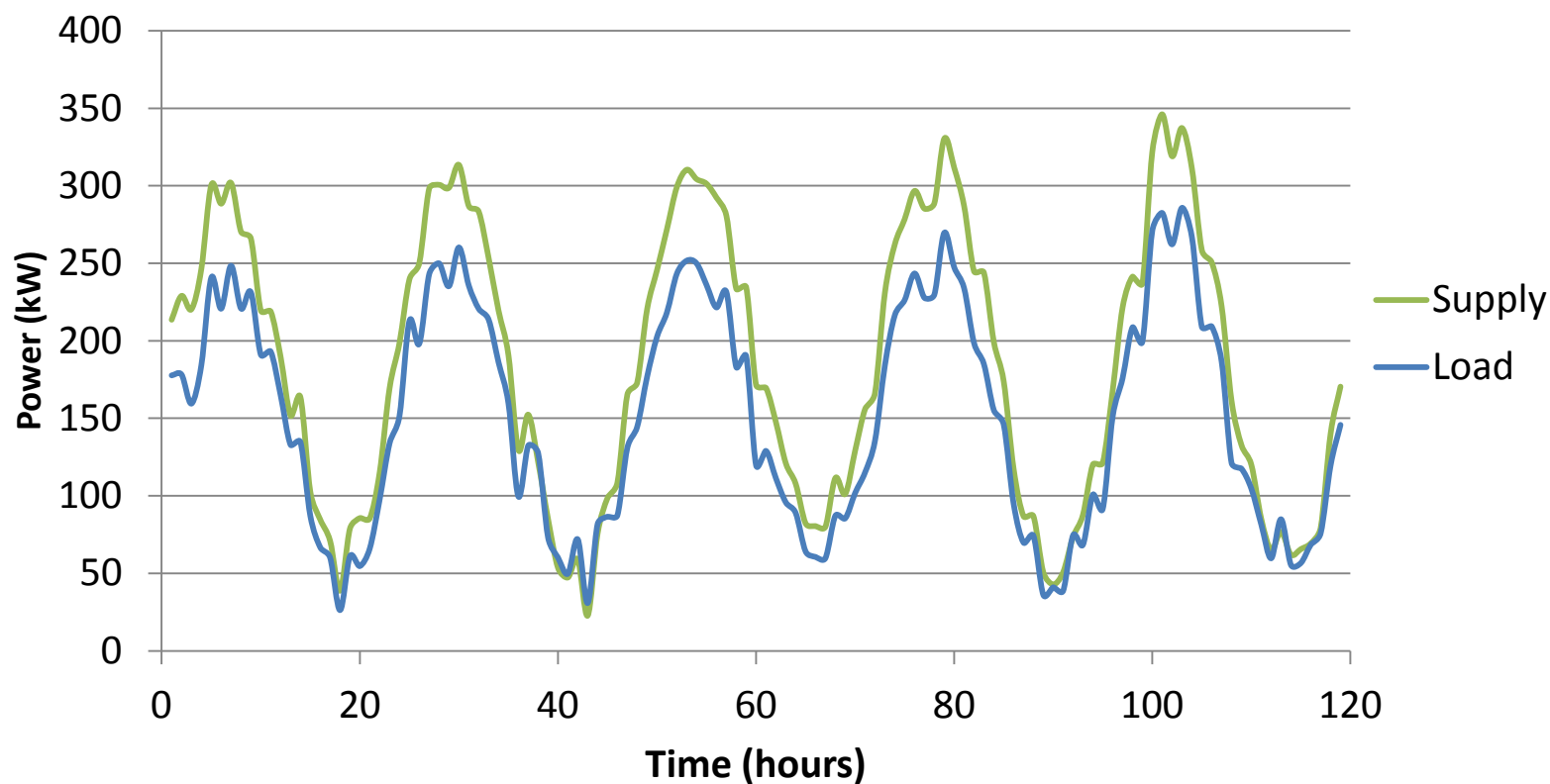
$$S(t_i) = (1 + \phi) \left(150 + 100 \sin\left(\frac{2\pi t}{24}\right) \right) + 50(0.0345\omega_{i-1} + 0.1552\omega_{i-2} + 0.2069\omega_{i-3} + 0.2586\omega_{i-4} + 0.3448\omega_i)$$

$$S(t_i) = (\delta + 150 + 100 \sin\left(\frac{2\pi t}{24}\right) + 50(0.0345\omega_{i-1} + 0.1552\omega_{i-2} + 0.2069\omega_{i-3} + 0.2586\omega_{i-4} + 0.3448\omega_i)$$

- The white noise terms ω_i and ε_i are highly (but not perfectly) correlated because we never have a perfect model of the load.
- The first approach **multiplies the load model by a factor** while the second **adds a fixed excess capacity**.
- Our preliminary results show that the **second approach is better**.

***Auto-Regressive**

Realization of Load and Sources



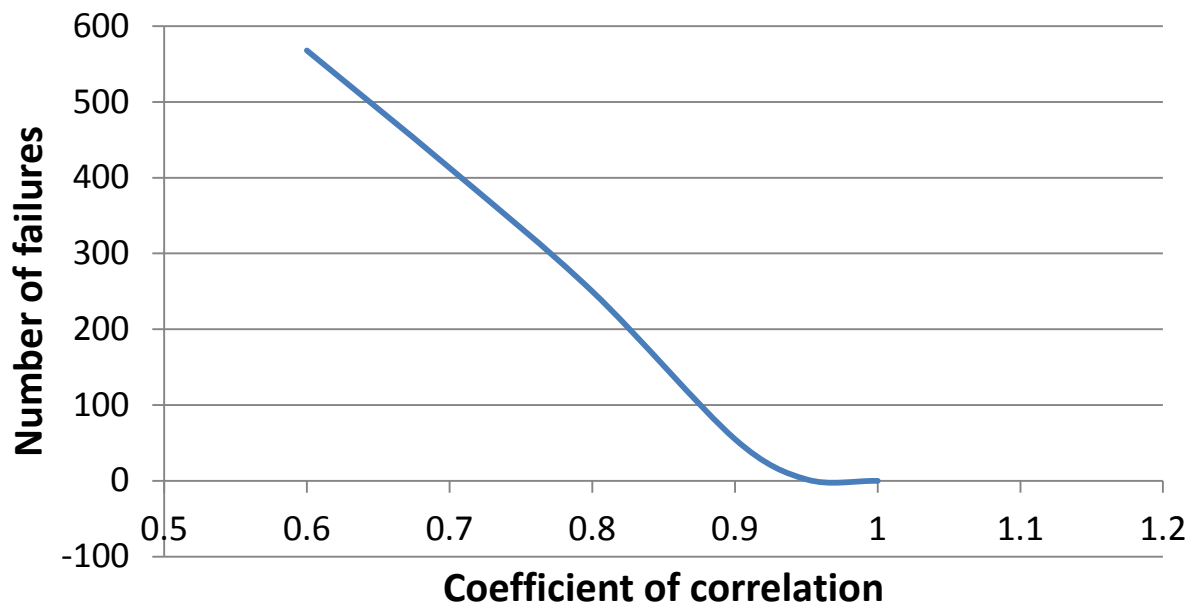
Comparison of Strategies

- We assume that the electricity price is 10 cents per KWh.
- Realizations of the microgrid load and supply random processes are generated for 8760 hours.
- For comparison purposes, we fixed the number of failures.
- Strategy 1 generates 328,695.3 kWh of excess energy over the course of the year. This amounts to \$32,869.53 in money spent for insurance against chance failures.
- Strategy 2 with an excess power of 20kW generates only 176,917.5 kWh of extra energy, which amounts to \$17,691.75.

Comparison of Strategies

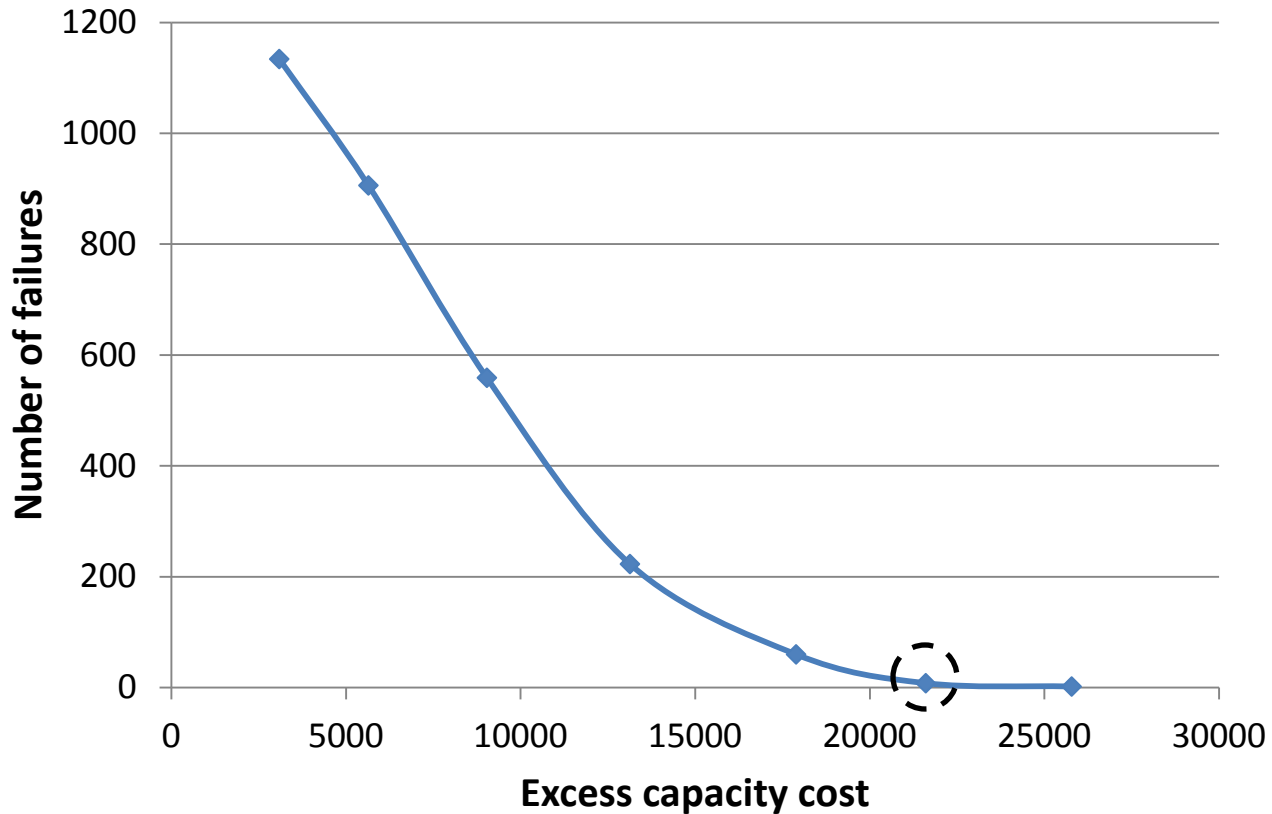
- As a result, we use Strategy 2 for further analysis.
- Building extra supply capacity as a percentage of load is wasteful because when the load is high, there is less likelihood of it increasing substantially anymore while the opposite is true when the load is low.
- Strategy 2 also gives provides an easier way to predict cost.
- We also propose that one should only look at the cost incurred in providing excess power as the **microgrid running cost**.

Sensitivity To The Correlation Between Load and Source



- The failures fall to zero when the supply is perfectly correlated with the load.
 - Good modeling of the load and responding with a supply that will meet that load quickly are essential.
 - Cost does not decrease much if correlation increases.

Pareto Front over Cost and Number of Failures



Design Details

- If the decision maker selects the design shown:
 - Strategy 2 to provide excess supply
 - Cost = \$21,602 in excess power
 - Number of failures = 8
 - $\delta = 25$ kW
 - MFFP = 97.4 hours
 - Correlation $\rho = 0.9$.

Conclusions

- An optimal microgrid architecture can be obtained, considering performance, reliability and lifecycle cost.
- The overall system must be treated as a **repairable system**
- This work proposes a **flexible approach** to microgrid design that **"learns"** from its behavior (loads and sources) and responds accordingly. This approach allows for significant reduction in computational effort.
- Our results showed the proper modeling of load is critical, so is responding with a **highly correlated supply**.
- Two strategies were compared, our results showed that to account for variability in load, one should respond with a supply that is **fixed kW above** the expected load.
- Other scenarios were also investigated such as: effect of correlation between load and source, as well as tradeoff between the attributes of cost and number of failures (Pareto front).

Thanks for your
attention

Q & A