On Using Storage and Genset for Mitigating Power Grid Failures

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Outline

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Power outages

- Developing countries:
  * Large demand-supply gap
  * Two-to-four hours daily outage is common[1]

[1] Tongia et al., India Power Supply Position 2010. Centre for Study of Science, Technology, and Policy CSTEP, Aug 2010

Power outages

- Developing countries:
  - * Large demand-supply gap
  - * Two-to-four hours daily outage is common[1]
- Developed countries:
  - * Storms, lightning strikes, equipment failures
  - * Eg. Sandy

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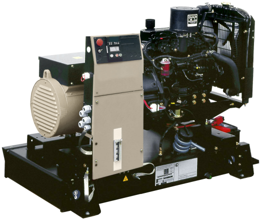
Diesel generator

- A residential neighbourhood augments grid power
- Usually from a diesel generator (genset)



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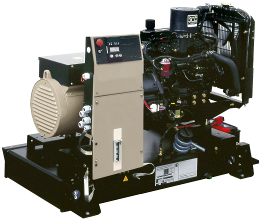

- High carbon footprint!

Storage battery

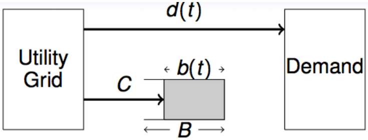

Figure: Grid available

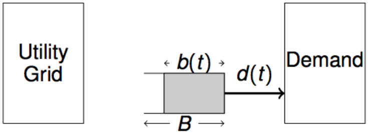

Figure: Power outage

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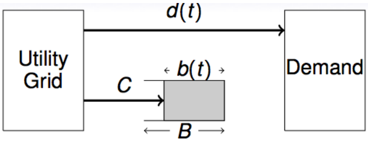

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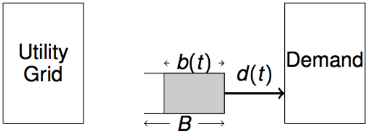
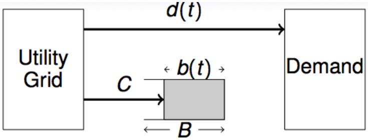


Figure: Power outage

- What if the battery goes empty during an outage?

Storage battery



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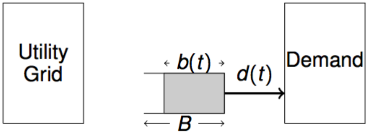

Figure: Power outage

- What if the battery goes empty during an outage?
- Storage is expensive!

Battery-genset hybrid system

- Use battery to meet demand
- If battery goes empty, turn on genset
- Both benefits

Goals

We wish to study:

(a) Minimum battery size to eliminate the use of genset

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(c) Scheduling power between battery and genset

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Factors

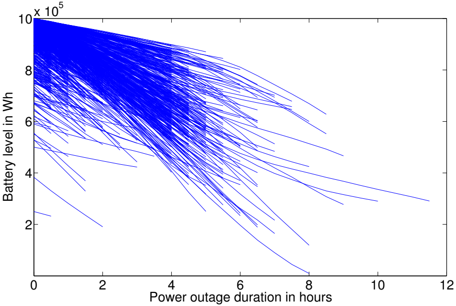

Figure: Battery trajectories

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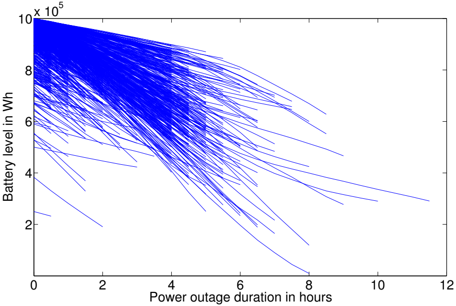

Figure: Battery trajectories

- Battery size
- Charging rate
- Demand during outage
- Outage duration
- Inter-outage duration

Related Work

- Mostly empirical
  * Both sizing and scheduling

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Related Work

- Mostly empirical
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- Analytical work usually assumes stationarity of demand
- No analytical work on battery sizing vs carbon trade-off
- Wang et al.[2] do battery sizing for renewables – do not model grid unreliability

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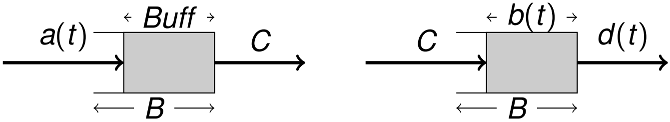
Name	*Description*
B	Battery storage capacity
C	Battery charging rate
$x(t)$	Grid availability 0 or 1
$d(t)$	Power demand
$b(t)$	Battery state of charge
$b^d(t)$	Battery deficit charge $= B - b(t)$
$l(t)$	Amount of loss of power

Background

- Analogy between loss of packet and loss of power[3]



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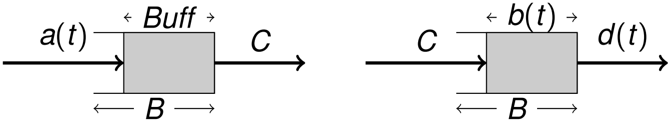

$$\Pr\{b(t) \leq 0\} = \Pr\{b^d(t) \geq B\}$$
$$= \Pr\{Buffer \geq B\} = \Pr\{l(t) > 0\}$$

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- Markov model
    - * Most results assume stationarity
- Network calculus
    - * Worst case analysis
- **Stochastic network calculus**

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  * Model human heights

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  * Model human heights
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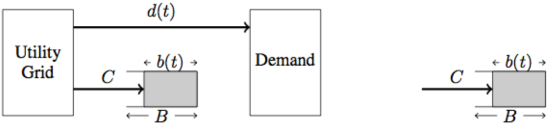
    $\Pr\{\text{height} > 6ft + \sigma\} \leq (1 - p_0)e^{-\lambda\sigma} = \varepsilon_g(\sigma)$
- Interested in modeling cumulative demand
  * Statistical sample path envelope

$$\Pr\left\{\sup_{s\leq t}\{A(s,t) - \mathcal{G}(t-s)\} > \sigma\right\} \leq \varepsilon_g(\sigma)$$

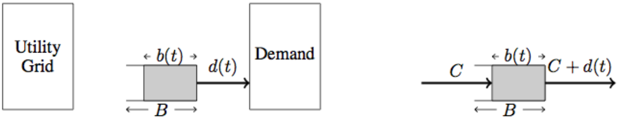
Outline

Modeling

- Transformation and effective demand



(a) Grid available



(b) Power Outage

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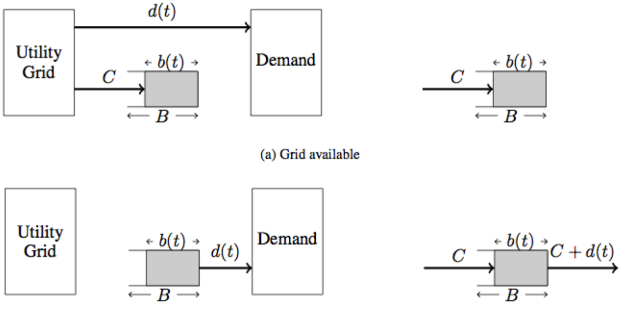

(a) Grid available

(b) Power Outage

$$d^e(t) = [d(t) + C](1 - x(t))$$
$$= [d(t) + C]x^c(t)$$

Sizing in absence of genset

Using an amendment of Wang et al.[4]

$$\Pr\{I(t) > 0\} \leq \min\left(\Pr\{x^c(t) > 0\}, \varepsilon_g\left(B - \sup_{\tau \geq 0}(\mathcal{G}(\tau) - C\tau)\right)\right)$$

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- Goal is to size battery such that probability of loss of power is at most ϵ^*,

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- Goal is to size battery such that probability of loss of power is at most ϵ^*, thus

$$\min\left(Pr\{x^c(t) > 0\}, \varepsilon_g\left(B - \sup_{\tau \geq 0}(\mathcal{G}(\tau) - C\tau)\right)\right) \leq \epsilon^*$$

$$\implies B \geq \left(\sup_{\tau \geq 0}(\mathcal{G}(\tau) - C\tau) + \varepsilon_g{}^{-1}(\epsilon^*)\right) I_{(\Pr\{x^c(t)=1\} > \epsilon^*)}$$

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Sizing in presence of genset

- Reduce carbon footprint
- For large gensets

$$\text{carbon emission} \sim \sum_t l(t)$$

- Scheduling becomes trivial (we'll come back later)

Sizing in presence of genset (contd.)

- Goal is to estimate expected total loss (carbon emission)

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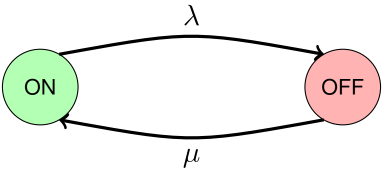
- Goal is to estimate expected total loss (carbon emission)
- Under some assumptions:

$$E\left[\sum_{t=1}^{T} l(t)\right] \approx \min\Bigg(\sum_{t=1}^{T} E\left[d(t)x^c(t)\right],$$

$$\Pr\{\max\left([D^e(s,t) - C(t-s) - B]_+\right) > 0\}.\sum_{t=1}^{T} E[d(t)]\Bigg)$$

Data set

- 4500 Irish homes
- Randomly selected 100 homes
- Two-state on-off Markov model for outage



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Use data set to compute 'best' parameters:

- Envelope $\mathcal{G} = \sigma + \rho t$

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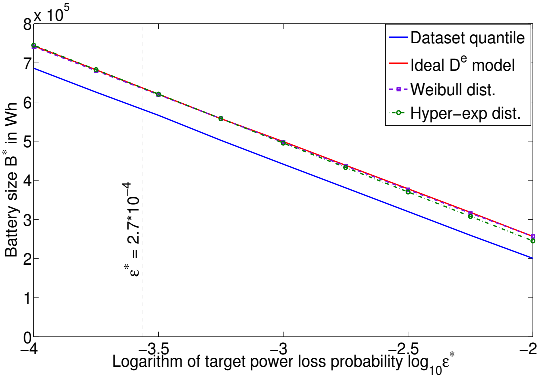
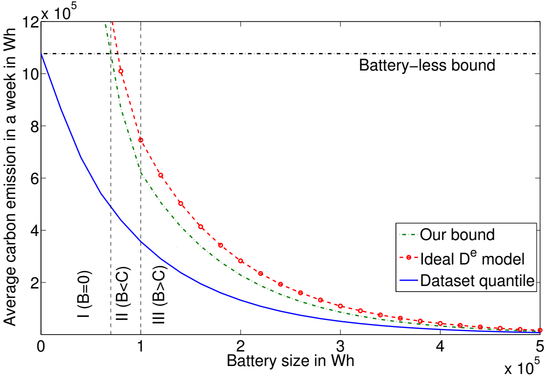
Results (absence of genset)



Results (presence of genset)



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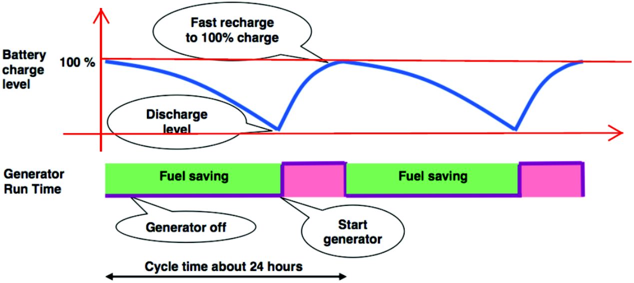
- Storage battery can help!



Problems

(a) Given a genset size, how to size battery and schedule power?

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We talk only about the former in this presentation

Battery usage

Theorem: Problem same as minimizing genset operation time

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Theorem: Problem same as minimizing genset operation time

- Offline optimal given by a mixed IP
- General offline problem NP-hard
- Online *Alternate scheduling*
- Competitive ratio

$$\frac{k_1 \frac{G}{C} + k_2}{k_1 + k_2}$$

Savings

- Before:

$$k_1 GT + k_2 \sum_{t=1}^{T} d(t)$$

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- After (under some assumptions):

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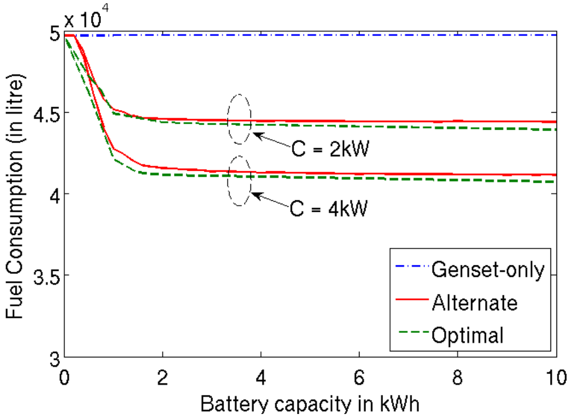
Beyond a small value, independent of battery size!

Result


x 10^4
5
4.5
4
3.5
3
0
2
4
6
8
10
Fuel Consumption (in litre)
Battery capacity in kWh
C = 2kW
C = 4kW
Genset-only
Alternate
Optimal

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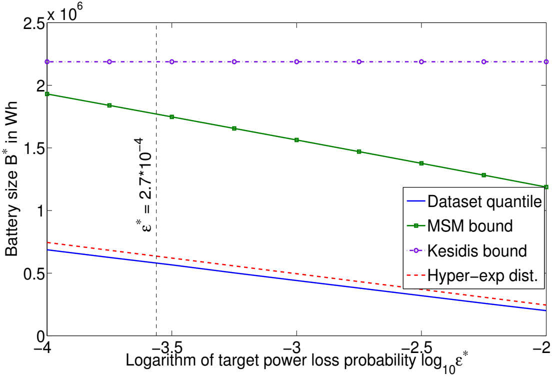
- Storage battery expensive
  - Reduce the size
- Minimum battery size required to avoid genset
- Trade-off between battery size and genset carbon footprint
- Power scheduling to improve genset efficiency

Limitations & Future Work

- Past predicts future
- Battery model: size and charging rate independent
- Lack of data from developing countries
- Technical assumptions

Appendix

Results (absence of genset)



Three modes

Three modes of battery-genset hybrid system operation:

1. Demand met by battery only
2. Demand met by genset only
3. Demand simultaneously met by battery and genset