Paper #??

A Framework to Quantify Resilience Built from the Customer Perspective

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Motivation

- Why we need to measure resilience
  - Need to align investment with desired results
  - Need to weigh alternatives
  - Need to measure performance
- Do not want to build parallel infrastructure to measure resilience
  - Use existing parameters
  - Minimize gap to familiarity
- Build up from individual cases to demonstrate applicability

Motivation

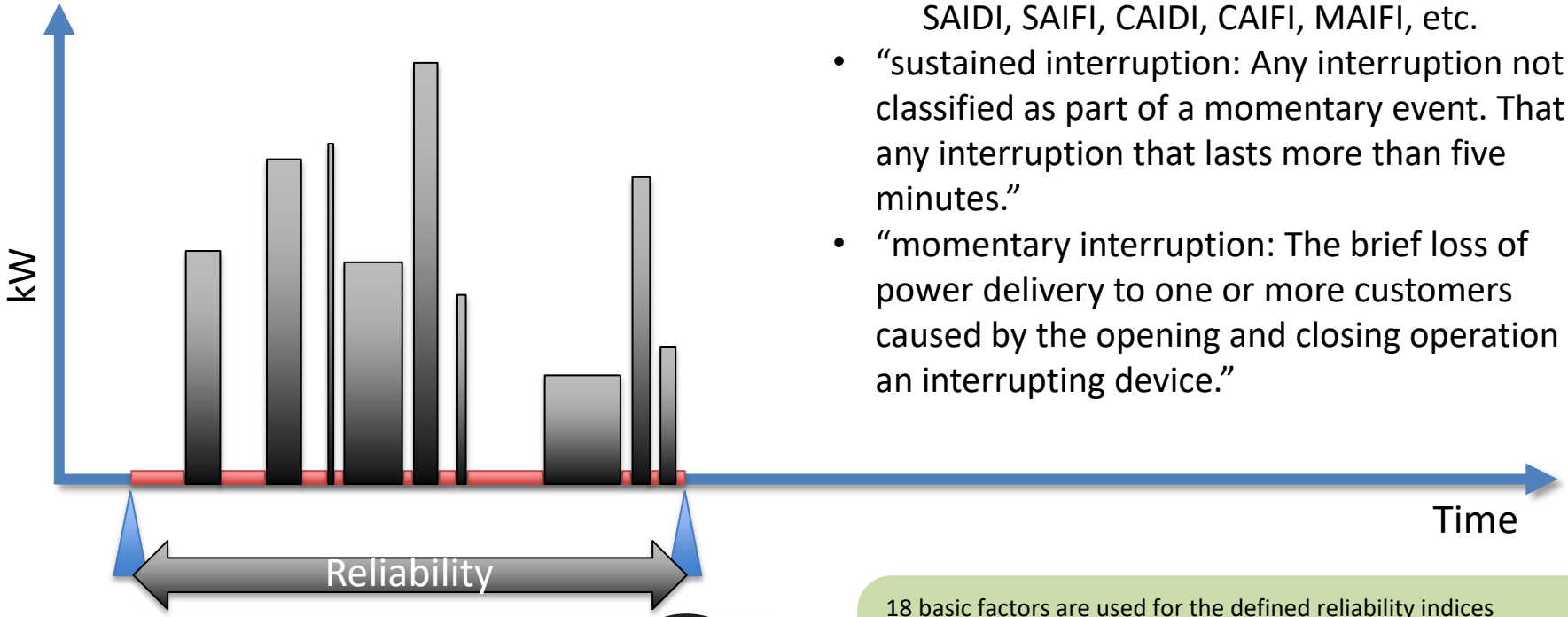
- Reliability metrics permit investment
  - Shorten interruption time vs $ to shorten interruption time
  - Fewer interruptions vs $ for fewer interruptions

- Reliability measures may or may not improve resilience
  - Was it there when I asked for it? (reliable)

    vs
  - Do I care if it is missing for x minutes? (resilient)

- Of note
  - If a service only has one type of source, the service is not very resilient against the loss of that source, regardless of how reliable the source may be
  - If a service has two sources, they are more resilient vs loss of one of them if both are available to meet the need. Both sources also have a reliability measure.

IEEE 1366-2012 Reliability Indices



SAIDI, SAIFI, CAIDI, CAIFI, MAIFI, etc.

- "sustained interruption: Any interruption not classified as part of a momentary event. That is, any interruption that lasts more than five minutes."
- "momentary interruption: The brief loss of power delivery to one or more customers caused by the opening and closing operation of an interrupting device."

18 basic factors are used for the defined reliability indices
- Only two are related to the physical properties of the system
  - Li, connected kVA load interrupted for each interruption event
  - LT, total connected kVA load served
- The rest are related to a count or time

IEEE IAS IEEE INDUSTRY APPLICATIONS SOCIETY IEEE PES Power & Energy Society® pels IEEE POWER

Resilience

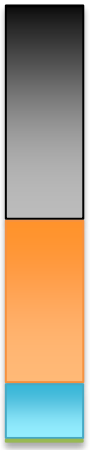
A perfectly resilient system can provide power 100% of the time it is wanted

- An individual's power resilience is defined by their ability to meet all of their power requirements at all times
  - For some, the appropriate level of resilience may be to rely entirely on plain old electric utility service (POEUS)
  - For others, adding other sources such as backup generation or uninterruptable power supplies (UPS) could be justifiable to add an additional layer of resilience against power disruption from potential utility outages

Resilience is measured at all times, not just during an incident

Resilience

- If I lose something, I can still function up to my [non/adjusted] need for some amount of time.
  - I need 4 kW, I have 4 kW
    - "need" is ∞ kWh = 4 + 4 + 4 + 4 …
  - I lose that 4 kW, but I find a different 3 kW for 2 hours
    - "need" is 6 kWh, adjusted demand
  - I lose that 3 kW, but I find a different 1 kW for 5 hours
    - "need" is 5 kWh, adjusted demand
  - I lose that 1 kW, but I find a different 12 W for 30 minutes
    - "need" is 0.006 kWh, adjusted demand



- Demand diminished as need adjusts - max demand is 3 kW
- Energy "need" is 11.006 kWh w/o POEUS
  - 2.75 hours at unadjusted need
  - 7.5 hours at adjusting need, could be longer

Resilience

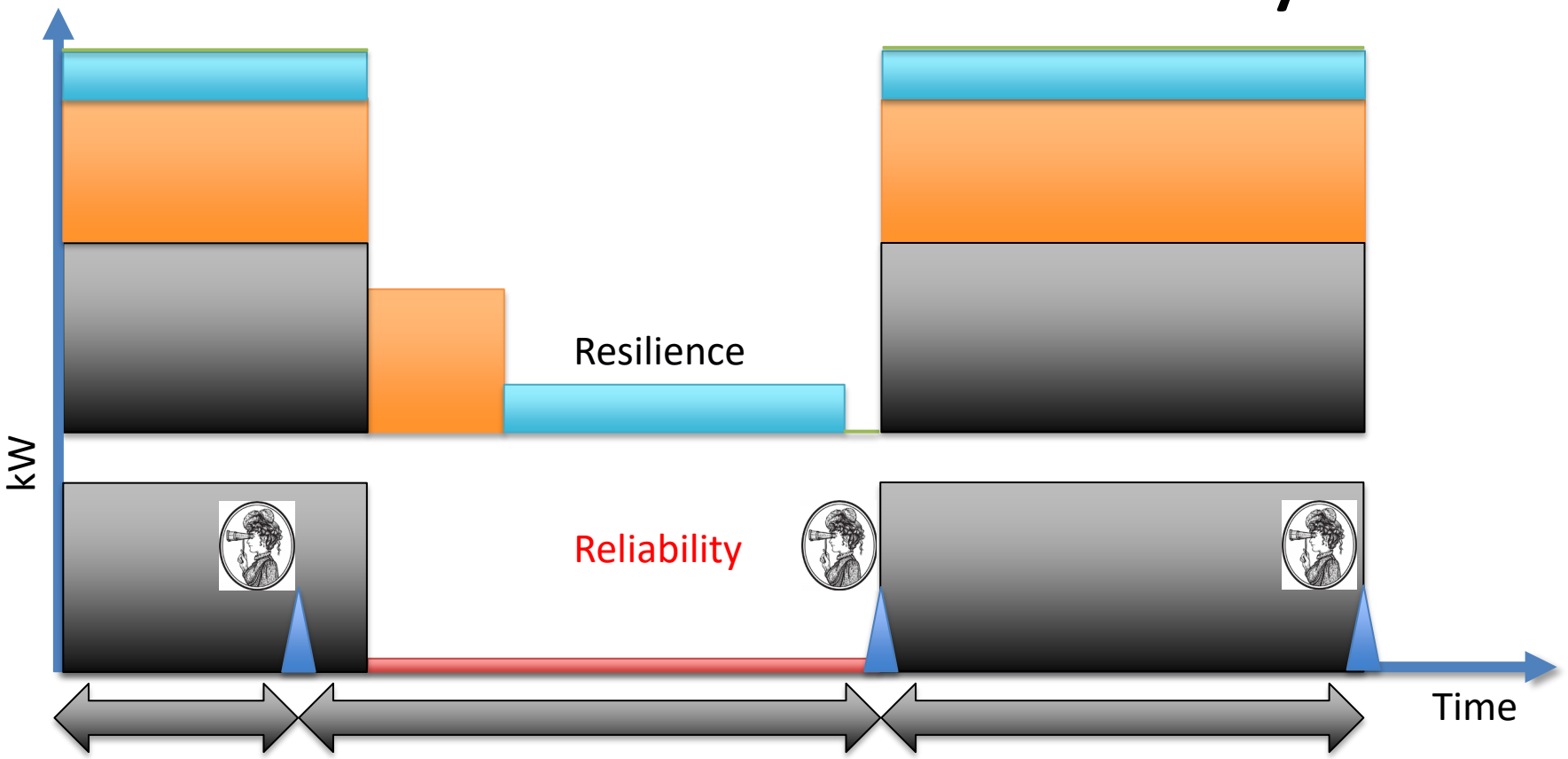
- I need 4 kW, I have 4 kW (POEUS)
- I lose that 4 kW, but I find a different 3 kW for 2 hours (Solar PV)
- I lose that 3 kW, but I find a different 1 kW for 5 hours (BESS)
- I lose that 1 kW, but I find a different 12W for 30 minutes (Battery)

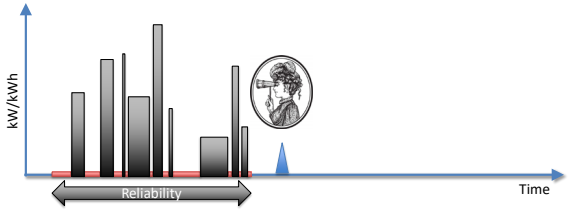
- If I adjust my “need” at each loss, this makes my resilience dynamic. If I insisted on “needing” 4 kW, my resilience for that amount decreases.

- If I “needed” the kW and it was not available, it was unreliable…

POEUS - Plain Old Electric Utility Service
PV - Photovoltaic
BESS - Battery Energy Storage System

Resilience and Reliability





Building a Metric

$$Resilience_{Individual}\,(Time) = \frac{P_{Potential} - P_{Excess}}{P_{Need}}$$

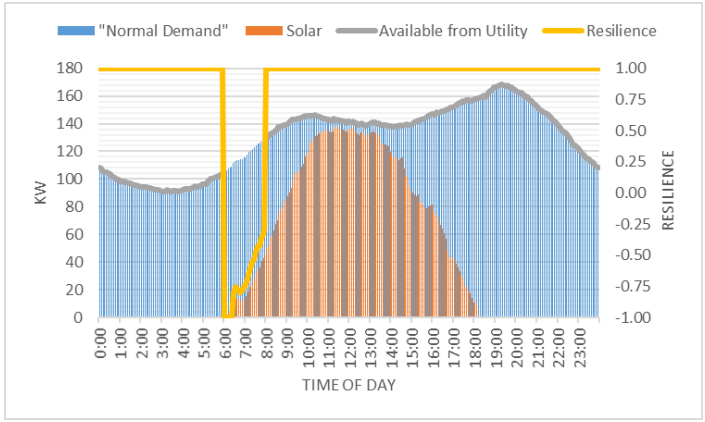
- *PPotential* is the potential power provided by resources at the given time.
  - Resources may be located on the individual's site, or otherwise available through the power system.
- *PExcess* is the excess power available, but not needed at that time by the individual
- *PNeed* is the amount of power needed by the individual at the given time.

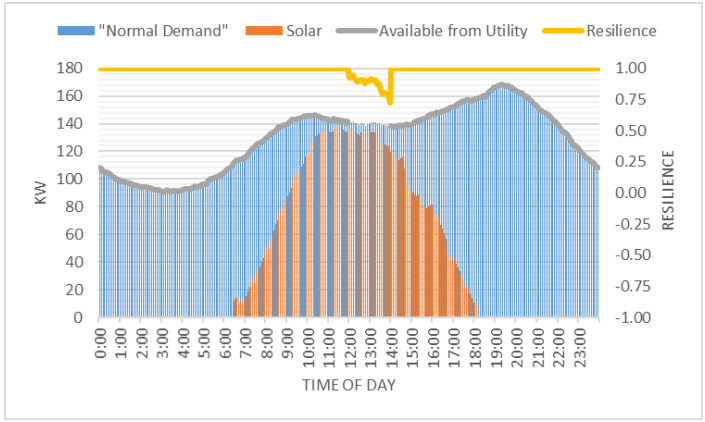
$$Resilience_{Grid}\,(Time) = \frac{\sum_1^n \frac{P_{Potential} - P_{Excess}}{P_{Need}}}{n}$$

Take the sum of each individual's resilience in a given system to come up with a grid resilience metric for *n* individuals

Applying a Metric *Individual, Time of Day*

- A negative resilience measure means that power needs (“Normal Demand”) were not fulfilled.
- A resilience measure of zero would indicate zero power requirements (“Normal Demand”) at that time.
- Outages at different times of the day have a different impact on Resilience





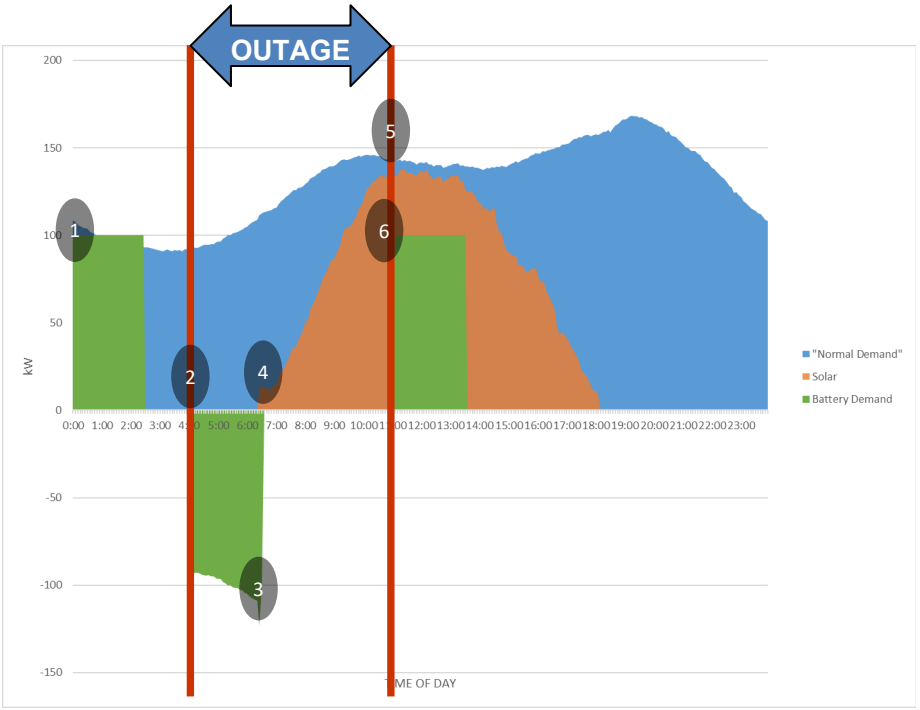
0.8595 Resilience for day 0.9895

$$Resilience_{Individual}\,(Time) = \frac{P_{Potential} - P_{Excess}}{P_{Need}}$$

Applying a Metric *Individual, Storage*

Outage from 4:00-11:00

1. Storage charges beginning at midnight
2. Begins discharging to meet load at 4:00
3. Runs out of charge
4. Solar starts to meet need
5. Utility service resumes
6. Battery recharges



$$Resilience_{Individual}\,(Time) = \frac{P_{Potential} - P_{Excess}}{P_{Need}}$$

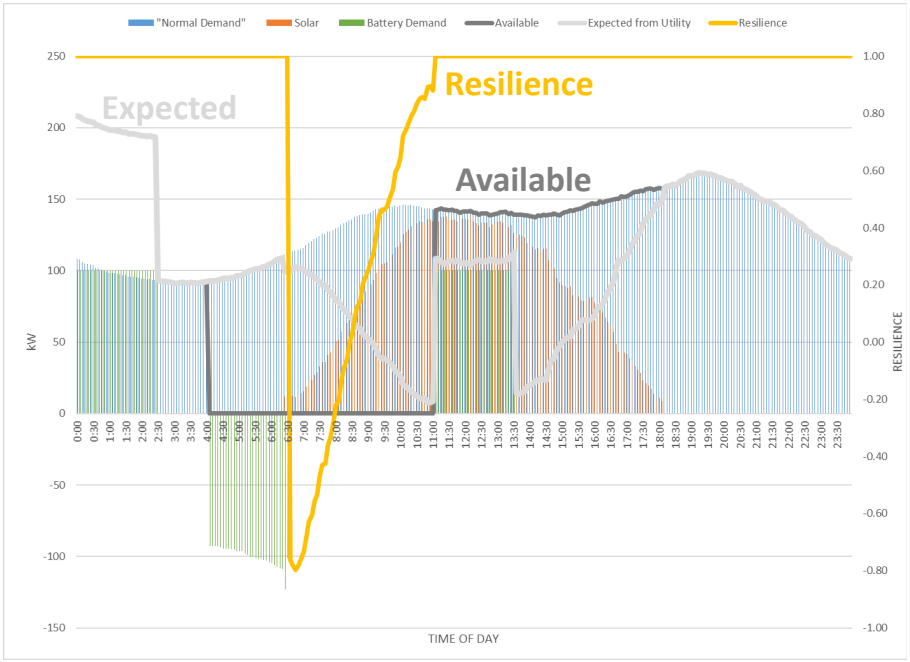
Applying a Metric *Individual, Storage*

Introduces new need:

- Expected from Utility
- Available from Utility
- How differentiated?

Do we really need to plan for a 7-hour outage?

- Planning around a standard outage duration using the reliability calculation for past performance could be a way to simplify system resilience planning
- Resilience during an outage



Resilience for day **0.83**

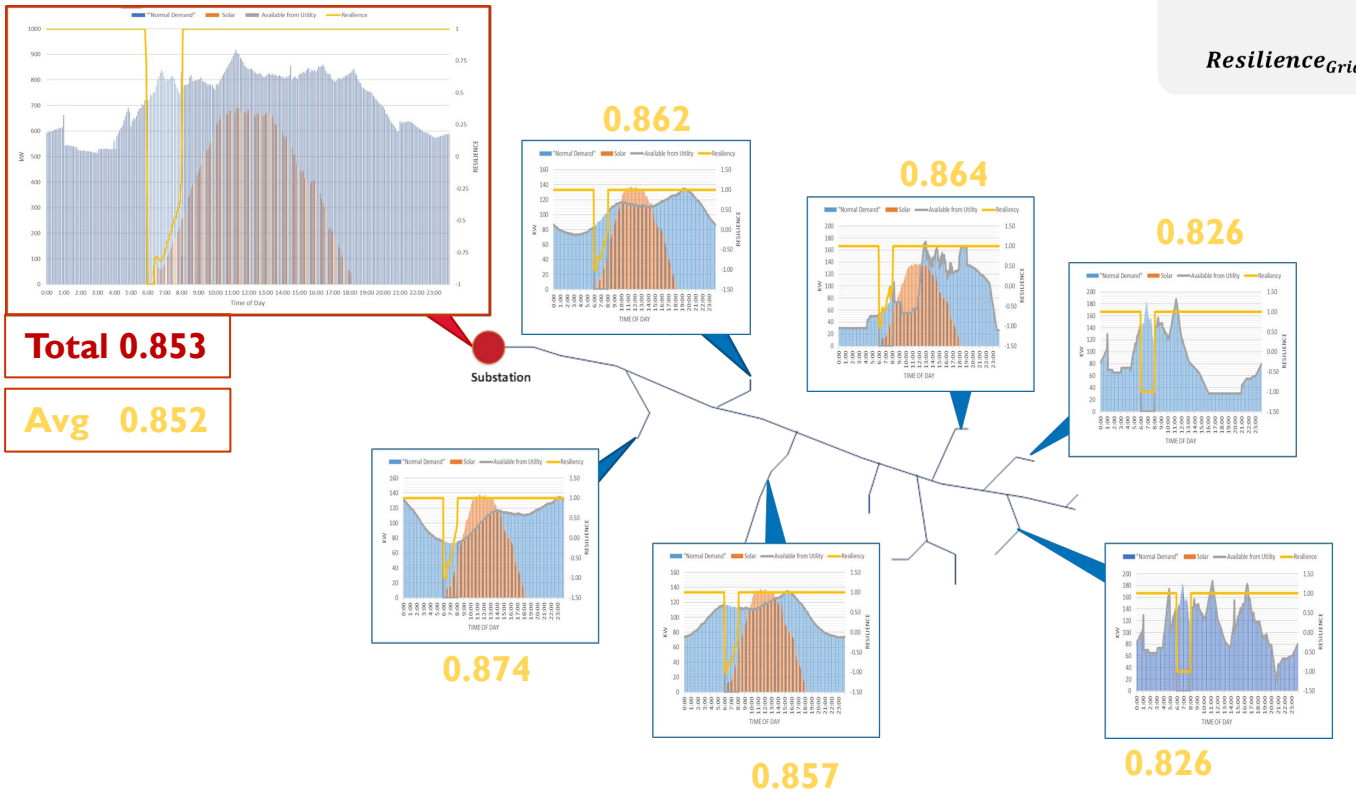
Resilience during 7-hour outage **0.53**

$$Resilience_{Individual}\,(Time) = \frac{P_{Potential} - P_{Excess}}{P_{Need}}$$

Applying a Metric *System Planning*

Two-Hour Outage from 6:00-8:00

$$Resilience_{Grid}\,(Time) = \frac{\sum_1^n \frac{P_{Potential} - P_{Excess}}{P_{Need}}}{n}$$



Applying a Metric *Making Investments*

- Quantifying the value to each customer of each interruption avoided may sound like a hyper-specified application of the Interruption Cost Estimator (ICE) and it very well may be.
- By doing so in a resilience manner, we are able to evaluate the ***ability of the system*** to avoid the outage, rather than the ***performance of the system*** in avoiding or minimizing an outage.

https://icecalculator.com/documentation

Next Steps

- Circulate, workshop, & test framework under a variety of circumstances
  - Including infrastructure variability
- Refine operational time across a planning horizon methodology
- Incorporate critical loads analysis
- Make a publicly available tool that allows users to consider their resilience strategies