A SUNNY RESILIENT ENERGY FUTURE

PRESENTED BY
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SAND2018-11263
“Early morning shot of Hurricane #Joaquin from @space_station before reaching #Bahamas. Hope all is safe. #YearInSpace” Scott Kelly, 10/2/2015.
PV deployment has come a long way…

…but none of these systems work during a grid outage!
We are here, and solar is ready to play major role.

Flexible demand and storage enable a solar powered future.

PV Eras

1. Birkenstock Era
2. Chicken Little Era
3. Essential Reliability Era
4. Mudskipper Era
5. Super Inverter Era
6. Grand Bargain Era

We are here, and solar is ready to play major role.
RELIABILITY 99.97%

What would it cost add another “9” of reliability?
Reliability focuses on average system performance, skips large-scale events, and does not consider consequences…
Large-scale events becoming more frequent…
Large-scale events becoming more frequent...
“You don’t really know better until you do better.”

Existing grid planning framework does not effectively deal with high-consequence events, even if those that are likely!
Resilience can be considered an extension of Reliability…

- Includes Reliability concepts, but also **low probability, high consequence** events.
- Not widely adopted for grid infrastructure investment. Need new **methods, metrics and tools**
- Focuses on system performance with respect to **commonly expected events** (component failure, etc.)
- **Widely adopted** for infrastructure investment decision-making.
Defining Resilience

Ability to **Prepare for, Withstand** and **Recover from** disruptions caused by major **Accidents**, **Attacks**, or **Natural Disasters**.

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What problem are we trying to solve?

- Improve resilience of the whole grid
- Improve resilience of infrastructure that supports critical services at selected locations
A consequence-based view of Resilience

<table>
<thead>
<tr>
<th>Measure</th>
<th>Examples of Resilience Metrics</th>
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<tbody>
<tr>
<td><strong>Economics</strong></td>
<td>Gross Municipal Product / Net Economic Losses</td>
</tr>
<tr>
<td></td>
<td>Change in Capital Wealth</td>
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<td>Business Interruption Costs</td>
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<tr>
<td><strong>People and Community</strong></td>
<td>Number of People Without Basic Services</td>
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<td></td>
<td>Lives at Risk</td>
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<td>Societal Burden to Acquire Services</td>
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</tbody>
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Image Credit: REUTERS / S. Stapleton
A Resilience Planning Framework

1. Evaluate Resilience Investments
2. Identify shocks and key infrastructures
3. Quantify consequences (resilience metrics)
4. Select Assessment Method and Data Collection
5. Analyze physical system performance

Stakeholder Engagement
Resilience Analysis using Economic and Community Metrics

Norfolk, VA

San Juan, PR

<table>
<thead>
<tr>
<th></th>
<th>100yr+0ft</th>
<th>100yr+1.5ft</th>
<th>100yr+3.0ft</th>
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<tbody>
<tr>
<td>Annual Direct Losses</td>
<td>$135 M</td>
<td>$182 M</td>
<td>$231 M</td>
</tr>
<tr>
<td>Annual Indirect Losses</td>
<td>$219 M</td>
<td>$296 M</td>
<td>$375 M</td>
</tr>
<tr>
<td>Total</td>
<td>$354 M</td>
<td>$478 M</td>
<td>$606 M</td>
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Total burden to acquire food for a random 34-microgrid portfolio

\[ H_c = \text{f} \quad \text{EE} \]

Social Burden
Social Burden

Each of these is a portfolio of candidate microgrids.
**Energy Resilience – A Case for PV**

- Rugged, dependable
- Modular, scalable, portable
- Fuel available onsite, everywhere
- **And** generates value all the time!

*As part of a grid-tied microgrid with storage and/or other fuel, depending on the application.*
Hybrid microgrid supporting USArmy’s Ft Carson in Colorado Springs, CO
Large hybrid microgrid supporting rail and ferry transportation in Newark, NJ (under development)
PV + Storage Microgrid supporting community resilience in Rutland, VT

Image Credit: Green Mountain Power
PV + Storage Microgrid for a water treatment facility in Cardwell, NJ

Image Credit: Eos Energy Storage
Necessary Institutional and Technical Considerations

- Resilience-based planning methods
- Advanced power electronics: Grid-tied grid-forming inverters
- New regulatory & business models
- Advanced grid architectures: Dynamic, Networked microgrids
- Proactive codes and standards
- Resilience by Design: Built-in Physical and Cyber Security
What problem would we solve with a large fleet of PV-based resilient microgrids?

- Improve resilience of the whole grid
- Improve resilience of infrastructure that supports critical services at selected locations

Bonus: access to a vastly larger market for solar!
Closing Argument

- Planning for resilience is an imperative
- Need practical methods, models, tools
- Solar can and must play a key role
- Time to think really big:

  Solar can indeed enable a sunny and resilient energy future!