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OBSERVATIONS OF PV SYSTEMS POST-HURRICANE

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Background

Like many remote islands the USVI is dependent on fossil fuel for the generation of electricity.

In 2010, the USVI established a goal to reduce fossil fuel-based energy use by 60% (based on a 2008 baseline) by 2025.

As a result, VIWAPA has been improving energy efficiency and diversifying energy resources: wind, solar, natural gas.

Photo source: www.seaglassvi.com/islands/us-virgin-islands/st-thomas/

Background

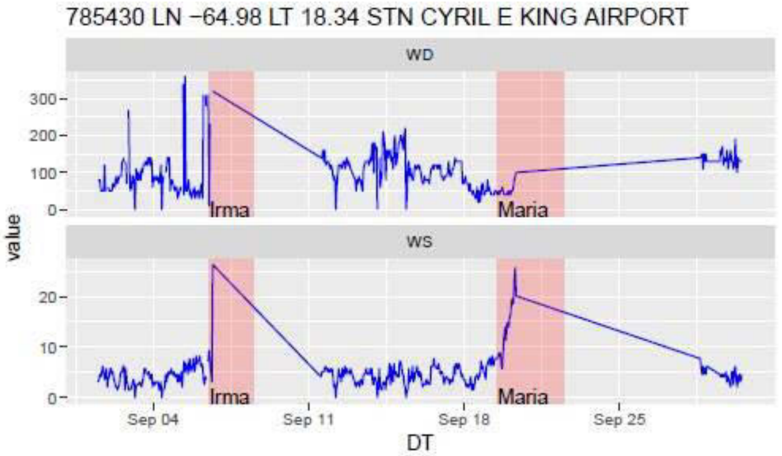
- Two Category 5 storms, Hurricanes Irma and Maria, damaged Saint Croix, Saint John, and Saint Thomas among other smaller islands.
    - Hurricane Irma hit the USVI on September 6 with the eye passing over St. Thomas and St. John.
    - On September 20th, the eye of Hurricane Maria swept near St. Croix with maximum winds of 175 mph.
- Estimated damages ~$7.5 billion. Generation fared well, but ~ 80-90% of the power transmission and distribution systems in the USVI were damaged.
- November 2017 estimates were in the range of $850 million in hurricane recovery funding to help “rebuild a more resilient electrical system.”

Statistics source: Congressional Research Service, https://fas.org/sgp/crs/row/R45105.pdf
Right photo sources: Eliza Hotchkiss, NREL
Structures on St Thomas December 2017

Background

- Wind speeds, direction and duration impact the performance of a PV array
  - Limited data due to weather stations and anemometers going offline

- Why did PV systems fail?
  - Was it poor workmanship or poor materials?
  - Was it a matter of needing to design differently?
  - Can systems be designed to resist 200 mph winds?
  - What are the costs of resilience improvements and are they worth it?



PV System Observations

St Thomas

- The PV installed at the airport (~385kW) along the runway only had a few panels damaged
- The Donoe array (~4MW) was significantly damaged
- Ron De Lugo rooftop and carport with various damages

St Croix

- Spanish Town array (~4MW) had about 17 panels damaged in Hurricane Maria
- Almeric had a ground mounted system (470kW) that was severely damaged

  **Designs referred to ASCE 7-10 code and wind speed of 145/165 mph.*

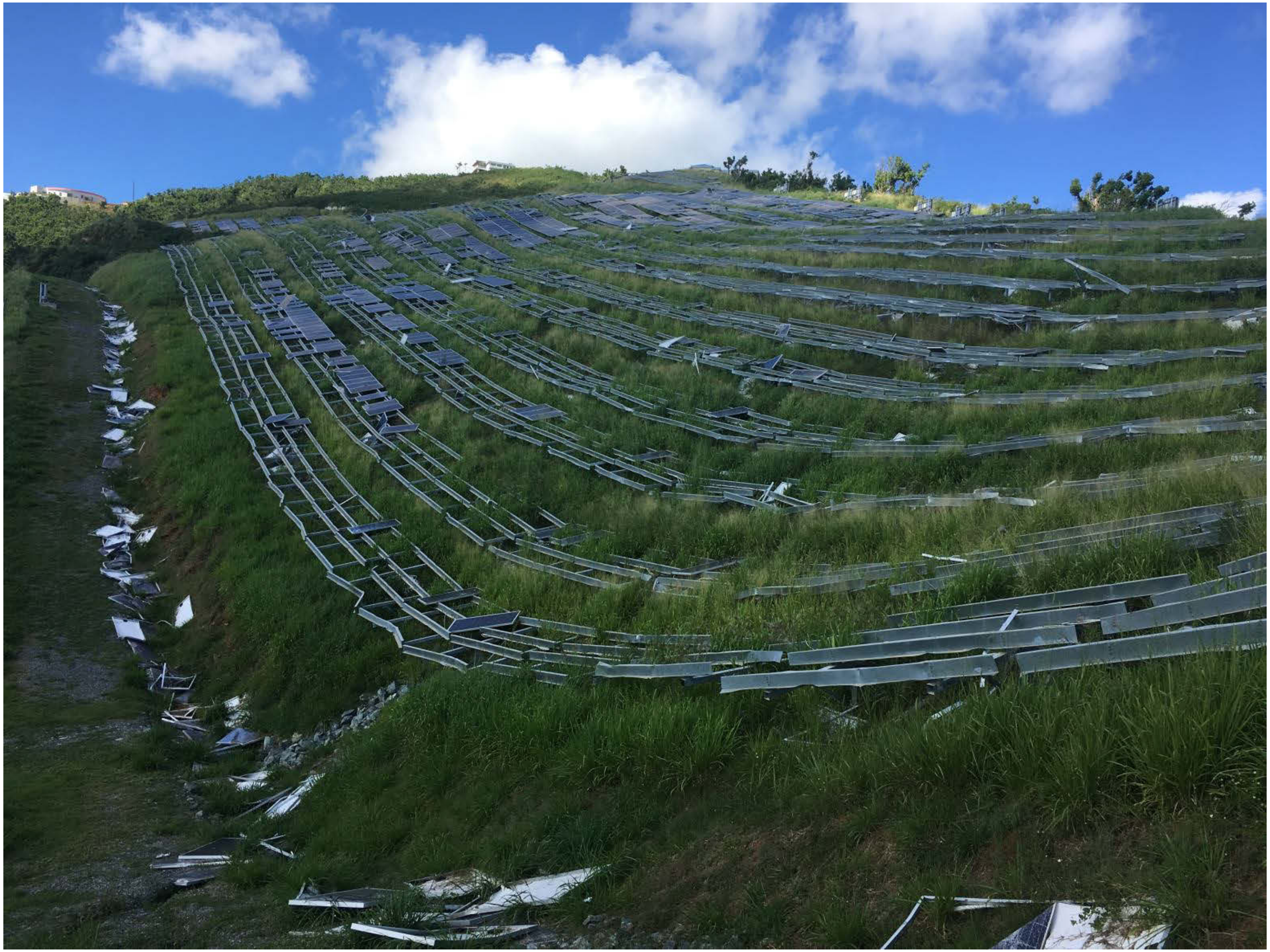
- Rooftop solar on all islands had various survival rates

St Thomas

Dedication of 4.2 MW PV plant in USVI (February, 2015)

Array pre-Irma (DOE photo)

PV Failures



Same plant after Hurricane Irma, December, 2017
Photo credit: Eliza Hotchkiss, NREL

PV Failures

Photo credits: Eliza Hotchkiss, NREL

PV Failures

Photo credits: Eliza Hotchkiss, NREL

Wind Direction and Speeds

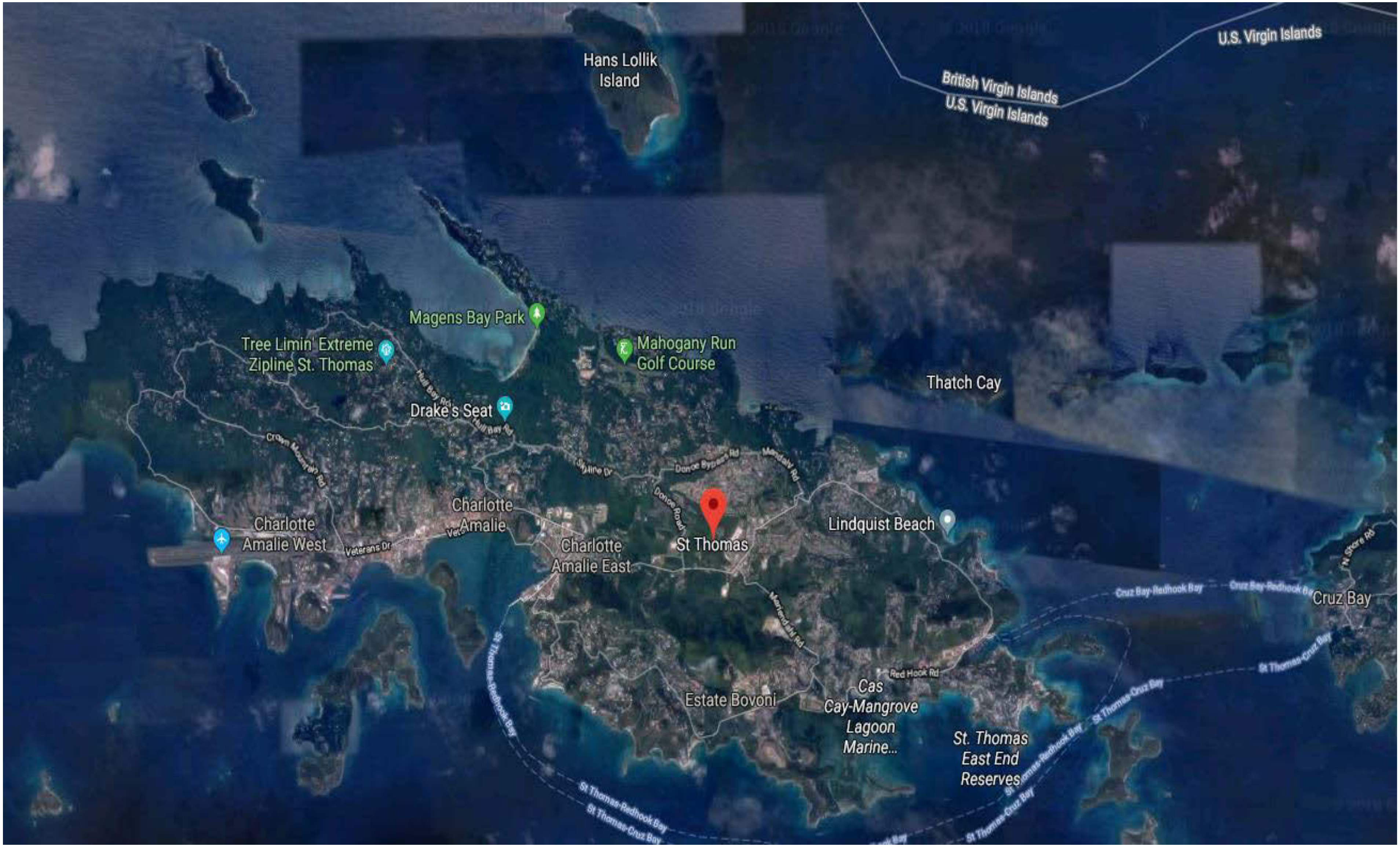
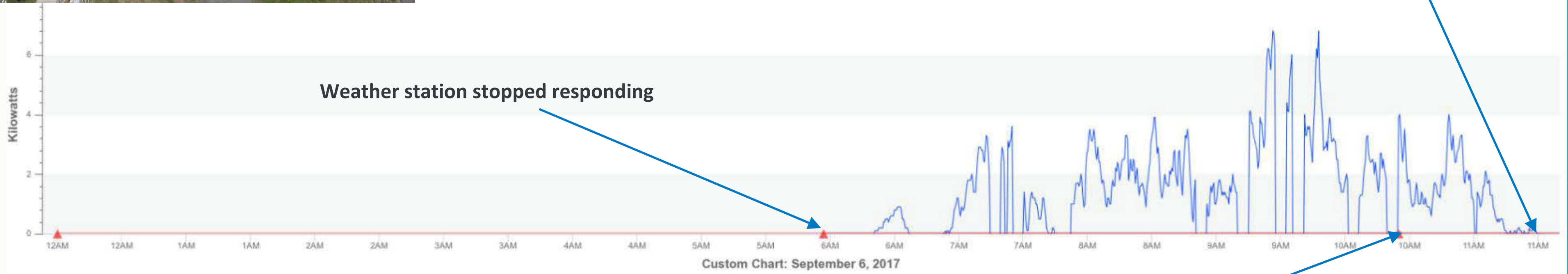


Image Source: Google Maps

St. Thomas Airport PV plant

- Inverter 1 – 135 kW
- Inverter 2 – 250 kW
- Last data received at 11:32am Sept 6, 2017



Data from September 6, 2017, provided by Vahan Gevorgian, NREL

Photo credit: top left, VI Office of Economic Opportunity top right, Eliza Hotchkiss, NREL

Rooftop PV systems

Photo credit: Eliza Hotchkiss, NREL

Roof Mounted PV Arrays

- Roof mounted PV prevalent across USVI
- Wind load criteria is included in ASCE 7-16 (residential and commercial)
- Performance varied greatly
  - Failure mainly due to clips that attach to rails
  - Panels became windborne debris
  - Panels also damaged due to debris (e.g. collapsed antennae)



Photo credits: Left photo (FEMA MAT); Right photos (Andy Walker and Ran Fu, NREL)

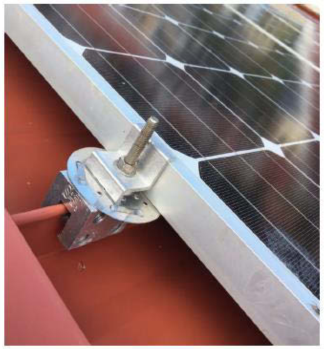
Rooftop PV system

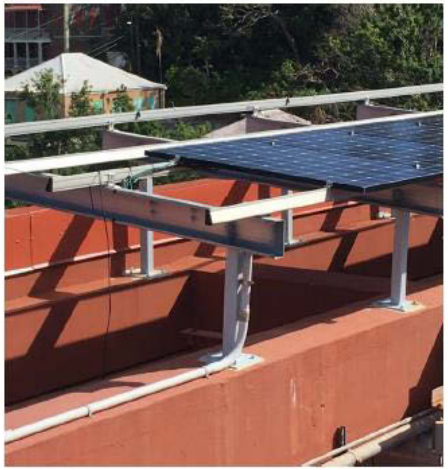
Photo credits: Eliza Hotchkiss, NREL

Mobile PV system

Photo credits: Eliza Hotchkiss, NREL

Lessons Learned: Uplift





Uplift was seen with modules hanging out over parapet walls (e.g. windward side of building during the storm) and modules were totally detached from the rack in the storm.

Recommendation:

- On existing arrays remove front row of modules, avoiding area of wind exposure.
- On new arrays, account for uplift and site panels to avoid overhang

Photo credits: Andy Walker and Ran Fu, NREL

Lessons Learned: Bolts and Torqueing

Bolts were missing from some brackets.

Recommendation:

- Install missing bolts and tighten to torque specifications
- Confirm torque specification during commissioning

Photo credits: Andy Walker and Ran Fu, NREL

Lessons Learned: Clamping

A commonly observed problem was that clamps holding the modules in position did not withstand sustained winds. Several end clamps were found in a bent condition indicating that bending of the end bracket released a module, creating motion/vibration, which then disengaged the next center clamp which held two modules down.

Materials:

- Center clamp was stainless steel, marked 1R HA14, 70 psf, ETL UL
- End clamp was made of aluminum and unmarked

Photo credits: Andy Walker and Ran Fu, NREL

Lessons Learned: Clamping

The clamps shown indicate the main failure (bent clamps) and a contributing factor related to the lateral braces which were held in place by only 2 self-tapping screws instead of four through-bolts. The frame on the right indicates a bolt ripping out of the framing.

Recommendation:

- Consider through-bolting rather than clamping module frames.
- A combination of clamps and through-bolts may be used.
- Use the adequate number of clamps per module, per specifications.

Photo credits: left, Andy Walker and Ran Fu, NREL, right, Eliza Hotchkiss, NREL

Lessons Learned: Electrical

Condition	Number of Strings	Affected Modules
Bad	35	420
Okay	55	660
Total	90	1080

Table. Results of string testing

Recommendation:

- For immediate deployment, move unbroken modules onto rack space where they are contiguous with modules of the same type and can be connected together electrically.
- Use stainless steel cabinets with multiple door attachments rather than single rod closures to prevent water intrusion.

Photo credits: Andy Walker and Ran Fu, NREL

How Can PV Become More Resilient?

We understand systems won't be 100% resilient 100% of the time, however, there may be some low-cost best practices or standards to improve resilience of PV systems:

- Standards and design specifications such as materials used in PV modules and racking systems (qualification testing, UL1703 IEC61215, NEC code)
- Installation verification (torqueing with a torque wrench, assembly, connections, acceptance tests (static and dynamic load tests – 300W panel 2mx1m)
- Maintenance of components (e.g., torqueing pre-hurricane season, electrical testing, etc.)
- Siting and design: differences in topography (sail or chimney/stack effect), racking installation (e.g., piers), soil conditions, overhang location, etc.
- Operational procedures, such as adjusting tilt of arrays pre-storm or cover with protective materials
- Costs and benefits associated with all of these measures

Thank you

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www.nrel.gov/resilience-planning-roadmap/

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