CCREEE
CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY
AN INSTITUTION OF CARICOM

USAID
FROM THE AMERICAN PEOPLE

NREL
Transforming ENERGY

Resilient Energy Platform

BATTERY STORAGE FOR RESILIENCE

June 1, 2021

SUPPORTED BY

german cooperation
DEUTSCHE ZUSAMMENARBEIT

IMPLEMENTED BY:
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Housekeeping-Zoom

Welcome to our webinar! Here are a few notes about using Zoom:

- You will be **automatically muted** upon joining and throughout the webinar
- Please add comments or ask questions in the **chat box.** We will have several breaks throughout for Q&A.
- If you have **technical issues**, please send a chat message directly to Galen Hare

The USAID-NREL Partnership

USAID and NREL partner to deliver clean, reliable, and affordable power to the developing world. The USAID-NREL Partnership addresses critical aspects of deploying advanced energy systems in developing countries through:

- Policy, planning, and deployment support, and
- Global technical toolkits.

www.nrel.gov/usaid-partnership

Global Technical Platforms

The USAID-NREL Partnership's global technical platforms provide free, state-of-the-art support on common and critical challenges to scaling up advanced energy systems.

REexplorer MAPPING OUR ENERGY FUTURE — www.re-explorer.org

Greening the Grid — www.greeningthegrid.org

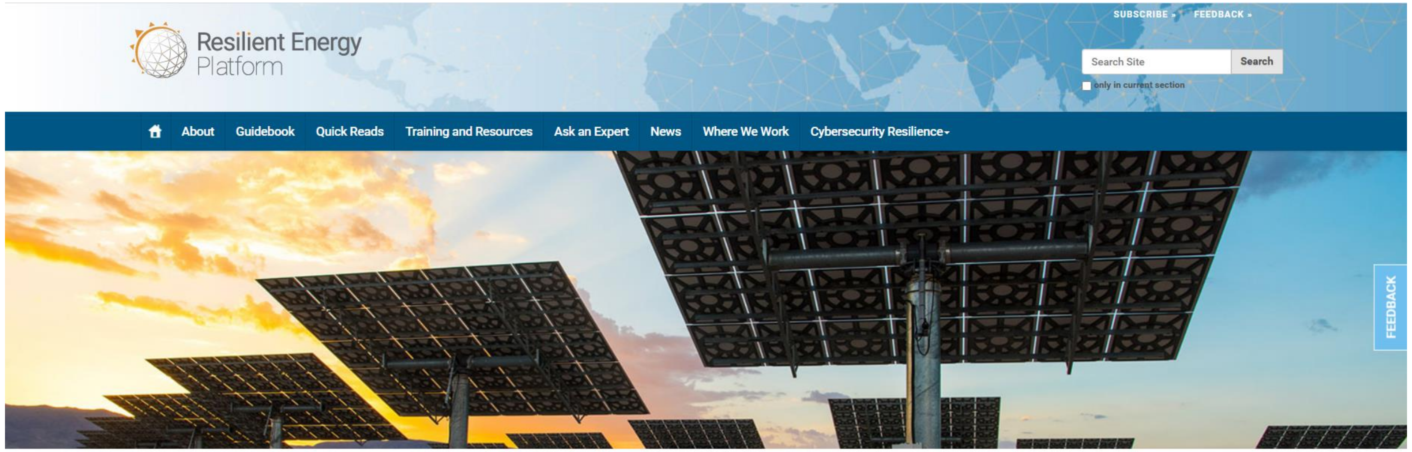
I-JEDI — www.i-jedi.org

Resilient Energy Platform — www.resilient-energy.org

Resilient Energy Platform

Developed through the USAID-NREL Partnership, the Resilient Energy Platform provides **expertly curated resources**, **training materials**, **tools**, and **technical assistance** to enhance power sector resilience.

The Resilient Energy Platform enables decision makers to **assess power sector vulnerabilities**, **identify resilience solutions**, and **make informed decisions** to enhance power sector resilience at all scales.



Developed through the USAID-NREL Partnership, the Resilient Energy Platform provides expertly curated resources, training materials, data, tools, and direct technical assistance in planning resilient, sustainable, and secure power systems.

www.resilient-energy.org

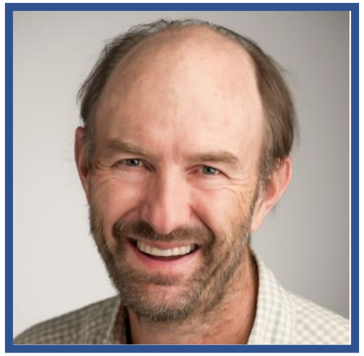
SPEAKERS

CCREEE
CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY

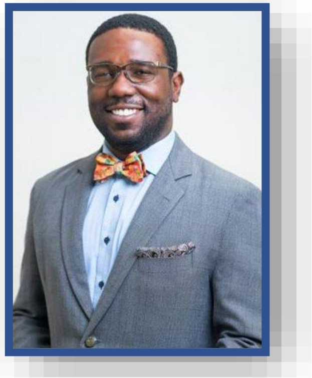
AN INSITUTION OF CARICOM

SPEAKER
EMMA ELGQVIST
RESEARCHER, NREL

SPEAKER
DAN OLIS
SENIOR ENGINEER, NREL



SPEAKER
OTTO VAN GEET, PE
PRINCIPAL ENGINEER, NREL



MODERATOR
GERALD LINDO, CCREEE

SPEAKER
JIM REILLY
ELECTRICAL ENGINEER – MICROGRID DEPLOYMENT, NREL

SPEAKER
RICK WALLACE KENYON
NREL

SPEAKER
MARK HANKINS
RE PROJECT ADVISOR, GET INVEST

MODERATOR
JAMES ELSWORTH
RESEARCH ENGINEER, NREL

SUPPORTED BY

german cooperation DEUTSCHE ZUSAMMENARBEIT

IMPLEMENTED BY: giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

USAID FROM THE AMERICAN PEOPLE

NREL Transforming ENERGY

Resilient Energy Platform

CIMH

AGENDA

- 1. Energy Storage for Resilience: Emma Elgqvist, NREL
- 2. REopt Model: Emma Elgqvist, NREL

Q&A

- 3. Puerto Rico Fish and Wildlife Service Iguaca Aviary Case Study, Otto Van Geet, NREL
- 4. U.S. Virgin Islands Utility Battery: Dan Olis, NREL

Q&A

- 5. Navy Pacific Missile Range Facility PV + BESS Case Studies: Jim Reilly, NREL
- 6. Inverter-based Operation of Power Systems: Electromagnetic Transient Simulations and Grid-forming Inverters: Wallace Kenyon, NREL

Q&A

- 7. Supporting Caribbean Energy Projects. Gerald Lindo, CCREEE
- Solar and Storage in SIDS. Mark Hankins, GET

Q&A and Wrap up.

ENERGY STORAGE FOR RESILIENCE

EMMA ELGQVIST, RESEARCHER, NREL

SUPPORTED BY

THE ENERGY SUPPLY IS IN THE MIDST OF A TRANSFORMATION

CCREEE
CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY

AN INSITUTION OF
CARICOM

- As costs decrease, renewable energy (RE) deployment is growing worldwide.
- Generation is increasingly distributed, with 31% of new capacity behind-the-meter.
- Renewable energy systems are coupled with battery storage to provide cost savings and resilient energy solutions.

EXISTING BACKUP POWER IS INSUFFICIENT IN SOME CASES

- On-site diesel fuel supply typically only lasts for a few days because sites may be limited in the amount of fuel they store on-site (due to financial, regulatory, or other constraints).
- It can be difficult to resupply backup diesel generators in the event of extended outages because natural disasters may damage fuel supply chains, or fuel may be diverted to higher priority needs.
- Backup diesel generators are infrequently used and are likely to fail if not properly maintained (a recent study found poorly maintained diesel generators have just a 50% probability of lasting 48 hours)
- Backup generators typically do not provide monetizable value streams while grid-connected.

PHOTO BY LARRY DURBIN, NREL 24490

SUPPORTED BY

ROLE OF BATTERY STORAGE FOR RESILIENCE

- Battery storage has long been used as an uninterruptable power source (UPS) for critical loads like data servers:
  - Typically state of charge kept ~100%
  - Typically not used for additional purposes
  - Typically duration is minutes to hours.
- When coupled with (a renewable) distributed energy generation source, battery storage can provide backup generation for extended periods of time (days to weeks):
  - Decrease the size of other backup generation
  - Extend limited fuel supply
  - Backup to backup power (redundancy)
  - Fully renewable backup (when coupled with renewables) that does not need refueling.
- Battery storage can provide revenue streams while grid-connected (unlike traditional backup assets).
- Today's presentation will cover considerations for using battery storage for backup power (resilience), while also generating revenue while grid connected, along with other distributed energy generation sources like renewable energy:
  - Note that this presentation does not cover resilience consideration for battery storage as it is related to siting best practices (i.e., elevating pads).

SUPPORTED BY

USE CASES FOR CUSTOMER SITED BATTERY STORAGE SYSTEMS

	UNITERRUPTIBLE POWER SOURCE (UPS)	OFF-GRID RE + STORAGE	GRID-CONNECTED ISLANDABLE	ON-SITE HOSTING
DESCRIPTION	Battery backup ready to be discharged	Providing continuous power in lieu of utility	Lowering cost of utility purchases and providing backup power during grid outage	Hosting large-scale generation for off-site sale
WHY/WHERE IT WORKS	• Sites with critical loads that have zero tolerance for disruption	• Remote sites with high fuel costs • Low grid reliability	• High demand charges • TOU rates • Ancillary service markets • Resilience requirements	• Deregulated market • Interested offtaker • Large land availability
PRIMARY POWER SUPPLY	Utility grid	Distributed energy resources (DERs) (typically including generators)	Grid + DERs	Utility grid
BACKUP	UPS	Not impacted by grid disruptions	DERs	DERs

TECHNO-ECONOMIC CONSIDERATIONS FOR GRID-CONNECTED STORAGE

CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY

AN INSITUTION OF CARICOM

- Many factors affect whether storage and distributed energy technologies can provide cost savings and resilience to your site.
- With increasingly integrated and complex systems, back-of-the-envelope calculations are no longer sufficient to determine distributed energy project potential.

VALUE STREAMS

COST OF ELECTRICITY

SITE LOAD

POLICIES

PHOTO BY DENNIS SCHROEDER, NREL 60074

VALUE STREAMS FOR BATTERY STORAGE

CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY

AN INSITUTION OF CARICOM

	SERVICE	DESCRIPTION	GRID	COMMERCIAL	RESIDENTIAL
DRIVEN BY UTILITY RATE STRUCTURE	Demand charge reduction	Use stored energy to reduce demand charges on utility bills		✓	✓
DRIVEN BY UTILITY RATE STRUCTURE	Energy arbitrage	Behind-the-meter: Energy TOU shift (from on-peak to off-peak hours)		✓	✓
UTILITY / REGIONAL PROGRAMS	Energy arbitrage	Wholesale: Buy during off-peak hours, sell during on-peak hours	✓	✓	
UTILITY / REGIONAL PROGRAMS	Demand response	Utility programs that pay customers to lower demand during system peaks		✓	✓
UTILITY / REGIONAL PROGRAMS	Frequency regulation and capacity markets	Stabilize frequency on moment-to-moment basis or supply spinning, non-spinning reserves (independent system operator/regional transmission operator)	✓	✓	
TRANSMISSION AND DISTRIBUTION	Voltage support	Insert or absorb reactive power to maintain voltage ranges on distribution or transmission system	✓		
TRANSMISSION AND DISTRIBUTION	T&D upgrade deferral	Deferring the need for transmission or distribution system upgrades (e.g., via system peak shaving)	✓	✓	✓

TECHNO-ECONOMIC CONSIDERATIONS FOR USING STORAGE FOR BACKUP POWER

CCREEE
CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY
AN INSITUTION OF CARICOM

- There are considerations for using RE and storage to provide backup power in the event of a grid outage (in addition to the ones for grid-connected-only systems).
- Different technology solutions have different costs and can provide different levels of resilience.

CRITICAL LOADS

OUTAGE DURATION

VALUE OF RESILIENCE

COST OF ISLANDING PV + STORAGE

PHOTO BY DAVID SHANKBONE, WIKIMEDIA COMMONS

CRITICAL LOADS

- Load served during a grid outage
- Usually different from typical load
  - Different shape, magnitude, peak timing
- Will impact technology selection and size for providing backup power
- Sites may not be known during initial assessments and may need to be estimated
- There may be different levels of critical loads:
  - Some that are very critical and need to be met all the time
  - Some that are nice to have and can be met when there is excess generation.

ESTIMATING CRITICAL LOAD

PERCENTAGE OF TYPICAL LOAD ESTIMATE

- Can be larger or smaller than typical load
- Easy to estimate if typical load is known
- Same shape as typical load.

METERED CRITICAL LOAD

- Most accurate
- Could be obtained from submeters of critical facilities or critical load panel(s)
- May have different shape (and time of peak).

MODELED PLUG LOADS

- Works well of critical load is only comprised of a few components.

CCREEE CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY
AN INSITUTION OF CARICOM
SUPPORTED BY
german cooperation
IMPLEMENTED BY: giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
USAID FROM THE AMERICAN PEOPLE
NREL Transforming ENERGY
Resilient Energy Platform
CIMH

OUTAGE DURATION

Length of outage can drive the technology selection.

SECONDS OR MINUTES
Battery UPS may be sufficient

DAYS
Battery supplemented by RE and traditional backup

WEEKS
On-site fuel supply may not be sufficient

Length of outage (shorter to longer)

QUANTIFYING, VALUING, AND MONETIZING RESILIENCE

AN INSITUTION OF CARICOM

CCREEE CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY

QUANTIFYING RESILIENCE

A resilience metric measures how resilient an energy system is. Performance-based metrics quantify the consequences that could be avoided as a result of a resilience investment:

- Customer outage time (hours)
- Load not served (kilowatt-hours)
- Number or percentage of customers experiencing an outage (# or %)
- Number of critical services (e.g., hospitals or fire stations) without power (#)
- Time to recovery (hours)
- Cost of recovery ($)

VALUING RESILIENCE

Determining the value of a resilience investment (in dollars) is an essential component of cost-benefit analysis. An accurate resilience value involves determining the avoided costs of an outage, including the direct and indirect costs incurred by the service provider, customers, and society:

- Loss of utility revenue ($)
- Cost of grid damages ($)
- Cost of recovery ($)
- Avoided outage cost ($)
- Loss of assets and perishables ($)
- Business interruption costs ($)

MONETIZING RESILIENCE

Resilience monetization determines what portion of the resilience value can be realized in cash flow to finance project implementation. Beyond the improved resilience itself, such an evaluation should consider all available revenue streams associated with the investment:

- Reduced insurance rates
- Reduced mortgage rates
- Government incentives
- Grid services value
  Resilience payment from site host

SOURCE: HTTPS://WWW.NREL.GOV/DOCS/FY19OSTI/74673.PDF

SUPPORTED BY german cooperation DEUTSCHE ZUSAMMENARBEIT IMPLEMENTED BY: giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH USAID FROM THE AMERICAN PEOPLE NREL Transforming ENERGY Resilient Energy Platform CIMH

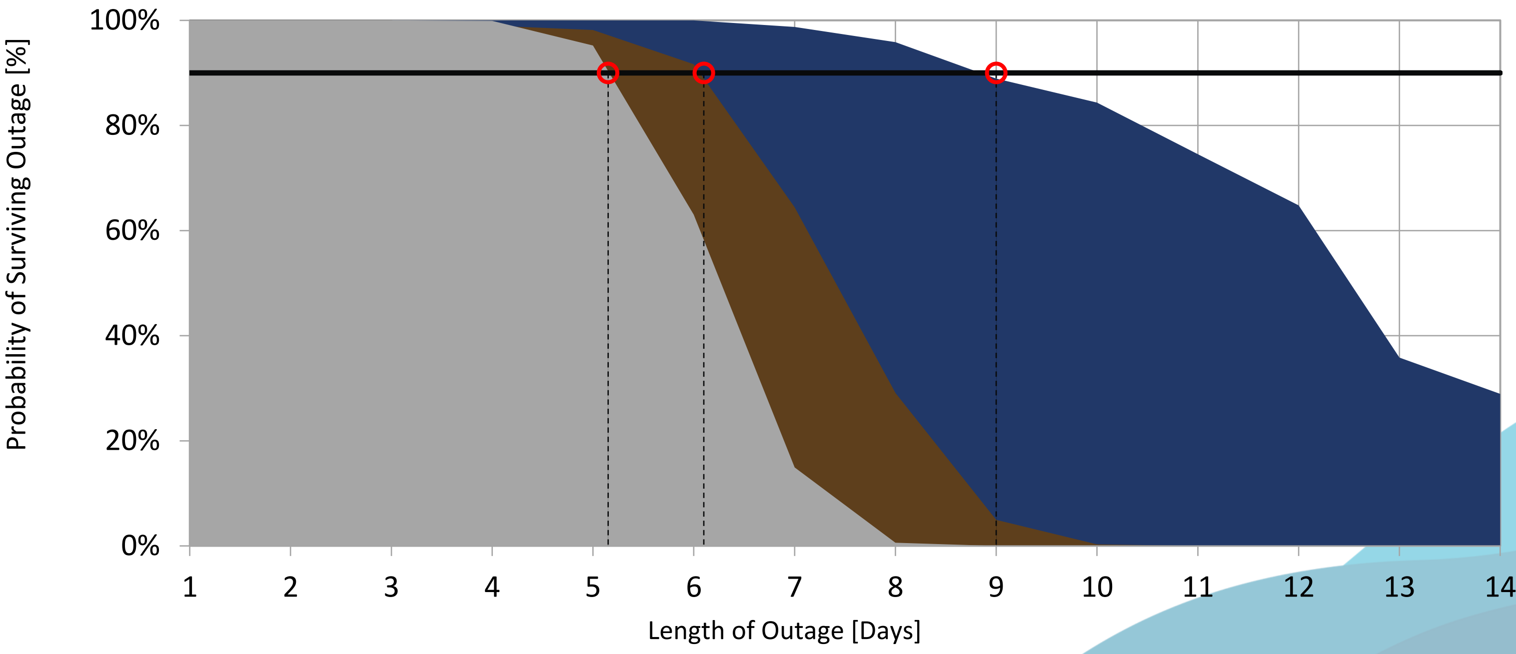
QUANTIFYING RESILIENCE BENEFITS OF DIFFERENT TECHNOLOGY SOLUTIONS

CCREEE
CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY

AN INSITUTION OF
CARICOM

- The probability of surviving an outage of a certain length from different technology combinations is shown.
- Increased system sizes provide added days of survivability but provide different value.

	Generator	Solar PV	Storage	Lifecycle Cost	Outage
1. Base case	2.5 MW	-	-	$20 million	5 days
2. Lowest cost	2.5 MW	625 kW	175 kWh	$19.5 million	6 days
3. Proposed system	2.5 MW	2 MW	500 kWh	$20.1 million	9 days



KATE ANDERSON ET AL. *INCREASING RESILIENCY THROUGH RENEWABLE ENERGY MICROGRIDS*. EXTON, PA: JOURNAL OF ENERGY MANAGEMENT. AUGUST 2017. HTTPS://WWW.NREL.GOV/DOCS/FY17OSTI/69034.PDF.

SUPPORTED BY

german cooperation
IMPLEMENTED BY: giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

USAID FROM THE AMERICAN PEOPLE

NREL Transforming ENERGY

Resilient Energy Platform

CIMH

REOPT MODEL

Overview/Review

REOPT LITE: FREE WEB TOOL TO OPTIMIZE ECONOMIC AND RESILIENCE BENEFITS OF DERS

Formulated as a mixed integer linear program, REopt Lite provides an integrated cost-optimal energy solution.

Drivers

Goals
Minimize Cost
Resilience
Emissions

Economics
Technology Costs
Incentives
Financial Parameters

Utility Costs
Energy Charges
Demand Charges
Escalation Rate

Technology Options

Renewable Generation
Solar PV, Wind

Conventional Generation
Electric Grid
Diesel Generators

Energy Storage
Batteries
Hot and chilled water TES

Combined Heat & Power
Reciprocating engine
Microturbine engine
Combustion engine

REopt Lite

reopt.nrel.gov/tool

Electric and Thermal Loads

Optimized Minimum Cost Solution

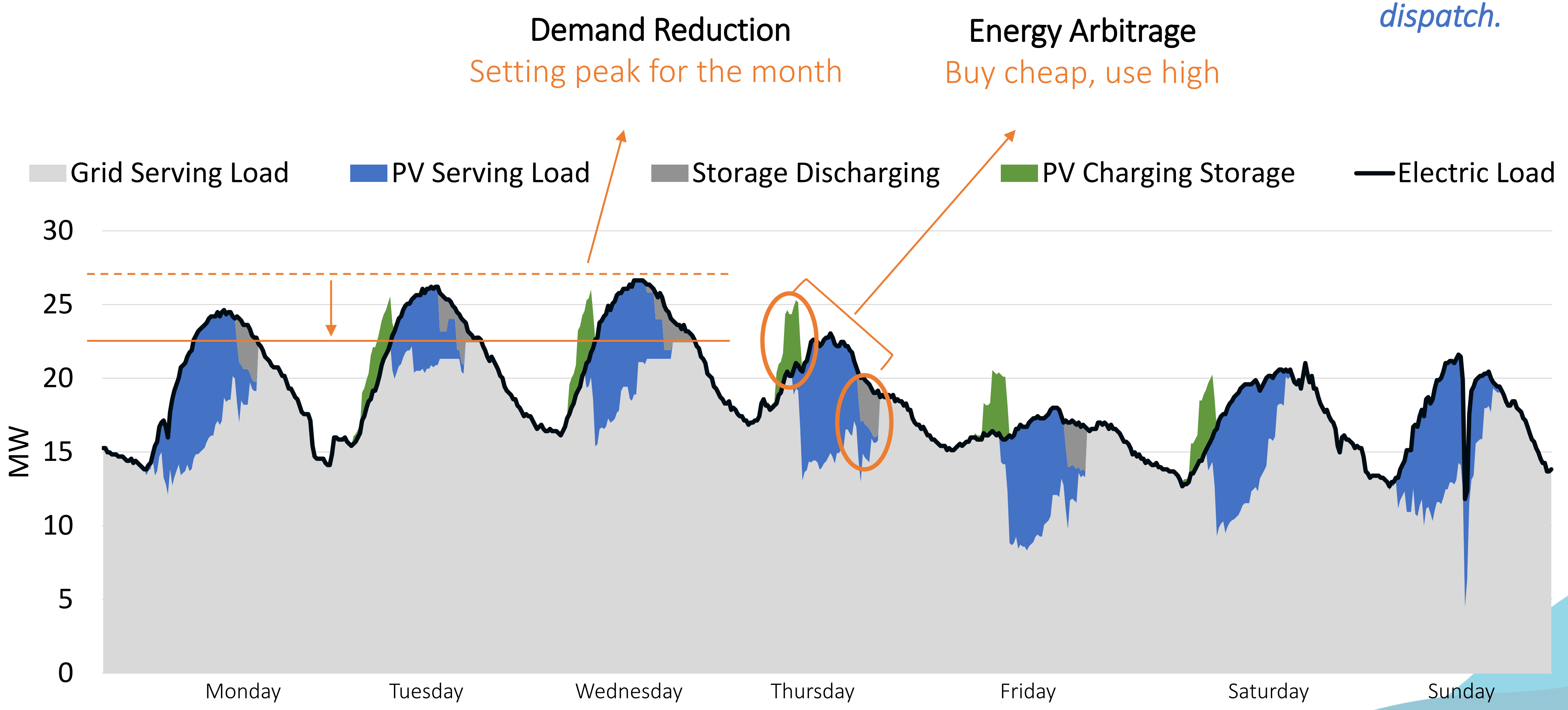
Technologies
Technology Mix
Technology Size

Operations
Optimal Dispatch

Project Economics
Capital and O&M Cost
Net Present Value

HOW DOES REOPT LITE WORK?

REopt Lite considers the trade-off between ownership costs and savings across multiple value streams to recommend optimal size and dispatch.

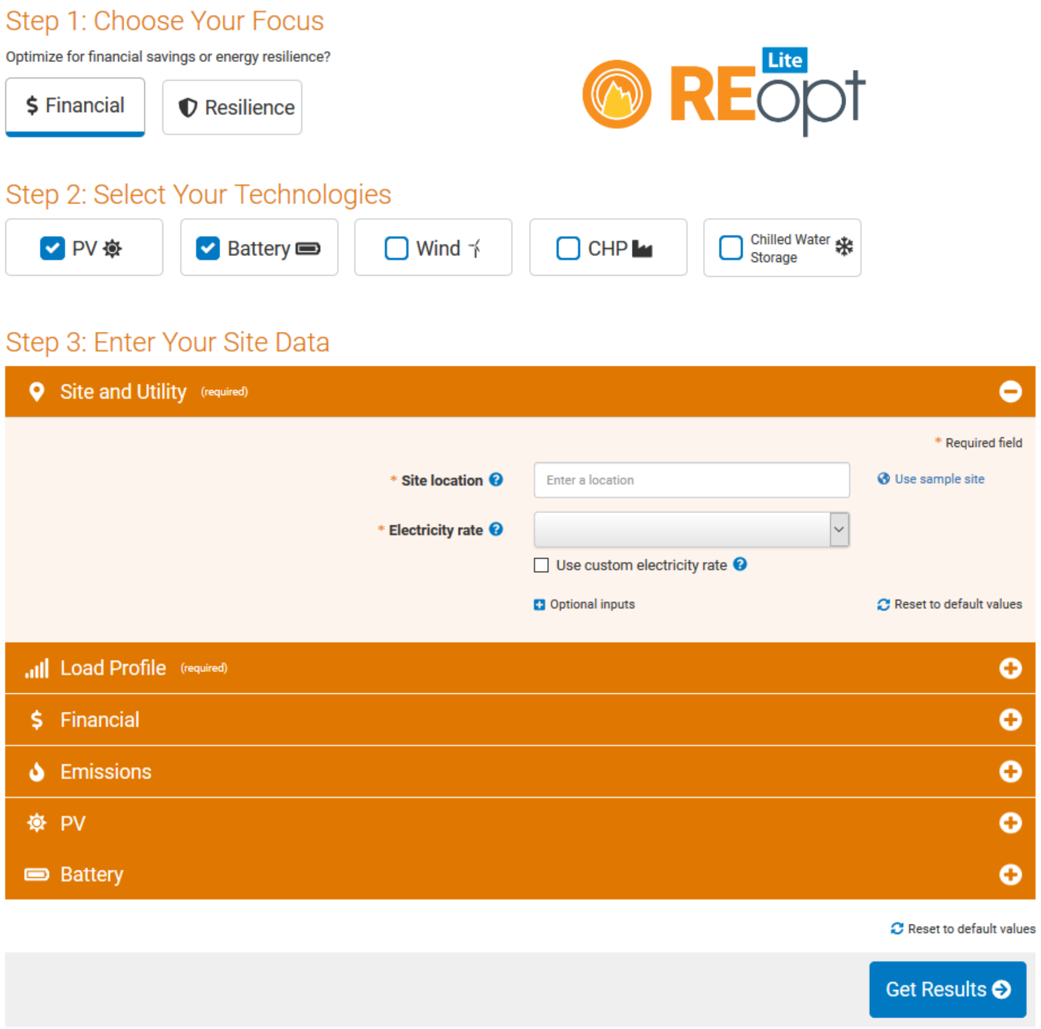


Example of optimal dispatch of PV and BESS

SUPPORTED BY

REOPT LITE USER INTERFACE

- REopt Lite is a web tool that offers a no-cost subset of NREL's more comprehensive REopt™ model;
- Financial mode optimizes PV, wind, CHP, and battery system sizes and dispatch strategy to minimize life cycle cost of energy; and
- Resilience mode optimizes PV, wind, CHP, and storage systems, along with backup generators, to sustain critical load during grid outages.
- Access REopt Lite at reopt.nrel.gov/tool.

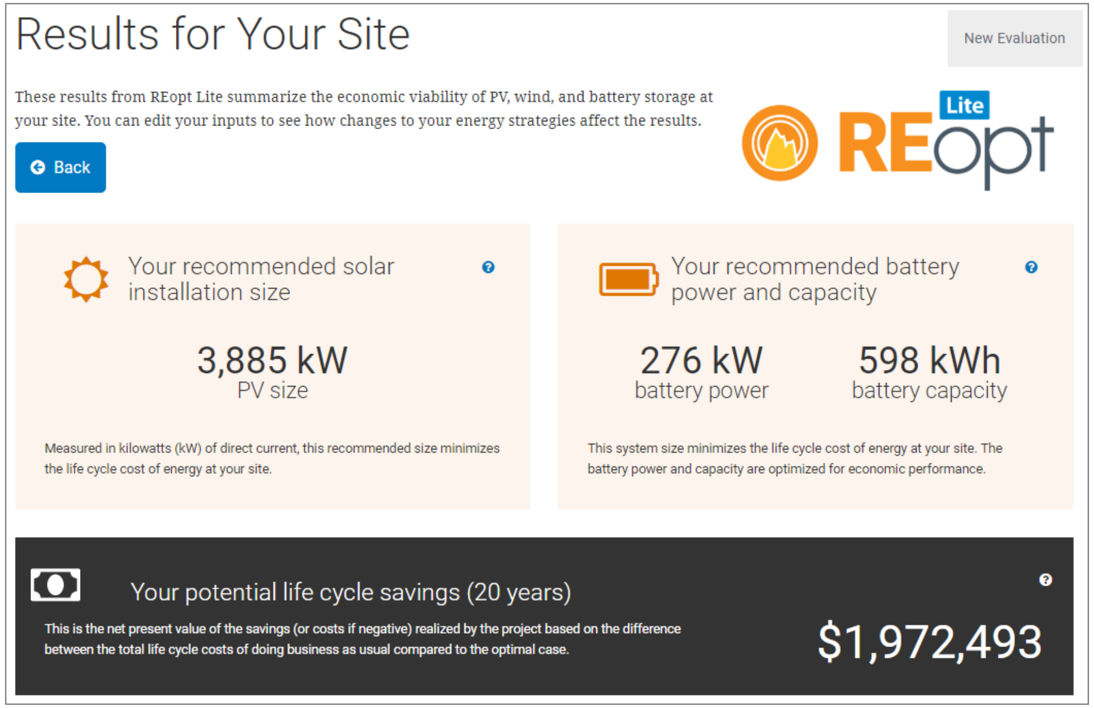


SUPPORTED BY

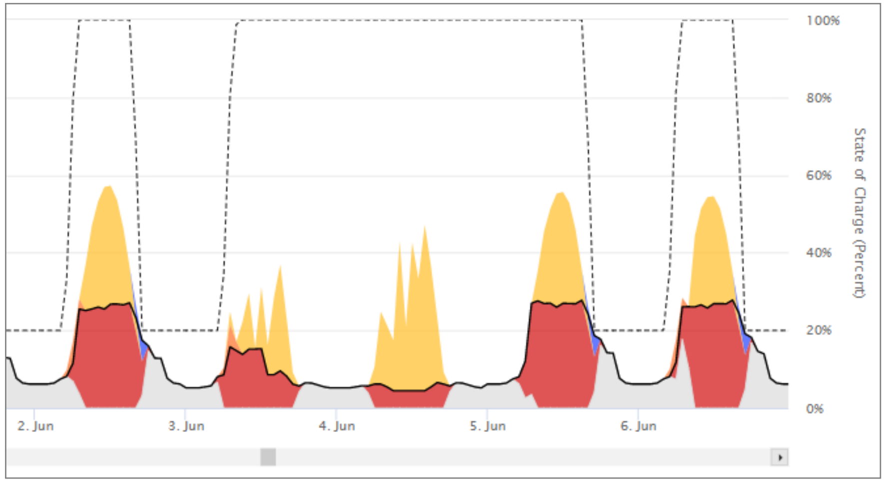
REOPT LITE KEY OUTPUTS

CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY

AN INSITUTION OF CARICOM



System Size and NPV



Hourly Dispatch

	Business As Usual	Financial	Difference
System Size, Energy Production, and System Cost			
PV Size	0 kW	113 kW	113 kW
Annualized PV Energy Production	0 kWh	132,000 kWh	132,000 kWh
Battery Power	0 kW	0 kW	0 kW
Battery Capacity	0 kWh	0 kWh	0 kWh
Net CAPEX + Replacement + O&M	$0	$133,318	$133,318
Energy Supplied From Grid in Year 1	132,000 kWh	65,384 kWh	66,616 kWh
Year 1 Utility Cost — Before Tax			
Utility Energy Cost	$18,112	-$404	$18,515
Utility Demand Cost	$0	$0	$0
Utility Fixed Cost	$0	$0	$0
Utility Minimum Cost Adder	$0	$0	$0

Detailed Financial Outputs

SUPPORTED BY

german cooperation

IMPLEMENTED BY: giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

USAID FROM THE AMERICAN PEOPLE

NREL Transforming ENERGY

Resilient Energy Platform

CIMH

ANALYSIS ENABLED BY API

- The REopt Lite API enables national-scale analysis of storage economics and impacts on adoption/deployment.
- Analysis questions include:
  - Where in the country is storage (and PV) currently cost-effective?
  - At what capital costs is storage adopted across the United States?
  - How does varying utility rate, escalation rates, and incentive structures impact storage profitability?
  - How (and where) can stationary storage support DC-fast-charging electric vehicle economics and deployment?

Where does investing in battery storage make economic sense?

Percent life cycle cost savings from deploying behind-the-meter BESS

Percent life cycle cost savings from deploying behind-the-meter BESS, potentially coupled with solar PV

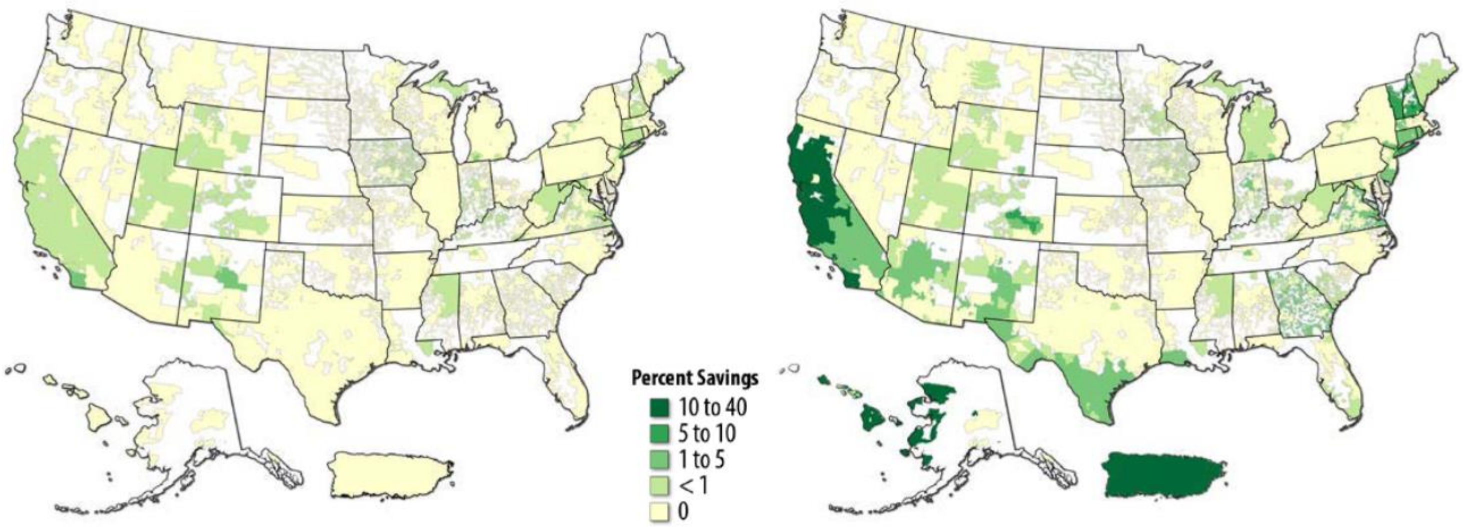
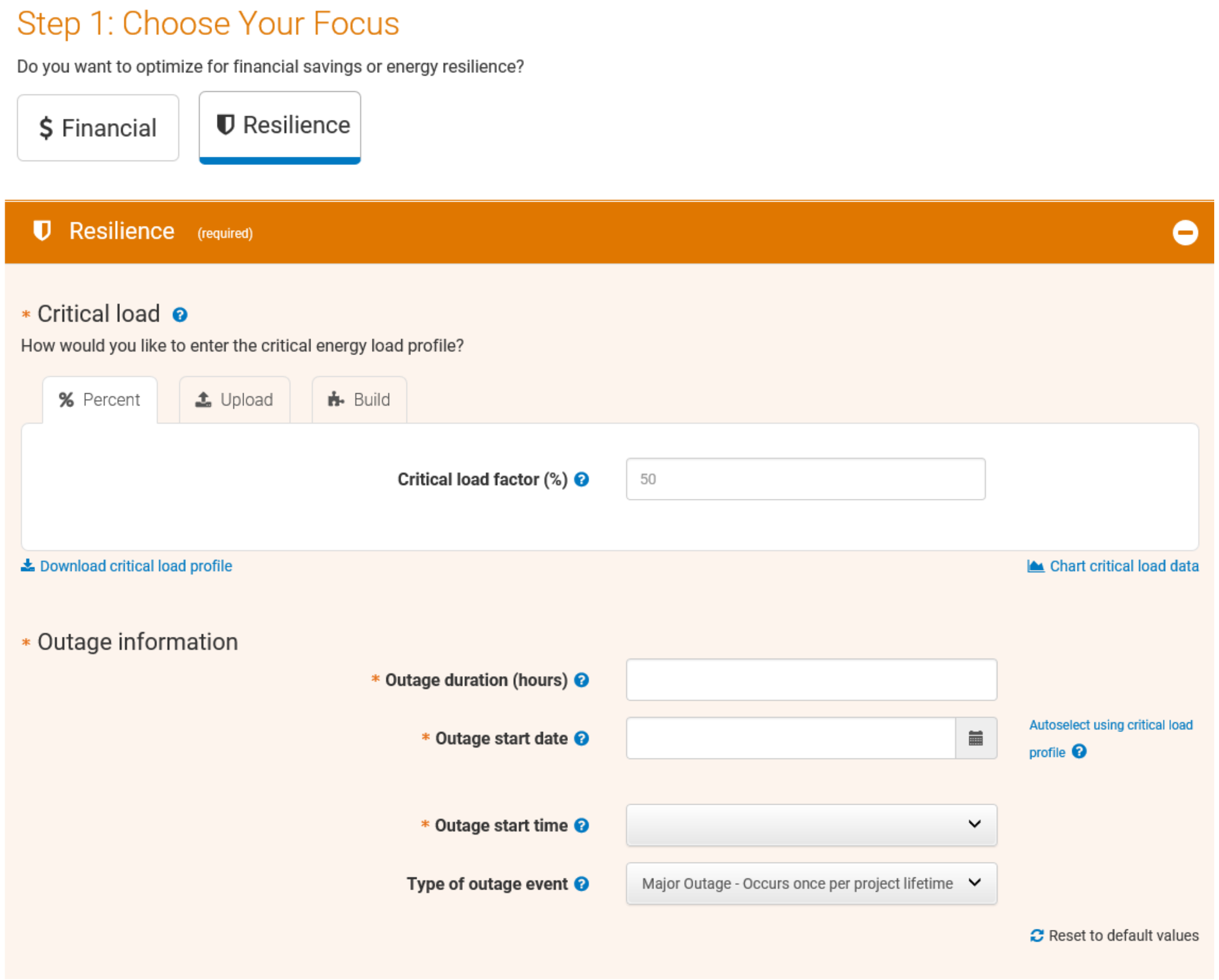


Figure 1. These maps show where in the United States there is potential for cost savings from implementing a behind-the-meter storage system alone (left), or in some cases with solar PV (right), compared to purchasing all electricity from the utility. Areas in green indicate percent life cycle cost savings (including utility costs as well as capital and operations and maintenance costs) of the deployed systems. Areas in yellow indicate that the area was evaluated, but a system would not provide life cycle cost savings. *Image from NREL*

WHERE AND WHEN DOES SOLAR PLUS STORAGE MAKE SENSE FOR COMMERCIAL BUILDINGS? NREL Researchers Make Their "BESSt" Guess Using REopt Lite Modeling Tool
https://www.nrel.gov/docs/fy21osti/77112.pdf

SUPPORTED BY

REQUIRED RESILIENCE INPUTS

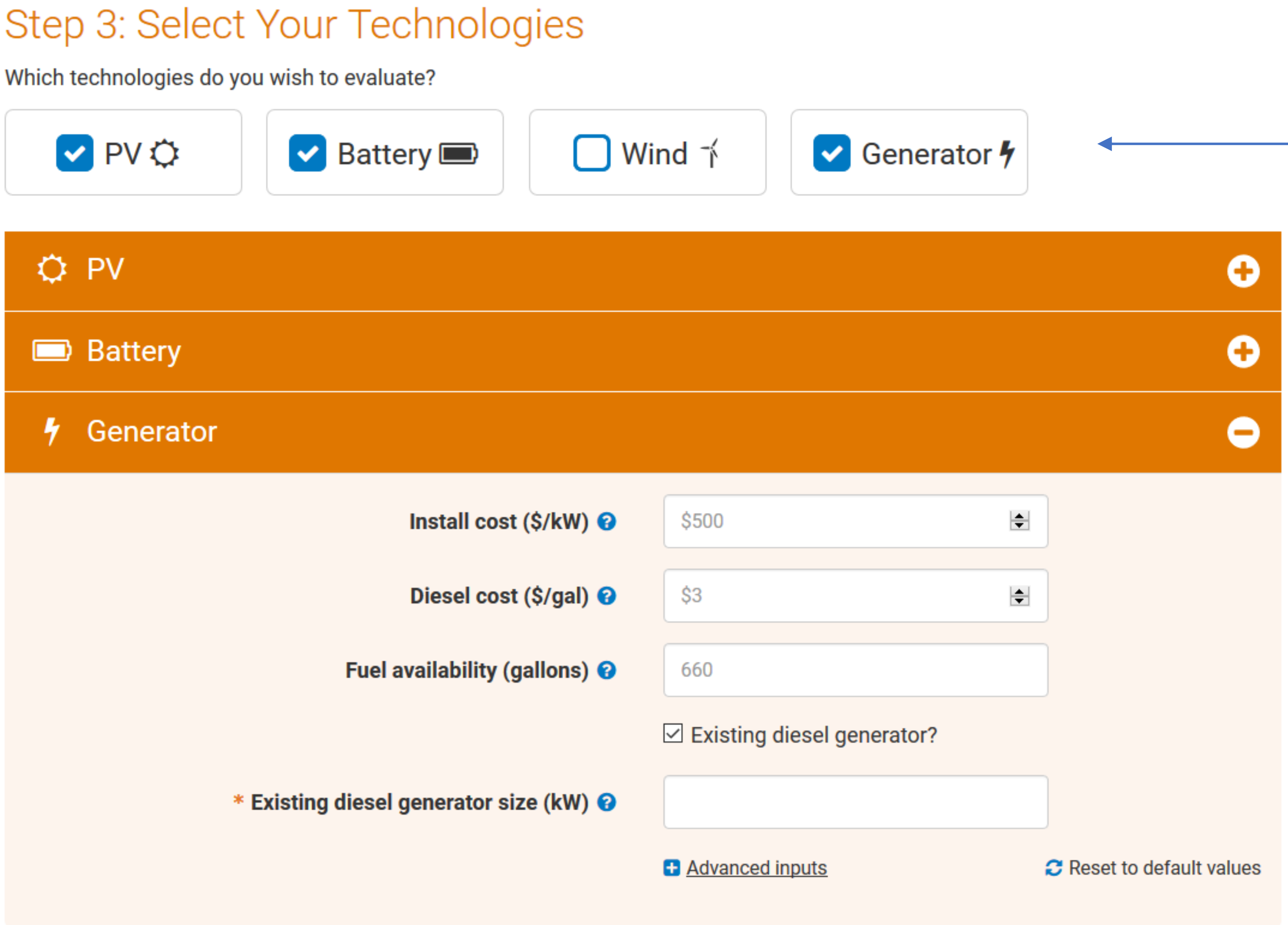


What load needs to be met during the outage?

When is the outage expected to occur, and how long will it last?

SUPPORTED BY

ADDITIONAL RESILIENCE INPUT: GENERATOR MODELING



Generator option for resilience evaluation

Specify existing generator, and/or let REopt Lite size it.

Defaults are for a diesel generator but can be modified.

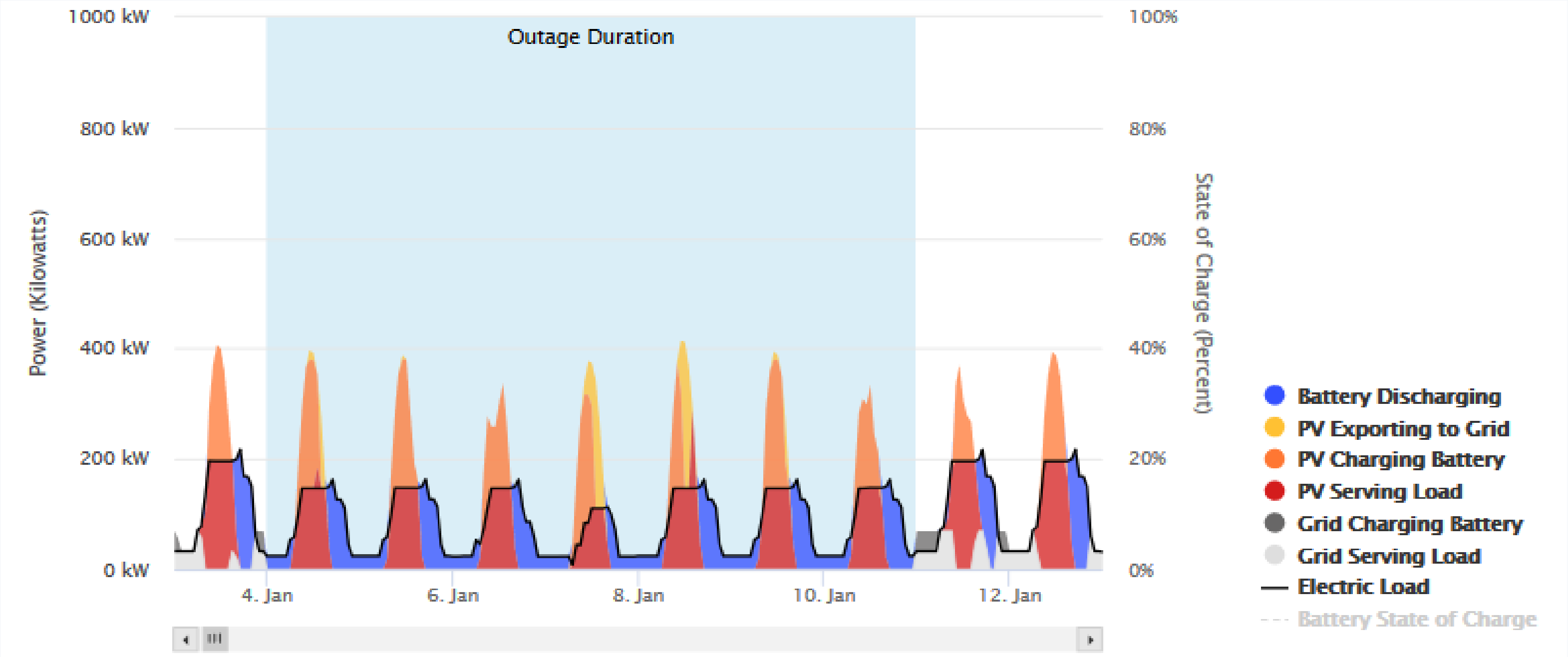
RESILIENCE OUTPUT: DISPATCH DURING OUTAGE

CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY

AN INSITUTION OF CARICOM

System Performance Year One

This interactive graph shows the dispatch strategy optimized by REopt Lite for the specified outage period as well as the rest of the year. To zoom in on a date range, click and drag right in the chart area or use the "Zoom In a Week" button. To zoom out, click and drag left or use the "Zoom Out a Week" button.



Zoom Out a Week | Zoom In a Week

Download Dispatch Spreadsheet

The specified outage event is highlighted in blue (lower load).

The load is met exclusively by the PV and storage that REopt Lite selected.

As soon as the outage ends, the site goes back to purchasing grid electricity.

SUPPORTED BY

USAID FROM THE AMERICAN PEOPLE

NREL Transforming ENERGY

Resilient Energy Platform

RESILIENCE OUTPUT: SYSTEM SIZED TO MEET OUTAGE

CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY

AN INSITUTION OF CARICOM

Your Potential Resilience

This system sustains the 75% critical load during the specified outage period, from January 4 at 12am to January 11 at 12am.

System survives specified 168-hour outage

This system sustains the critical load for 72% of all potential 168 hour outages throughout the year.

72% System survives 72% of 168-hour outages

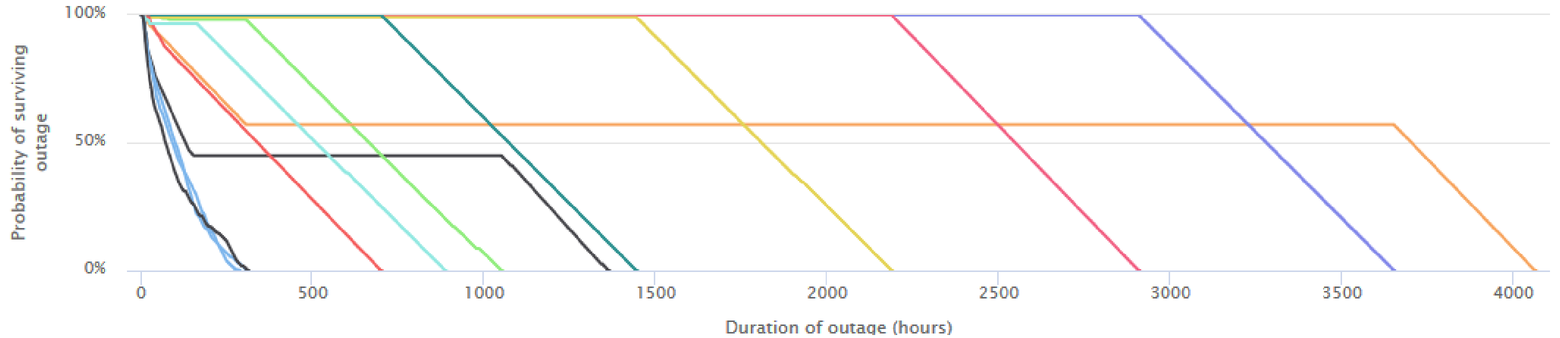
REopt Lite optimizes system size and dispatch to survive specified outage.

Outage Simulation

Evaluate the amount of time that your system can survive grid outages.

Yearly | Monthly | Hourly

This shows the amount of time your system will sustain the critical load for outages of varying duration, grouped by the month in which the outage starts



REopt Lite simulates outages of varying length throughout the year.

SUPPORTED BY

german cooperation

IMPLEMENTED BY: giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

USAID FROM THE AMERICAN PEOPLE

NREL Transforming ENERGY

Resilient Energy Platform

CIMH

Q&A

PUERTO RICO FISH AND WILDLIFE SERVICE IGUACA AVIARY CASE STUDY

OTTO VAN GEET, PE, RESEARCHER, NREL

SUPPORTED BY

AVIARY PV HYBRID POWER SYSTEM

- Captive-breeding facility for the Puerto Rican parrot
- Remote site with very unreliable, expensive grid power
- Grid power down for months after hurricanes
- Aviary critical load power provided by diesel generators

Analysis Overview

- NREL used the **REopt** tool for renewable energy integration and optimization to evaluate the techno-economic potential of adding **solar + storage** at a federal facility in Puerto Rico
- The analysis focused on **optimal technology sizing** to minimize life-cycle energy cost and a **resilience** evaluation to quantify the outage survival benefits of pairing onsite PV + storage with the existing diesel generator with a fixed fuel supply
- The resilience analysis considered solar + storage sizing for meeting a **24- and 48-hour** outage

Analysis Methodology

Scenarios

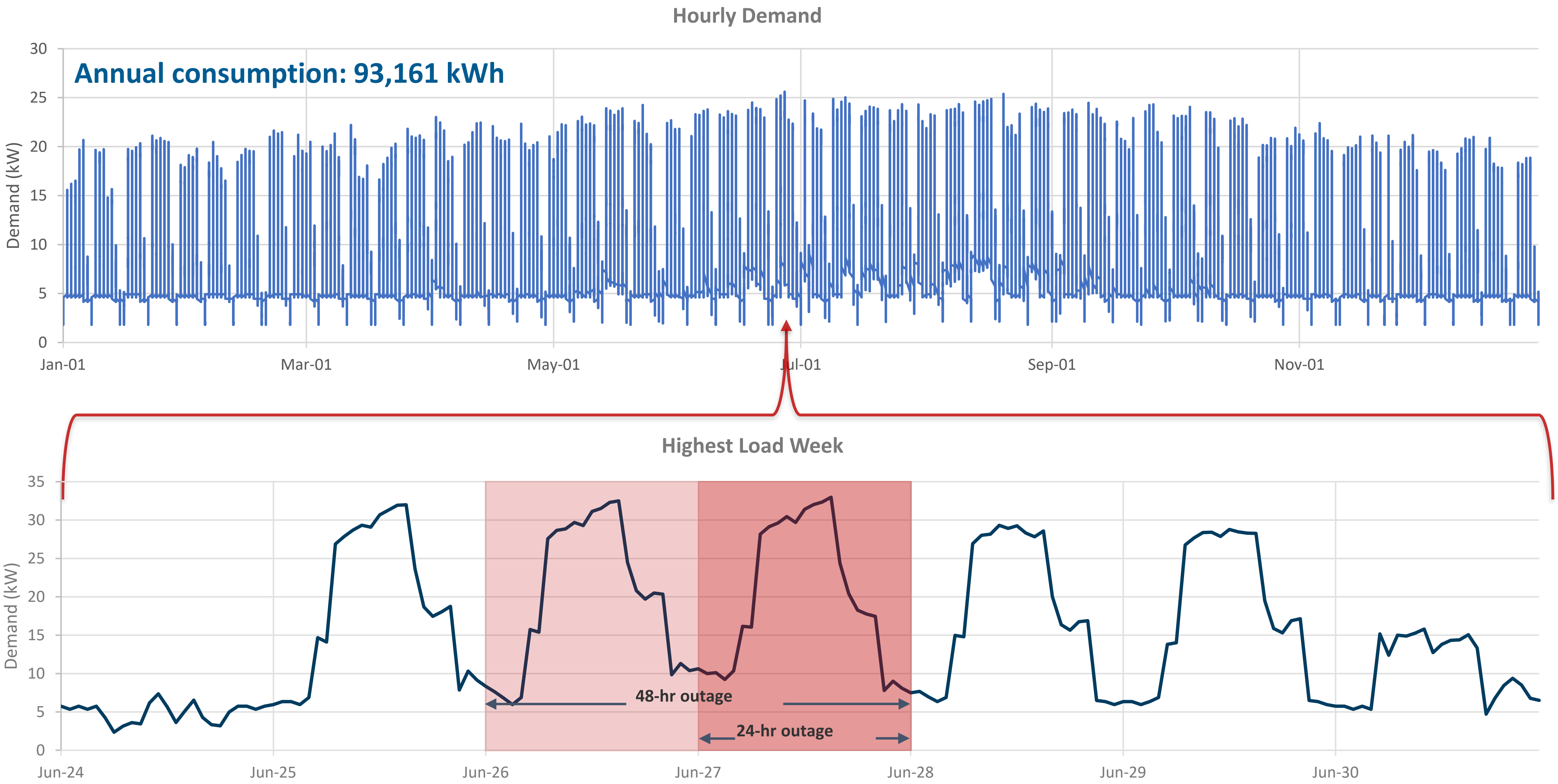
Sizing	Grid-tied	Outage
Economics	**1. PV and storage sized by REopt to maximize savings** →	Outage benefit calculated
Resilience	Grid connected benefits calculated	← **2. PV and storage sized to survive utility outages at minimum cost**

Load Data

- Annual energy consumption data was provided by the site.
- The initial analysis simulates hourly load data by scaling the closest matching DOE commercial reference building*:
  - Building type: **Small Office**
  - Annual consumption: **93,161 kWh**
  - Climate zone: **1A**

*https://energy.gov/eere/buildings/commercial-reference-buildings

Load Profile



Utility Rate

- A representative PREPA rate tariff was chosen for the initial analysis:
  - **General Service at Secondary Distribution Voltage** – for non-residential service with a load lower than 50 kVA

Rate Components	Cost
Base Tariff	$0.08449 / kWh
Riders	
Fuel Charge Adjustment (FCA)	$0.083323 / kWh
Purchased Power Charge Adjustment (PPCA)	$0.046752 / kWh
Contribution in Lieu of Taxes (CILT) – Municipalities	$0.005376 / kWh
Subsidies, Public Lighting (Municipal), and other Subventions (SUBA)	$0.014011 / kWh
Energy Efficiency (EE)	$0 / kWh
Total	**$0.233952 / kWh**

Sources: http://energia.pr.gov/wp-content/uploads/2018/01/Exhibit-C-Revised_CLEAN.pdf
https://aeepr.com/es-pr/Site-Servicios/Manuales/PREPA%20New%20Rate%20Structure%20Presentation%20-%20Internet.pdf

Resilience Considerations

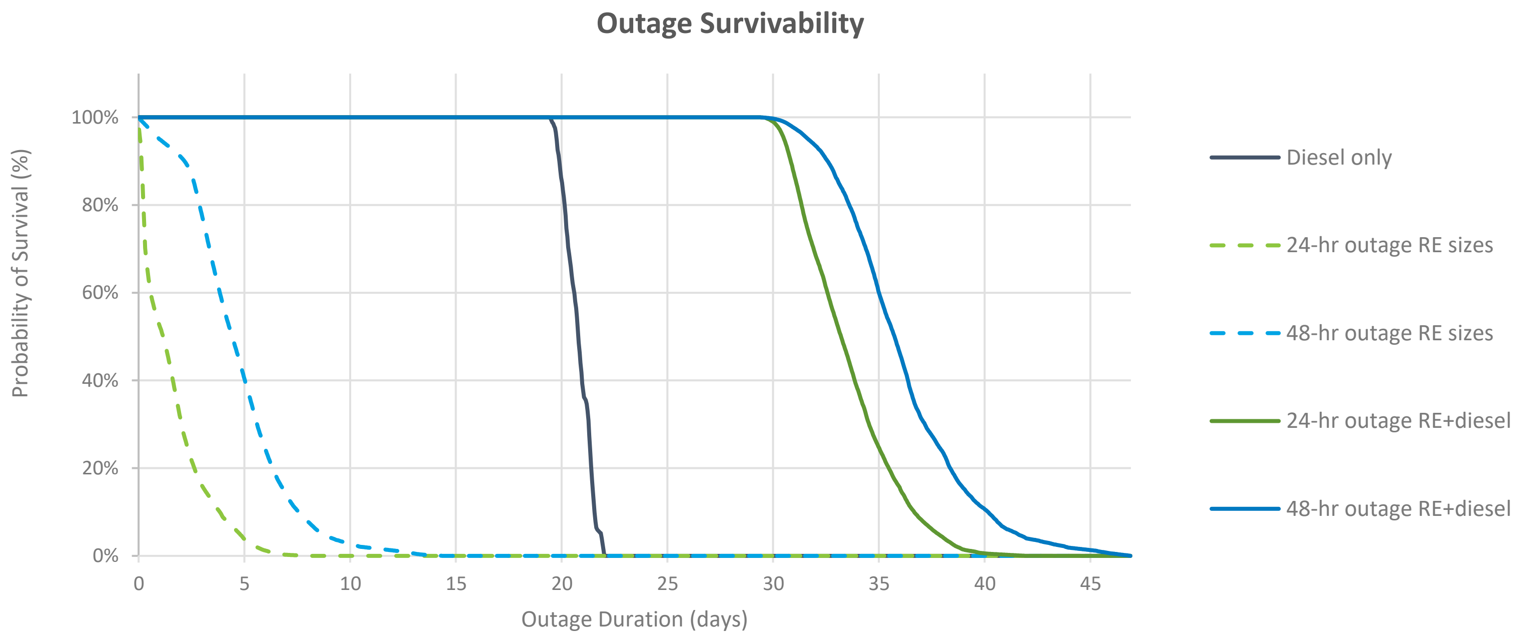
- Outage survival goals: **24 hours**, **48 hours**
- Critical load: **50%** of typical load
- Existing assets:
  - **60 kW** generator
  - **600 gallons** of diesel stored on site
- Scenarios considered:
  - Sizing PV and storage to meet the outage survival requirement

Results

	Base Case	No Net Metering			Net Metering Available		
	Baseline Design	Grid-connected optimal*	24-hour outage, PV+BESS	48-hour outage PV+BESS	Grid-connected optimal*	24-hour outage, PV+BESS	48-hour outage PV+BESS
PV size (kW)	–	26	26	26	26	26	26
Battery size (kWh)	–	–	97.7	174.5	-	97.7	174.5
Inverter size (kW)	–	–	6.9	8.0	-	6.9	8.0
Capital cost** ($)	–	$78,000	$140,813	$185,272	$78,000	$140,813	$185,272
Total life-cycle cost ($)	$365,180	$326,090	$375,293	$418,693	$306,782	$369,594	$414,053
Net present value ($)	–	$39,090	-$10,113	-$53,513	$58,398	-$4,414	-$48,873
Life-cycle savings (%)	–	10.7%	-2.8%	-14.7%	16.0%	-1.2%	-13.4%
RE penetration (%)	0%	34.1%	37.8%	38.1%	39.3%	39.3%	39.3%

* PV shuts off during grid outages because no battery is sized
** Capital costs include the present value of the battery replacement
*** Additional islanding costs and control equipment are not factored into the current analysis

Resilience Results



	Diesel only	24-hr outage RE sizes	48-hr outage RE sizes	24-hr outage RE + diesel	48-hr outage RE + diesel
Max survival (hrs)	528	188	345	1,005	1,126
Min survival (hrs)	466	0	0	706	706
Average survival (hrs)	498.7	37.0	112.2	804.2	865.7

- The existing diesel generator is able to meet average outage durations of approximately three weeks, fulfilling the site's outage survival goal of 24-48 hours
- PV+storage systems sized to survive the specific 24- and 48-hour outages, are able to meet average outage durations of 34 - 36 days respectively when paired with the existing diesel system

Conclusion and Next Steps

- Grid-connected operation:
  - PV is cost effective at the site, with the maximum size (26 kW) recommended for installation regardless of the availability of net metering programs
    - Installing PV reduces the total life-cycle cost of the site by 16% if net metering is available or 11% if net metering is not available, achieving a renewable energy penetration level of over 30%
  - Storage is not cost effective because federal agencies cannot take advantage of available incentives

- Resilience and outage conditions:
  - The existing diesel generator is able to survive average outage durations of approximately 3 weeks
  - However the generator is oversized (60 kW vs. 5.3 kW of average critical load) and running at such low loading could have implications on efficiency and asset life
  - PV+storage can be used to meet outage survival goals at an increase in total life-cycle cost of 1-3% for a 24-hr outage or 13-15% for a 48-hr outage, depending on the availability of net metering

- Next steps:
  - Evaluate bids for the 26 kW storm hardened PV, 100 kWh battery system
  - Award and install system

CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY

AN INSITUTION OF CARICOM

US VIRGIN ISLANDS CASE STUDY

DAN OLIS, RESEARCHER, NREL

SUPPORTED BY

PRESENTATION OVERVIEW

- Project Objectives
  - Decrease operating costs
  - Increase resilience
- Utility has planned microgrid projects that include batteries for St. Thomas, St. John, and St. Croix
- This presentation is on the St. Croix battery system

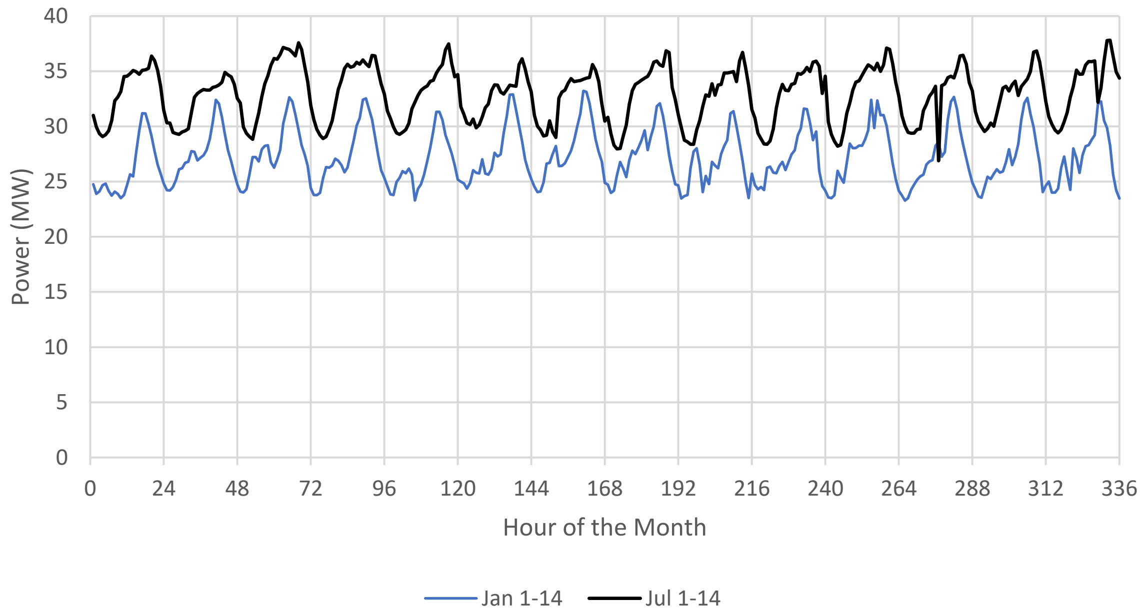
USVI OVERVIEW

- Two independent systems
  - St. Croix
  - St. Thomas. Also serves St. John via undersea cable
- Utility is the Virgin Island Water and Power Authority
- NREL is providing technical assistance to VIWAPA with funding from the US Federal Emergency Management Agency (FEMA) and the Department of Energy (DOE)
- Utility scale PV and BESS are planned for St. Croix and NREL is involved with some of the due-diligence on integrating these into the system

SUPPORTED BY

ST. CROIX SYSTEM OVERVIEW

- 38 MW peak, 30 MW average load
- Combustion turbines and reciprocating engines
  - Diesel and propane
- 4.2 MW-ac PV purchased from an independent power producer

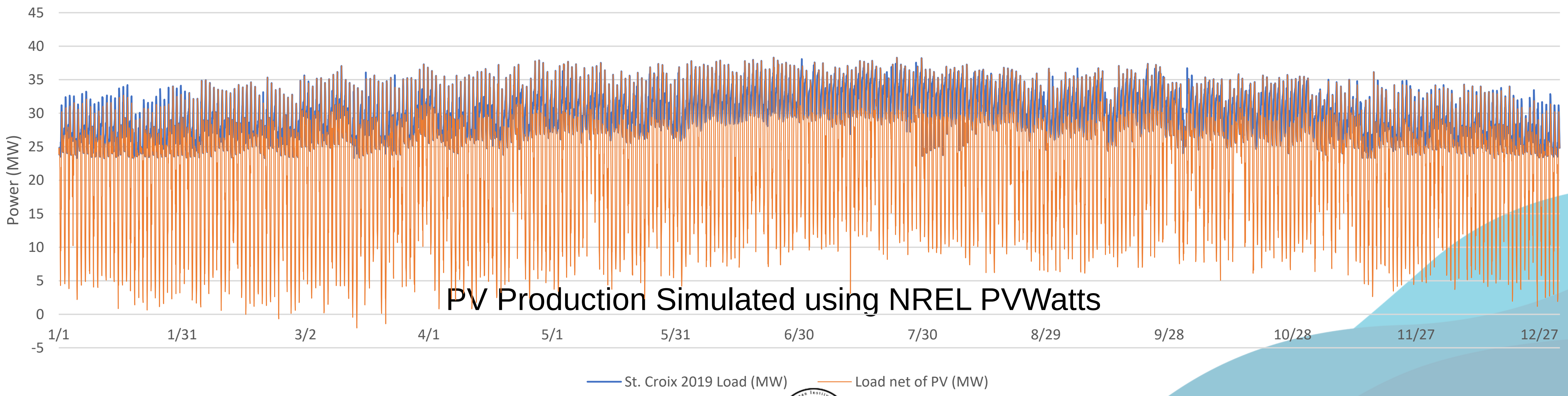


2017 loads; net of existing PV

SUPPORTED BY

ST. CROIX PROJECT SCOPE

- PV systems: 18 MW-ac & 10 MW-ac
- Battery system: 10 MW – 20 MWh
- Controls and sectionalizing equipment to permit electrical separation of power system into two parts
- Detailed engineering design has not begun so concept design subject to change
- Projects funded by US federal government

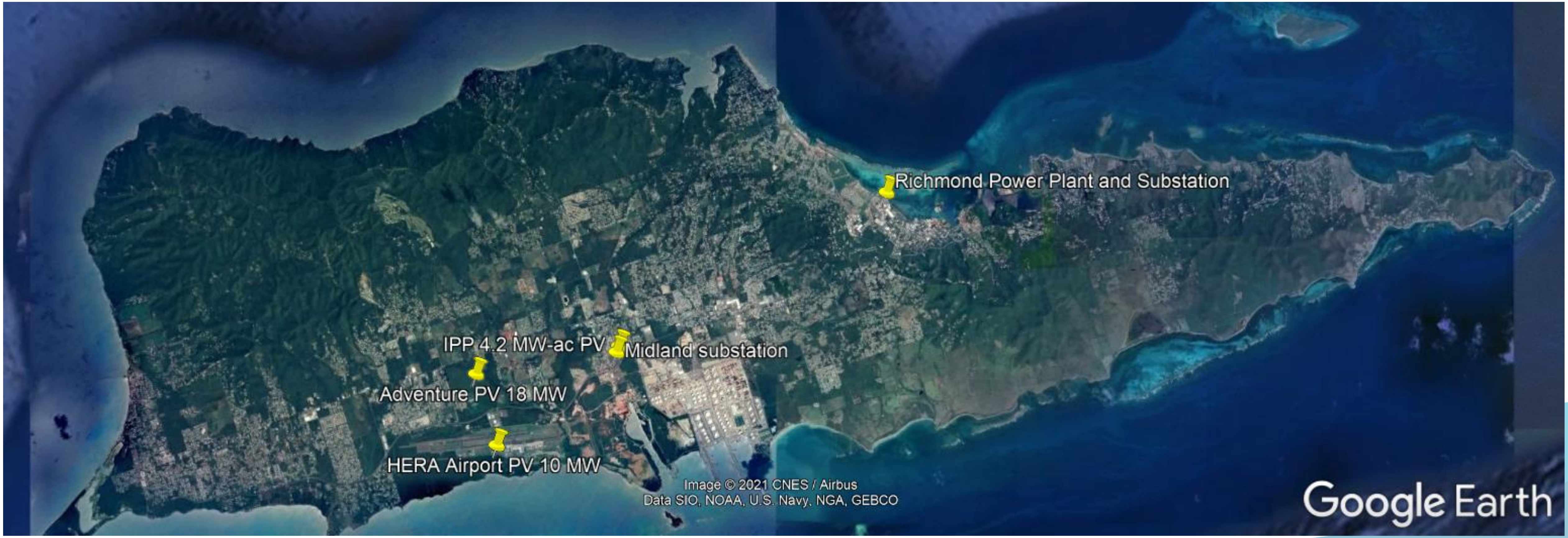


SUPPORTED BY

ST. CROIX MAP

CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY

AN INSITUTION OF CARICOM



SUPPORTED BY

german cooperation

IMPLEMENTED BY: giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

USAID FROM THE AMERICAN PEOPLE

NREL Transforming ENERGY

Resilient Energy Platform

CIMH

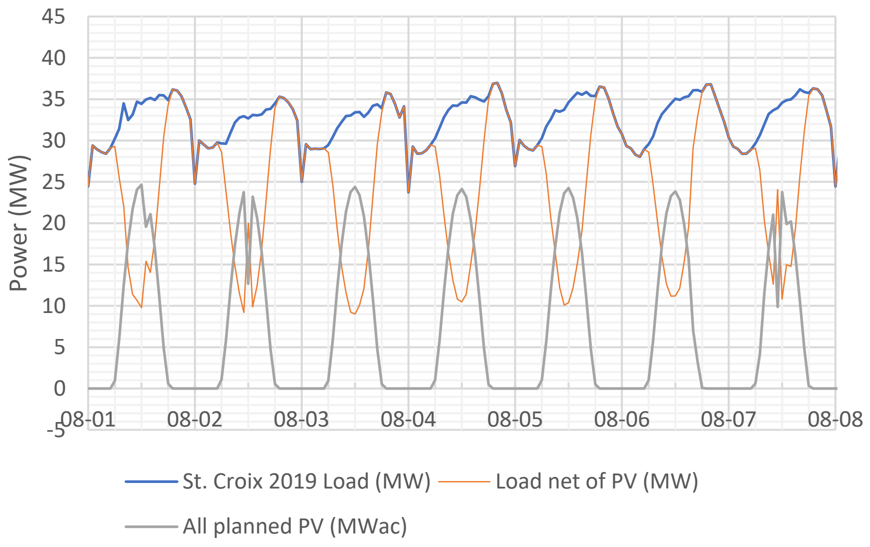
BATTERY USE CASES

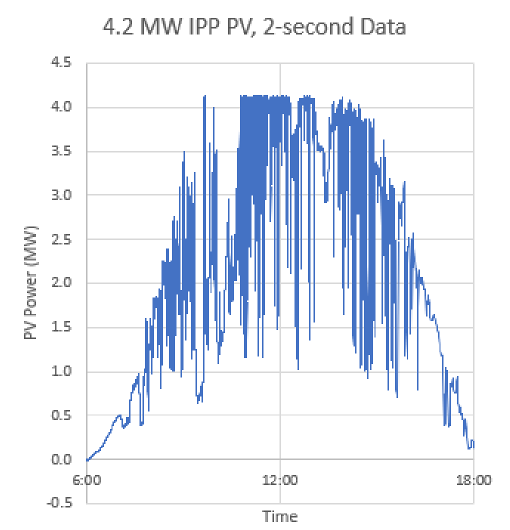
<u>Normal operations</u>

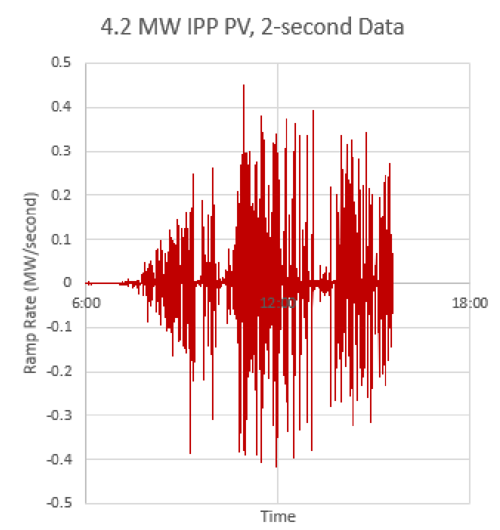
- Provide spinning reserve / improve reliability
- Support thermal generation in meeting high net-load ramp rates
- Shift PV production to afternoons or evenings
- Dampen PV dynamics

<u>Contingency</u>

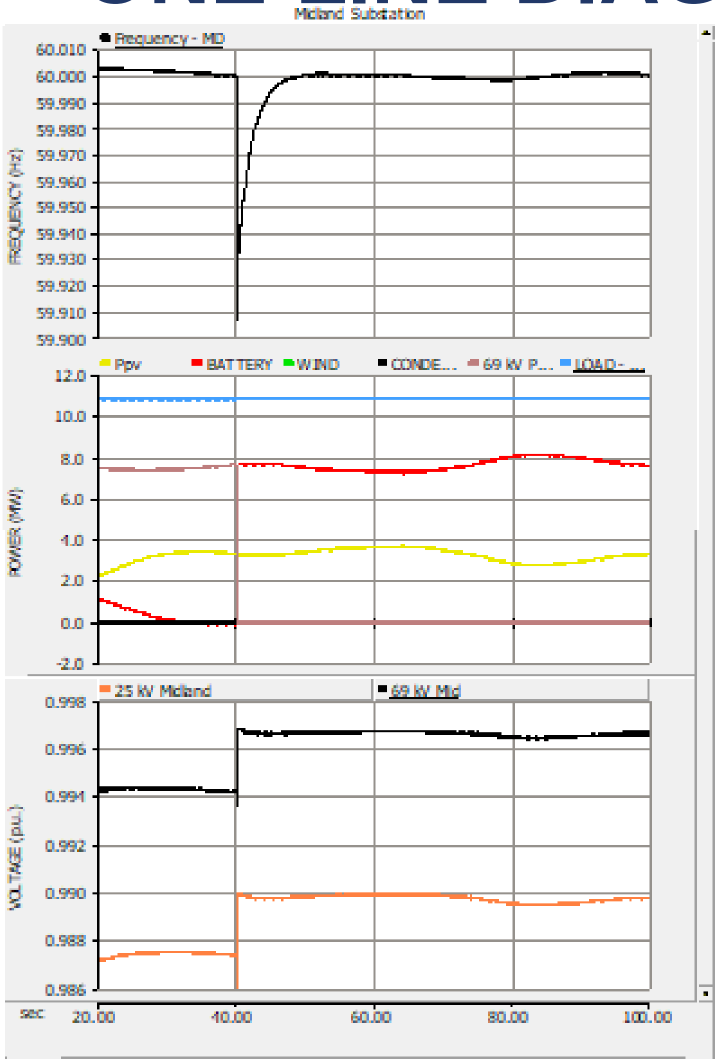
- Provide rapid response power injection to stabilize severe contingencies
- Provide ‘grid-forming’ to west end microgrid in the event of loss of central station power
- PV+BESS microgrid critical loads include: airport, fire and police, National Guard, emergency shelter

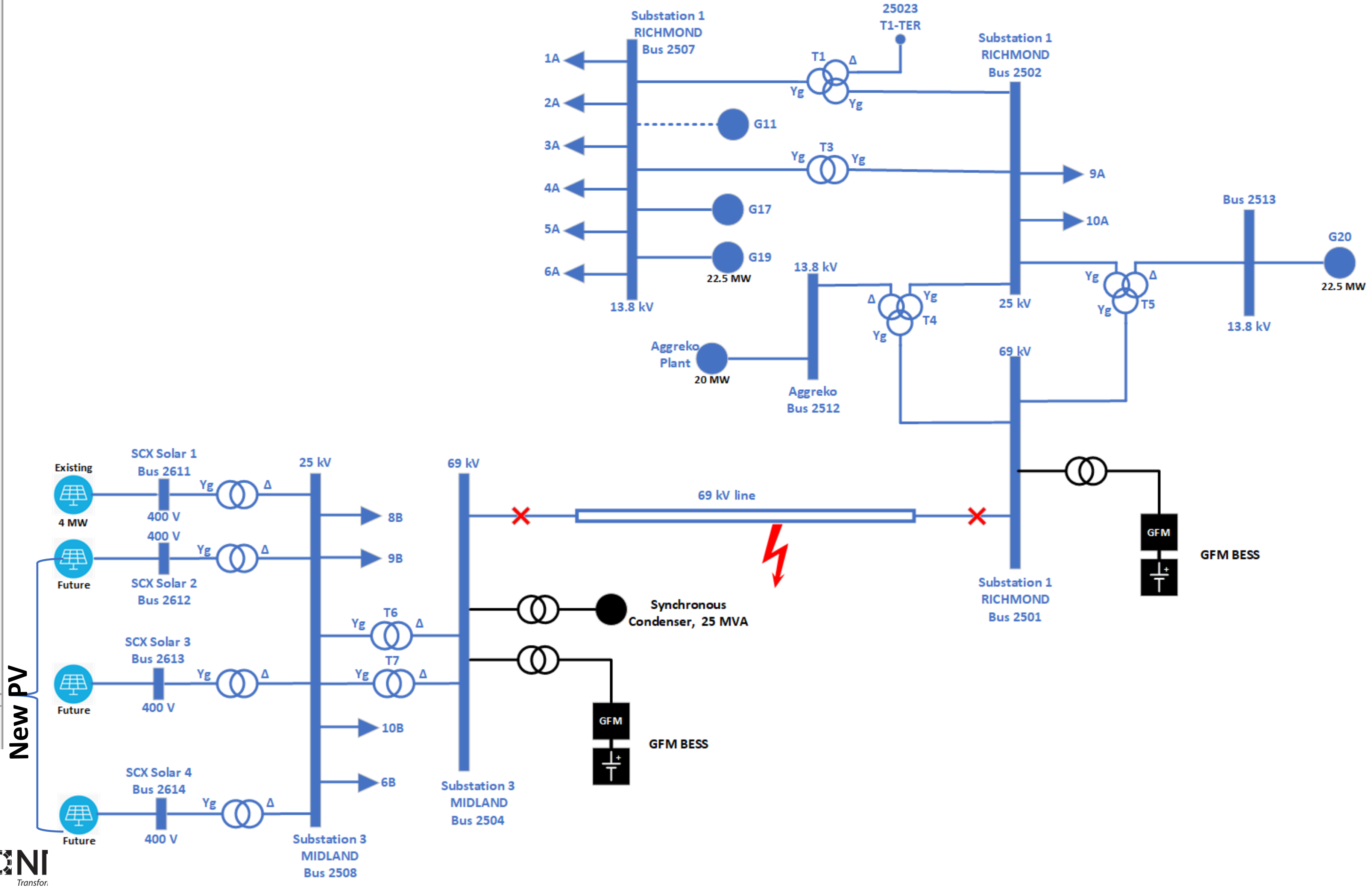






ONE-LINE DIAGRAM





Q&A

THANK YOU!

CONTACT INFO

NAVY PACIFIC MISSILE RANGE FACILITY PV+ BESS CASE STUDIES

Jim Reilly, Electrical Engineer – Microgrid Deployment

SUPPORTED BY

PMRF BEHIND-THE-METER PV + BESS

Demonstration Site: Navy Pacific Missile Range Facility, Kauai, Hawaii (HI)

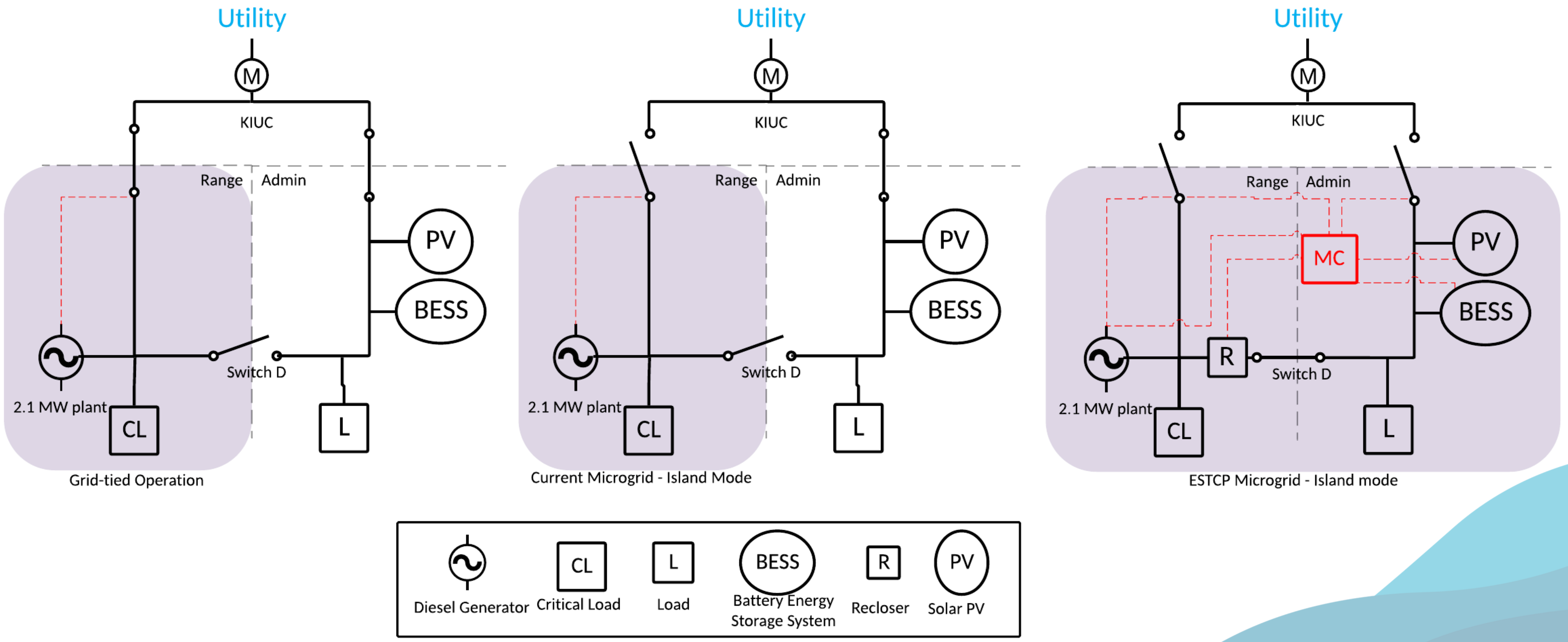
Demonstration Challenge - Many PV inverters across the US Department of Defense were not capable of remote curtailment, providing Reactive Power support, and operation in a microgrid.

Demonstration solution - Implement firmware upgrades to 2010 PV inverters, energy storage system to reduce curtailment and peak shave, and central control system to coordinate normal and islanded operation to reduce diesel fuel consumption.

Main Components and Sequence

- **Peak Load –** 945 kW peak load
    - Range operations and Administrative Area split between two circuits
- **Power Plant –** Diesel power plant runs range operations cirtuit from 8 to 4 pm, 5 days a week supporting flying range operations.
    - Six diesel generators sized 300 to 500 kW each.
- **2010 - Six Rooftop PV Arrays** - installed to reduce administrative area demand – curtailed to 28% of capacity
    - 610 kW total ranging from 50 kW to 260 kW
        - The original Interconnection Agreement (IA) with KIUC only allowed B355 and B359 to be connected in 2011 = 175 kW total.
- **Phase 1 in 2013 - EMS 1** - 80 kW/75 kWh Flooded Lead Acid BESS was installed (Navy funded with Honeywell and NREL)
        - Static curtailment - Pulled DC fuses on PV strings)
        - Dynamic AC circuit breaker on 260 kW array was used to trip if system approached export to utility.
        - EMS 1 - to reduce curtailment, support power quality, and increase curtailed PV output to 465 kW. PV is disconnected to power administrative area from power plant in island mode
- **Phase 2 in 2021 - EMS 2** – 55 kW/122 kWh Lithium-Ion batteries (ESTCP funded with KBR Wiley, Honeywell, and NREL)
    - Dynamic curtailment based on ladder logic, 5% increments of curtailment after BESS cannot absorb more PV.
- Demonstration to occur in July 2021, final report will be published in spring 2022 to https://www.serdp-estcp.org

EXISTING VS. NEW ISLANDED OPERATION



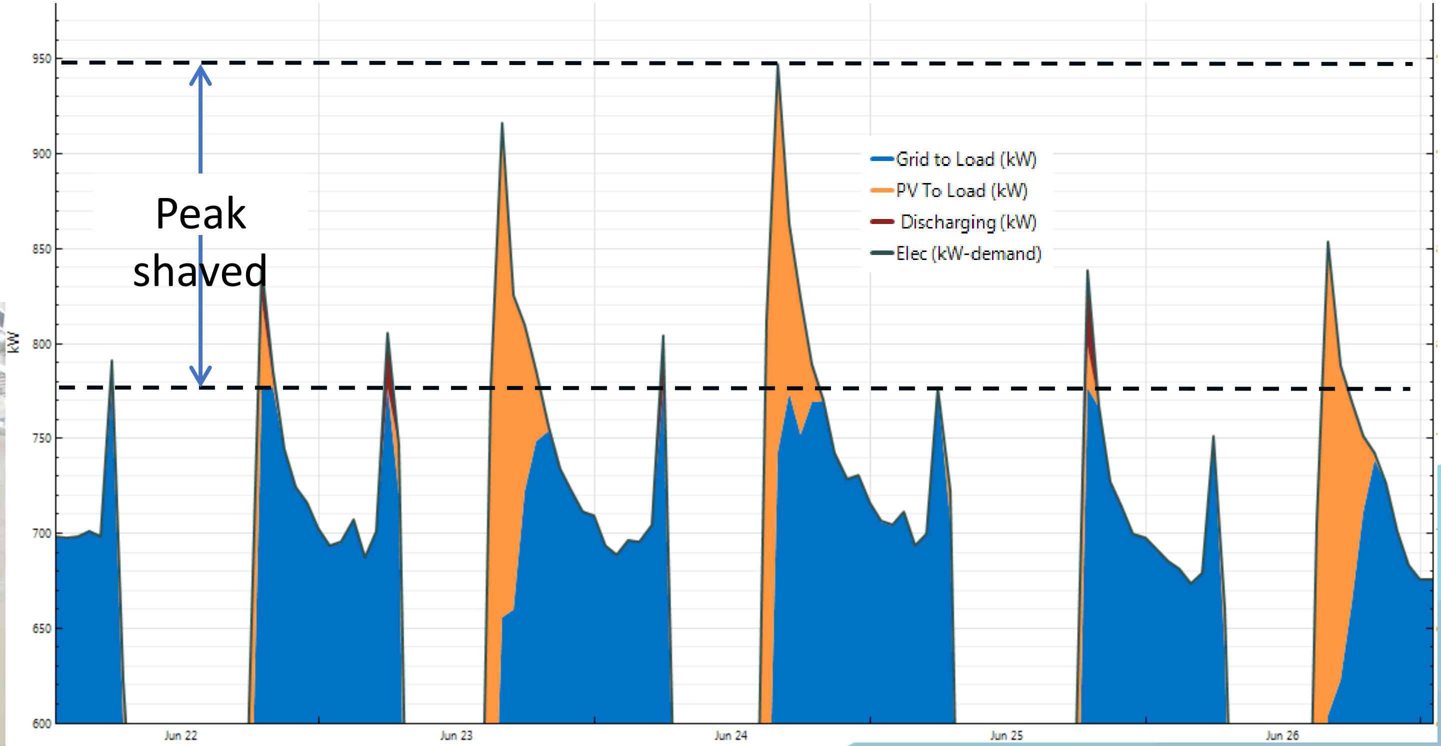
SUPPORTED BY

NREL PV AND BESS REOPT MODELING

CCREEE
CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY
AN INSITUTION OF CARICOM

5 example days in June

- PV provides bulk of the peak shaving
- Battery is discharged (red spikes at bottom)
- to incrementally shave additional peaks.
- The combined PV generation (orange) plus small, strategic discharges from battery (red) reduce the utility demand (blue).
- **Peak demand reduced by PV + BESS**
    - From 946 kW to 776 kW
- NREL performed Controls Hardware in the Loop testing at ESIF on a scaled version of the network
    - Validate controls
    - Cyber penetration testing



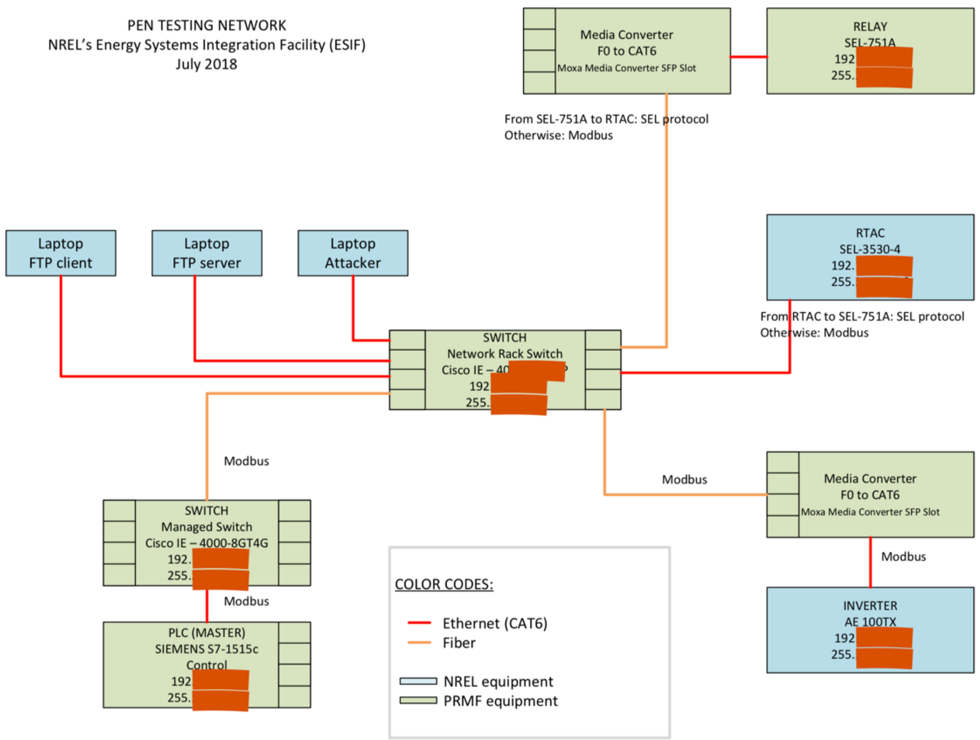
56

ESIF CYBERSECURITY PENETRATION TESTING

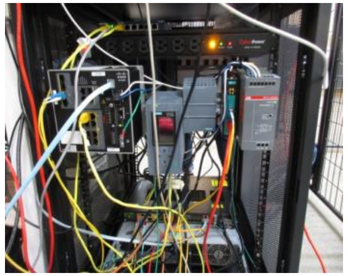
CCREEE CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY

AN INSITUTION OF CARICOM

- NREL performed Controls Hardware in the Loop testing at the Energy System Integration Facility
    - Scaled control network and collaboration between engineering firm and NREL for controls valuation
    - Cyber penetration testing - Results informed security protocols for PMRF EMS and BESS control system



SEL RTAC 3530 and Cisco 4010



Siemens PLC and Cisco 4000

SEL 751A

Comparable AE inverter to those installed at PMRF

KAUAI, AES, AND PMRF PV+BESS FRONT OF THE METER – UTILITY SCALE

- **Who:** Kauai Island Utility Company , AES, and US Navy partnership
- **Where:** Navy Pacific Missile Range Facility, Kauai, Hawaii
- **How:** Enhanced Use Lease on U.S. Navy property, 25+ year term
- **Generation:**
  - Solar PV - 19.3 megawatts of ground-mount solar PV
  - Energy Storage - 30 MW/70 MWh Li-Ion
- **Why:** Two main operating modes
  - Normal grid conditions – AES will sell power to KIUC, 25 year PPA
    - PV and BESS will offset diesel power generation on Kauai
    - BESS will support power quality and store solar PV
    - Will displace 2.8 million gallons of diesel fuel generation
  - Islanded operation – AES PV + BESS will island with PMRF loads
    - In the event of a short-term or extended grid outage, BESS can support PMRF for 50+ hours without PV, if fully charged at time of outage. Runtime will be significantly extended by PV
- **NREL support:** 2019 Hardware-In-the Loop testing
  - Scaled PV + BESS in Controllable Grid Interface environment
  - Microgrid controls, power quality demonstration, controls validation

Photo: AES Corporation

430 kW PV array
Scaled to 19.3 MW

1 MW/1 MWh battery
Scaled to 30 MW : 70 MWh

CCREEE – CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY
AN INSITUTION OF CARICOM

SUPPORTED BY german cooperation; IMPLEMENTED BY giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH; USAID FROM THE AMERICAN PEOPLE; NREL Transforming ENERGY; Resilient Energy Platform; CIMH

INVERTER-BASED OPERATION OF POWER SYSTEMS: ELECTROMAGNETIC TRANSIENT SIMULATIONS AND GRID-FORMING INVERTERS WITH THE MAUI POWER SYSTEM

Rick Wallace Kenyon, Researcher
National Renewable Energy Laboratory + University of Colorado Boulder

CCREEE CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY
AN INSITUTION OF CARICOM

SUPPORTED BY
IMPLEMENTED BY: giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
USAID FROM THE AMERICAN PEOPLE
NREL Transforming ENERGY
Resilient Energy Platform
CIMH

FOCUS

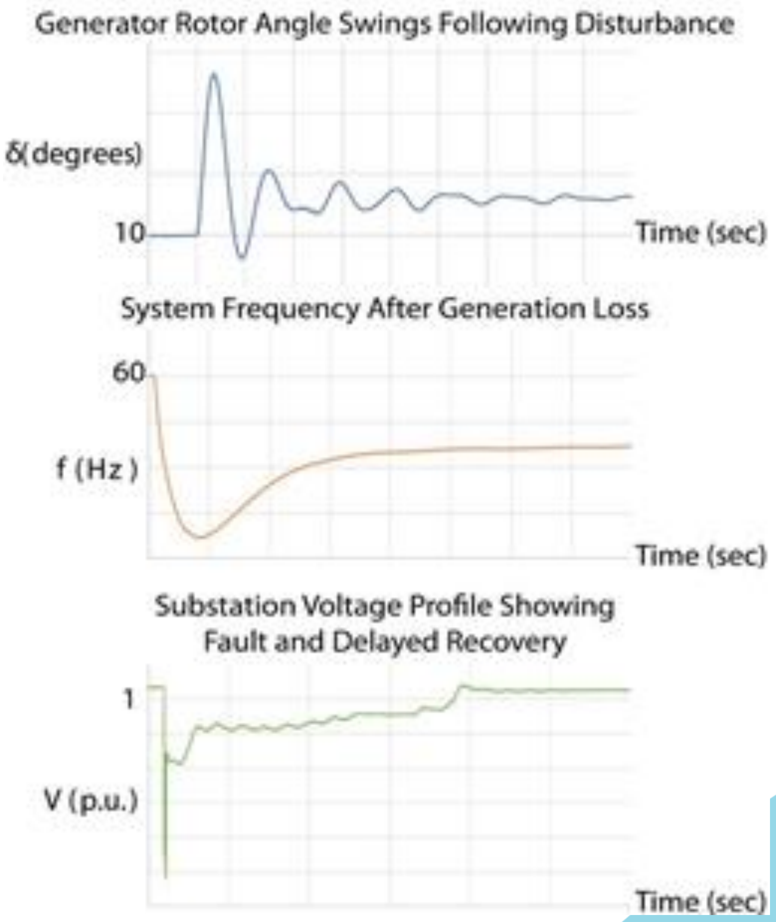
- Interest is the general stability, resilience, and simulation of power systems with very high penetrations of inverter-based resources using the Maui power system
  - What are the impacts to the power system dynamics with these high-penetrations of renewables?
  - Are traditional dynamic simulation software sufficient to capture these changed dynamics?

- Storage plays a key role in these systems both as
  - A source of headroom for load-generation imbalances
  - An energy source for grid-forming inverter controls that have shown preliminary capabilities of stabilizing these very high inverter based-resource penetrations
  - Many others

SCOPE OF PRESENTATION IS SHORT-TERM DYNAMICS

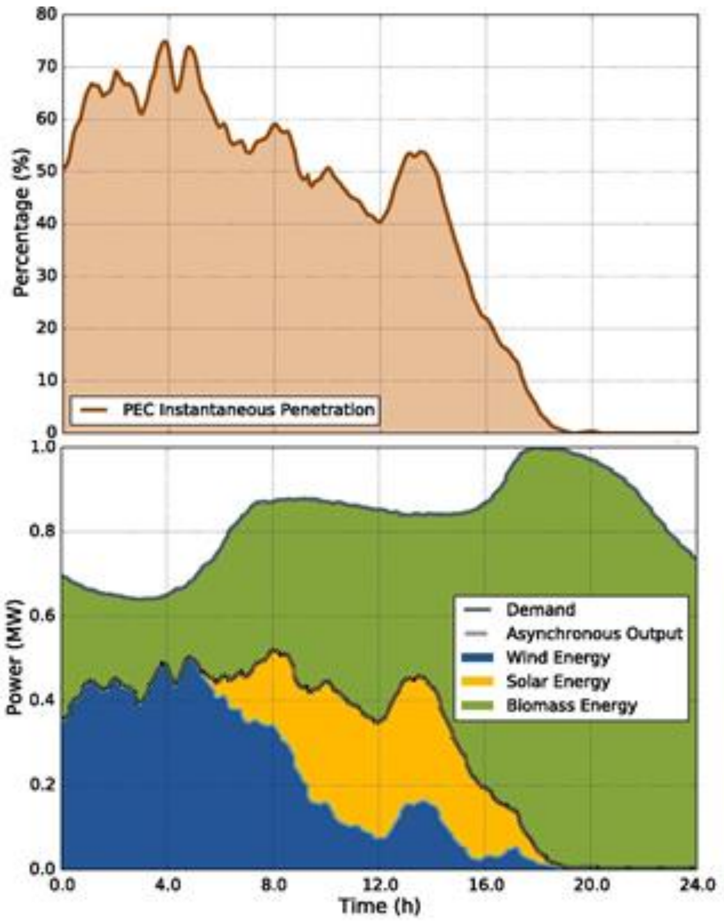
- Load-generation balance
  - Sub-second (inertial time scale)
  - Seconds (primary frequency response time scale)

- Voltage and frequency transient stability
  - Resilience to faults
  - Resilience to loss of generation/load
  - Resilience to loss of system strength



SUPPORTED BY

INSTANTANEOUS PENETRATION IS IMPORTANT



- Substantial variations in generation type online can occur throughout a single day

- Simple test system day-dispatch (not Maui):
  - Peak instantaneous: 75%
  - Total energy served by IBRs: 39%

- Many of the challenges associated with high inverter-based resource (IBR) penetrations are a function of the portion of power delivered at a particular time, not the aggregate energy delivered over a period of time

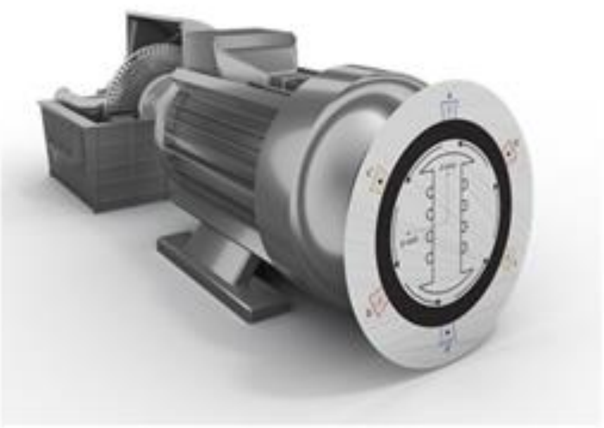
[1] "Stability and control of power systems with high penetrations of inverter-based resources," R.W. Kenyon, et al., *Solar Energy*, 2020

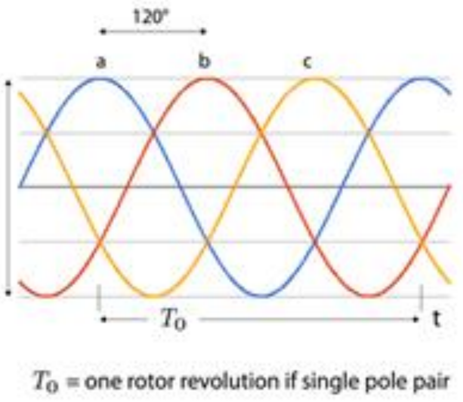
SUPPORTED BY

SYNCHRONOUS GENERATORS

CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY

AN INSITUTION OF CARICOM

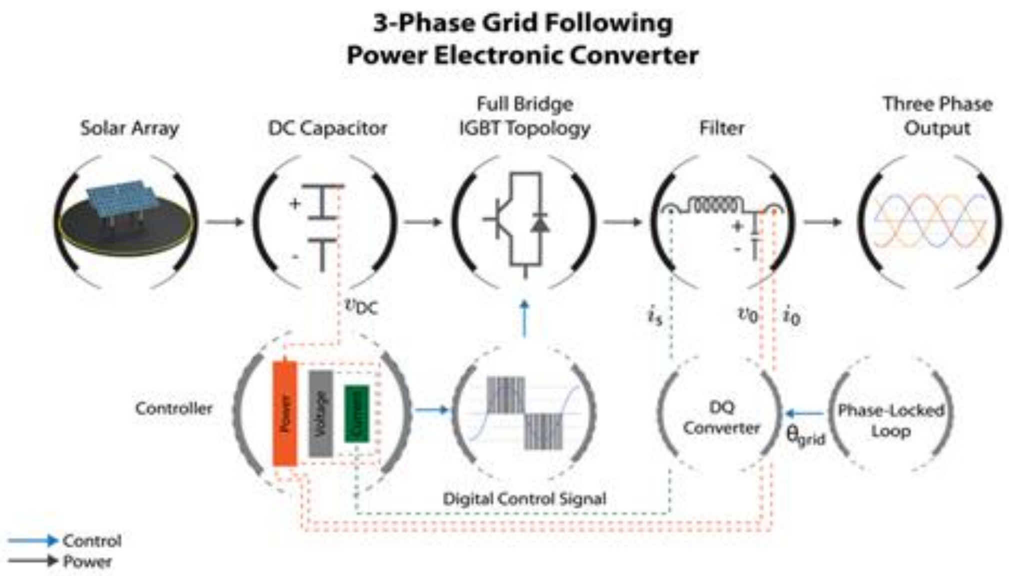




- A synchronous generator (SG) naturally generates a sinusoidal output voltage waveform; these are *grid-forming* devices
  - A de-facto voltage source on the power system
  - A large mass (the turbine/machine) is electromagnetically coupled to the AC power system
    - Embeds inertial characteristics
- Governors, which change mechanical power, are relatively slow (> 0.5 seconds)
  - Load perturbations initially met by inertial energy
- Large, transient overcurrents in faulted conditions (4 – 7 times rated)
  - Basis for many protection systems

[1] "Stability and control of power systems with high penetrations of inverter-based resources," R.W. Kenyon, et al., *Solar Energy*, 2020

GRID-FOLLOWING (CONVENTIONAL) INVERTERS



- Inverter tracks an existing, sinusoidal waveform with a phase-locked loop and bases all control objectives on the assumed presence of this waveform
  - Hence, *grid-following ("GFL")*

- A collection of cascaded dynamical control systems
  - Phase-Locked Loop
  - Inner Current Loops
  - Power Loops

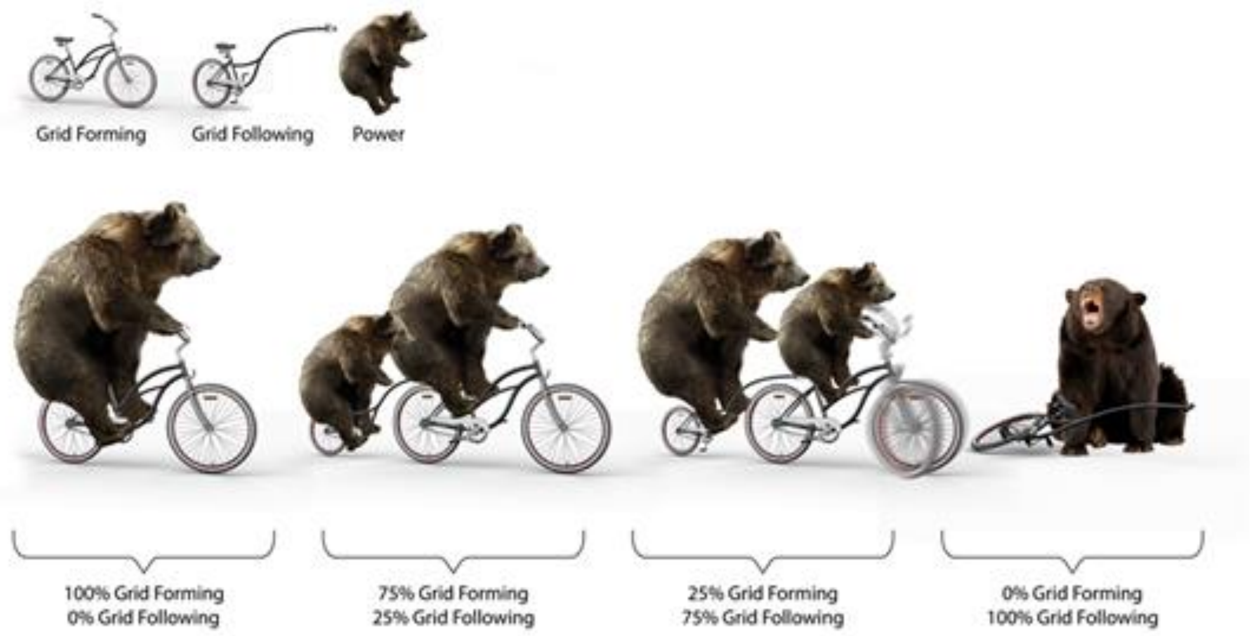
- Auxiliary Control
  - Grid Support Functionality, Limiting, Fault Behavior, Ride-through, etc.

- ***Not modelled in our studies is the pulse width modulation control and associated power electronic switching***

[1] "Stability and control of power systems with high penetrations of inverter-based resources," R.W. Kenyon, et al., *Solar Energy*, 2020

WHAT HAPPENS WITH FEWER GRID FORMING ASSETS?

CCREEE
CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY
AN INSITUTION OF
CARICOM



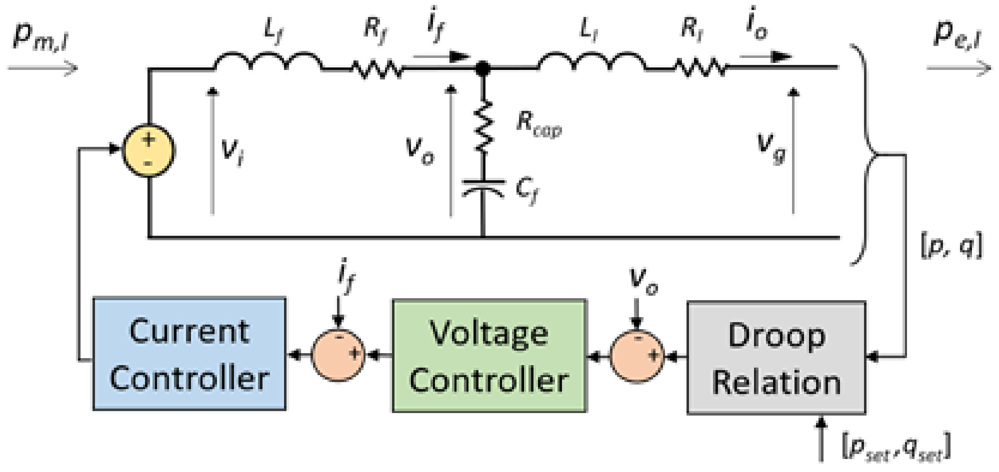
Here, Grid-Forming is a broad term including Synchronous Machines

- With fewer grid-forming assets online, the *stiffness* of the AC voltage is reduced
- This impacts the stability of assets that require a voltage waveform to operate; i.e., GFL inverters
- Not necessarily a low-inertia problem, although there is a relation if the only grid-forming assets involved are SGs

[1] "Stability and control of power systems with high penetrations of inverter-based resources," R.W. Kenyon, et al., *Solar Energy*, 2020

SUPPORTED BY
german cooperation DEUTSCHE ZUSAMMENARBEIT
IMPLEMENTED BY: giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
USAID FROM THE AMERICAN PEOPLE
NREL Transforming ENERGY
Resilient Energy Platform
CIMH

GRID-FORMING (GFM) INVERTERS

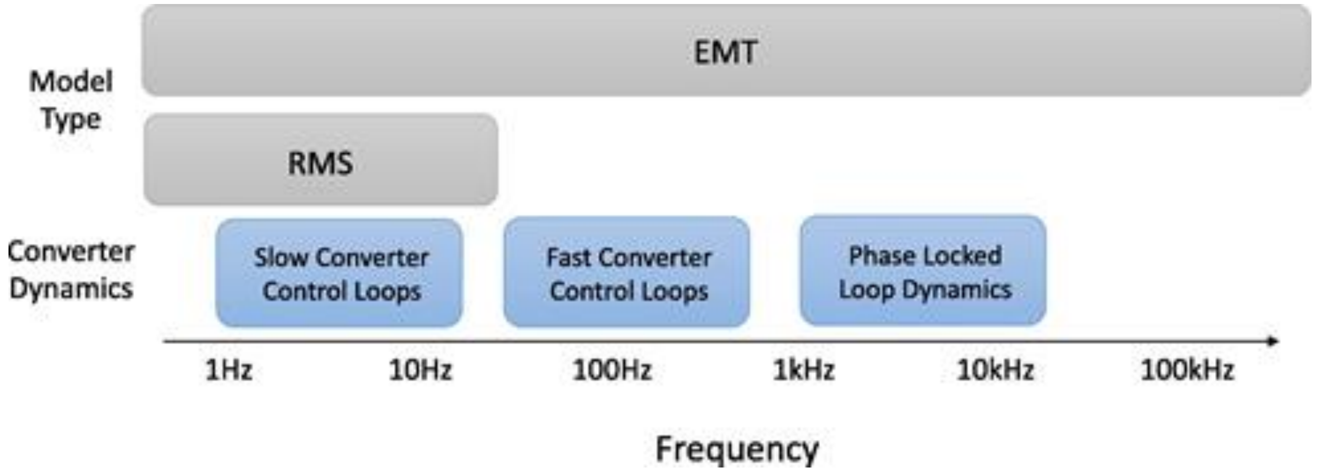


- A *grid-forming* inverter generates an AC voltage waveform at the output terminals
  - Acts as a voltage source
  - Control schemes are designed to accomplish various power flow objectives
- ***Requires headroom (storage and/or curtailment) for operation***
- Grid-forming inverters have been used for decades in off-grid/islanded applications:
  - *grid-connected GFM inverters in parallel with SGs and/or other inverters is new*
- Some limitations compared to the grid-forming SGs, such as over-current capabilities
  - But, not required to follow second-order frequency dynamics

[2] "Research Roadmap on Grid-Forming Inverters", Y. Lin et al., NREL/TP-5D00-73476, Nov 2020
[3] R.W. Kenyon, et al., "Open-Source PSCAD Grid-Following and Grid-Forming Inverters and a Benchmark for Zero-Inertia Power System Simulations," KPEC 2021

SUPPORTED BY

ELECTROMAGNETIC TRANSIENT (EMT) SIMULATIONS

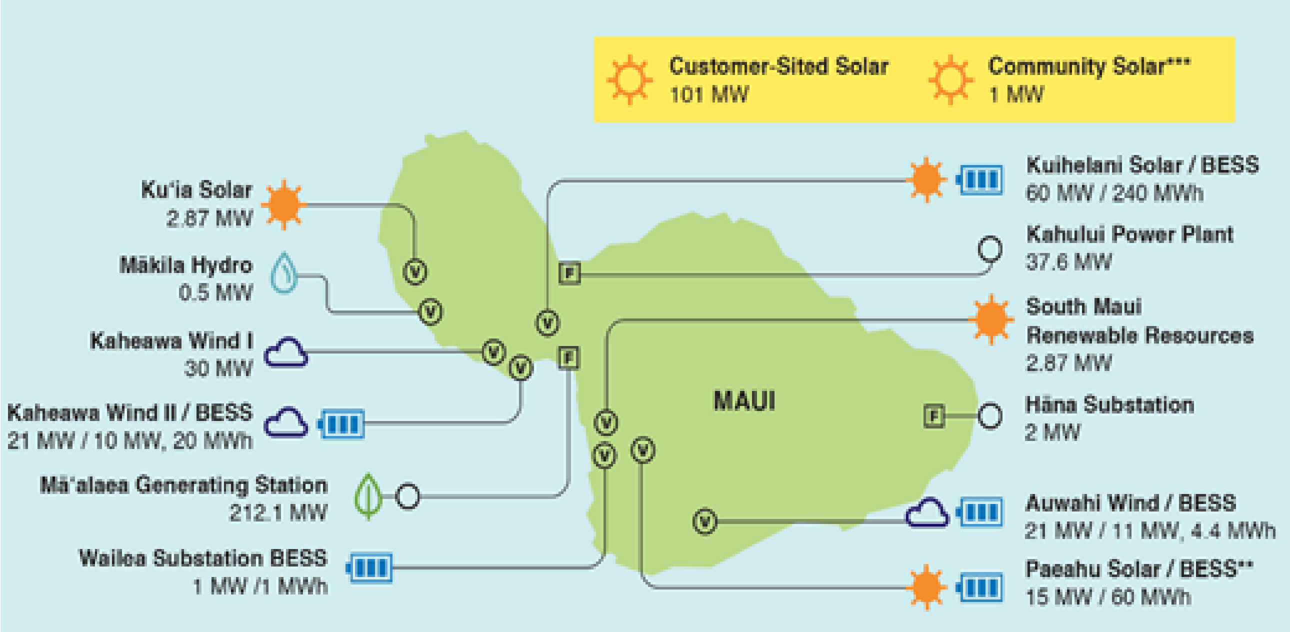


- Traditional **positive sequence phasor domain simulation tools** (PSSE, PSLF, …) capture most conventional power system electromechanical modes well, but do not model waveforms and **can miss dynamics below a few Hz**
- Electromagnetic transient simulation tools (PSCAD, EMTP, …) can simulate AC waveforms on arbitrarily small timesteps, so can capture full IBR dynamics
- Model runtimes are orders of magnitude slower (hours vs. seconds)

MAUI BACKGROUND

- Hawaiian Electric expects Maui to be the first large island capable of operating with 100% inverter-based power resources, possibly by 2023
  - 2020 peak: ~89.5% IBR (DER and wind)
  - interconnected power system (~200 MW peak)
  - highly distributed utility-scale generation
  - 69 kV voltage backbone

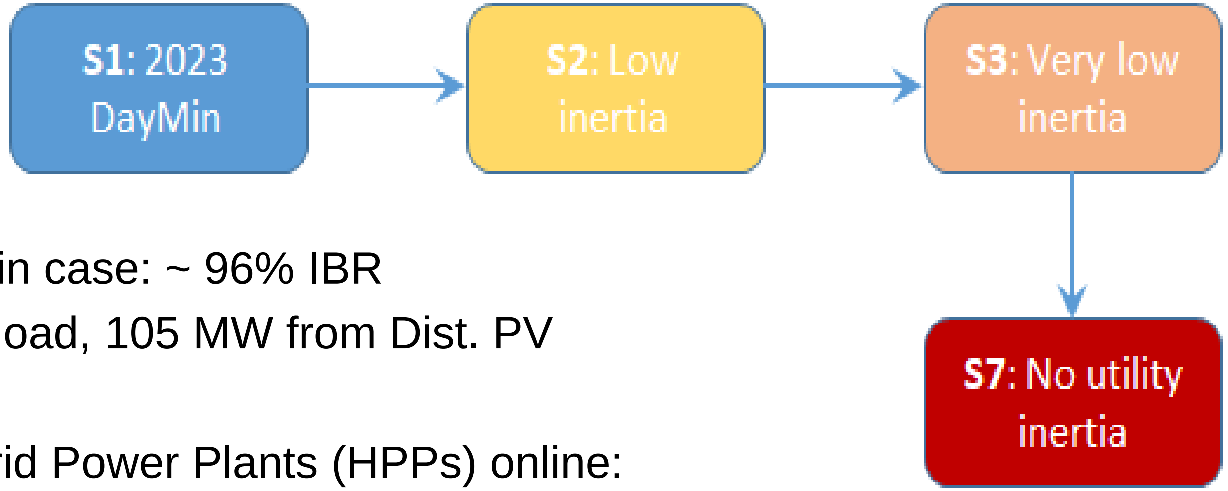
- NREL currently performing EMT study (PSCAD), validated model against field date

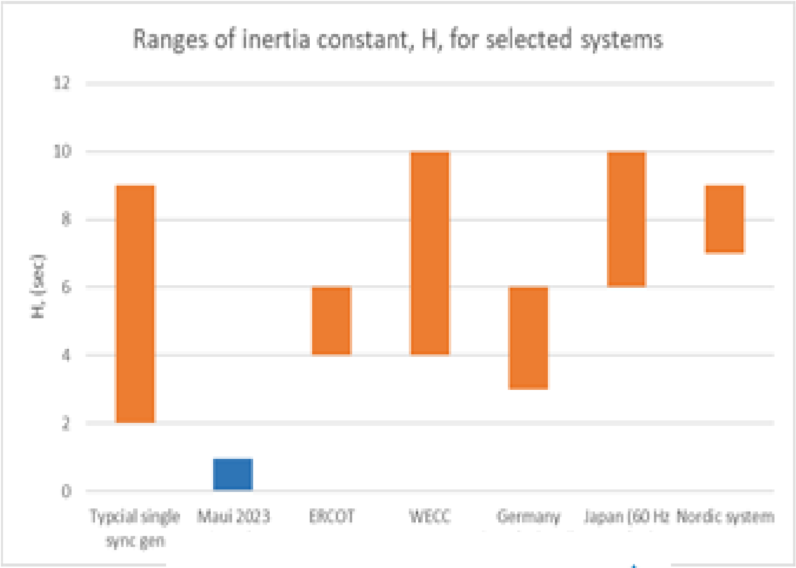


•These studies are just steps in a complex due-diligence process working towards operating Maui in an unprecedented way

[4] "Validation of Maui PSCAD Model: Motivation, Methodology, and Lessons Learned," R. W. Kenyon, B. Wang, A. Hoke, J. Tan, B. Hodge, *IEEE NAPS*, April 2021. https://www.osti.gov/biblio/1760667

SIMULATION BASE CASE: "SCENARIO 1"



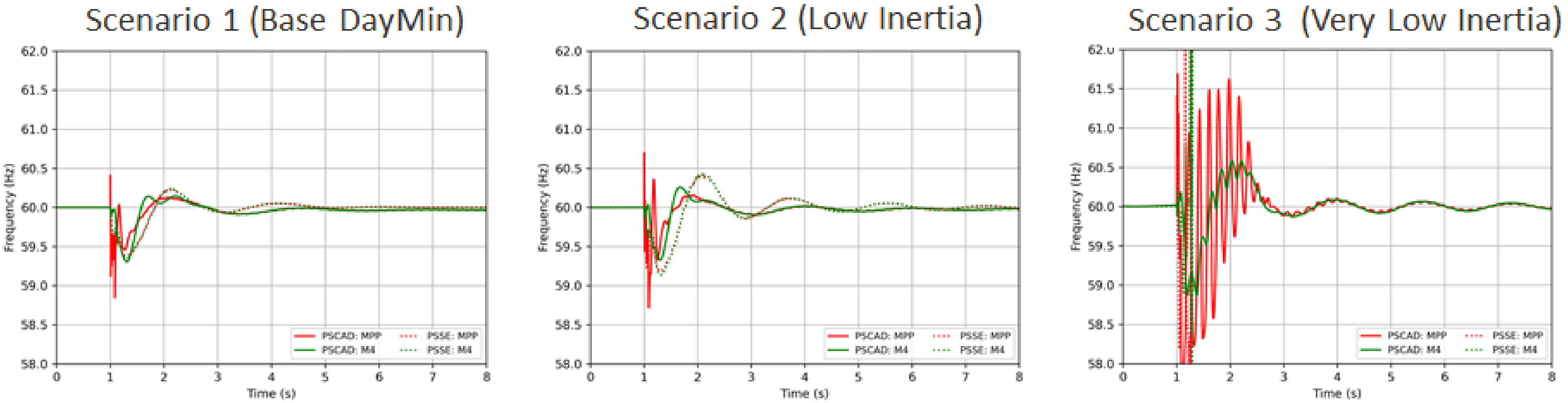


Note: We use "inertia" as a proxy metric for online synchronous machines

2023 DayMin case: ~ 96% IBR

- 145 MW load, 105 MW from Dist. PV
- Two Hybrid Power Plants (HPPs) online:
  - 60 MVA and 15 MVA, GFL devices
  - Dispatched at 6 and 0 MW, respectively
- Inertia: 370 MVA·s; Inertia constant H = 0.97 s (~1 order of magnitude below typical systems)
  - 75% is sourced via 6 synchronous condensers
- Will compare results of PSSE and PSCAD

FAULT AT LOW SHORT CIRCUIT RATIO BUS - FREQUENCY

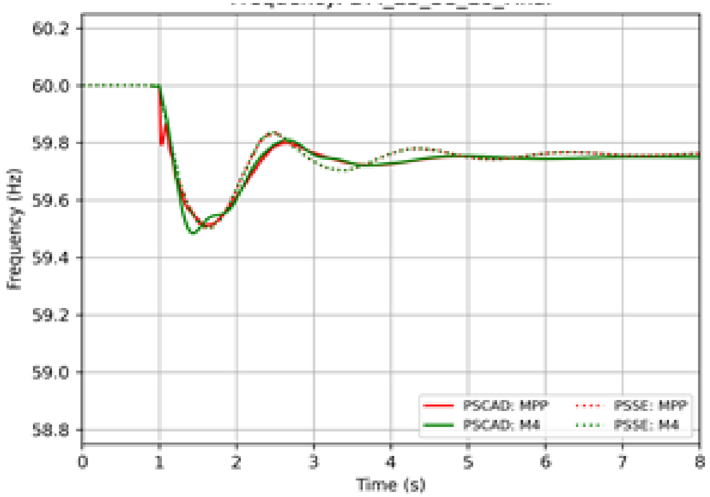


PSCAD: MPP is a PLL-measured frequency. PSCAD: M4 is a generator shaft rotation speed derived frequency

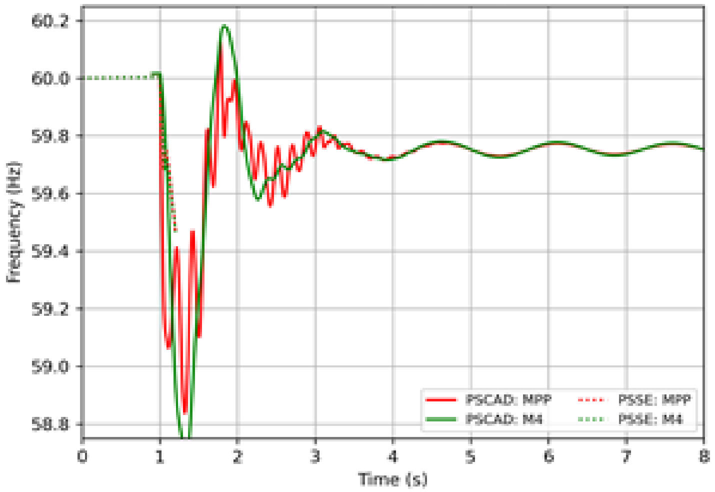
- Scenario 1 --> Scenario 3: fewer voltage sources and reduced inertia
  - Exacerbated oscillatory modes in S3, both in damping and quantity
- PSSE simulation for Scenario 3 is numerically unstable shortly after the fault
- Scenario 7 is not shown, but not viable/stable with no voltage source devices online

EVENT 8 – LOSS OF GENERATION: FREQUENCY

Scenario 1 (Base DayMin)



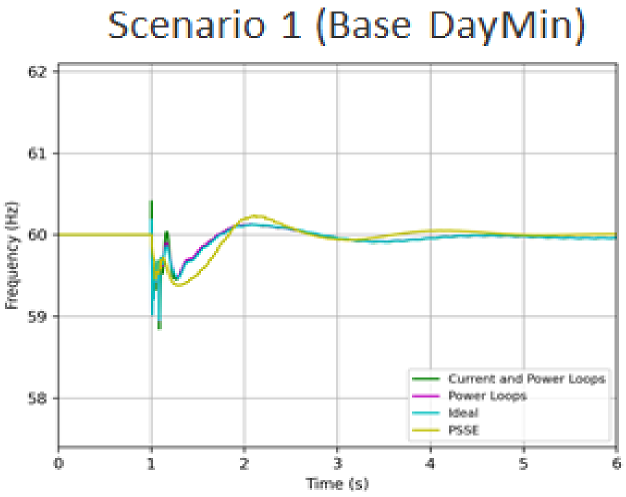
Scenario 3 (Very Low Inertia)

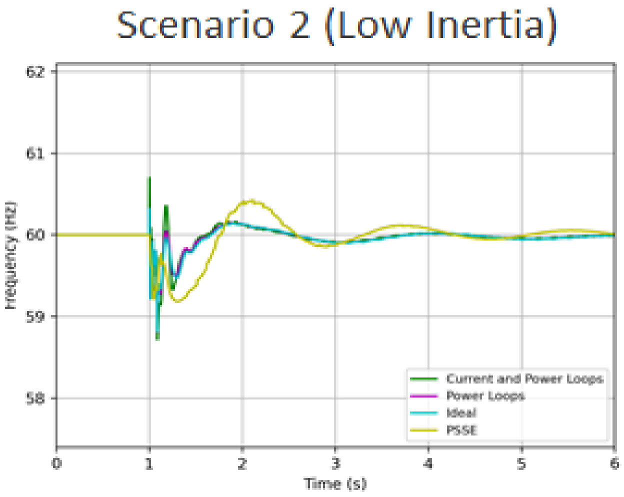


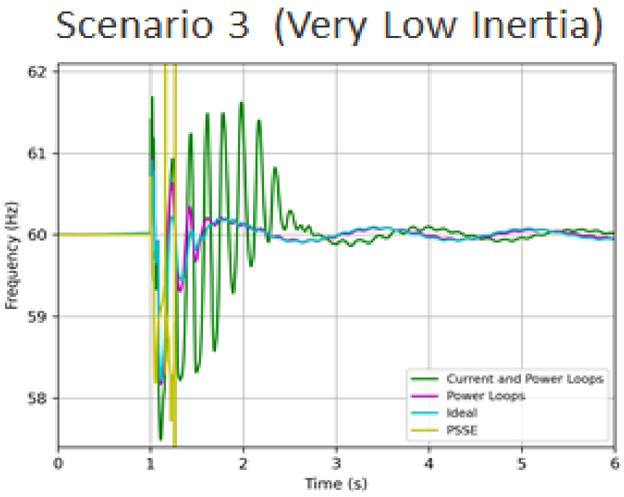
PSCAD: MPP is a PLL-measured frequency. PSCAD: M4 is a generator shaft rotation speed derived frequency

- Scenario 1 versus Scenario 3: reduced inertia and fewer voltage sources
  - Lower nadir, larger ROCOF, as expected
  - No voltage perturbation, yet large oscillations still present in PLL-derived frequency

INFLUENCE OF INNER CONTROL LOOPS: FREQUENCY







- Reduce the order of the dynamic GFL models in PSCAD
  - Ideal control is similar to PSSE implementation, current and power loops closest to actual devices

- Substantial oscillatory modes exacerbated with full order models, compared to far larger damping/magnitude reduction with lower order models

- ***Full order required to capture relevant dynamics!***

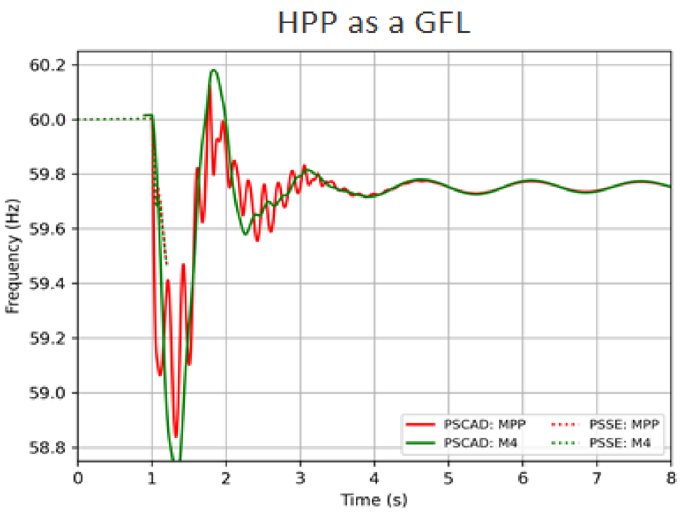
SUPPORTED BY

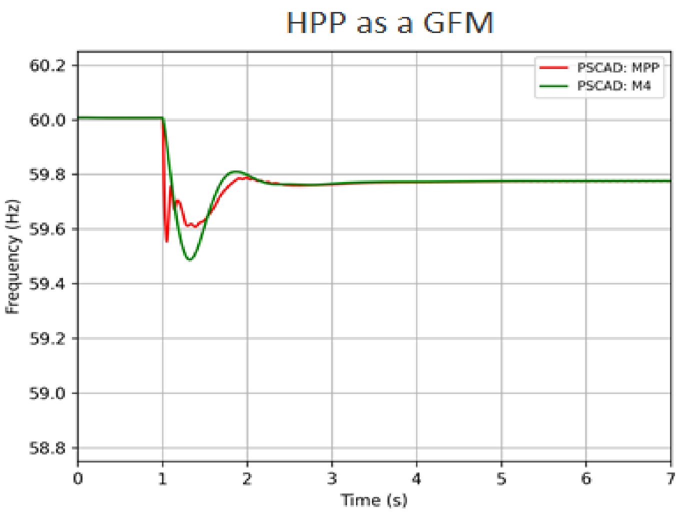
IMPROVED STABILITY WITH GRID FORMING (GFM) INVERTERS

- Substituted a single GFM (30 MVA) HPP inverter for a GFL (30 MVA) in previously unstable case
  - Significant improvement in S3 system response

- Only simulated a generation loss; comparing Scenario S3 results

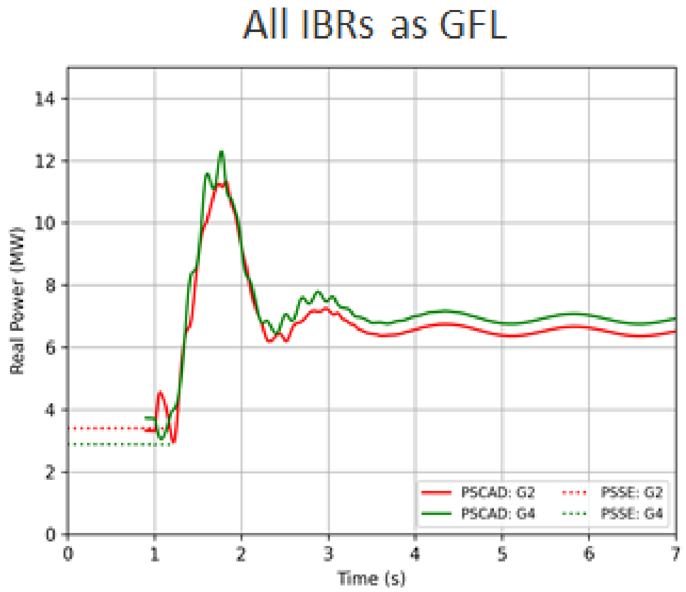
SCENARIO 3: LOSS OF LARGEST GENERATOR - FREQUENCY

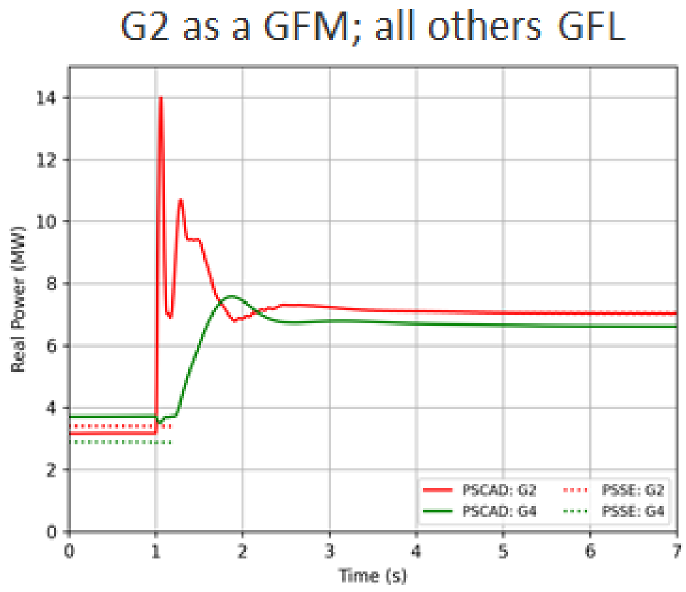




- Substantial increase in primary damping; major reduction in faster modes
- Nadir is raised significantly (58.7 to 59.5 Hz), and ROCOF improved (despite no increase in inertia)

SCENARIO 3 LOSS OF GENERATION: HPP OUTPUT POWER





- GFL (green) device requires a change in frequency as a signal to adjust power export.
  - *Note that the power injection is itself a type of disturbance, due to the current source operation of the GFL device*
- As a GFM (red), active power is extracted by the network from the device due to the operation as a voltage source maintaining phase angle and hence frequency.
  - Power isn't *injected*, it's *extracted*. GFM control inherently provides FFR (among other things).

SUPPORTED BY

SUMMARY

- Phasor-domain simulation faces numerical instability and misses key system dynamics in some low-inertia/few voltage forming devices scenarios

- Modeling inverter control loops (power and current) of GFL devices is required to detect faster modes in the system response under very weak grid conditions

- Presence of a single GFM (30 MVA) greatly increases damping, ROCOF, and nadir of primary frequency mode
  - Stabilizes faster modes
  - Mitigates instability of remaining GFLs
  - Presumably need two GFMs for N-1 reliability

- ***<u>Note</u>: These simulations focus on transient stability and do not consider other topics necessary for 100% IBR operation, e.g. protection, reserves, resource adequacy…***

Q&A

THANK YOU!

Rick Wallace Kenyon

Richard.kenyon@nrel.gov

SUPPORTED BY

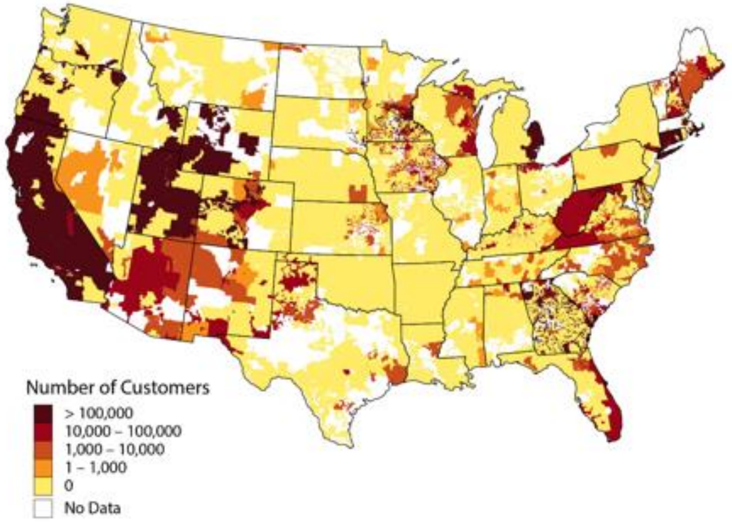
- Backup Slides

TYPICAL ELECTRICITY BILL COMPONENTS

CCREEE
CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY

AN INSITUTION OF
CARICOM

BILL COMPONENT	HOW IT IS BILLED	HOW STORAGE CAN HELP
ENERGY CHARGES	• Billed based on amount of electricity (kWh) consumed • Cost can vary by TOU and by season	Shift usage from high TOU periods to low TOU period
DEMAND CHARGES	• Billed based on maximum demand (kW) during certain period, typically maximum demand each month • Cost can vary by time of use and by season	Reduce usage during peak demand period
FIXED CHARGES	• Fixed cost billed monthly • Determined by rate schedule, not consumption	Not typical

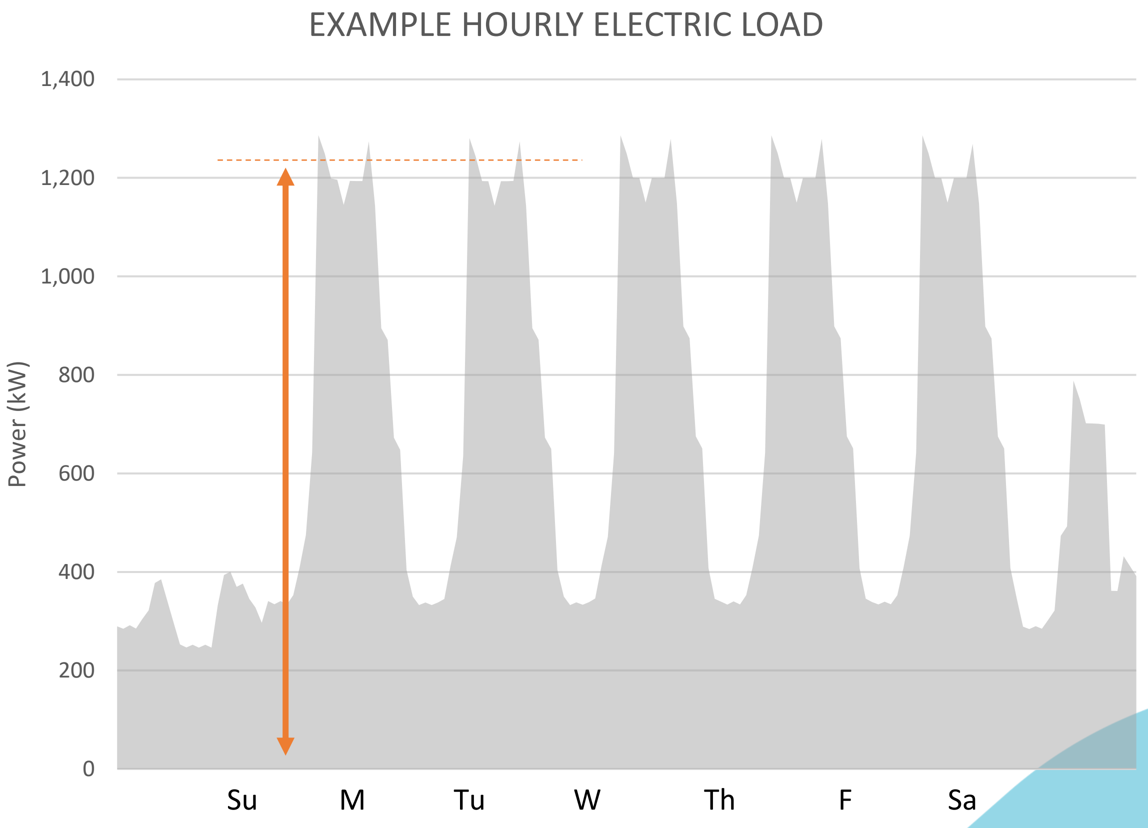


NUMBER OF COMMERCIAL CUSTOMERS WHO CAN SUBSCRIBE TO TARIFFS WITH DEMAND CHARGES OVER $15/KW

SOURCE: IDENTIFYING POTENTIAL MARKETS FOR BEHIND-THE-METER BATTERY ENERGY STORAGE: A SURVEY OF U.S. DEMAND CHARGES
HTTPS://WWW.NREL.GOV/DOCS/FY17OSTI/68963.PDF

ELECTRICITY USAGE

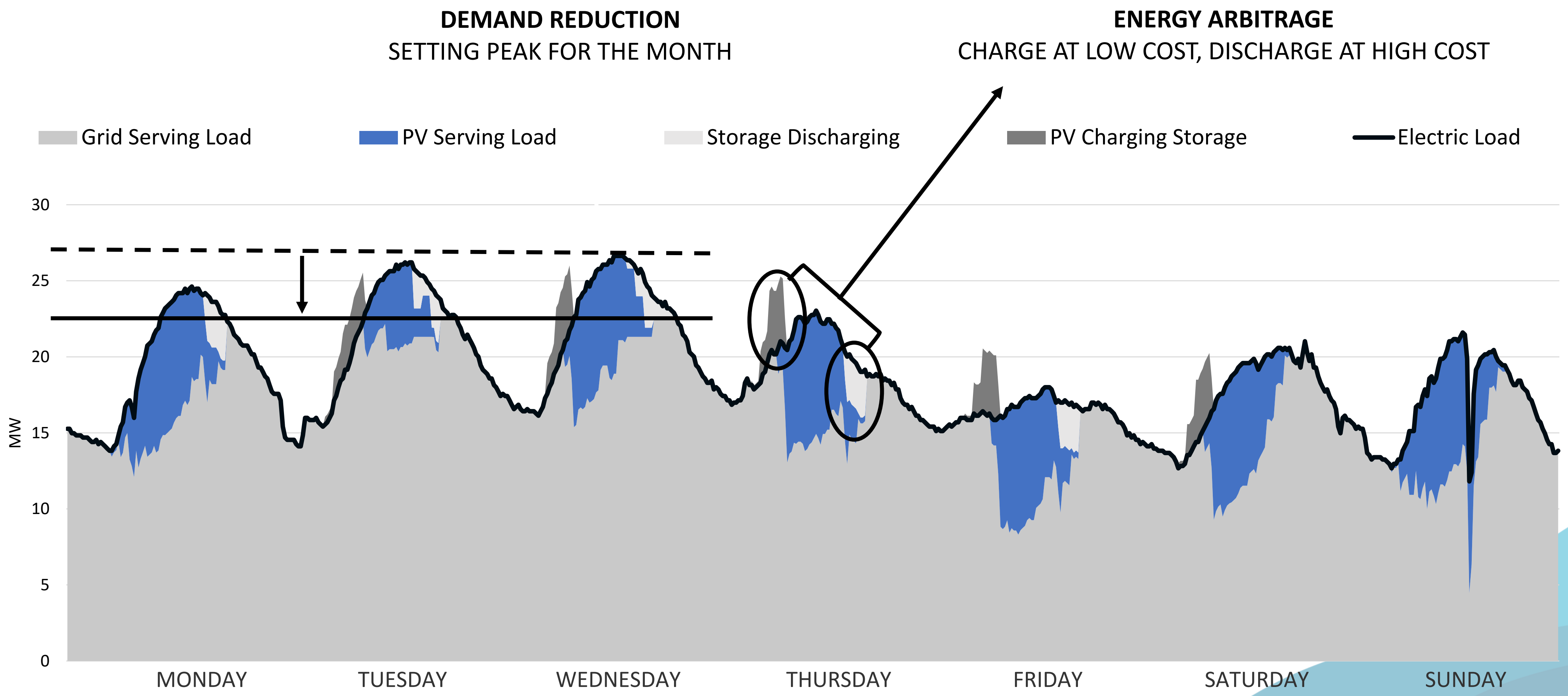
- A site's electric load is characterized by the amount of electricity consumed and when that electricity is consumed.
- Common electricity use characteristics include total electricity consumption (light blue shaded area) and maximum electricity consumption at a given time (red line).
- Advanced meters typically track a site's electricity consumption on an hourly or 15-minute basis; this is referred to as interval data.



EXAMPLE OF DEMAND REDUCTION AND ENERGY ARBITRAGE

AN INSITUTION OF CARICOM

CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY



SUPPORTED BY

NET METERING VERSUS NET BILLING

NET METERING	NET BILLING
Most common compensation mechanism in the United States	Growing popularity in the United States
Energy generation in excess of on-site consumption credited, typically at retail rate	All energy exports from the system credited at a sell rate typically below the retail rate of electricity. All imports debited at the retail rate.
Grid operates as "financial storage," allowing consumers to bank their photovoltaic (PV) generation to use later	Weaker incentive for stand-alone PV
Typically not an effective incentive for pairing storage with PV	Stronger incentive for storage-plus-PV rates as it encourages self-consumption of PV generation

SOURCE: ZINAMAN ET AL. 2017

TIME-VARIANT SELL RATE DESIGN

CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY

AN INSITUTION OF CARICOM

- Can encourage storage deployment
- Can align customer behavior with system needs
- Hawaii Smart Export:
  - Encourage pairing of storage and PV
  - Encourage afternoon exports.

ISLAND	12 a.m. – 9 a.m. (₵/kWh)	9 a.m. – 4 p.m. (₵/kWh)	4 p.m. – 12 a.m. (₵/kWh)
Oahu	14.97	0	14.97
Maui	14.41	0	14.41
Lanai	20.79	0	20.79
Molokai	16.64	0	16.64
Hawaii	11	0	11

SOURCE: HAWAIIAN ELECTRIC COMPANY 2019

SUPPORTED BY
german cooperation
IMPLEMENTED BY: giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
USAID FROM THE AMERICAN PEOPLE
NREL Transforming ENERGY
Resilient Energy Platform
CIMH

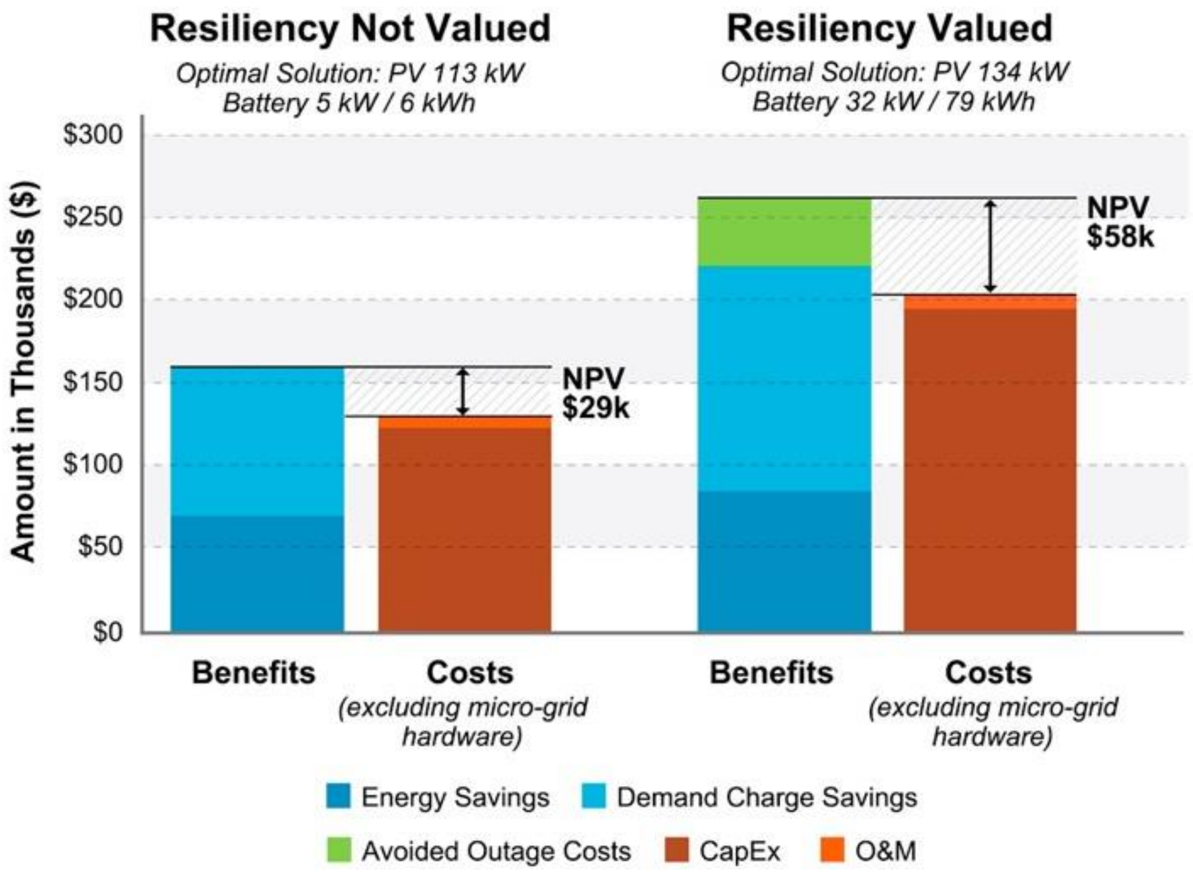
VALUING RESILIENCE

CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY

AN INSITUTION OF CARICOM

Implementing a value of resilience into a least-cost optimization can influence the "optimal" PV + storage system at a given site:

- Increases PV capacity
- Increases battery size and duration
- Increases the overall NPV



SOURCE: HTTPS://WWW.NREL.GOV/DOCS/FY19OSTI/74673.PDF

GRID-CONNECTED VS. ISLANDABLE PV + STORAGE COMPONENTS

- Distributed generation assets
- Energy storage
- Inverter

PV + STORAGE PROJECT

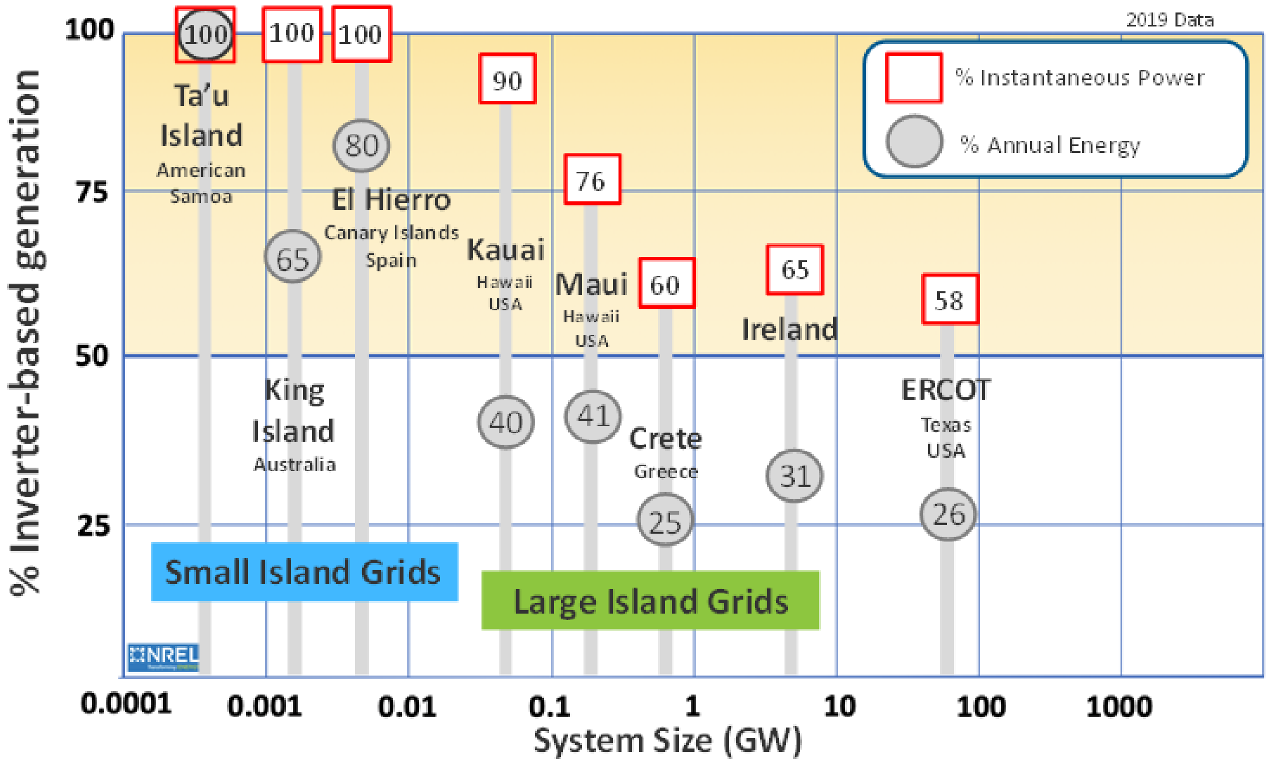
- Interconnected loads
- Conductors
- Switching devices to island from the utility grid:
  - Disconnect switch
  - Transfer switches (automatic or manual).
- Protection devices:
  - Protective relays/circuit breakers
  - Recloser
  - Fuses.
- Power factor correction:
  - Voltage regulator
  - Capacitor.
- Microgrid control software and hardware:
  - This is an often-overlooked cost component of a microgrid
  - This can be a significant portion of the overall microgrid's cost (Especially for smaller microgrid systems).

WHAT YOU NEED TO ISLAND (=$$)

Cost depends on:

- *Complexity/size of system(s)*
- *Controller sophistication*
- *Interconnection Voltage*

WIND AND SOLAR IN SYNCHRONOUS AC POWER SYSTEMS AS A PERCENTAGE OF INSTANTANEOUS POWER AND ANNUAL ENERGY



[1] "Stability and control of power systems with high penetrations of inverter-based resources," R.W. Kenyon, et al., *Solar Energy*, 2020