INTEGRACIÓN EFICIENTE DE
ENERGÍAS RENOVABLES VARIABLES
AL SISTEMA COLOMBIANO

PROVIDENCIA ISLAND WHITE PAPERS:
HAWAII, USA: A GRID PLANNING CASE STUDY FOR PROVIDENCIA ISLAND, COLOMBIA

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On November 16, 2020, Hurricane Iota struck Providencia Island. Home to fewer than 7,000 residents, the Category 5 hurricane damaged over 95 percent of Providencia Island's energy and road infrastructure, property, and motor vehicles, causing its electricity grid to collapse overnight. The Colombian government took immediate action to address this catastrophe, and within 100 days, almost all electricity was restored. However, a realization emerged: while Providencia previously relied entirely on fossil fuels, Hurricane Iota created an opportunity for the island to rebuild a more sustainable and resilient energy infrastructure that could better withstand the ever-growing effects of climate change.

Together with USAID, ECOPETROL, the U.S. Department of Energy's National Renewable Energy Laboratory (NREL), the Scaling Up Renewable Energy (SURE) program, the United States Energy Association (USEA), and Colombia Inteligente, (then) President Iván Duque Márquez announced a working group in Colombia's Ministry of Mines and Energy. The working group conducted high-level technical analyses and workshops which led to the development of these four White Papers. The Providencia Island White Papers are a set of 4 papers designed to guide Providencia Island's sustainable energy transition. However, each paper also serves as a valuable resource for any islanded power system looking to transition to renewable energy sources.

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List of Acronyms

DER	distributed energy resource
HECO	Hawaiian Electric Company
IEEE	Institute of Electrical and Electronics Engineers
NCRE	nonconventional renewable energy source
PV	photovoltaic

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1 Introduction

Hawaii, having successfully integrated nonconventional renewable energy sources (NCREs) for a hybrid electricity grid, may serve as a guide for technical specifications and interconnection policy on Providencia Island. While the two islands do not represent completely analogous contexts, several common factors make the lessons learned in Hawaii applicable to Providencia Island (Table 1). This white paper offers a case study detailing the challenges posed by island contexts and solutions found to reach high penetration of NCREs in Hawaii.

Table 1. Hawaii and Providencia Island Overview

	HAWAII	PROVIDENCIA ISLAND
Population	1.42 million	5,000
Land Area	16,638 km^2	17 km^2
Islanded Grid?	Yes	Yes
Electricity Rates Higher than National Average?	Yes	Yes
Number of Electric Utilities	4	1
Primary Source of Electricity	Imported Petroleum	Imported Diesel
Share of Electricity Generation from Renewable Sources	26.8%	0.0%
Dominant NCRE	Residential Rooftop Photovoltaic (PV)	N/A
Sector Driving Development and Financing of NCREs	Private	Public

Source: Hawaiian Electric 2018, NREL 2015

2 Hawaii Context

Approximately 1.42 million people inhabit Hawaii, a U.S. state and archipelago of eight major islands located in the North Pacific Ocean. Each of the eight major islands operates an isolated grid and none have been interconnected using submarine transmission cables, despite prior considerations to interconnect the islands of Lanai, Molokai, and Maui with Oahu (Hawaii State Energy Office 2016; NREL 2011). In 2018, electricity generation was derived from 61.3% petroleum, followed by 11.9% coal, 26.8% renewables (9.3% residential solar, 4.9% wind, 2.9% geothermal, 2.8% biomass, 1.9% utility-scale solar, and 0.9% hydro), and 4.0% other (Hawaii State Energy Office 2019).

3 Islanded Grid Challenges and Considerations

Islanded grids (i.e., networks not interconnected with larger transmission systems) require the respective utility to perform all functions of grid management that might otherwise be performed by a regional organization (e.g., regional transmission operators). If only one utility exists in each island grid, as in Hawaii and on Providencia Island, that utility is solely responsible for generation, distribution, transmission, load management, and reliability. When integrating NCREs such as solar and wind, the utility must take additional steps to maintain system integrity and reliability.

To this end, the Hawaiian Electric Company (HECO) Grid Modernization Strategy offers a template for grid planning and updated technology to facilitate two-way generation via the following measures (HECO 2017):

- Wide-scale implementation of advanced meters
- Demand response programs
- Distribution automation
- Distributed energy resource (DER) management
- Data collection
- Improved cybersecurity.

Both Hawaii and Providencia Island primarily depend on imported fossil fuels for electricity generation due to the islands' limited land area and lack of interconnection to other transmission networks. As a result, residents on Hawaii and Providencia Island experience electricity rates higher than the national average of the United States and Colombia, respectively. Hawaii has the highest electricity rates of any U.S. state, largely due to dependence on imported petroleum. As of 2019, Hawaii's utility rate stood at approximately $0.30/kWh, triple the U.S. average of $0.10/kWh.

High electricity rates favor the installation of renewable technologies with lower levelized costs of energy over the generator's lifetime, given that capital costs for system upgrades and new infrastructure to accommodate NCREs do not exceed rate savings. In Hawaii, the dominant NCRE installed has been residential rooftop PV purchased privately by residents and facilitated by the local utility HECO via an incentive net energy metering program.[1] This market-based approach accelerated the growth of the Hawaiian solar industry and resulted in small-scale, customer-sited rooftop solar installations roughly tripling in capacity since 2015 (EIA n.d.). Additionally, it allowed for gradual integration of PV, a DER, within the existing grid. More caution may be needed on Providencia Island, given that high penetration of DERs will be centrally planned by public entities and will occur instantaneously rather than building up capacity over time.

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[1] HECO's net energy metering program, allowing over 60,000 customers to easily interconnect new rooftop PV systems to the grid since its inception in 2005. In 2013, HECO began requiring customers to seek interconnection approval for <10-kW systems prior to installation, rather than simply notifying HECO post-installation, as was the prior policy. This resulted in far fewer sales, as customers faced utility review delays and unpredictable connection fees, likely contributing to the net energy metering program's end in 2015 (Hawaiian Electric "Net Energy" n.d.).

4 Intentional Islanding, Communications, and Microgrids

To ensure grid reliability and facilitate two-way generation using advanced technologies, Providencia Island may seek to allow generators such as rooftop PV to establish an intentional island,[2] continuing to supply power to meet local load during a larger utility grid outage. Such intentional islands or microgrids could comprise a single building or aggregate load from multiple sources, facilitated by advanced communications systems.

This feature may increase electricity reliability for communities vulnerable to grid failure due to extreme weather events such as hurricanes (Krishnan and Gaonkar 2012).

The Hawaii Public Utilities Commission created the Market Facilitation Working Group in July 2018 to draft a Microgrid Services Tariff to enable microgrids which provide backup power during grid outages; HECO's proposed Microgrid Services Tariff, released March 30, 2020, is currently under revision (Hawaiian Electric "Microgrid" n.d.). The planned deployment of hierarchical and peer-to-peer communications of advanced meters, routers, and repeaters via a radio frequency mesh network will allow intentional islanding of microgrids (HECO 2017).

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[2] Microgrids or intentional islands are distinguished from backup power by their ability to operate both independently from the grid (e.g., "islanded") as well as in parallel (e.g., "grid-tied").

5 HECO Technical and Policy Specifications for a Solar-Heavy Grid

Grid planners on Providencia Island may seek to implement standardized technical specifications and interconnection policy for DERs to ensure system stability, reliability, and uniformity. In Hawaii, HECO has followed the technical specifications of Institute of Electrical and Electronics Engineers (IEEE) 1547, *Standard for Interconnecting Distributed Resources with Electric Power Systems* since 2011, requiring that DERs have advanced capabilities to operate smoothly alongside utility-quality components. IEEE 1547 was first implemented in 2003 and has been updated with complementary standards several times since then, most recently in 2018 and 2020 (IEEE n.d.).

Additionally, several rules outline HECO's requirements for interconnection of generating facilities on the customer's premises (Rule 14H), self-supplying customer facilities (Rule 22), grid-supplying customer facilities (Rule 23 and 24), and net energy metering program (Rule 27), and will be detailed in sequence here.

5.1 Rule No. 14: Service Connections and Facilities on Customer's Premises

HECO's Interconnection Rule 14H, requiring advanced inverter capabilities and frequency and voltage ride-through specifications, was revised February 20, 2018, ahead of the publication of IEEE 1547-2018 on April 6, 2018. The current technical specifications required by Rule 14H are detailed in the following section.

5.1.1 Advanced Inverter

An advanced inverter is defined as "a Generating Facility's Inverter that performs functions that, when activated, can autonomously contribute to grid support by providing dynamic reactive/real power support, voltage and frequency Ride-Through, ramp rate controls, communication systems with ability to accept external commands, and other functions" (Hawaiian Electric 2018c).

Rule 14H contains the following sections detailing operating requirements for both non-inverter and advanced inverter-based generating facilities:

- Prevention of Interference
- Disconnection of Generating Facility for Utility Reasons
- Personnel and System Safety
- Synchronization
- Voltage Regulation
- Unintended Islanding
- Disconnection for Faults
- Voltage Disturbances

Protective trip limits are defined by voltage and frequency ranges detailed in Table 2.

Table 2. Voltage Ride-Through Protective Trip Limits for Advanced Inverters

VOLTAGE AT POINT OF INTERCONNECTION (% OF NOMINAL VOLTAGE)	OPERATING MODE	RIDE-THROUGH UNTIL (S)	DEFAULT MAXIMUM TRIP TIME (S)
V > 120	Cease to Energize	N/A	0.16 (1)
120 ≥ V > 110	Mandatory Operation	0.92	1
110 ≥ V > 100	Continuous Operation (Volt-Watt)	N/A	N/A
100 > V ≥ 88	Continuous Operation	N/A	N/A
88 > V ≥ 70	Mandatory Operation	20	21
70 > V ≥ 50	Mandatory Operation	10-20	11-21 (2)
50 > V	Momentary Cessation	N/A	2

(1) Must trip time under steady state condition. Inverters will also be required to meet the Company's Transient Overvoltage criterion (TrOV-2). Ride-Through shall not inhibit TrOV-2 requirements.

(2) May be adjusted within these ranges at manufacturer's discretion.

Source: Hawaiian Electric 2018

Table 3. Frequency Ride-Through Protective Trip Limits for Advanced Inverters

FREQUENCY AT POINT OF INTERCONNECTION	OPERATING MODE	RIDE-THROUGH UNTIL (S)	DEFAULT MAXIMUM TRIP TIME (S)
f > 64.0* or 65.0+	Permissive Operation	None	0.16
64.0* or 65.0+ ≥ f > 63.0	Mandatory Operation (Freq-Watt)	20	21
63.0 ≥ f > 60.0	Continuous Operation (Freq-Watt)	Indefinite	N/A
60.0 > f ≥ 57.0	Continuous Operation	Indefinite	N/A
57.0 > f ≥ 50.0	Mandatory Operation	20	21
56.0* or 50.0+ > f	Permissive Operation	None	0.16

* Values for islands Oahu, Maui, and Hawaii only.

+ Values for islands Molokai and Lanai only.

Source: Hawaiian Electric 2018

Rule 14H also lists technology-specific requirements for three-phase synchronous generators, induction generators, and inverter systems (see p. 43–44 of Hawaiian Electric 2018c).

6 Inverter Manufacturer Certification Testing Requirements

HECO's Source Requirements Document Version 2.0 (SRD V2.0) details the certification testing requirements inverter manufacturers must meet to interconnect and operate DERs on the company's grid, meeting both IEEE 1547.1-2020 and UL 1741 Supplement SA (first supplemental version) or SB (second supplemental version) requirements, as applicable.

The following performance categories are required (Hawaiian Electric 2020):

1. Normal operating performance: Category B for voltage regulation performance and reactive power capability requirements (IEEE 1547-2018, Clause 5)
2. Abnormal operating performance: Category III for disturbance ride-through requirements (IEEE 1547-2018, Clause 6).

Likewise, Category B/III is recommended for both normal and abnormal operating performance on Providencia Island, given its system characteristics.

6.1 Frequency Ride-Through and Droop

Ranges for both frequency ride-through and frequency droop ranges used in Hawaii are expanded compared to ranges recommended by IEEE 1547 to accommodate Hawaii's smaller, isolated island grids and higher vulnerability to equipment failure.

6.2 Storage

Distributed generating facilities incorporating energy storage devices must obtain an interconnection review pursuant to Rule 14H and HECO's Interconnection Standards. Advanced inverter systems may operate in larger power factor ranges for four-quadrant storage operations given additional anti-islanding protection as determined by HECO. The following information is requested for storage systems (Hawaiian Electric 2018c):

- Is the system self-excited with the potential to island (i.e., will the equipment package include an onsite storage system)? [ ] No [ ] Yes
- Energy Storage (if applicable): [ ] Stand-by power supply [ ] Serving isolated load [ ] Other
- Will the Distribution Grid be used to charge the storage Device? [ ] No [ ] Yes (provide manufacturer's data sheet for charger)
- If yes, what times of the day do you expect to charge your storage device?

6.2.1 Rule No. 22: Customer Self-Supply

Systems within this program must be under 100 kW and designed to serve on-site load at the customer generator's premises. Export of power across the point of interconnection may be permitted to provide grid support during emergency conditions, utilizing advanced meters installed by the utility. Any single-event export of power lasting longer than 30 seconds will result in a trip and 5-minute reconnection by HECO of the customer's generating facility (Hawaiian Electric 2018b).

6.2.2 Rule No. 23 and Rule No. 24: Customer Grid-Supply and Grid-Supply Plus

Systems within this program must be under 100 kW. Export of power across the point of interconnection is permitted, utilizing advanced meters installed by the utility. Customers will receive monetary credits on their electricity bill for kWh inadvertently exported to the grid. Customers must install and maintain interconnection facilities, including “circuit breakers, relays, switches, synchronizing equipment, monitoring equipment, and control and protective devices and schemes” (Hawaiian Electric 2016; Hawaiian Electric 2018a).

6.2.3 Rule No. 27: Net Energy Metering Plus

The provisions from Rule No. 22 apply. In addition, customers will receive monetary credits on their electricity bill for each kWh inadvertently exported to the grid (Hawaiian Electric 2018d).

7 Takeaways for Providencia Island Grid Planners

Special considerations exist for island grids seeking to smoothly integrate DERs, such as rooftop PV, with an existing fossil fuel-based grid without compromising system stability and reliability. Grid planners on Providencia Island may seek to follow Hawaii’s example by standardizing technical specifications of generators, particularly for advanced inverter components. Additional measures may include advanced metering to allow for automation of demand response, dispatch and curtailment, and data collection. More complex communications networks and strengthened cybersecurity to protect such networks might also be considered.

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