INTEGRACIÓN EFICIENTE DE
ENERGÍAS RENOVABLES VARIABLES
AL SISTEMA COLOMBIANO

PROVIDENCIA ISLAND WHITE PAPERS: OVERVIEW OF TECHNICAL REQUIREMENTS FOR INTERCONNECTION

Michael Ingram

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INTEGRACIÓN EFICIENTE DE ENERGÍAS RENOVABLES VARIABLES AL SISTEMA COLOMBIANO

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
IEEE	Institute of Electrical and Electronics Engineers
VAR	volt-ampere reactive

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1 Introduction

Electric utilities typically name three top priorities in providing electric service to their customers (Dhillon 1983): (1) ensuring the safety of the public and utility workers while (2) delivering reliable and good-quality electric service and (3) providing service at an economic cost. Another important goal is to avoid damage to electric distribution and customer equipment. Anything that could negatively affect these priorities is therefore a concern.

At lower penetration levels, the impact of distributed energy resources (DERs) and other inverter-based resources might not be significant. As the DER penetration increases, however, issues related to line loading, grid voltage, and system frequency during normal and disturbed operations could be a concern for the bulk power system. Hence, suitable care must be taken to ensure that the impact is addressed appropriately in planning and operating assessments.

This issue brief will provide an overview of key technical requirements for inverter-based resources—including DERs[1]—to support the reliable and safe operation of the Providencia Island electrical grid.

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[1] For simplicity's sake, the term "distributed energy resources" and DERs are used throughout this paper to reference inverter-based resources where the technical requirements are generalized, similar, or essentially equal regardless of the rating of the resource.

2 Context on Typical Utility Priorities

2.1 Safety

The safety of electric utility workers and the public is a primary utility concern. Every day, utility workers perform high-risk activities, such as working nearby or in contact with energized high-voltage systems, often at extreme heights or in confined spaces. Consistently, the U.S. Bureau of Labor Statistics (BLS 2019) ranks electrical line work as one of the most dangerous jobs in the United States. In conjunction with formal safety standards—typically other codes or laws provide requirements for safety clearances, grounding, and arc flash protection—technical requirements for interconnection should be written to minimize potential risks to the public or electric utility workers. Technical requirements for DERs that can be coordinated with utility protection—such as unintentional islanding, ride-through, and cease-to-energize settings—help to meet this objective.

2.2 Good-Quality Electric Service and Reliable Operation

With respect to good quality and reliable operations in the context of interconnected DER, two notions are often used to describe two complex and multifaceted concepts: (1) do no harm, and (2) perform as good citizens of the grid. At a minimum, interconnected DERs should not harm or degrade service quality by distorting voltage or current (e.g., harmonics, voltage flicker). And, especially in islanded grids, DERs should ideally act as good citizens to prevent outages and contribute to ancillary services (e.g., ride-through, frequency regulation).

Within the 1547-2018–Institute of Electrical and Electronics Engineers (IEEE) Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces (IEEE Std 1547-2018),[2] requirements for DER output power quality are quantifiable and include limits on injection of DC and harmonics causing distortion, voltage fluctuations, contributions to overvoltage at the point of connection.[3]

In addition, the DER should be a dependable and reliable resource of electrical energy that operates compatibly with the local grid. Because the electric power system can be a harsh environment, performance requirements for DER "immunity and withstand" are included in IEEE Std 1547-2018. Protections from the impact of a "harsh environment" include, for example, shielding from electromagnetic interference and surge withstand. Requirements that fall under this topic are built-in—that is, compliant DERs inherently have these capabilities.

2.3 Economic Cost

Overall project costs can vary based on a variety of factors, some of which are unrelated to technical interconnection factors. But adoption of technical standards such as IEEE Std 1547-2018 can help to reduce the cost of implementing and operating DER in many ways, including increasing uniformity of design, minimizing expensive custom solutions, and sharing best practices.

As the cost of renewable generation and energy storage systems decrease, and as DERs enable on-site generation that reduces utility bills and enables backup power, technical requirements must allow for

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[2] IEEE Std P2800 "Draft Standard for Interconnection and Interoperability of Inverter-Based Resources Interconnecting with Associated Transmission Systems" is expected to be published in late 2021 or early 2022.

[3] IEEE Std 1547-2018 is available at https://standards.ieee.org/standard/1547-2018.html. NREL continues to develop publicly available resources on the standard (https://www.nrel.gov/grid/ieee-standard-1547/). A quick reference guide to the technical requirements in IEEE 1547-2018 is accessible at https://www.nrel.gov/docs/fy20osti/75184.pdf.

DERs to carry out these performance capabilities. Traditionally, utilities and regulators have performed cost-benefit analyses for reliability investments, but not for resilience investments (Murphy 2020).

A lack of uniform and transparent procedures for addressing interconnection rule changes can result in implementation issues or inefficiencies, such as unclear, lengthy, and complicated interconnection rules that can increase distributed generation “soft costs” (i.e., non-hardware costs). This can further delay the deployment of DERs and jeopardize time-constrained national and state policy goals, such as renewable energy targets, or limit participation in emerging techno-economic trends. Additionally, misconstructed interconnection rules are at risk of becoming mired in stakeholder conflicts.

2.4 Protection of Electric Distribution and Customer Equipment

Power system protection serves two primary functions: the protection of the grid (equipment and stable delivery of power) and the protection of the public (including employees). IEEE Std 1547-2018 specifies requirements to address the protection of electric power system and customer equipment. These include requirements and criteria for enter service and synchronization, as well as capabilities to support the grid under abnormal conditions (e.g., ride-through of voltage disturbances, frequency disturbances, rate of change of frequency, and voltage phase angle changes).

3 Considerations for Providencia Island

In a broader sense, technical requirements for protection bridge all three of the utility priorities: safety, reliable and good-quality service, and economic cost.

In addition to leveraging the technical capabilities afforded by standard compliant DERs, engineers on Providencia Island will likely need to evaluate existing sensing and protective equipment. While the existing diesel plant will remain, the planned utility-scale solar and battery storage facilities will change power flows in both direction and magnitude. Consequently, voltage regulators, reclosers, and protective systems must be reviewed under new circumstances. Another critical issue likely ahead for Providencia Island is the availability of fault current. This will be very different than from the system today as more inverter-based DER are connected to the main grid. Protective devices, such as overcurrent relays, line fuses, circuit breakers, and reclosers, may not operate as expected. An emerging solution to reductions in inertia and fault current, as well as providing voltage and reactive power regulation, involves converting displaced synchronous generators into synchronous condensers (or installing synchronous condensers), which has been done on Kauai, Hawaii, for example (Hoke et al. 2021) and might be a consideration for Providencia Island.

4 Bulk System and Distribution: Diverging Objectives

Even in a vertically integrated power system, such as the one operated by Sociedad Productora de Energía del Archipiélago de San Andres, Providencia y Santa Catalina, it is important to recognize the "naturally diverging objectives between [bulk] and distribution system operation" (NERC 2020), as illustrated in Figure 1. IEEE Std 1547-2018 addresses this by requiring coordination between distribution providers and regional reliability coordinators. For effective adoption at Sociedad Productora de Energía del Archipiélago de San Andres, Providencia y Santa Catalina, these diverging objectives require coordination between distribution engineers and those engineers responsible for reliability, protection coordination and regulation (i.e., bulk system considerations).

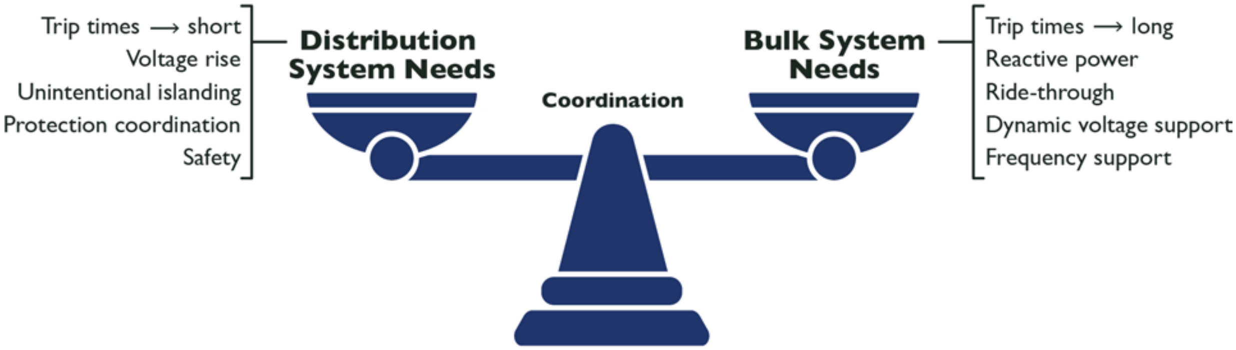

Figure 1. Addressing diverging objectives through coordination

5 Technical Requirements for Interconnection

Especially in an island power system, like Providencia Island, the basic requirements for DERs are to contribute to power system stability—that is, to remain connected during a wide range of disturbances, including underfrequency, over-frequency, undervoltage, overvoltage, high rates of change of frequency, and fast changes in the voltage phase angle—and to support voltage during normal operations.

Due to their rotational inertia, the diesel generators on Providencia Island inherently resist changes in frequency. Similarly, the machines' flux linkage resists changes in voltage, injecting very high amounts of current (beyond the generator's continuous rating) when a fault occurs. As the energy mixture changes on the island, so too must the planning, modeling, and development of these reliability services.

At low penetration levels, DERs may not pose a significant risk to bulk-system reliability. Yet, at current penetration levels planned for Providencia Island, the aggregate effects of DERs present both challenges and opportunities for planning, design, and operation of the bulk system.

Considerations to planning and operations include:

- Ability to model and forecast net load (i.e., electrical load minus DER production)
- Impacts that DERs have by offsetting gross load, resulting in the displacement of generation providing various essential reliability services
- Impacts that DERs have on balancing generation and demand
- Coordinating ride-through and trip settings to manage DER performance following large disturbances (e.g., generator trip).

Decisions related to ride-through capability and trip settings should be addressed in the near term because the aggregate impact will accumulate over time, and large-scale reconfiguration or retrofit of DERs could be challenging and costly. Table 1 provides a comparison of ride-through requirements in IEEE Std 1547 to Hawaii's interconnection rule (i.e., Rule 14).

Table 1. Comparison of Ride-Through Requirements

DER PERFORMANCE CATEGORIES FOR ABNORMAL GRID CONDITIONS	IEEE STD 1547-2018 (CATEGORY III DER)[A]	HAWAII RULE 14[B]
Ride-through of abnormal voltage and frequency	Mandatory capability	Mandatory for inverter-based
Voltage ride-through	Required	Required (activated)
Frequency ride-through	Required	Required (activated)
Rate-of-change-of-frequency ride-through	Required (3.0 Hz/s)	Not required
Voltage phase angle change ride-through	Required	Not required
Frequency droop (frequency-power)	Required	Required (activated)
Inertial response	Permitted	Not required
Dynamic voltage support	Permitted	Not required

a Designed for all bulk system needs and distribution system reliability/power quality needs. Coordinated with existing requirements for very high DER levels (e.g., California, Hawaii). Source: IEEE 2018

b Source: Hawaiian Electric 2020

5.1 Frequency Regulation Requirements

Frequency regulation is critical to system operations and may have special considerations for island grids. In the U.S. state of Hawaii, frequency ride-through and frequency droop ranges are slightly expanded from those recommended by IEEE 1547-2018 to accommodate Hawaii's island nature (smaller, isolated grid) and higher vulnerability to equipment failure, as highlighted in Table 2. Inverter manufacturers are required to meet SRD V2.0 values for certification testing to interconnect and operate DERs on the utility's grid.[4]

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 or SB requirements, as applicable.

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[4] Testing procedures for frequency ride-through can be found in IEEE 1547.1-2020, 5.5.3 (low-frequency test) and 5.5.4 (high-frequency test) (Hawaiian Electric 2020). Testing procedures for frequency droop can be found in IEEE 1547.1-2020, 5.15.2 (capability above nominal frequency), and 5.15.3 (capability below nominal frequency).

Table 2. Comparison of IEEE 1547-2018 (Category III) and HECO's SRD V2.0 Frequency Ride-Through Requirements

FREQUENCY RANGE (HZ)		OPERATING MODE		MINIMUM TIME (S) (DESIGN CRITERIA)	
1547-2018	**SRD V2.0**	**1547-2018**	**SRD V2.0**	**1547-2018**	**SRD V2.0**
f > 62.0	f > 65.0	No ride-through requirements apply to this range			
61.2 < f ≤ 61.8	63.0 < f ≤ 65.0	Mandatory Operation[a]	Mandatory Operation[a]	299	299
58.8 < f ≤ 61.2	50.0 < f ≤ 63.0	Continuous Operation[a,b]	Continuous Operation[a,b]	Infinite[c]	Indefinite
57.0 ≤ f < 58.8	50.0 ≤ f < 57.0	Mandatory Operation[a]	Mandatory Operation[a]	299	299
f < 57.0	f < 50.0	No ride-through requirements apply to this range			

[a] Any DER shall provide the frequency-droop (frequency-power) operation for high-frequency conditions specified in 6.5.2.7.

[b] DER of Category I may provide the frequency-droop (frequency-power) operation for low-frequency conditions specified in 6.5.2.7. DER of Category III shall provide the frequency-droop (frequency-power) operation for low-frequency conditions specified in 6.5.2.7 of IEEE 1547-2018.

[c] For a per-unit ratio of Voltage/frequency limit of V/f ≤ 1.1.

Source: Hawaiian Electric 2020

5.2 Voltage Regulation Requirements

Maintaining voltage within appropriate levels is one of the most important responsibilities for distribution utilities. Utilities employ a variety of devices to maintain the voltage within these levels, including capacitors and voltage regulators. In the United States, the appropriate voltage level is defined by ANSI standard C84.1 (NEMA 2016) and is typically referenced in utility electric service requirements and interconnection rules.[5]

Table 3 lists the base voltage ranges and limits and corresponding per-unit values for residential single-phase systems specified in ANSI C84.1.

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[5] International Electrotechnical Commission Std 60038 *IEC Standard Voltages* is effectively the international equivalent of ANSI C84.1 and defines utilization and service voltage tolerances.

Table 3. ANSI Voltage Ranges and Limits for Residential Single-Phase Systems[6]

	NOMINAL SYSTEM VOLTAGE	SERVICE VOLTAGE		UTILIZATION VOLTAGE	
	V, (p.u.)	Minimum V, p.u.)	Maximum V, (p.u.)	Minimum V, (p.u.)	Maximum V, (p.u.)
Voltage Range A	**120, (1.00)**	**114, (0.95)**	**126, (1.05)**	**108, (0.90)**	**125, (≈1.04)**
Voltage Range B	**120, (1.00)**	**110, (≈0.92)**	**127, (≈1.06)**	**104, (≈0.87)**	**127, (≈1.06)**

Like the familiar utility equipment for managing circuit voltage (i.e., capacitors and regulators), modern DER inverters also have voltage-regulating capability. These capabilities can play an important role in helping to regulate distribution voltages by providing both active and reactive power support. Simply by modulating the phase angle of the inverter's output current with respect to voltage, the inverter can source or sink reactive power, in effect acting like a capacitor or inductor and decreasing or increasing the voltage change in the distribution conductors. An inverter can also modulate its active power magnitude, which changes the voltage drop (or rise) on the distribution conductors.

For Providencia Island, voltage regulation capability for all DERs should be considered and likely required. The recommended types of voltage regulation (i.e., modes) include constant power factor, constant reactive power, voltage-reactive power, active power-reactive power, and voltage-active power. Additionally, for utility-scale plants, dynamic response of the DER to any changes in reactive power shall be positively damped with a damping ratio of 0.3 or better.

- In the constant power factor mode, the DER modulates reactive power to hold the ratio of active and reactive power constant as active power changes (i.e., constant power factor).
- In the constant reactive power mode, the DER maintains a constant reactive power output regardless of active power output.
- In the voltage-reactive power (i.e., volt-ampere reactive or VAR) mode, also known as volt-VAR mode, the DER actively controls its reactive power output as a function of voltage, which typically acts to push local voltage back towards nominal. For utility-scale DER, this mode should be the default setting to improve bulk system voltage stability and power transfer capability.
- In the active power-reactive power mode, also known as Watt-VAR or P-Q mode, the DER actively controls the reactive power output as a function of the active power output.

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[6] Please refer to ANSI C84.1-2016 for a more complete discussion of requirements.

- In the voltage-active power mode, also known as the volt-watt mode, the DER actively limits its maximum active power as a function of the voltage. Unlike the other modes, volt-watt may be enabled in conjunction with other modes to reduce the occurrence of very high voltages.

Determining the appropriate and beneficial modes for voltage regulation is not trivial. Instead, many factors affect how well these voltage regulation capabilities perform when applied in a specific location, including variations in feeder topology, impedance, configuration, and loading. The complexity of the engineering study and modeling necessary to determine the best operational mode(s) tends to parallel the penetration of DER shares on the system. Yet, rather than attempting to tune individual settings for each DER, the most common industry approach to date is to select a single profile—for each operational class, whether utility-scale or distribution-level—that works reasonably well for all DERs in a service territory.

5.3 Interoperability Considerations

Integrating control, monitoring, and system modeling could help optimize the investment in equipment and resources. Additionally, integration of these features can help meet the significant changes in generation, distribution, and management of energy to provide for reliable, safe, resilient, and affordable electric service to Providencia Island. This integration will depend on the extent to which diverse equipment and systems are interoperable.

Simply stated, interconnection is distinguished from interoperability by the magnitude of the signals exchanged. IEEE Std 1547-2018 defines interoperability as “the capability of two or more networks, systems, devices, applications, or components to externally exchange and readily use **information** securely and effectively” (emphasis added) (IEEE 2018).

Virtually all energy planning and distribution grid management functions require knowledge of basic electrical quantities, such as active and reactive power, voltage, and frequency. The increase in intelligent grid-edge devices on Providencia Island will increase the need for data and information exchanges among devices and systems. Traditional functions—such as planning, operation, and protection—need these types of information, and they are critical for newer capabilities, such as the provision of ancillary services, forecasting load, and distributed generation. In addition to data and information exchange, DER control—the means of affecting equipment behavior by using externally derived set points to meet specific objectives—is a component of interoperability that may be required. Examples include the capability of DERs to respond to inputs for distribution-level services, such as voltage regulation, VAR support, scheduling, and dispatch (e.g., controlled curtailment and capacity management).[7] This hierarchy of interoperability capabilities is outlined in Figure 2.

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[7] While it is technically possible for small-scale DERs to provide many of the same services that utility-scale DERs can, practical concerns about communications and monitoring economies often limit what is requested from small DERs.

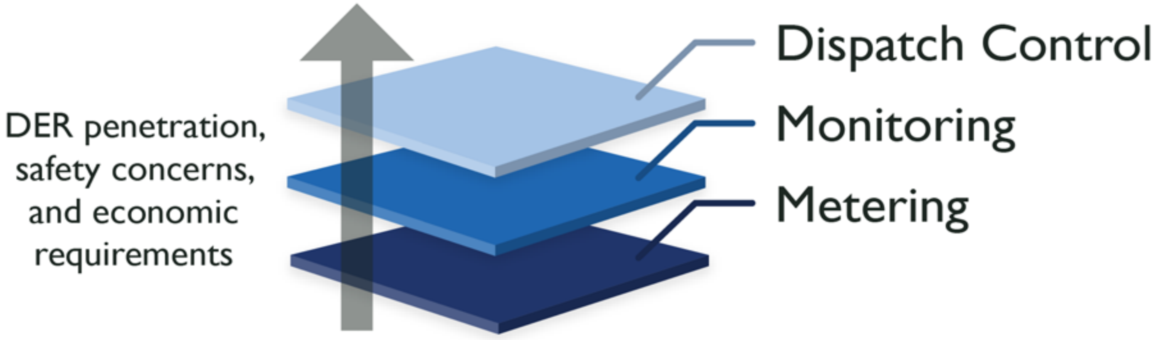

Figure 2. Hierarchy of communications and interoperability of DERS

Mandatory information elements capable of being exchanged at the DER communications interface fall into the following four categories: nameplate information, configuration information, monitoring information, and management control information (IEEE 2018). Advanced DERs (i.e., IEEE Std 1547-2018 compliant), respond to external management control using four functions: disable permit service, limit active power, change functional mode, and change parameters for control and protective functions.[8]

Along with interoperability comes the added risk of cybersecurity. While beyond the scope of this paper, it is recommended that the same level of cyber and physical security risk management and controls be applied to the utility-scale solar and storage plant, given these systems' roles in the reliable and safe operation of the grid on Providencia Island.

5.4 Modeling and Analysis

Whereas the transient behavior (i.e., short timescale) of synchronous machines, such as the generators on Providencia Island, is defined by physics, the behavior of inverter-based DERs is largely software-defined and operates on a sub-cycle timeframe. Compounding these challenges of definition and timescale is the modeling toolset; the predominant modeling and simulation tools[9] used to assess power system stability operate in the phasor domain and were designed to capture the dominant dynamics of rotating generators. Generally, these tools do not simulate AC waveforms or phase imbalance and use time steps of a few milliseconds.

Based on modeling and analysis for Aruba, Puerto Rico, and Maui, Hawaii, NREL experience (Hoke et al. 2021) has shown that when analyzing the stability of island power systems that have very high shares of DERs, it is sometimes necessary to include inverter controller aspects that cannot be well represented in the phasor domain. Electromagnetic transient modeling tools[10] use time steps of tens or a few hundreds of microseconds to simulate the full voltage and current waveforms of all three phases.

The inertia and primary frequency response of an island power system can be estimated by injecting small-signal, noninvasive active power perturbations into the network via the DER inverter and measuring the system frequency. The frequency of the active power perturbations is varied from a

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[8] Draft IEEE Std P2800 includes similar language and requirements for utility-scale DERs.

[9] Power System Simulator for Engineering and Positive Sequence Load Flow are two examples of commercial tools that operate in the phasor domain.

[10] Electromagnetic Transient Program and Power Systems CAD are two examples of electromagnetic transient modeling and simulation tools.

fraction of a hertz to a few tens of hertz, and the recorded system response is used to obtain a transfer function from the injected active power perturbations to the system frequency. The response of this so-called frequency response transfer function can be used for estimating the system inertia and primary frequency response (Hoke et al. 2021).

5.5 Energy Storage Systems

Energy storage can provide a variety of power system “services” ranging from renewable energy integration, power quality, backup power, frequency response, (synthetic) inertia, spinning reserve, and black start. Yet these services are not necessarily stackable, technically or economically. For example, to provide the optimal backup, the energy storage system should be maintained at or near full capacity at all times to respond to an unplanned outage. Maintaining full capacity prevents the storage system from providing grid support services such as regulation, frequency response, and inertial response. Even if a storage system is a technically capable of providing a suite of multiple services, additional cycling may reduce asset life. Without the benefit of market-defined values prioritizing these services to define the capacity, energy rating, and operational philosophy (e.g., depth of discharge, for example), analysis is required to establish trade-offs (Bowen et al. 2019).

Grid-forming capability is one of these trade-offs that is important to Providencia Island.

5.6 Grid-Forming Inverters

At a high level, control strategies might be classified as follows:

- Grid Following: Primarily rely on using a phase-lock-loop to lock onto the grid phasor and have fast control loops to regulate the active and reactive injected current or power.
- Grid-Forming: Control strategies, for independent operation, that regulate voltage and frequency.
- Hybrid: Combination of these control strategies, resulting in a “hybrid” control scheme.

Existing control structures used by the majority of inverter-connected generation are commonly referred to as grid-following, wherein the DER acts as a power-regulated current source from a grid perspective. Grid-following controls work best when connected to a strong power system[11] where there is only a small change in voltage at the inverter terminals. However, in relatively weak grids (i.e., low system impedance and/or low mechanical inertia (Kundur 1994), that approach can lead to instability as the DER tries to track the grid voltage phasor. To operate in a weak grid or in a system in which much of the generation is provided by DER, a more robust inverter control and hardware are required to provide grid-forming capabilities. Simply stated, grid-forming inverters can independently regulate voltage and frequency.[12]

On Providencia Island, the operational expectation is that DERs will serve load in a stable, reliable, and secure manner with fewer (i.e., one) or no synchronous machines present. And, when connected in an interconnected network with various types of resources, these DERs will operate harmoniously with the other resources.

Sufficient headroom must be available for the inverter the entire time it is operated as grid-forming. When the current limit is reached, the DER will protect itself and stop functioning in grid-forming mode. The

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[11] “Strong” essentially means that the equivalent impedance looking into the grid is quite low. Alternatively, another metric often used is short-circuit ratio. For a generator or DER, short-circuit ratio is the ratio of short circuit apparent power (MVA) from a three-line-to-ground fault to the rating of the DER (NERC 2017).

[12] The terms grid-following and grid-forming do not have universally accepted definitions. Consequently, these terms should be accompanied by additional context when specifying DER equipment or defining interconnection requirements that describes the reasonable expected performance required.

DER must switch to a different mode of operation to respect its hardware limits. Such overcurrent is very likely to occur during sudden large voltage changes (e.g., short-circuit fault). Similarly, sufficient energy headroom must always be present for the DER to respond to sudden phase angle changes (sometimes called phase angle jumps). Lack of available capacity to absorb energy from the grid (i.e., headroom) or, conversely, not enough stored energy will limit grid-forming mode (Matevosyan 2019).

5.7 Restoration and Black-Start Capability

Grid-connected energy storage may have the ability to form and sustain an electrical island if they are to be designated as part of a black-start[13] cranking path. This may require new control topologies or modifications to settings that enable this functionality. Black-start conditions may cause large power and voltage swings that must be reliably controlled and withstood by all black-start resources (i.e., operation under low short-circuit grid conditions). For battery energy storage systems to operate as black-start resources, assurance of energy availability as well as a designed energy rating that ensures energy availability for the entire period of restoration activities is required. At this time, it is unlikely that most legacy battery energy storage systems can support system restoration activities as a stand-alone resource; however, they may be used to enable startup of subsequent solar PV, wind, or synchronous machine plants.

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[13] Black-start-capable means the generator or DER can self-start and energize an electric power system that has no other energy sources.

6 Conclusion

Electric utilities—like Sociedad Productora de Energía del Archipiélago de San Andres, Providencia y Santa Catalina—typically name three top priorities: safety, reliable operation, and low-cost service. The achievement of these priorities provides the foundation for a resilient grid, which people and businesses on the island rely on every day. With the planned increase in inverter-based resources and the introduction of energy storage, well-considered technical requirements for DER interconnection will be critical to maintain Providencia Island's security, economy, and way of life. Adopting IEEE Std 1547-2018, including the more advanced performance capabilities for voltage and frequency ride-through, will simplify interconnection as well as help to maintain a safe, reliable grid on Providencia Island. Utilization of reactive power capabilities available in 1547-compliant DER will improve the regulation and quality of delivered voltage and increase circuit hosting capacity, which may reduce the delivered cost of energy.

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INTEGRACIÓN EFICIENTE DE ENERGÍAS RENOVABLES VARIABLES AL SISTEMA COLOMBIANO

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