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Utilizing Excess Capability of BPS-Connected Inverter-Based Resources for Frequency Support

NERC Inverter-Based Resource Performance Subcommittee (IRPS)
Informational Webinar

April 19, 2022 | 1:00 p.m. – 3:00 p.m. Eastern

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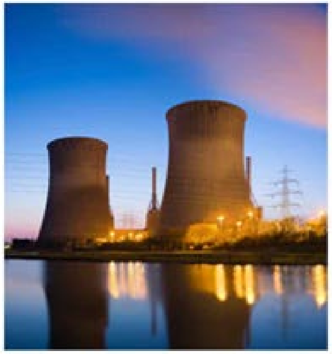

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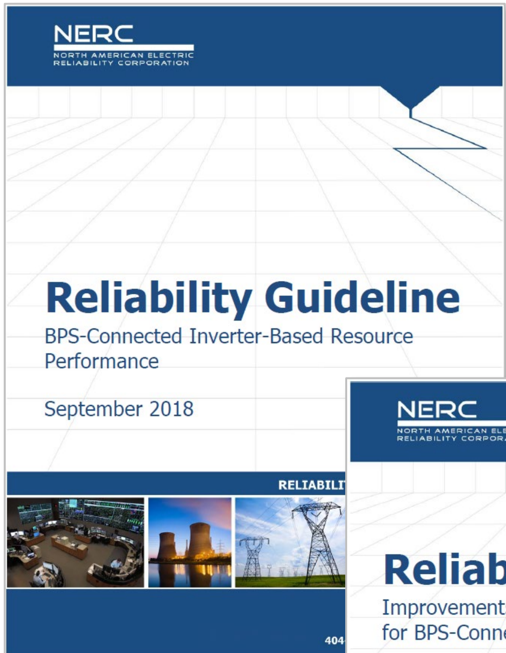
IRPS Materials

Background



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Reliability Guideline

BPS-Connected Inverter-Based Resource Performance

September 2018

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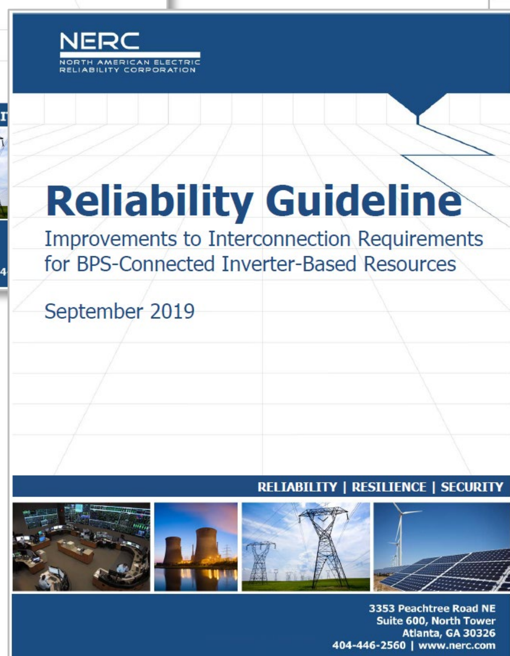

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Reliability Guideline

Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources

September 2019

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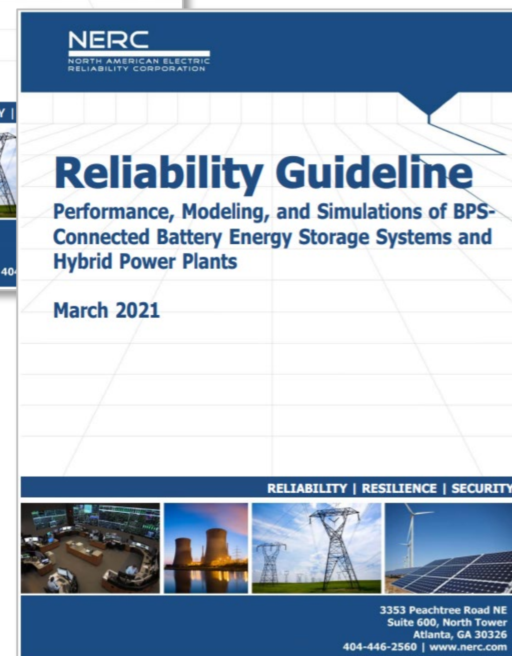
Fast Frequency Response Concepts and Bulk Power System Reliability Needs

NERC Inverter-Based Resource Performance Task Force (IRPTF)
White Paper

March 2020

RELIABILITY |



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Reliability Guideline

Performance, Modeling, and Simulations of BPS-Connected Battery Energy Storage Systems and Hybrid Power Plants

March 2021

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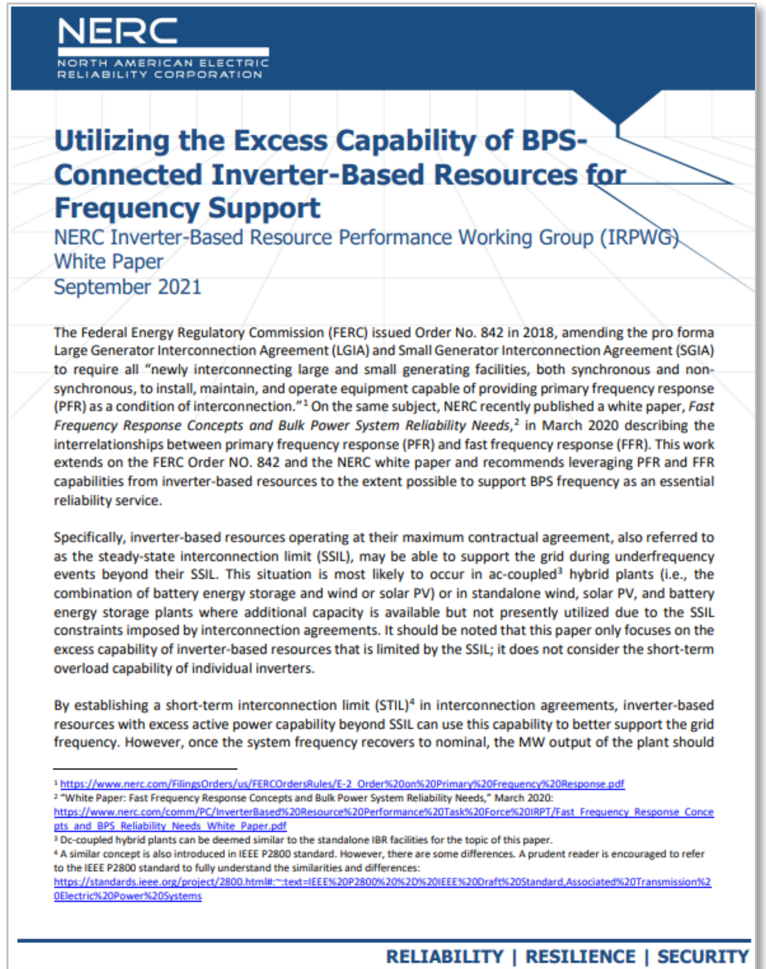
Reliability Guidelines, Security Guidelines, Technical Reference Documents, and White Papers Page
Inverter-Based Resource Performance Task Force Page

Background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Utilizing the Excess Capability of BPS-Connected Inverter-Based Resources for Frequency Support

NERC Inverter-Based Resource Performance Working Group (IRPWG)
White Paper
September 2021

The Federal Energy Regulatory Commission (FERC) issued Order No. 842 in 2018, amending the pro forma Large Generator Interconnection Agreement (LGIA) and Small Generator Interconnection Agreement (SGIA) to require all "newly interconnecting large and small generating facilities, both synchronous and non-synchronous, to install, maintain, and operate equipment capable of providing primary frequency response (PFR) as a condition of interconnection."[1] On the same subject, NERC recently published a white paper, *Fast Frequency Response Concepts and Bulk Power System Reliability Needs*,[2] in March 2020 describing the interrelationships between primary frequency response (PFR) and fast frequency response (FFR). This work extends on the FERC Order NO. 842 and the NERC white paper and recommends leveraging PFR and FFR capabilities from inverter-based resources to the extent possible to support BPS frequency as an essential reliability service.

Specifically, inverter-based resources operating at their maximum contractual agreement, also referred to as the steady-state interconnection limit (SSIL), may be able to support the grid during underfrequency events beyond their SSIL. This situation is most likely to occur in ac-coupled[3] hybrid plants (i.e., the combination of battery energy storage and wind or solar PV) or in standalone wind, solar PV, and battery energy storage plants where additional capacity is available but not presently utilized due to the SSIL constraints imposed by interconnection agreements. It should be noted that this paper only focuses on the excess capability of inverter-based resources that is limited by the SSIL; it does not consider the short-term overload capability of individual inverters.

By establishing a short-term interconnection limit (STIL)[4] in interconnection agreements, inverter-based resources with excess active power capability beyond SSIL can use this capability to better support the grid frequency. However, once the system frequency recovers to nominal, the MW output of the plant should

[1] https://www.nerc.com/FilingsOrders/us/FERCOrdersRules/E-2_Order%20on%20Primary%20Frequency%20Response.pdf
[2] "White Paper: Fast Frequency Response Concepts and Bulk Power System Reliability Needs," March 2020: https://www.nerc.com/comm/PC/InverterBased%20Resource%20Performance%20Task%20Force%20IRPT/Fast_Frequency_Response_Concepts_and_BPS_Reliability_Needs_White_Paper.pdf
[3] Dc-coupled hybrid plants can be deemed similar to the standalone IBR facilities for the topic of this paper.
[4] A similar concept is also introduced in IEEE P2800 standard. However, there are some differences. A prudent reader is encouraged to refer to the IEEE P2800 standard to fully understand the similarities and differences: https://standards.ieee.org/project/2800.html#:~:text=IEEE%20P2800%20%2D%20IEEE%20Draft%20Standard,Associated%20Transmission%20Electric%20Power%20Systems

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Utilizing the Excess Capability of BPS-Connected Inverter-Based Resources for Frequency Support

Accessing the White Paper

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Home > Committees > Reliability Guidelines, Security Guidelines, Technical Reference Documents, and White Papers

Reliability Guidelines, Security Guidelines, Technical Reference Documents, and White Papers

The NERC Reliability and Security Technical Committee (RSTC) subcommittees develop Reliability (Operating and Planning), Security Guidelines, and technical reference documents, which include the collective experience, expertise and judgment of the industry. The objective of the reliability guidelines is to distribute key practices and information on specific issues critical to promote and maintain a highly reliable and secure bulk power system (BPS). Reliability guidelines are not binding norms or parameters to the level that compliance to NERC's Reliability Standards is monitored or enforced. Rather, their incorporation into industry practices is strictly voluntary. Reviewing, revising, or developing a program using these practices is highly encouraged. All current and draft guidelines can be found at the links below.

Reliability Guidelines

Type	Doc ID	Description	Approval Date	Subgroup
Draft Reliability Guidelines (5)				
Approved Reliability Guidelines (23)				

Security Guidelines

Type	Doc ID	Description	Approval Date	Subgroup
Approved Security Guidelines (21)				

Technical Reference Documents

Type	Doc ID	Description	Approval Date	Subgroup
Draft Technical Reference Documents (3)				
Approved Technical Reference Documents (11)				

White Papers

Type	Doc ID	Description	Approval Date	Subgroup
Transmission Planning (1)				
Modeling and Verification (1)				
Inverter-Based Resource Performance (4)				
		White Paper: Odessa Disturbance Follow-Up	12/15/2021	IRPWG
		White Paper: Grid Forming Technology	12/15/2021	IRPWG
		White Paper: Utilizing Excess Capability of BPS-Connected IBRs for Frequency Support	12/15/2021	IRPWG
		White Paper: San Fernando Disturbance Follow-Up	6/24/2021	IRPWG

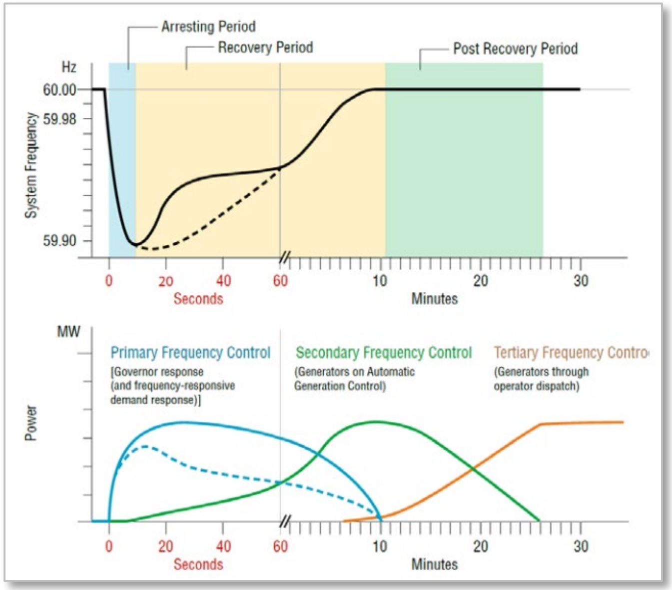
Reliability Guidelines, Security Guidelines, Technical Reference Documents, and White Papers Page

Webinar Outline

White Paper Overview	Farhad Yahyaie, Siemens PTI Canada
Developer/GO/GOP/BA Perspectives	Kenneth Silver, 8minute Solar Energy
Equipment Manufacturer Perspectives	Gary Custer, SMA Patrick Hart, GE
Transmission Planning Perspectives	Cho Wang, AEP
Additional Perspectives	Jens Boemer, EPRI Deepak Ramasubramanian, EPRI
Q&A	Ryan Quint, NERC All

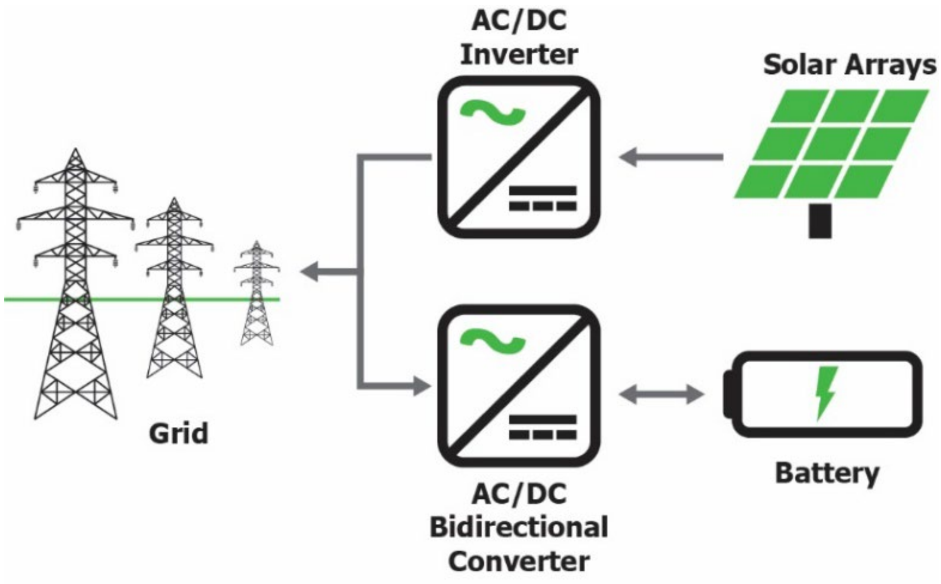
White Paper Overview

- FERC Order 842 (2018)
  - Requires newly interconnecting large and small generating facilities (synchronous and non-synchronous), to install, maintain, and operate equipment capable of providing primary frequency response (PFR) as a condition of interconnection
- NERC White Papers/Guidelines (2018-2022)
  - Recommended active power/frequency performance
  - Establishment of interconnection requirements
  - Leveraging fast frequency response (FFR) for BPS reliability needs



White Paper Overview

- Objective
  - Leverage PFR and FFR capabilities from inverter-based resources to the extent possible to support BPS frequency as an essential reliability service
- Terminology
  - **S**teady-**S**tate **I**nterconnection **L**imit (SSIL)
  - **S**hort-**T**erm **I**nterconnection **L**imit (STIL)



White Paper Overview

- Terminology
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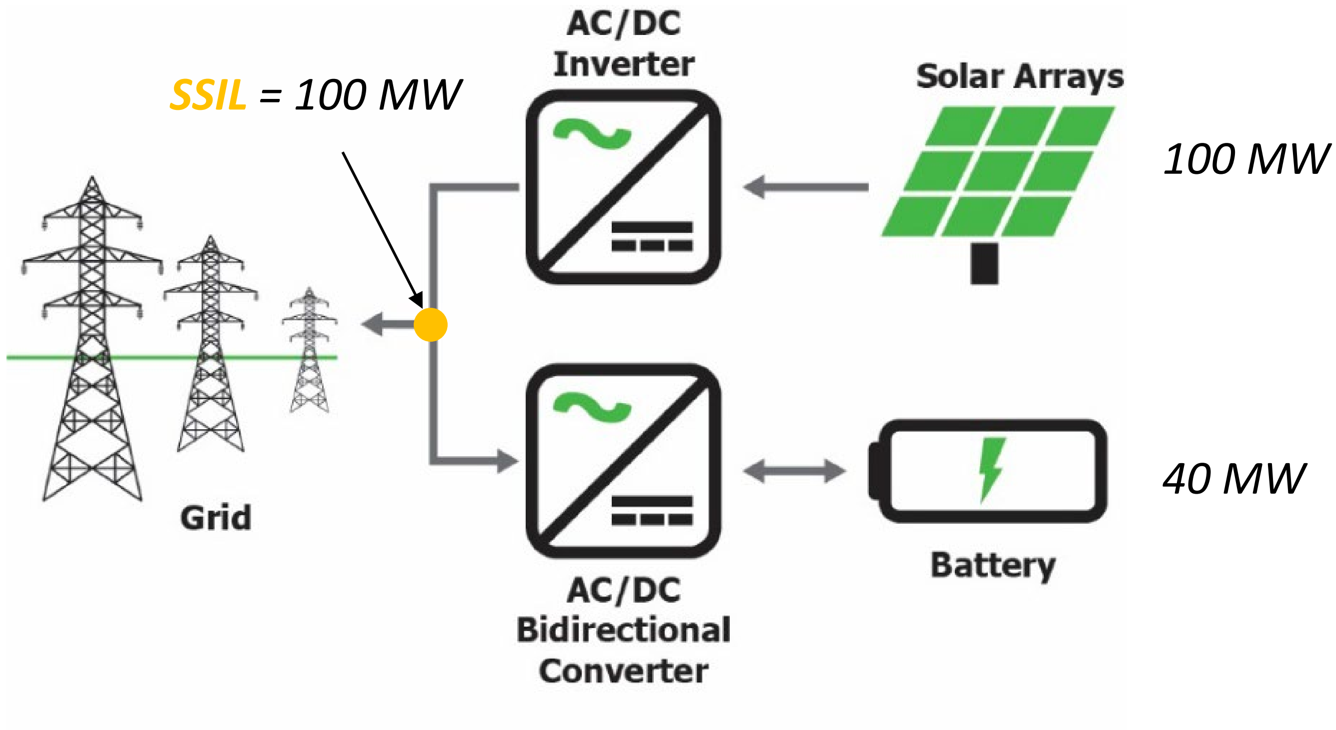


White Paper Overview

Recommendations for Utilizing the Excess Capability of BPS-Connected Inverter-Based Resources for PFR and FFR Support

Recommendation	Applicability
The *pro forma* LGIA and SGIA should be amended to specify conditions under which the SSIL and STIL of the facility established in the interconnection agreement would complement each other to enable the facility to respond to underfrequency events and provide PFR or FFR to the BPS for the duration until the frequency is restored.	Federal Energy Regulatory Commission (FERC)
Transmission Owners (TOs), in coordination with their Transmission Planner (TP) and Planning Coordinator (PC), should update local interconnection requirements per NERC FAC-001 to permit operation of all newly interconnecting inverter-based resources to provide PFR and FFR while operating at their SSIL up to their STIL. PFR and FFR requirements should focus on the required performance—droops, dead-bands, response times, and reaction times.[5]	TOs, TPs, PCs
TPs and PCs should evaluate and enhance their interconnection study processes per NERC FAC-002 to ensure the added provision of FFR and PFR from inverter-based resources does not adversely affect BPS reliability or stability. Adequate simulations are needed to ensure all system operating limits are met with these capabilities enabled. TPs and PCs should review, amend, and file their *pro forma* interconnectio to clarify SSIL and STIL to support PFR or FFR whenever excess capability i TPs and PCs should also ensure any transmission planning studies includin of resources are appropriately modeled in underfrequency load sheddin effective version of NERC PRC-006.	TPs, PCs

Recommendations for Utilizing the Excess Capability of BPS-Connected Inverter-Based Resources for PFR and FFR Support

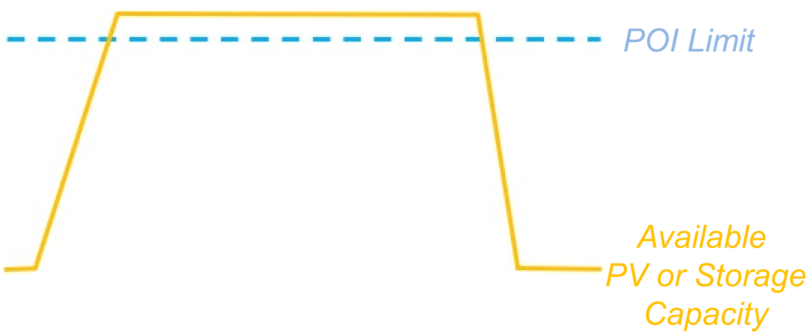
Recommendation	Applicability
Equipment manufacturers, developers, Generator Owners (GOs), and Generator Operators (GOPs) of BPS-connected inverter-based resources that have excess capabilities and able to provide additional active power (above SSIL) to support frequency response should utilize the STIL established by interconnection agreements or requirements. If the agreements and requirements are amenable to this functionality being enabled, it should be functionally available per FERC Order No. 842. Any provision of additional active power should not hinder or limit the capability to provide reactive power to the BPS and take into account the facilities' required power factor limits relative to the SSIL established in the interconnection agreement as well as active or reactive current priority control settings.	Inverter and plant-level controller manufacturers, inverter-based resource developers, GOs, GOPs
Reliability Coordinators (RCs) and Transmission Operators (TOPs) should ensure the additional active power generated by resources exceeding their SSIL up to their STIL to provide PFR or FFR would not cause any adverse impacts to reliability and stability of the BPS during real-time operations. This includes ensuring that no system operating limits are exceeded and operational planning assessments and real-time assessments are reflective of these additional capacities from inverter-based resources. Balancing Authorities (BAs) should ensure awareness of the on-line FFR and PFR capabilities to ensure sufficient reserves to support BPS frequency immediately following sudden loss of generation or sudden increase in load events.	RCs, TOPs, BAs

Benefits and Value Proposition for Varying Entities

What is the value to each entity for utilizing frequency response capability from inverter-based resources that is currently restricted due to existing interconnection requirements?

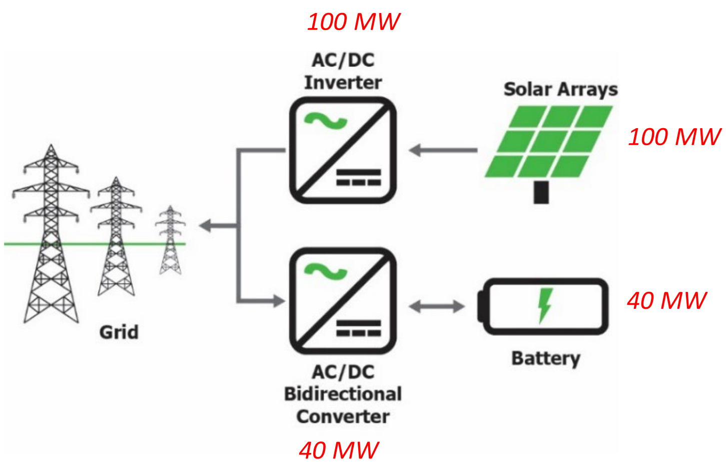
Where Does Such Capability Exist?

- Solar PV Only – excess power stuck behind POI
  - Installed PV AC capacity is often greater than POI in order to generate to capacity for less-than-optimal conditions, reach POI capacity earlier and remain at capacity longer, and compensate for degradation and equipment outages
- Storage Only – excess power stuck behind POI
  - Installed storage capacity is often greater than POI to compensate for battery degradation and to maintain capacity during component outages

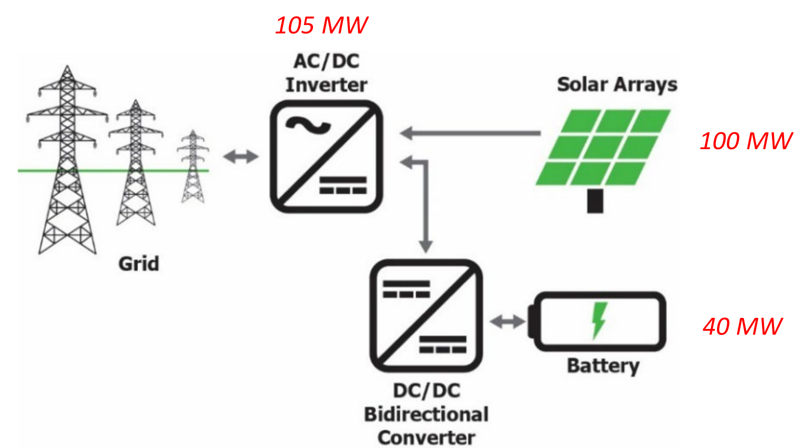


Where Does Such Capability Exist?

- Solar PV + Storage – combined power greater than POI
  - PV + Storage total capacity is typically greater than the POI limit especially for AC coupled systems
  - Ex.: 100 MW PV and 40 MW battery will be connected behind a 100 MW POI limit



AC-Coupled Hybrid Plant



DC-Coupled Hybrid Plant

Benefits to Developers and GOs/GOPs

- Developer:
  - Off-taker can put excess capability into the ancillary service market
  - Generate some additional energy without additional development cost
  - Creates value for power and energy stuck behind the POI

- Generator Owner/Operator:
  - Additional capability can participate in the ancillary service market
  - Generate some additional energy
  - Creates value for power and energy stuck behind the POI

Values to BAs/TOPs

- Balancing Authority/Transmission Operator:
  - Larger accessibility for procuring frequency response (possible reduced cost)
  - Provides frequency response when resource would otherwise be a maximum
  - Improved BA frequency response
  - BAL-003 compliance
  - Greater dispersion of frequency resources – better frequency control
  - Increased system reliability

Equipment Manufacturer Perspectives

How can this technology be leveraged and what does it take?

Key Attributes

- Three basic technologies driving solar and BESS inverter-based projects today:
  - Solar PV + Wind
  - Solar PV + DC-Coupled BESS
  - AC-Coupled BESS

Key Attributes

PV & Wind

- *DC Voltage varies as Inverter tracks MPP of PV array.*
- *Very fast AC Voltage control.*
- *Frequency control possible in **one direction** only unless plant AC output is oversized or you hold a reserve. Also contingent on sun shining or wind energy present.*
- *Frequency response >250 ms for PV and >1sec for wind.*

PV + DC-Coupled BESS

- *DC voltage of battery interfaced to inverter via a DC-DC converter.*
- *Voltage control possible.*
- *Frequency control possible with sufficient battery charge.*
- *Charge battery from the PV array and/or the grid.*
- *Voltage & Freq. response time same as PV.*

AC-Coupled BESS

- *DC voltage is somewhat fixed as governed by the battery.*
- *Complex dynamic AC Voltage control. Q related to DCV.*
- *Frequency control possible with sufficient battery charge.*
- *Frequency response <250 ms.*

Inverter-Level vs. Plant-Level Frequency Control

- Plant controller gets POI frequency information from POI power quality meters
- For solar PV, frequency control is best accomplished in the plant controller:
  - Plant controller can command solar PV inverters to operate at less than 100% AC output
  - Co-located BESS may be needed to augment solar PV energy outside of the solar production day
- FFR frequency control is best accomplished in the inverter

Solar PV Frequency Control

- FERC Order 842 requires frequency control capability and operational use
- Solar PV plants are typically sized for the AC interconnection
- Example:
  - Solar PV plant can be oversized on AC side if permitted by interconnection entity. Provide the potential AC capability to increase active power during a grid frequency dip.
    - AU grid governance body runs each solar PV plant at 85-90% capacity to provide a buffer for frequency control
  - Ability to use oversized capability allows plant operator to not have to run the reserve on other facilities that can provide frequency response

BESS Frequency Control

- Charging/discharge active power used to regulate grid frequency
- These systems are typically less than 2 hour systems
- Capability can generally meet FFR requirements
  - Example: Can meet ERCOT 250 ms response requirement

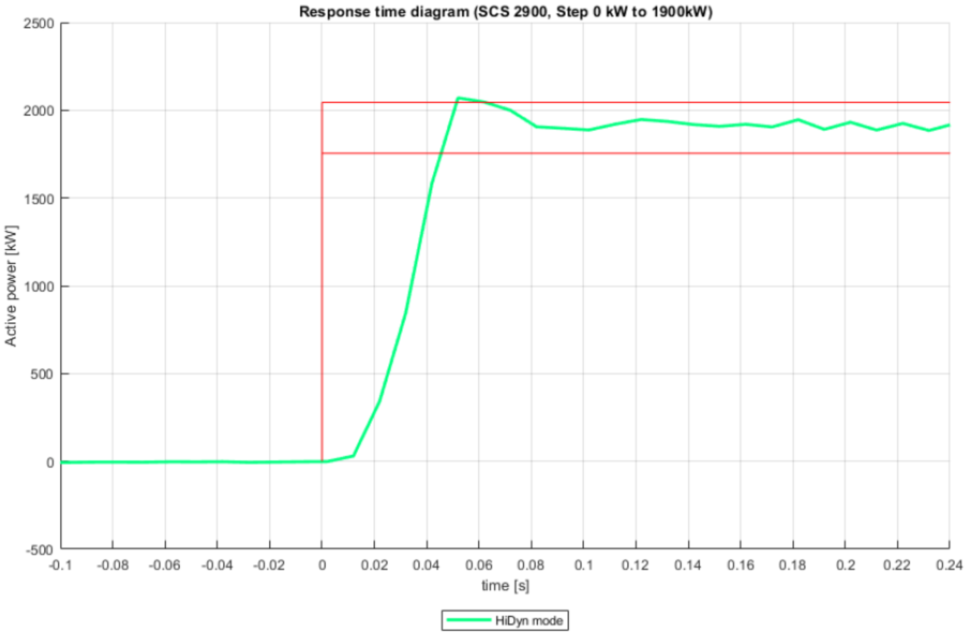


Diagram 1: Step response P=0kW to P=+1900kW; HiDyn mode with setting A)

Field Demonstration PFR with SSIL/STIL

Facility: Eolica Coromuel

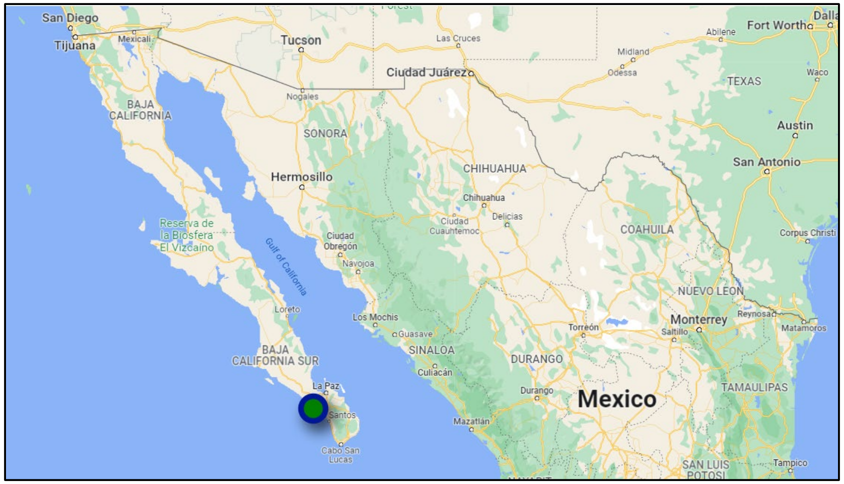
Developer: Eurus Energy America Corporation

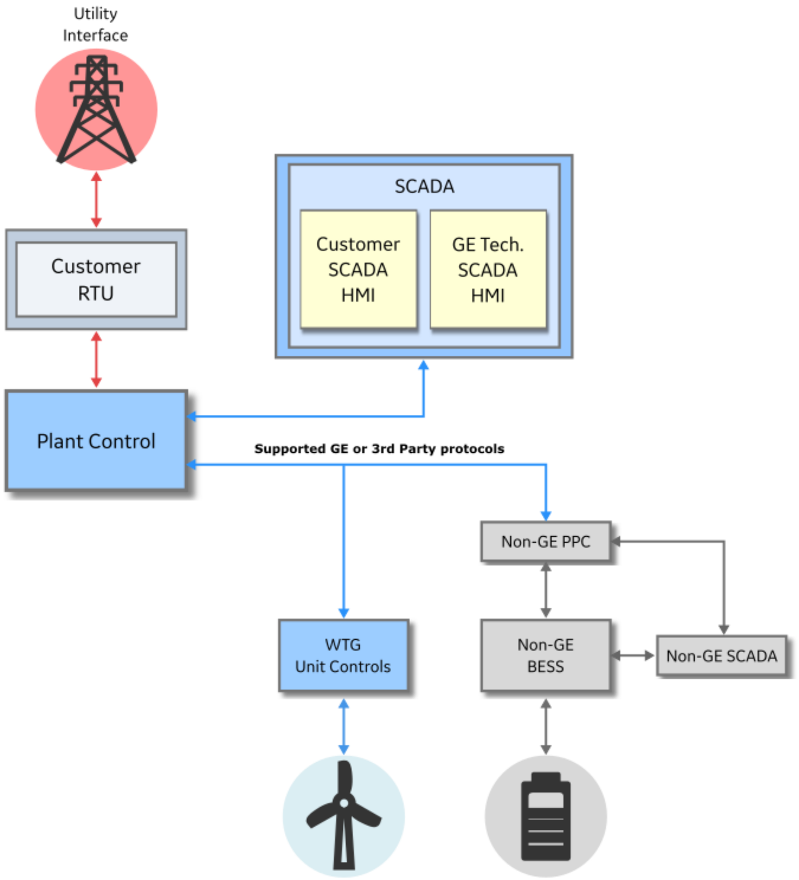
Park Type: Hybrid – AC-Coupled Wind + Storage

- Wind – Nameplate Rating of 50 MW
- BESS 10MW x 10MWh

Services and Prioritization:

1. Primary Frequency Response with the requirement to not exceed 55 MW STIL (**S**hort **T**erm **I**nterconnection **L**imit)
2. 50MW Park SSIL (**S**teady **S**tate **I**nterconnection **L**imit)
3. Utility Setpoint Tracking
4. Ramp Rate Limit of Renewable Generation

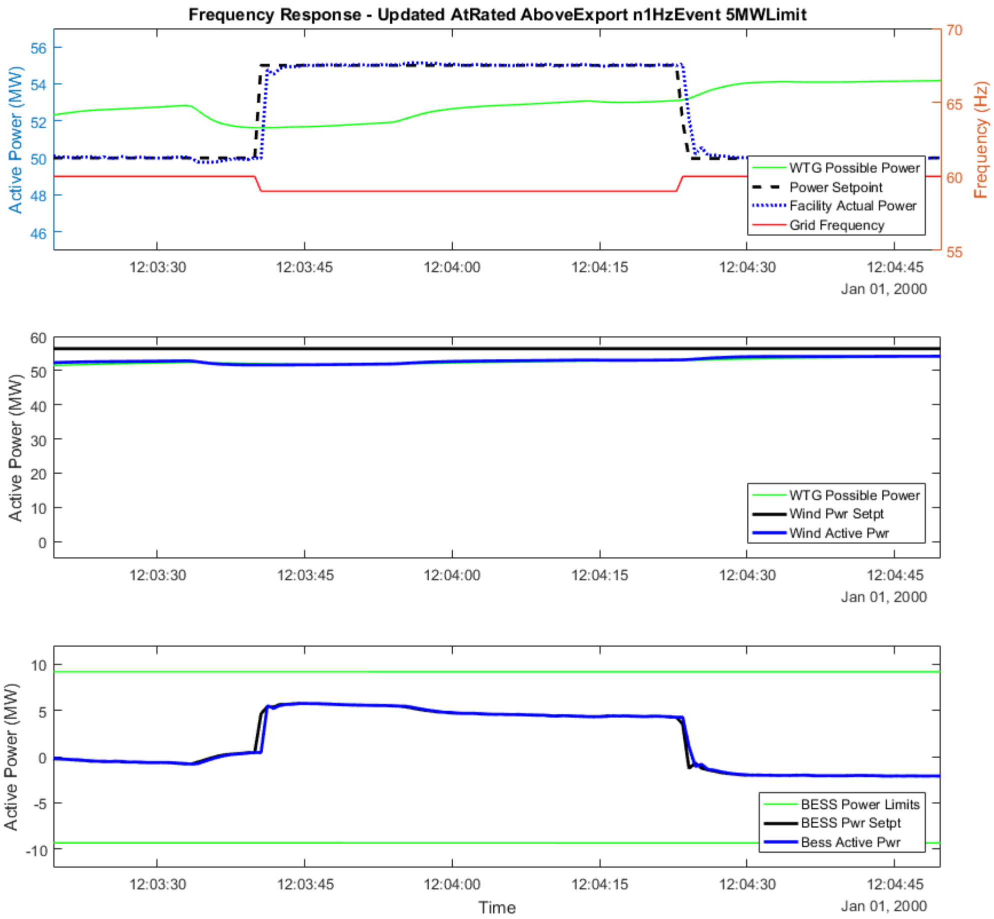




Field Demonstration – Test and Results

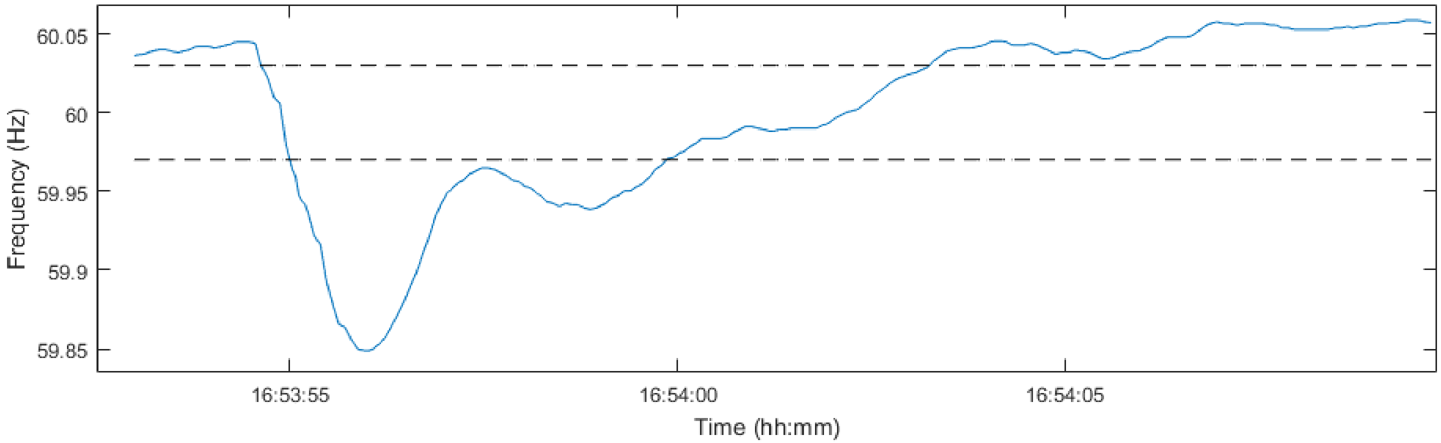
- **Test Objectives:**
  - This test was conducted to demonstrate the underfrequency performance at the boundaries of the standard operating regions
- **Notes on Test Case:**
  - The design allows a limit to be set on the amount above a rated park power (50 MW) setpoint the frequency response logic is allowed to exceed.
- **Test Configuration Settings:**
  - WTG Possible Power: ~50 MW
  - Frequency Droop Setting: 4%
  - Deadband Boundaries: +/- 17 mHz
  - Droop Magnitude Base: Registered Power
  - Droop Reference: Actual Power at initial time of Event
  - BESS Initial State-of-Charge: 50%
  - Net Negative Exceedance limit: 0 MW
  - Export Limit MW exceedance limit: 5 MW
  - Curtailment Limit MW exceedance limit: 5 MW

Test Case: WTGs at Rated – 1 Hz Underfrequency

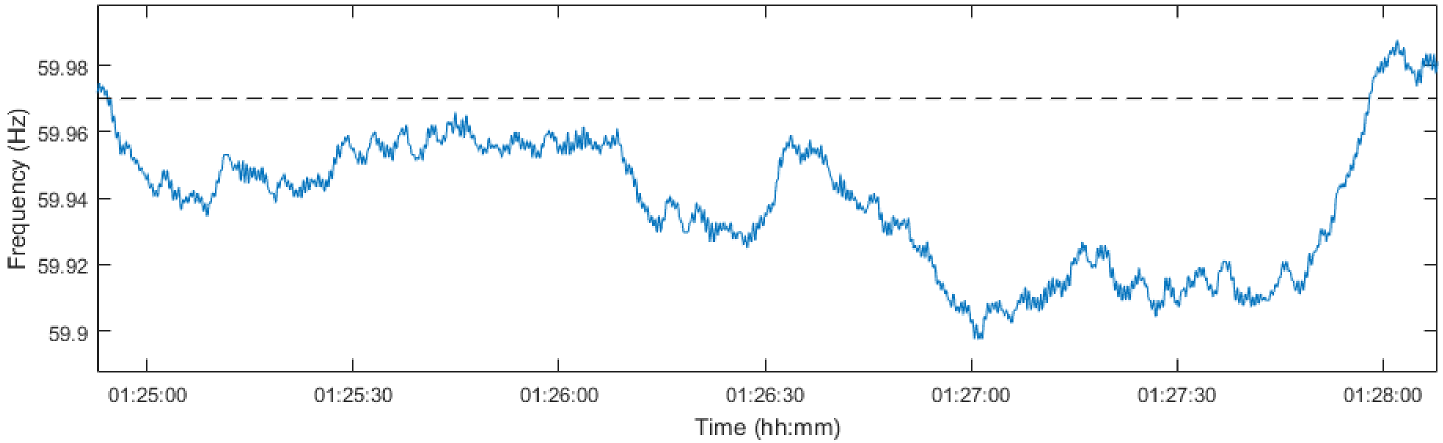


Types of Frequency Events

Short Duration, Large Frequency Excursions



Long Duration (Pseudo Steady-State), Small Frequency Deviations



Frequency Events – Power and Energy

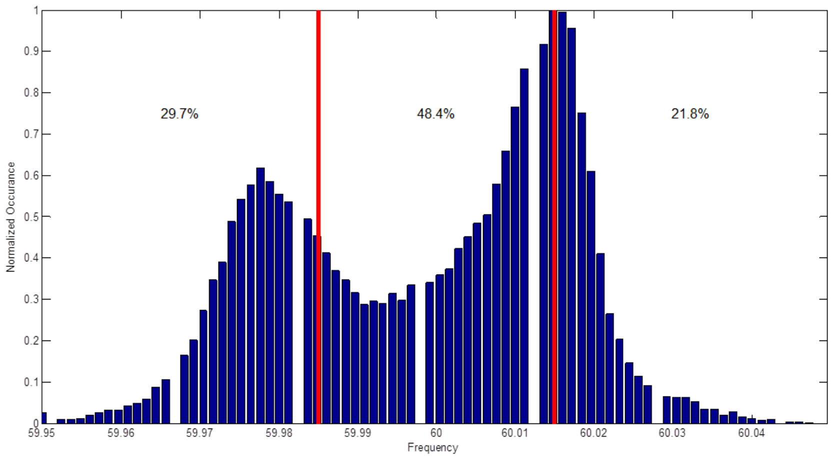
Takeaways:

- ***Energy Content is minimal**. Frequency Response services are a primarily power oriented and of short duration. Metrics will depend on the market and grid requirements.*

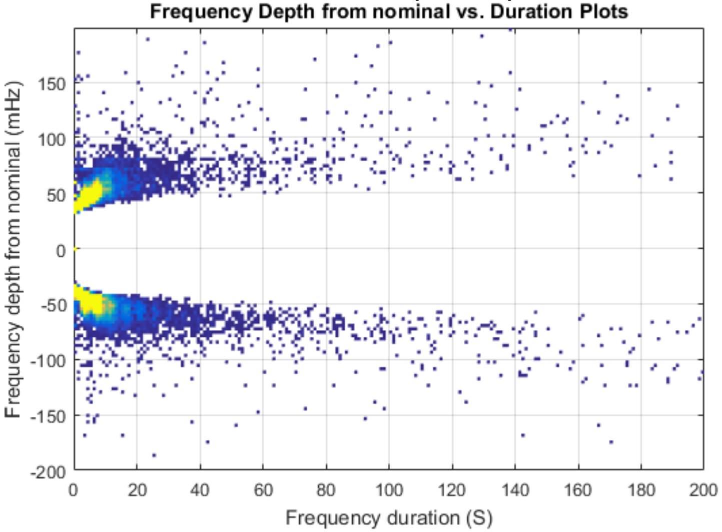
  For example: ERCOT's 17mHz deadbands result in:
    - *Underfrequency response of 0.17% Annual Energy Production*
    - *Overfrequency response of 0.13% Annual Energy Production*

- *Frequency is always dithering and frequency events (frequency outside deadbands) **occur continuously for small deadbands**.*

- *Frequency events are typically tiny in magnitude, wherein measurable events are typically >100mHz. **Equipment is not allowed to decide what to respond to.***



Plant in Mexico (Slide 22)
Frequency Depth from nominal vs. Duration Plots



For a 42 day period in Q1 2020 for a 150MW facility in ERCOT:	Total (42 days)	Per Day
Number events	436,932	10,403
Time Spent in Frequency Response (Hours)	381.6 hours	9.1 hours
Total droop up requested (request for additional energy produced)	*89.43 MWh* *(0.17% AEP)*	2.1 MWh/day
Total droop down requested (request for curtailment)	*-70.01 MWh* *(0.13% AEP)*	-1.7 MWh/day
Average depth of Droop Request	*6.52 mHz (POI delta of 0.41MW assuming 4% droop)*	
Average Duration of Event	*2.3 seconds*	
Average Duration within DB prior to event	*6.1 seconds*	

Planning Perspectives

What do transmission planners need to model and study this additional capability?

Current and Proposed Practices

- Current practice:
  - IBRs can provide *fast frequency response (FFR)* and *primary frequency response (PFR)*…but presently **cannot exceed** the *steady-state interconnection limit (SSIL)* of the facility established in the interconnection agreement.
- Proposed IBR frequency response:
  - If IBRs are used to provide FFR and PFR, and exceed the SSIL of the facility established in the interconnection agreement, additional considerations are needed, including:
    - **Time Duration:** FFR, PFR, are within a few minutes' scale. The duration of frequency support will be a short temporary time. Plants need to return to the SSIL no later than the short time duration.
    - **Deadband for Frequency Control:** IBR shall only produce additional power output exceeding SSIL during low frequency conditions. Plants need to return to the SSIL once the system frequency rises above the threshold.
    - **Short-Term Interconnection Limit (STIL):** New stability limits need to be established. Study is required before operation.

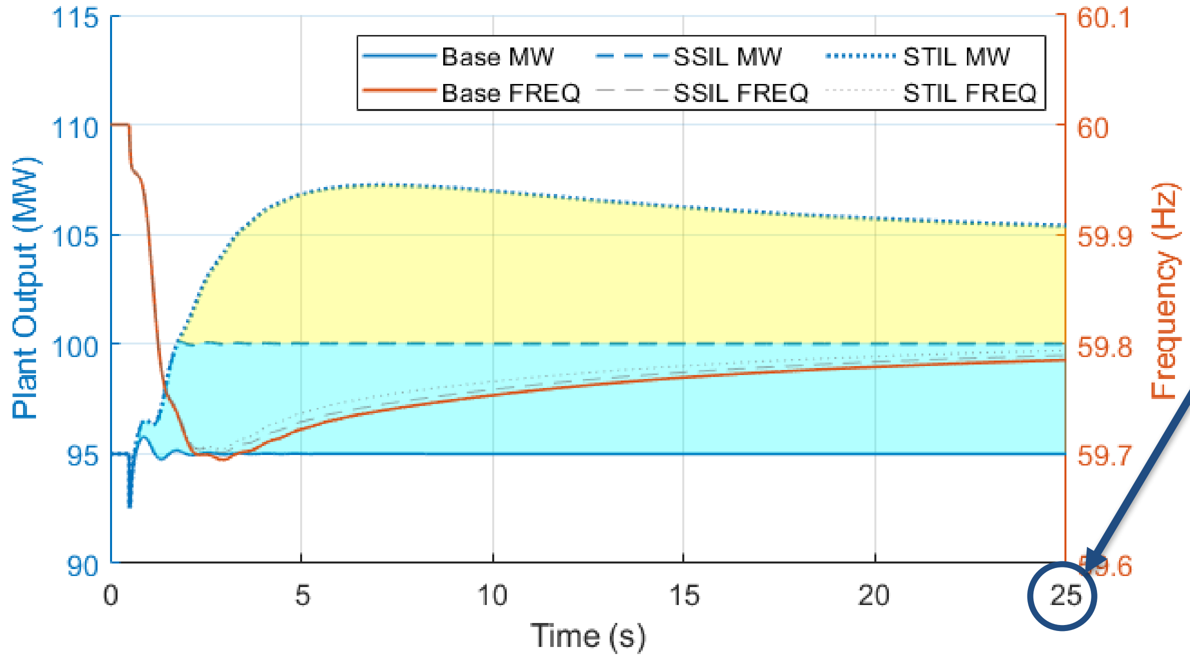
Standard Library Dynamic Models for IBRs

Description	Model Name	Applicability Notes
Converter	REGC_B	All IBR: voltage source interface model
	REGC_A*	All IBR: current source model
Electrical control	REEC_D	Enhanced model for all types of IBRs
	REEC_A	Type 3 and 4 WTGs, solar PV
	REEC_C**	Battery energy storage
Plant controller	REPC_B	For controlling multiple devices
	REPC_C	Enhanced model for controlling single device
	REPC_A**	For controlling single device
Ride-through protection	LHVRT	Voltage ride-through
	LHFRT	Frequency ride-through

**Models can have numerical issues in low short circuit grids*
*** Models are still valid but have an improved version.*
For more details on hybrid plant modelling see "White Paper on Modeling Hybrid Power Plant of Renewable Energy and Battery Energy Storage System" (here)

Example of Frequency Response of Hybrid Plant (Solar PV + BESS)

Scenarios Considered	Plant Total Dispatch (MW)	Plant Total Capacity (MW)	Limit (MW)
Base Case (no Freq. response)	95	140	100, SSIL
SSIL Case (Freq. response with steady-state interconnection limit)	95	140	100, SSIL
STIL Case (Freq. response with short-term interconnection limit)	95	140	> 100, STIL



Note that the simulation lasts for only 25 seconds. Plant output shall return back below SSIL after the FR period.

*Simulation performed in PSSE v34.7 using REGCA1, REECA1, REAX4BU1, and PLNTBU1 models.

Example of Frequency Response of Hybrid Plant (Solar PV + BESS)

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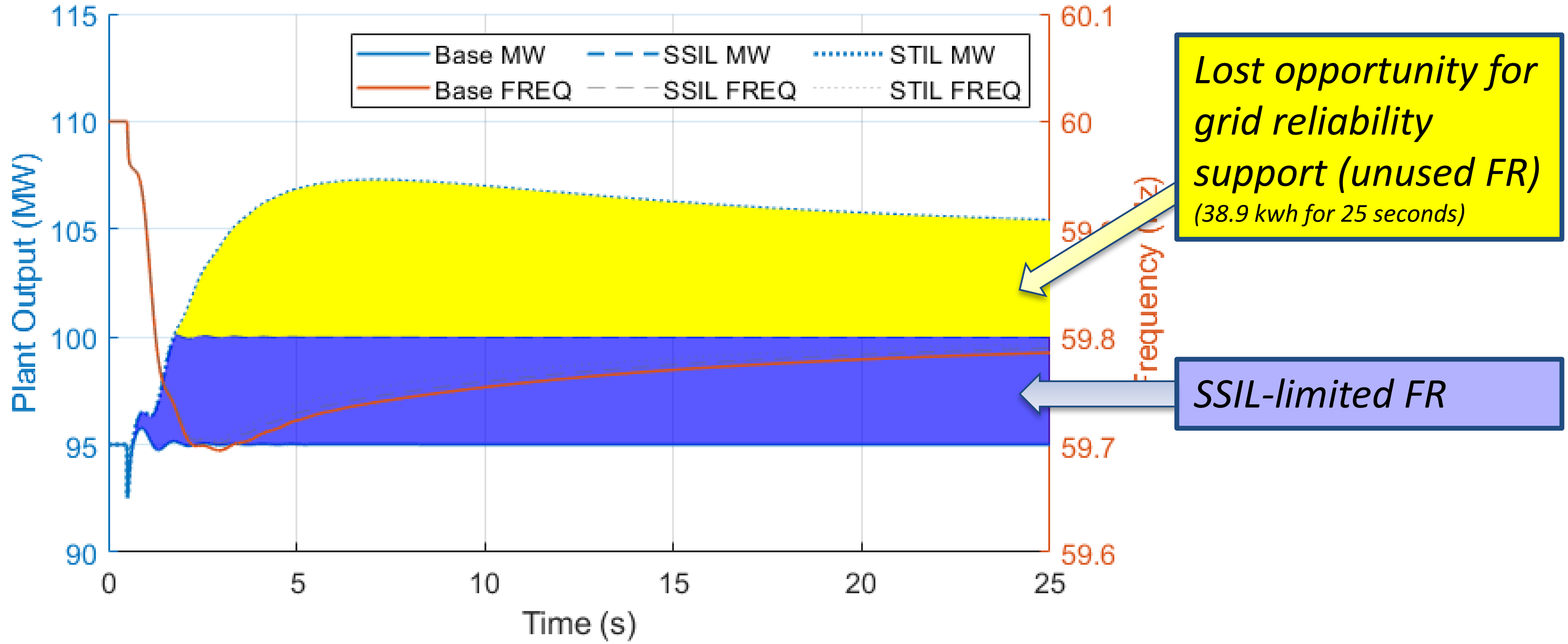

IEEE 2800-2022 and R&D Perspectives

How do we leverage the IEEE 2800 standard and what future work do we need to explore in this area?

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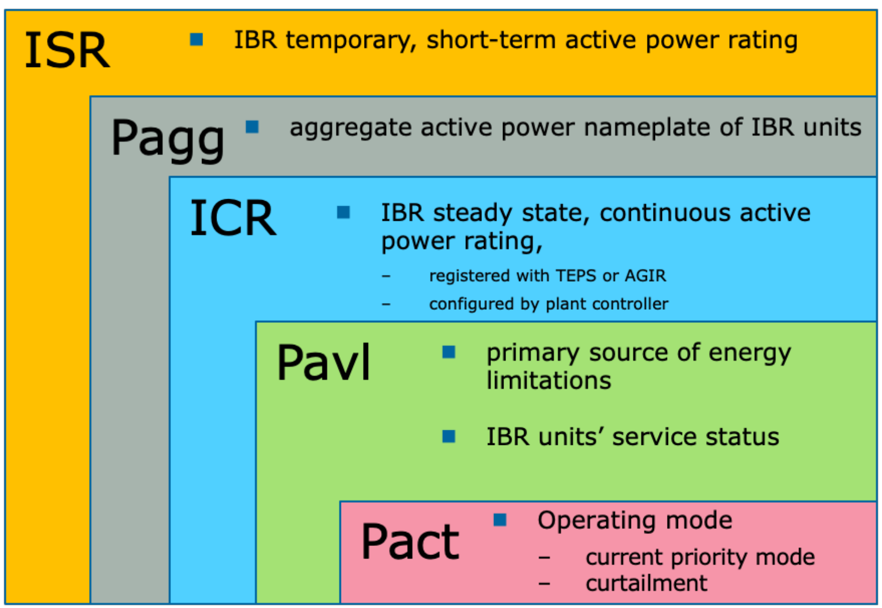
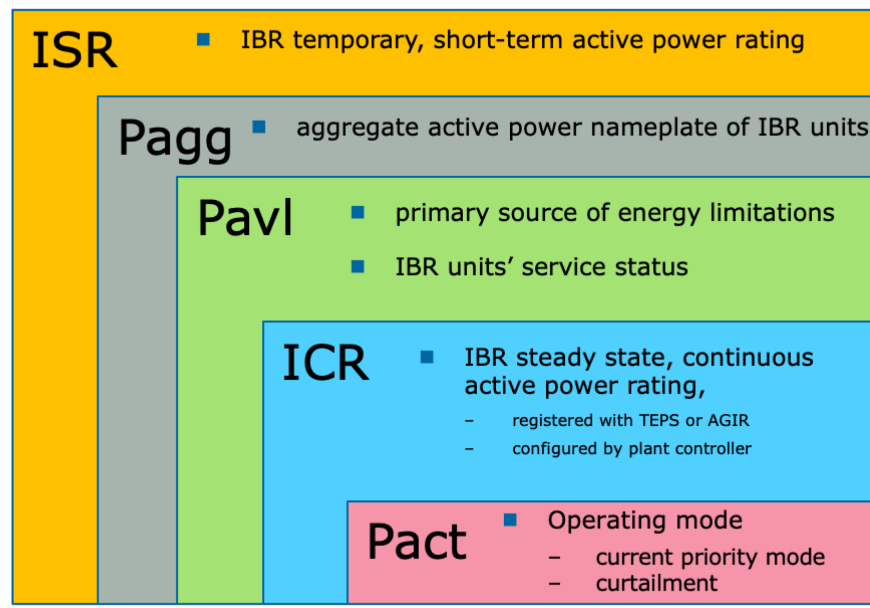
IEEE 2800 Terminology

NERC White Paper	IEEE 2800
Not defined	Available Active Power (Pavl)
Steady-State Interconnection Limit (SSIL)	IBR Continuous Rating (ICR) IBR Continuous Absorption Rating (ICAR)
Short-Term Interconnection Limit (STIL)	IBR Short-Term Rating (ISR)

Case 1: ICR > Pavl



Case 2: Pavl > ICR



IEEE 2800 and Primary Frequency Response

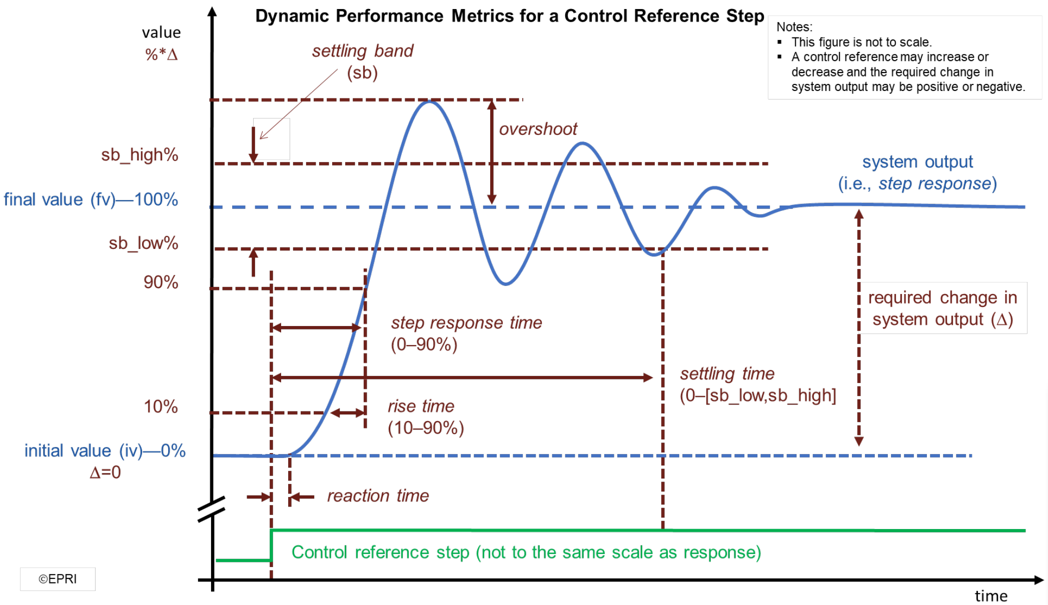


Figure 5(a) from IEEE P200 Draft 6.3 (December 2021)

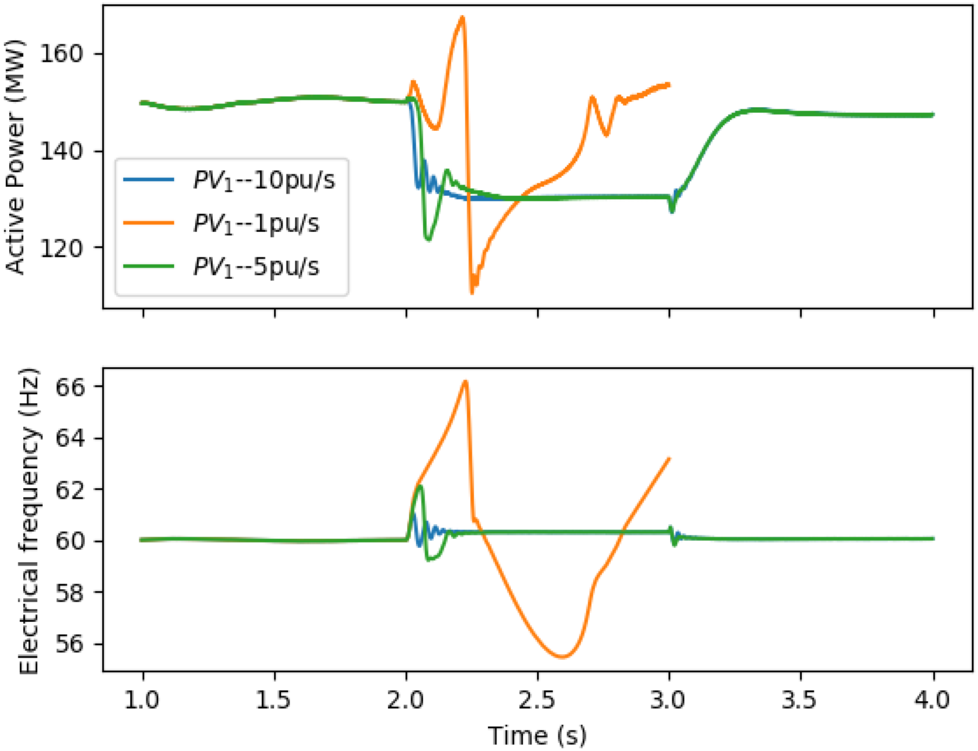
	Units	Default Value	Minimum	Maximum
Reaction time	seconds	0.50	0.20 (0.5 for WTG)	1
Rise time	seconds	4.0	2.0 (4.0 for WTG)	20
Settling time	seconds	10.0	10	30
Damping Ratio	% of Change	0.3	0.2	1.0
Settling band	% of Change	Max (2.5% of change or 0.5% of ICR)	1	5

Table 10 from Draft 5.1 of IEEE P2800 Draft Standard

- Table 10 specifies minimum capability to be met
- Change in IBR plant power output may not be required to be greater than maximum ramp rate of plant
  - Should be as fast as technically feasible
- 15mHz - 36mHz deadband with 2% - 5% droop

Source Behind Resource May Influence Delivery of Response

- A low inertia power network needs fast injection of current to mitigate imbalances.
- Suitable choice of ramp rate limit can bring about a stable response

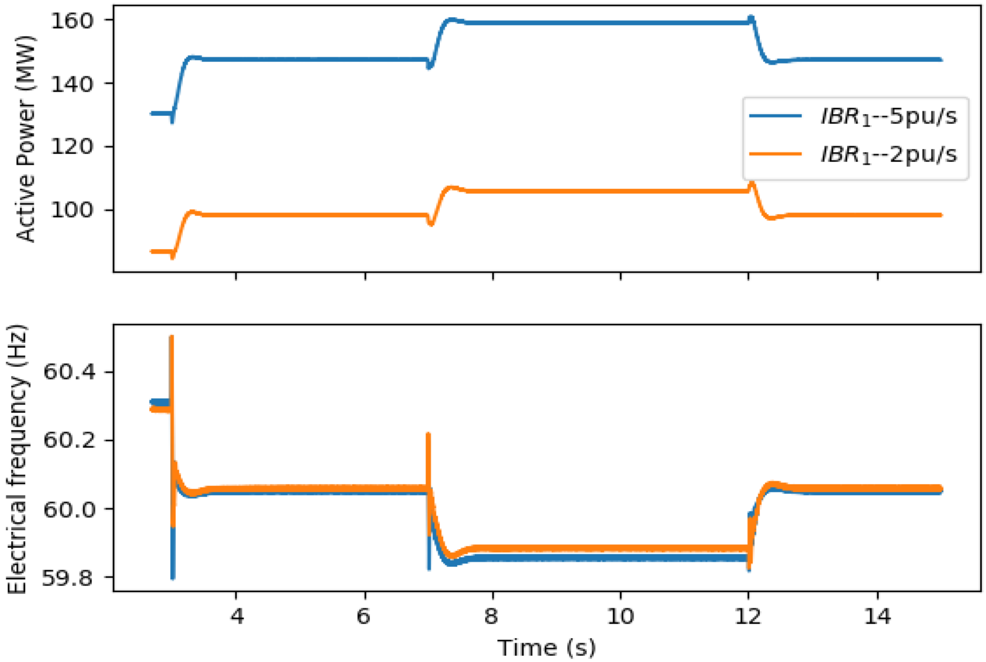


Maximum ramp rate influenced by source behind the inverter

Batteries can tolerate higher ramp rates as opposed to wind turbines

Lower Ramp Rate Requires More Responsive Resources

- Possible to obtain stable frequency control in a high IBR network, with lower ramp rates
- Requires more resources to share the change in energy burden
- Any form of IBR device/control can have inherent ramp rate limits



Important to recognize this if newer IBRs have to additionally support older IBRs

5pu/s – Two PV plants of 200 MVA each
2pu/s – Three PV plants of 100 MVA each

Where Do We Go From Here?

Recommendations for Utilizing the Excess Capability of BPS-Connected Inverter-Based Resources for PFR and FFR Support	
Recommendation	**Applicability**
The *pro forma* LGIA and SGIA should be amended to specify conditions under which the SSIL and STIL of the facility established in the interconnection agreement would complement each other to enable the facility to respond to underfrequency events and provide PFR or FFR to the BPS for the duration until the frequency is restored.	Federal Energy Regulatory Commission (FERC)

Questions and Answers

If interested in participating in the NERC Inverter-Based Resource Performance Subcommittee (IRPS), please reach out to Ryan Quint (ryan.quint@nerc.net).