INTERCONNECTION
INNOVATION e-XCHANGE
U.S. DEPARTMENT OF ENERGY

Forum for the Implementation of Reliability Standards for Transmission (i2X FIRST) | 11/26/24

An initiative spearheaded by the Solar Energy Technologies Office and the Wind Energy Technologies Office

BERKELEY LAB

EPRI

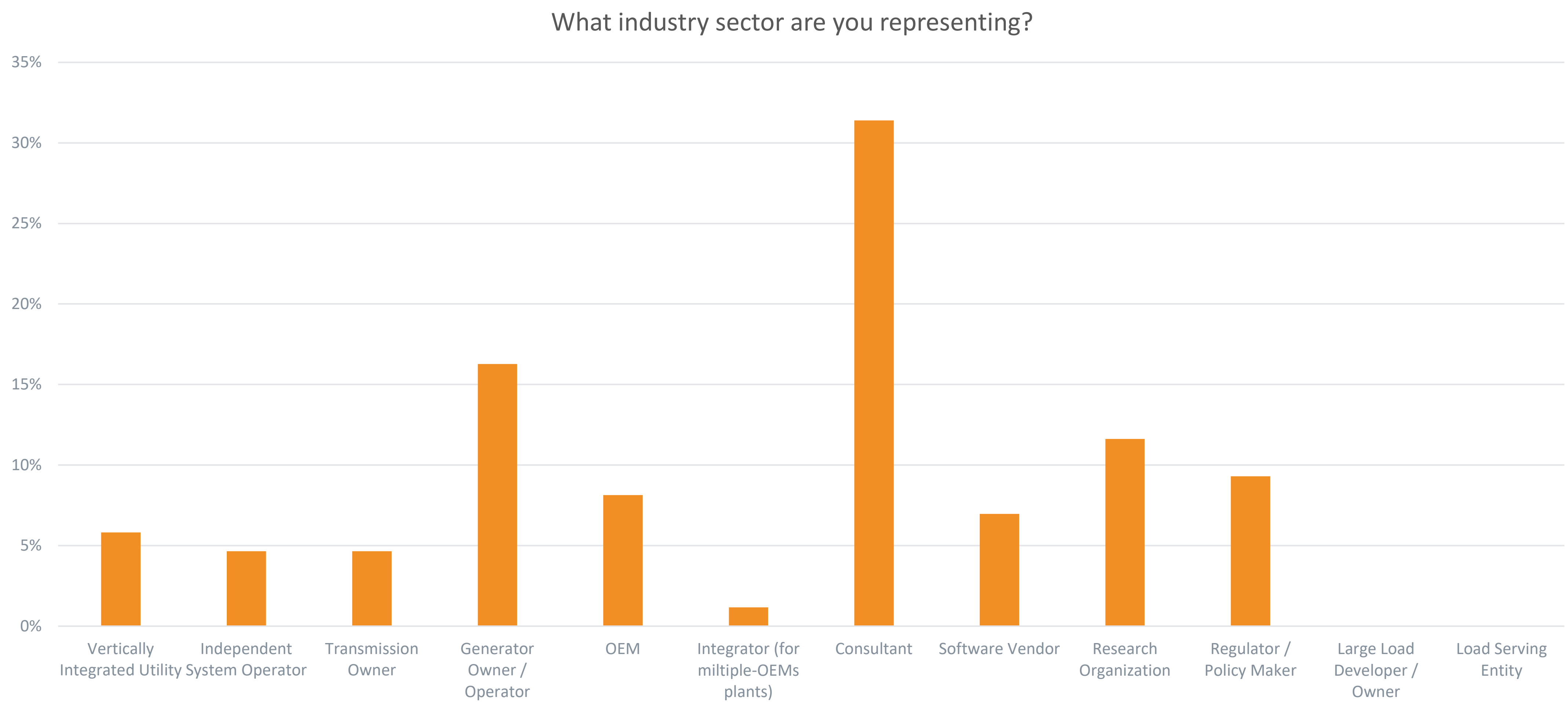
ESIG

The first half of this meeting call is being recorded and may be posted on DOE's website or used internally. If you do not wish to have your voice recorded, please do not speak during the call. If you do not wish to have your image recorded, please turn off your camera or participate by phone. If you speak during the call or use a video connection, you are presumed consent to recording and use of your voice or image.

Polling Question 1

What industry sector are you representing?

[Go to **slido.com** and enter event code **FIRST7**, then go to **Polls** tab]

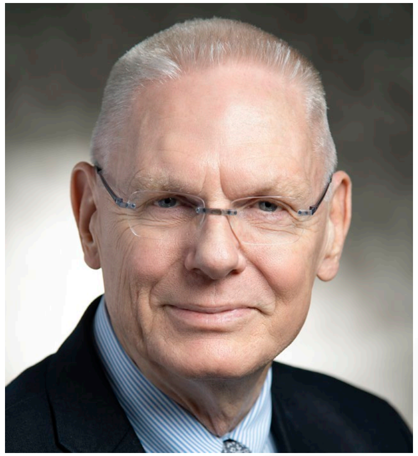

What industry sector are you representing?
35%
30%
25%
20%
15%
10%
5%
0%
Vertically Integrated Utility
Independent System Operator
Transmission Owner
Generator Owner / Operator
OEM
Integrator (for miltiple-OEMs plants)
Consultant
Software Vendor
Research Organization
Regulator / Policy Maker
Large Load Developer / Owner
Load Serving Entity

Key Goals and Outcomes from i2X FIRST

- To facilitate understanding and adoption of new and recently updated standards relevant for existing and newly interconnecting wind, solar and battery storage plants
- The Forum will convene the industry stakeholders to enable practical and more harmonized implementation of these interconnection standards.
- The presentation portion of the meeting will be recorded and posted, and presentation slides will be shared.
- Additionally, the leadership team will produce **a summary of each meeting** capturing:
  - Recommended best practices
  - Challenges
  - Gaps that require future work

Leadership Team

Cynthia Bothwell, Boston Government Services, contractor to DOE’s Wind Energy Technologies Office



Robert Reedy, Lindahl Reed, contractor to DOE’s Solar Energy Technologies Office

Will Gorman, Lawrence Berkley National Laboratory

Jens Boemer, Electric Power Research Institute

Julia Matevosyan, Energy Systems Integration Group

Ryan Quint, Elevate Energy Consulting

Summary of the i2X FIRST Workshop, Conformity Assessment

- Session 1: **Need for Conformity Assessment and IEEE P2800.2 Progress Update** – Ryan Quint, Elevate Energy Consulting; Alex Shattuck, NERC; Andy Hoke NREL/IEEE P2800.2 Chair
- Session 2: **IBR Plant Modelling and IEEE P2800.2 Design Evaluation** – Alex Shattuck NERC/SG3 P2800.2 Co-lead; Miguel Cova Acosta, Vestas; Billy Yancey, EPE
- Session 3: **IEEE 2800.2 Design Evaluation, Model Validation and Benchmarking** – Andrew Isaacs, Electranix/SG3 P2800.2 Co-lead, Miguel Cova Acosta, Vestas
- Session 4: “As-Built” Evaluation and Commissioning Testing – Chris Milan, CrestCura/SG4 P2800.2 Co-lead

Meeting summary, recording & presentations are posted here (click on Past Events at the bottom of the page)

Key Themes from the i2X FIRST Workshop, Conformity Assessment

- **Harmonizing Standards:** Interconnection standards such as, e.g. IEEE 2800-2022 and P2800.2 enhance interconnection processes, improving IBR models, plant designs, and conformity assessments.
- **Improving Conformity Assessments:** IEEE P2800.2, expected by 2026, will guide model validation, design evaluations, and performance assessments. Many ISO/RTO are already requiring some degree of conformity assessments with applicable requirements. Balance is needed with the resourcing, effort, and time involved.
- **IBR Unit and Plant Model Validation:** Validating IBR unit models forms the basis for accurate plant models, aiding comprehensive IBR plant design evaluations. Coordination between OEMs and developers is needed.
- **Design Evaluation:** IBR plant design evaluation done in the EMT domain involves tests to ensure conformity with applicable requirements. These tests should be conducted on the final plant design to avoid rework. The tests are being developed by the IEEE P2800.2 WG to align with the IEEE 2800-2022 requirements, plus additional informational tests to provide deeper performance insights for the IBR plant.
- **Balancing Workload:** Conformity assessment practices such as, e.g. IEEE P2800.2 practices are likely to increase workload, necessitating automation to streamline conformity assessments.
- **As-Built Testing:** As-built verification and **c**ommissioning tests verify the IBR plant matches design evaluations and to validate the plant model to some extent with commissioning test measurements

Upcoming i2X FIRST Meetings

1. May 28th, 2024, 11 a.m.- 1 p.m. ET: Introduction of Evolving Standards Landscape
2. June 25th, 2024, 11 a.m.- 1 p.m. ET: IEEE2800 Ride Through Requirements
3. July 30th, 2024, 11 a.m.- 1 p.m. ET: IEEE2800 Ride Through Requirements, OEM Readiness
4. August 20th, 2024, 11 a.m.- 1 p.m. ET: IEEE2800 Ride Through Requirements, OEM Readiness, cont.
5. September 24th, 2024, 11 a.m.- 1 p.m. ET: Measurements for Performance Monitoring and Model Validation
6. October 24th, 2024 hybrid, full day, during ESIG Fall Workshop, Providence, RI: Conformity Assessment
7. November 26th, 2024, 11 a.m.- 1 p.m. ET: IEEE 2800 Active-Power—Frequency Response Requirements
8. December 17th, 2024, 11 a.m.- 1 p.m. ET:
9. January 28th 2025, 11 a.m.- 1 p.m. ET:
10. February 25th 2025
11. March 20th, 2025 hybrid event during ESIG Spring Workshop, Austin, Texas: Conformity Post Commissioning

Sign up for all future i2X FIRST Meetings here: https://www.zoomgov.com/meeting/register/vJItceuorTsiErIC-HInpPbWuTUtrYQAuoM#/registration

Follow DOE i2X FIRST website: https://www.energy.gov/eere/i2x/i2x-forum-implementation-reliability-standards-transmission-first for meeting materials & recordings and for future meeting details & agendas

Active-Power—Frequency Response Requirements– Agenda

- I2x FIRST Intro (10 mins) – Julia Matevosyan, ESIG
- IEEE 2800-2022 Clause 6 *Active Power – Frequency Response Requirements* (15 mins) – Mahesh Morjaria, Terabase Energy
- Wind Generation Frequency Response Capabilities (15 mins) – Miguel Duarte Campos, Vestas
- ISO Experience with Frequency Response Performance (15 mins) – Nitika Mago, ERCOT
- Q&A and Structured Discussion (45 mins) – led by Julia Matevosyan, ESIG
  - IEEE2800-2022, Clause 6 vs FERC Order 842
  - Fast Frequency Response Capability Requirement

Virtual Meetings Code of Conduct

1. *Assume good faith and respect differences*
2. *Listen actively and respectfully*
3. *Use "Yes and" to build on others' ideas*
4. *Please self-edit and encourage others to speak up*
5. *Seek to learn from others*

Mutual Respect . Collaboration . Openness

Stakeholder Presentations

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Mutual Respect . Collaboration . Openness

Q & A Session

Interactive Group Discussion Topics

Topic #1: IEEE2800-2022, Clause 6 vs FERC Order 842

- Please go to slido to make comments and add questions of your own: **slido.com** and enter event code **FIRST7**
- For verbal commentary, please use the raise hand feature and we will call on you
- Additional related / associated questions:
  - What is your perspective on how IEEE2800-2022 Clause 6 can be implemented compared with the directives of FERC Order 842?
  - Is capability required by FERC Order 842 currently being assessed during interconnection process, commissioning testing, enabled and assessed during post-commissioning operation?
  - Are there any important decision points that should be discussed between the TS owner/operator and IBR owner/developer to ensure conformity with frequency response requirements under range of operating conditions?

Topic #2: Fast Frequency Response Capability Requirement

- Please go to slido to make comments and add questions of your own: **slido.com** and enter event code **FIRST7**
- For verbal commentary, please use the raise hand feature and we will call on you
- Additional related / associated questions:
  - What should TS owner/operators and transmission planners be looking for in terms of leveraging the fast frequency response (FFR) capability from IEEE 2800-2022 compliant IBRs?
  - How should use of that functionality be balanced with the need for stable response in weak grid areas?
  - Does that require a detailed study for every interconnecting IBR plant? How to balance this need for reliability impact assessment with the resourcing, effort, and time involved

I2X FORUM FOR THE IMPLEMENTATION OF RELIABILITY STANDARDS FOR TRANSMISSION (I2X FIRST)

IEEE 2800—Standard for PFR/FFR

Presented by Mahesh Morjaria

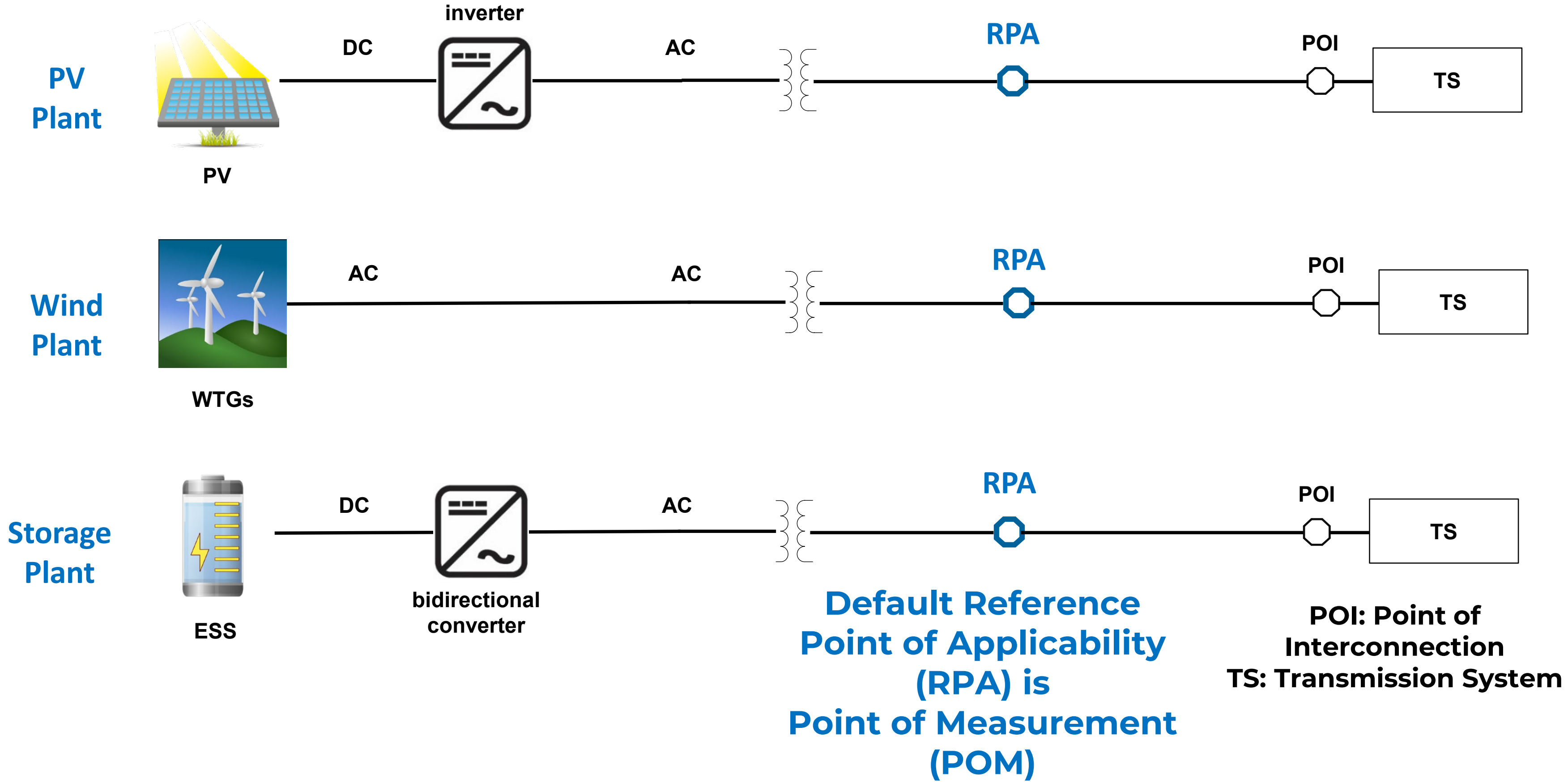
EVP, Technical Strategy
Terabase Energy, Inc

Nov 26, 2024

Terabase

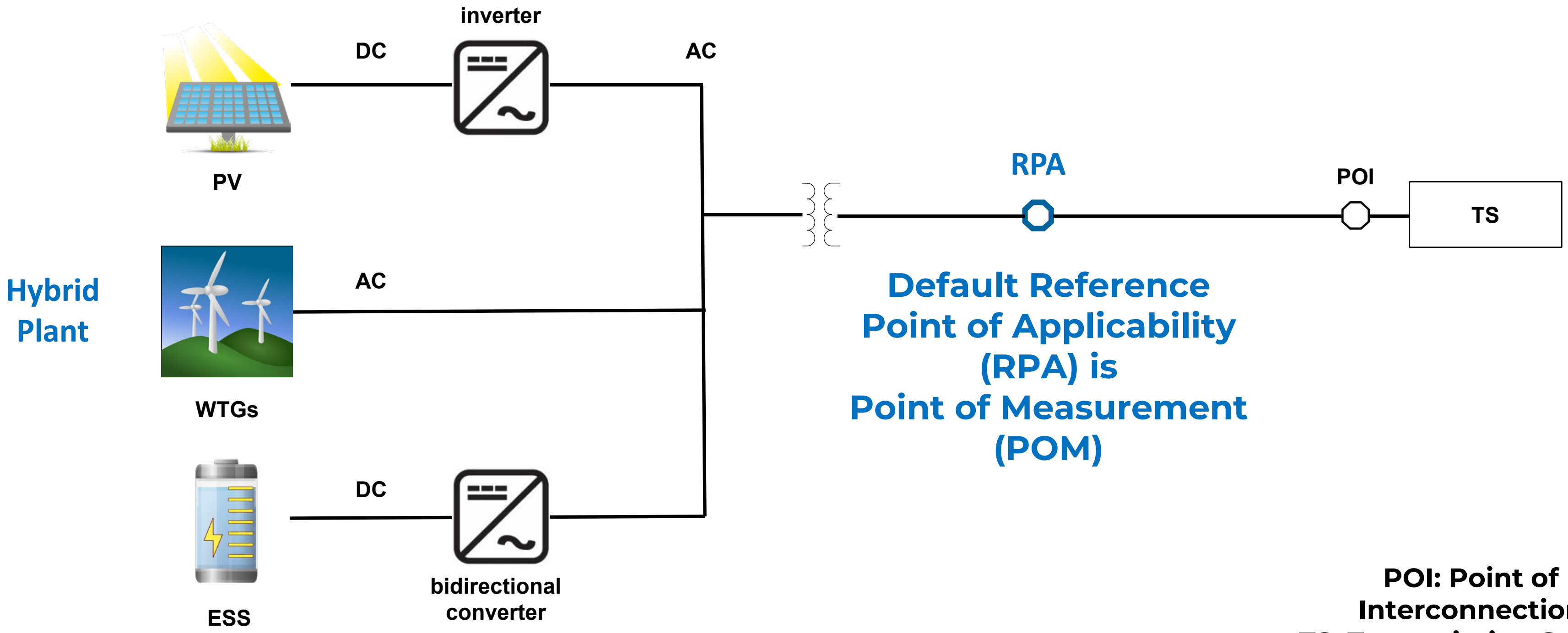
Examples for Inverter-Bases Resources (*IBR)* Plants

in scope



Example *hybrid IBR plant*, ac-coupled

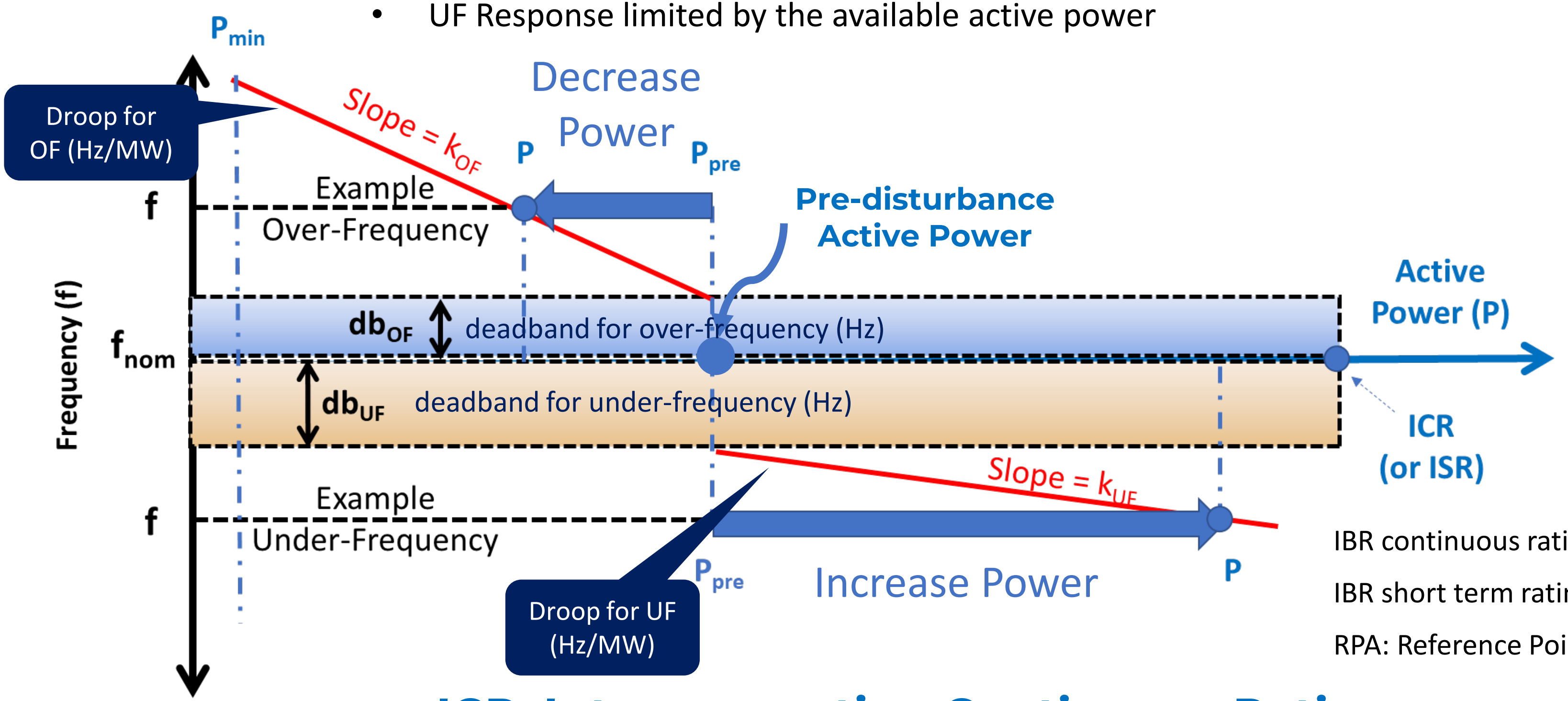
in scope



POI: Point of Interconnection
TS: Transmission System

Primary Frequency Response (PFR) of an IBR at RPA

- The PFR capability shall meet the performance requirement as shown below
- Within continuous and mandatory operation region for frequency & voltage
- UF Response limited by the available active power



IBR continuous rating (ICR) or

IBR short term rating (ISR).

RPA: Reference Point of Applicability

ICR: Interconnection Continuous Rating

PFR Parameters

Table 9— Parameters of primary frequency response for *IBR plant*

	units	Default Value	Minimum	Maximum
db_{uf}	Hz	0.06% x f_{nom}	0.025% x f_{nom}	1.6% x f_{nom}
db_{of}	Hz	0.06% x f_{nom}	0.025% x f_{nom}	1.6% x f_{nom}
k_{uf}[66]		5%	2%[67]	5%
k_{of}		5%	2%	5%

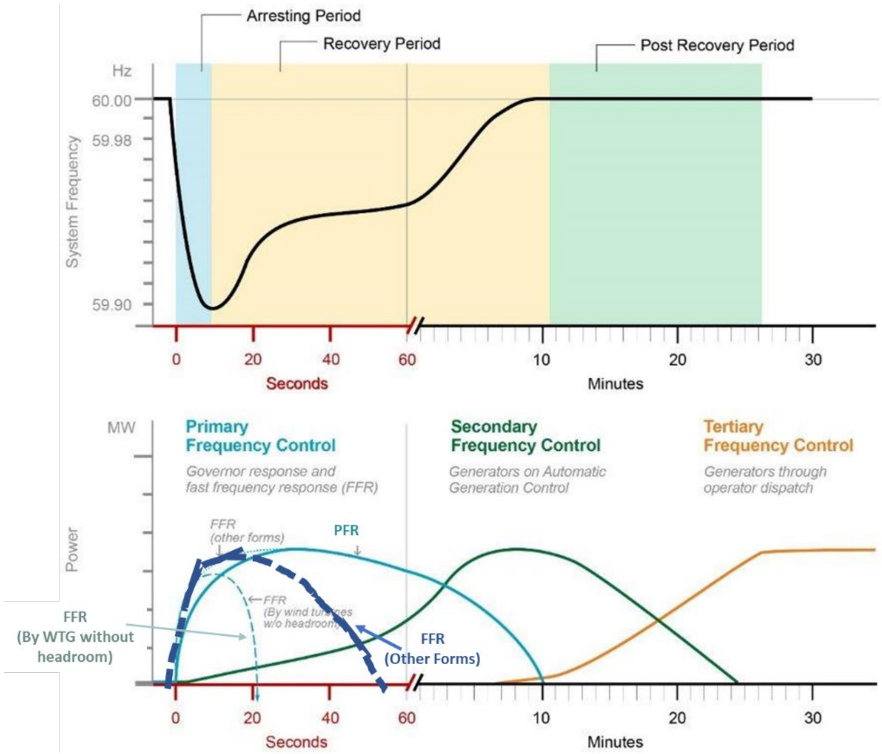
PFR Dynamic Response

Table 10 —Parameters of active power-frequency response dynamic performance for *IBR plant*

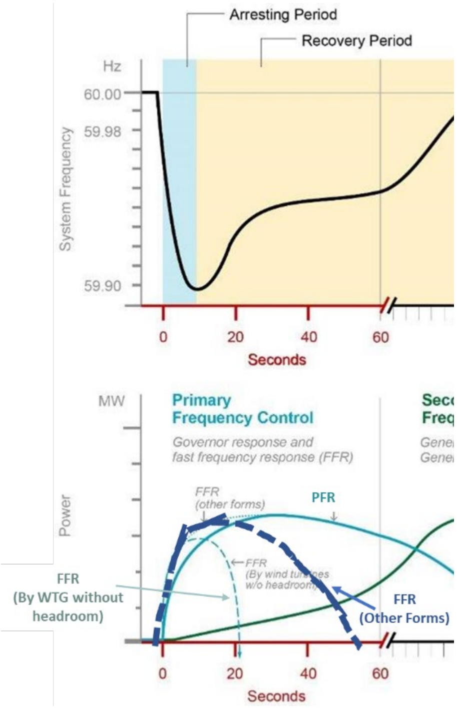
	Units	Default Value	Minimum	Maximum
Reaction time	seconds	0.50	0.20 (0.5 for WTG)	1
Rise time	seconds	4.0	2.0 (4.0 for WTG)	20
Settling time	seconds	10.0	10	30
Damping Ratio	% of Change	0.3	0.2	1.0
Settling band	% of Change	Max (2.5% of change or 0.5% of ICR)	1	5

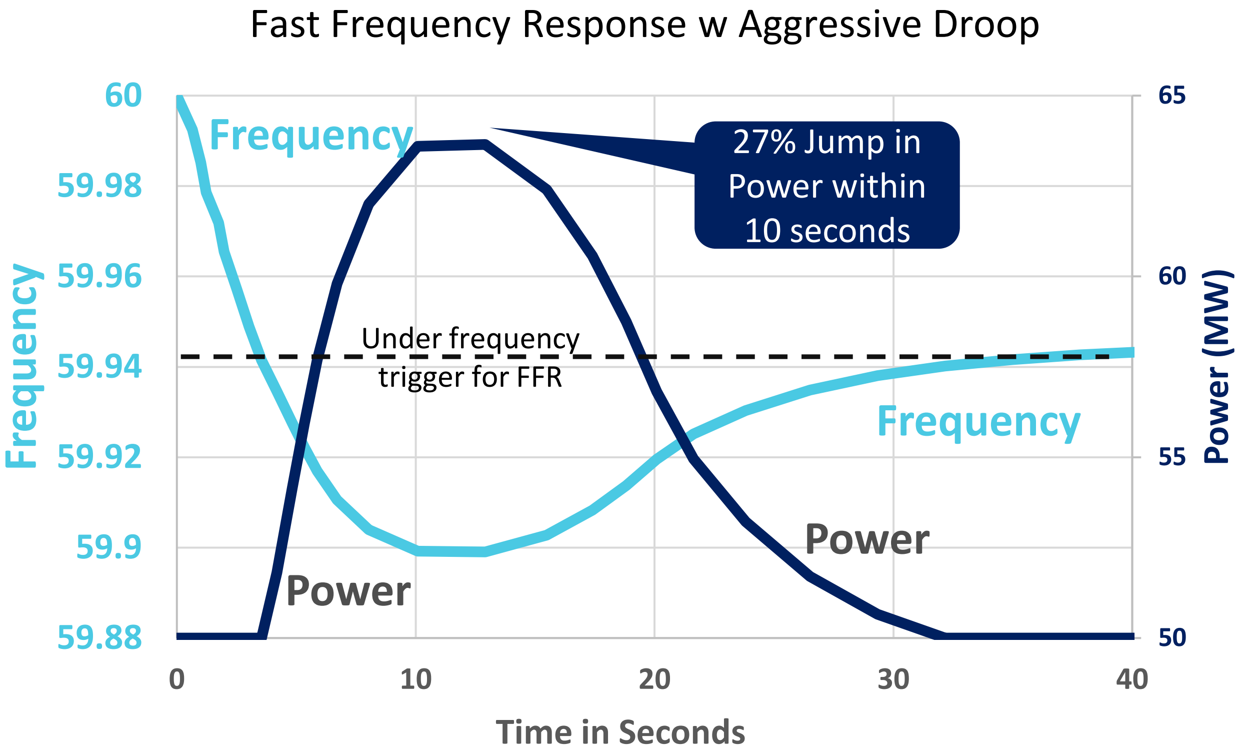
Fast Frequency Response (FFR) Capability of an IBR

- All IBR shall have FFR capability for under-frequency conditions
- FFR capability may be deployed for the purposes of ancillary service offering
- The FFR response time capability, shall be adjustable from 1 second or below including the reaction time for triggering FFR



Fast Frequency Response of a PV Plant With Reserve





FFR Capability of an IBR

- FFR and PFR shall actuate independently from each other and shall complement each other in power output as follows:

$$p = min\{p_{avl}, p_{pre} + p_{PFR} + p_{FFR1} + p_{FFR2} + p_{FFR3} + p_{FFR4}\}$$

- FFR1: FFR proportional to frequency deviation
- FFR2-FFR4: Triggers for FFR other than those based on frequency deviation may be specified based on ROCOF, or a combination of frequency deviation and ROCOF
- FFR from Wind Turbine Generator (WTG) has also been defined: The temporary increase of IBR plant active power output shall be equal to at least 5% of the total rated power of the WTGs that are in service and operating at or above 25% of rated power

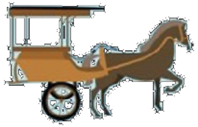
Capability versus Utilization

Capability:

"Ability to Perform or Provide Service"

Scope of IEEE Std 2800

- Functions
- Ranges of available settings
- Minimum performance specifications



Examples

- Frequency Response
  - Primary frequency response
  - Fast frequency response
- Ride-Through
  - Voltage ride-through
  - Current injection during ride-through
  - Consecutive voltage ride-through
  - Frequency ride-through
  - ROCOF ride-through
  - Phase angle jump ride-through

Utilization of Capability:

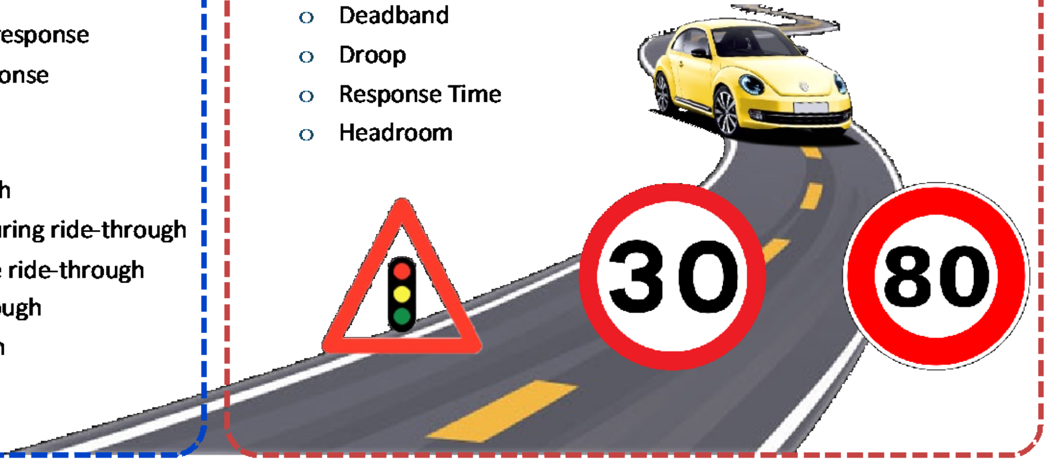
"Delivery of Performance or Service"

Scope of Interconnection or Ancillary Services Agreement

- Enable/disable functions
- Functional settings / configured parameters
- Operate accordingly (e.g., maintain headroom, if applicable)

Examples

- Deadband
- Droop
- Response Time
- Headroom



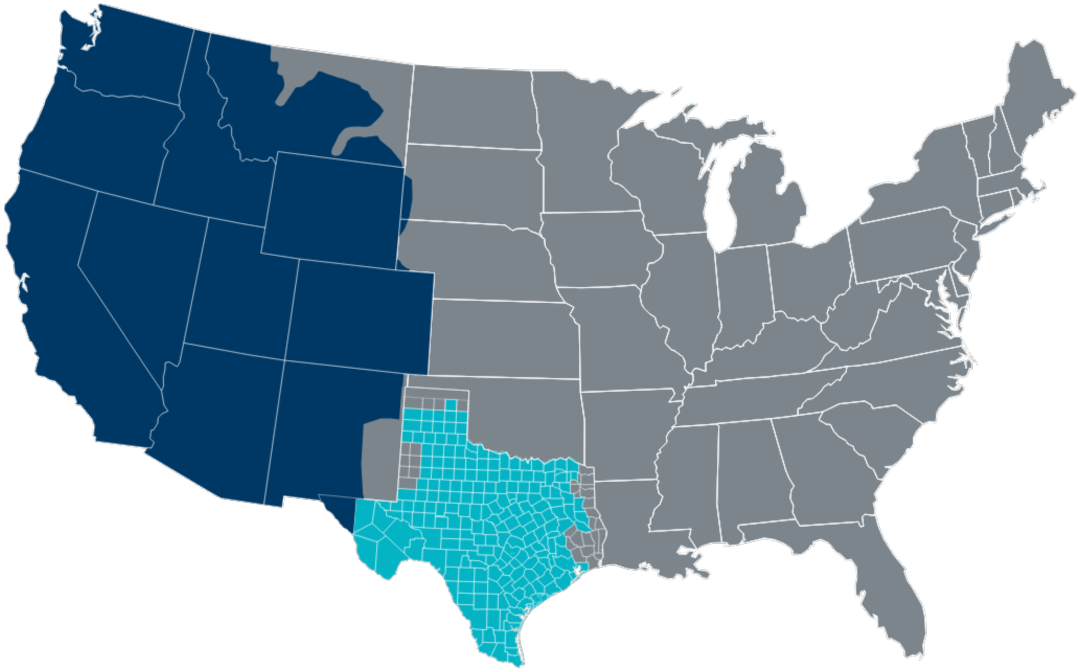
Source: EPRI, 2021

ERCOT's Experience Frequency Response Performance Presentation

Nitika Mago
Balancing Operations Planning
ERCOT

i2x FIRST
Nov 25, 2024

The ERCOT Region



US

Interconnections

- Western Interconnection
  Includes El Paso and Far West Texas
- ERCOT Interconnection
- Eastern Interconnection
  Includes portions of East Texas and Panhandle region

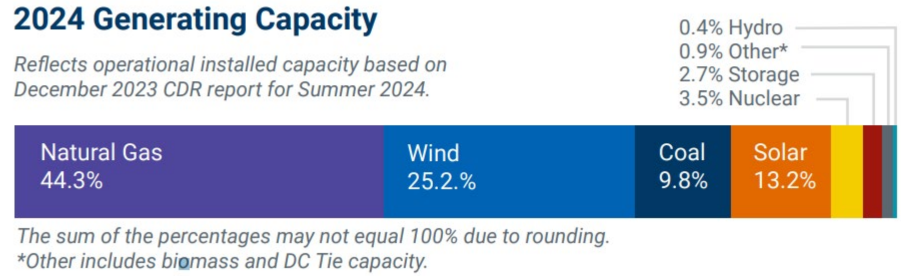
The interconnected electrical system serving most of Texas, with limited external connections

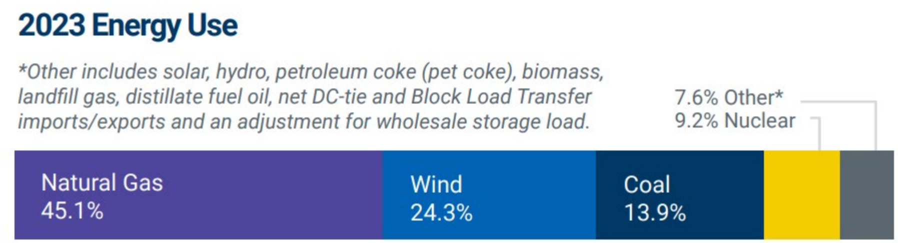
- 90% of Texas electric load; 75% of Texas land
- 85,508 MW peak, Aug. 10, 2023
- More than 54,100 miles of transmission lines
- 1,250+ generation units (including PUNs)

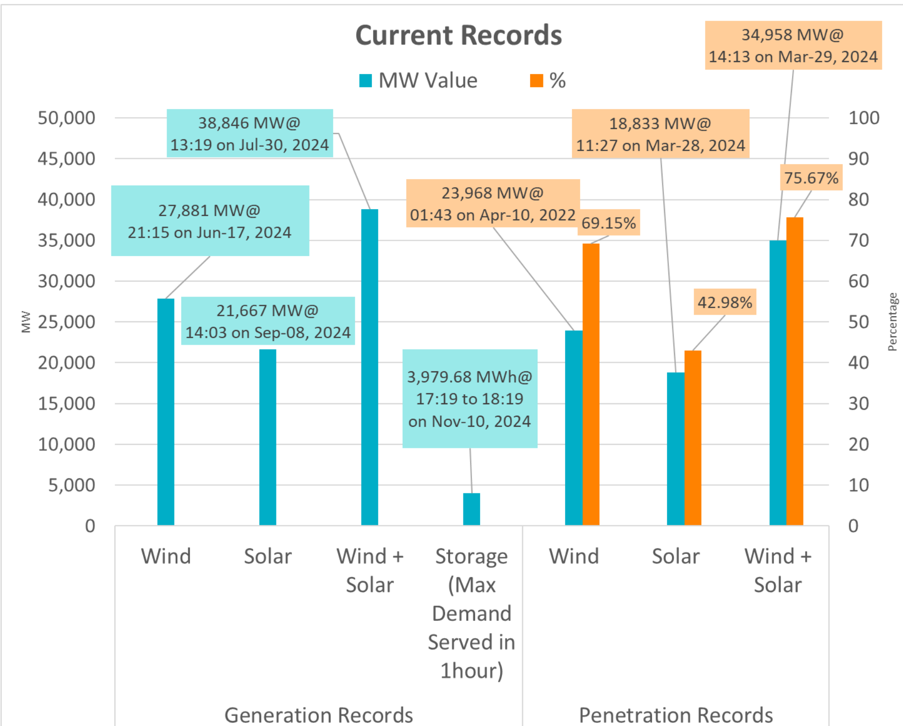
ERCOT connections to other grids are limited to ~1,220 MW of direct current (DC) ties, which allow control overflow of electricity

FACTS

- ERCOT is an islanded electrical grid in North America with a high penetration of utility scale wind and solar resources.
- ERCOT operates a 5-min energy only market in Real Time. ERCOT procures Ancillary Services (AS) in Day Ahead Market.
- ERCOT does not have a capacity market like some of the other ISOs.
- Since implementation of 2010 Nodal energy markets, ERCOT has operated with three types of Ancillary Services.
  - ERCOT has reviewed and revised the AS methodology annually to adapt the evolving needs of the ERCOT grid and to become more efficient in responding to the additional operational risks
  - ERCOT added a fourth AS namely ERCOT Contingency Reserve Service (ECRS) in summer 2023.
- *ERCOT expects to transition to a 5-min market that co-optimizes energy and AS procurement in Real Time in late 2026.*





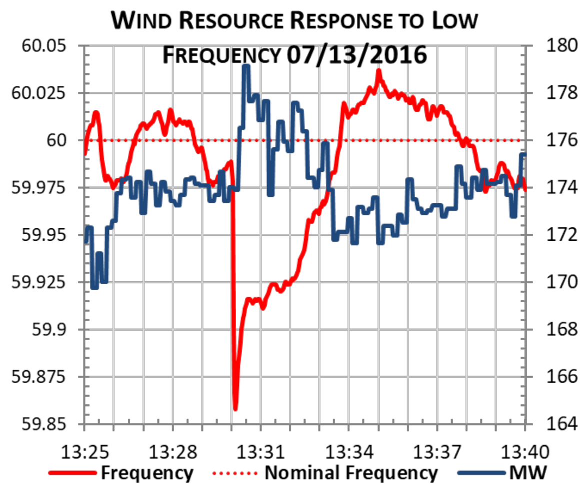


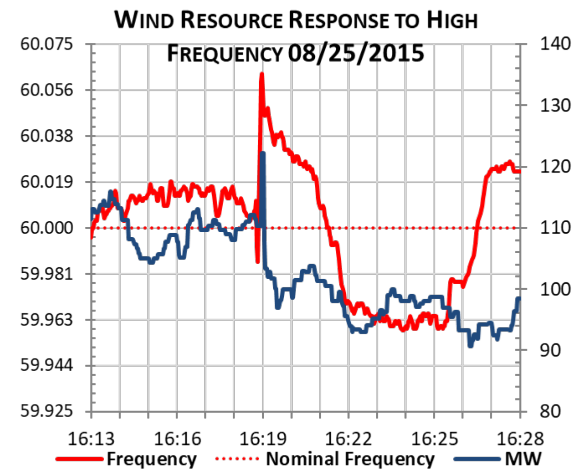
Grid Code: Primary Frequency Response Requirement

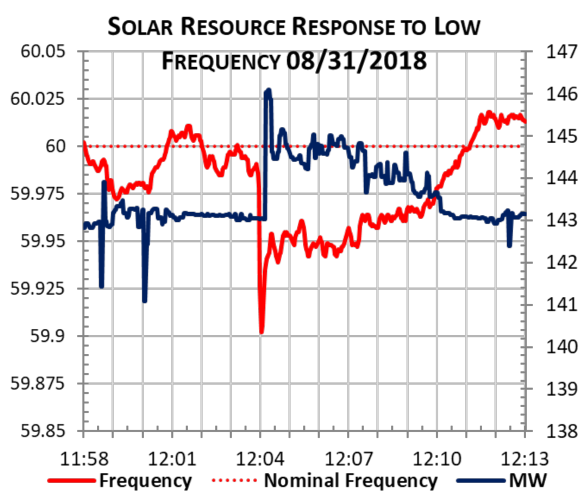
All online resources including Inverter-based resources are required to assist in ERCOT's frequency control and provide a "governor-like" response to frequency deviations when they have headroom/legroom.

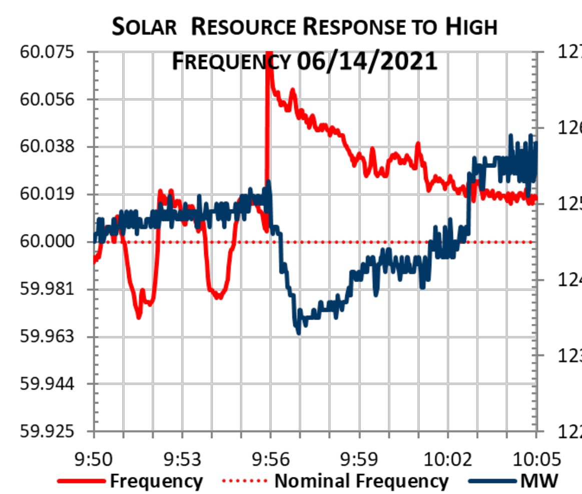
Resource Type	Max. Deadband
Steam Turbines with Mechanical Governors	+/- 0.034 Hz
Hydro Turbines with Mechanical Governors	+/- 0.034 Hz
All Other Generating Units/Generating Facilities/ESRs	+/- 0.017 Hz
Controllable Load Resources	+/- 0.036 Hz

Generator Type	Max. Droop % Setting
Combustion Turbine (Combined Cycle)	4%
All Other Generating Units/Generating Facilities/ESRs/Controllable Load Resources	5%





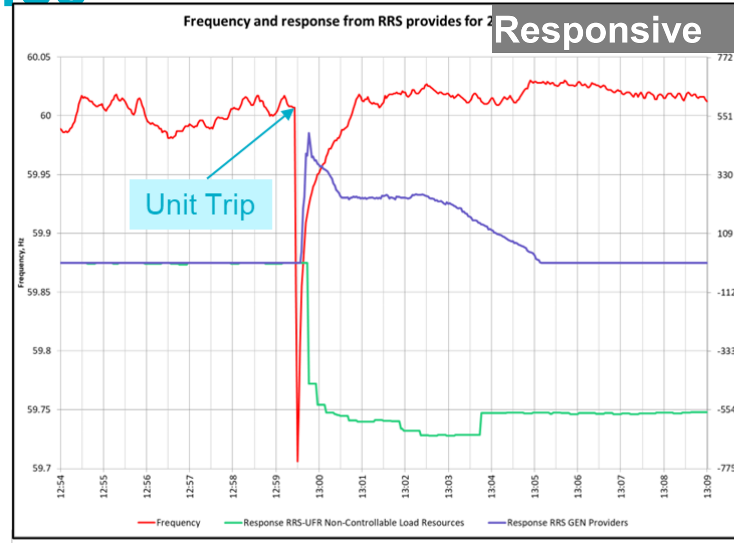


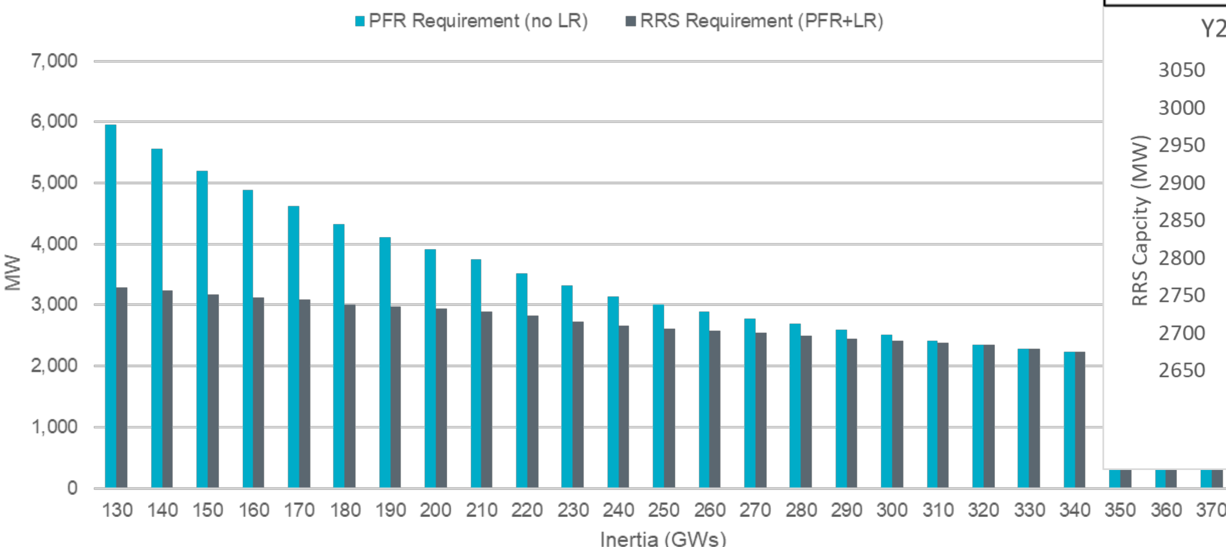


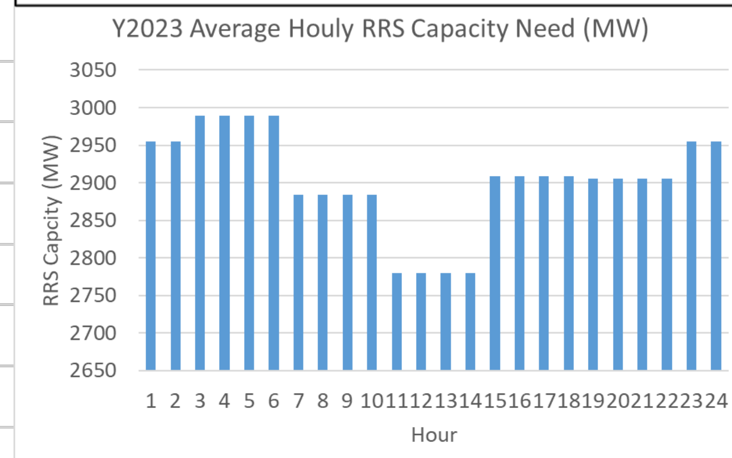
Responsive Reserve Ancillary Service

- Responsive Reserves (RRS) are procured to meet ERCOT's obligation under NERC's BAL-003. Specifically, RRS is procured to ensure sufficient capacity is available to respond to frequency excursions for the trip of two largest units (2805 MW) without triggering frequency load shed (UFLS) @59.3Hz. RRS quantities for any hour are set based on expected inertia in that hour.

- This service is typically provided by supply side resources such as Generation Resources and energy storage resources and demand with high set underfrequency relays.







Low Load; High Wind

System Conditions

High Load; Low Wind

Low Inertia ⟷ **High Inertia**

Ancillary Service: Responsive Reserve Requirement

AS - Frequency Response

RESPONSIVE RESERVE SERVICE (RRS)

2020

- Fast Frequency Response (FFR)
- Load Resources on Under Frequency Relay (UFR)
- Primary Frequency Response (PFR)

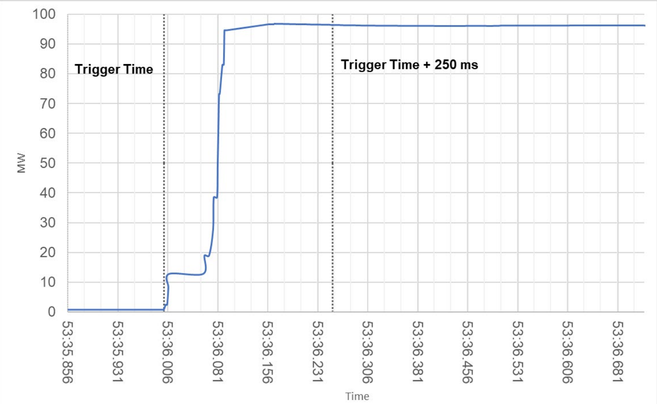
2,300 to 3,335 MW*

FFR
- Triggered at 59.85 Hz and full response in 15 cycles
- Once deployed, sustain for up to 15 mins. Once recalled, restore within 15 mins
- Maximum 450 MW of RRS may be provided by FFR Resources

PFR
- PFR capable capacity reserved on generators or Controllable Load Resources (CLR)
- Minimum 1,150 MW must be provided by resources capable of PFR
- Capacity that is used to provide RRS-PFR must be capable of being sustained for 1 hour

Load Resources with under frequency relay (UFR)
- Triggered at 59.70 Hz and full response in 30 cycles
- Sustain until recalled. Once recalled, restore within 3 hours
- Beyond the minimum PFR, up to 60% of total RRS can come from Load Resources on UFR or FFR

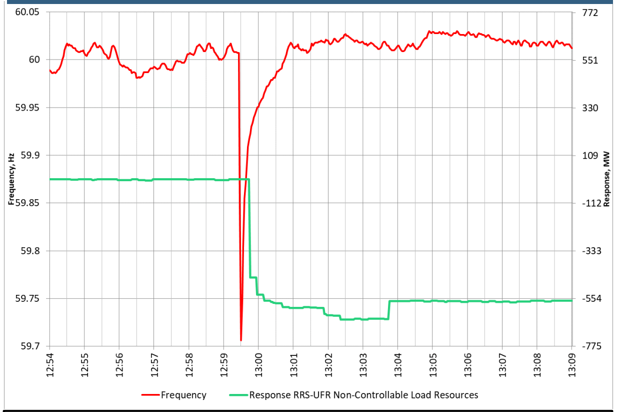
Fast Frequency Response (FFR)



What is RRS-FFR? The automatic self-deployment and provision by a Resource of their obligated response within 15 cycles after **frequency meets or drops below 59.85 Hz**. Resources must be capable of sustaining their obligated response for **at least 15 minutes**.

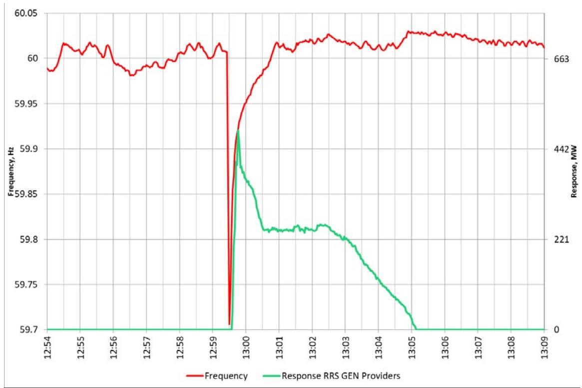
FFR can help reduce the minimum level of Inertia at which ERCOT grid can operate reliably. With 450 FFR MW Critical inertia reduces from 100 GW.s to 88 GW.s.

Load Resources on Under Frequency Relay (UFR)



What is RRS-UFR? *Load/Industrial facilities can use an under-frequency relay to* automatically self-deploy and provide their obligated response within 30 cycles after **frequency meets or drops below 59.7 Hz**. Resources must be capable of sustaining their obligated response till recalled.

Primary Frequency Response (PFR)



What is RRS-PFR? *Continuous PFR capable capacity is reserved on Generation, Storage or demand capable of following ERCOT dispatch. Minimum 1,150 MW must be provided by resources capable of PFR.*

*Quantities in this slide are posted as a part of 2023 Ancillary Service Methodology effort posted on Dec 5, 2022 TAC.
For Discussion Purposes Only. The intent of this slide is to represent Ancillary Service (AS) Framework after ECRS is implemented around mid 2023. Protocol language prevails to the extent of any inconsistency with this one-page summary.

Performance Monitoring: BAL-001-TRE

- NERC Regional Standard BAL-001-TRE, Primary Frequency Response (PFR) in the ERCOT Region governs PFR related performance requirements for the ERCOR fleet.

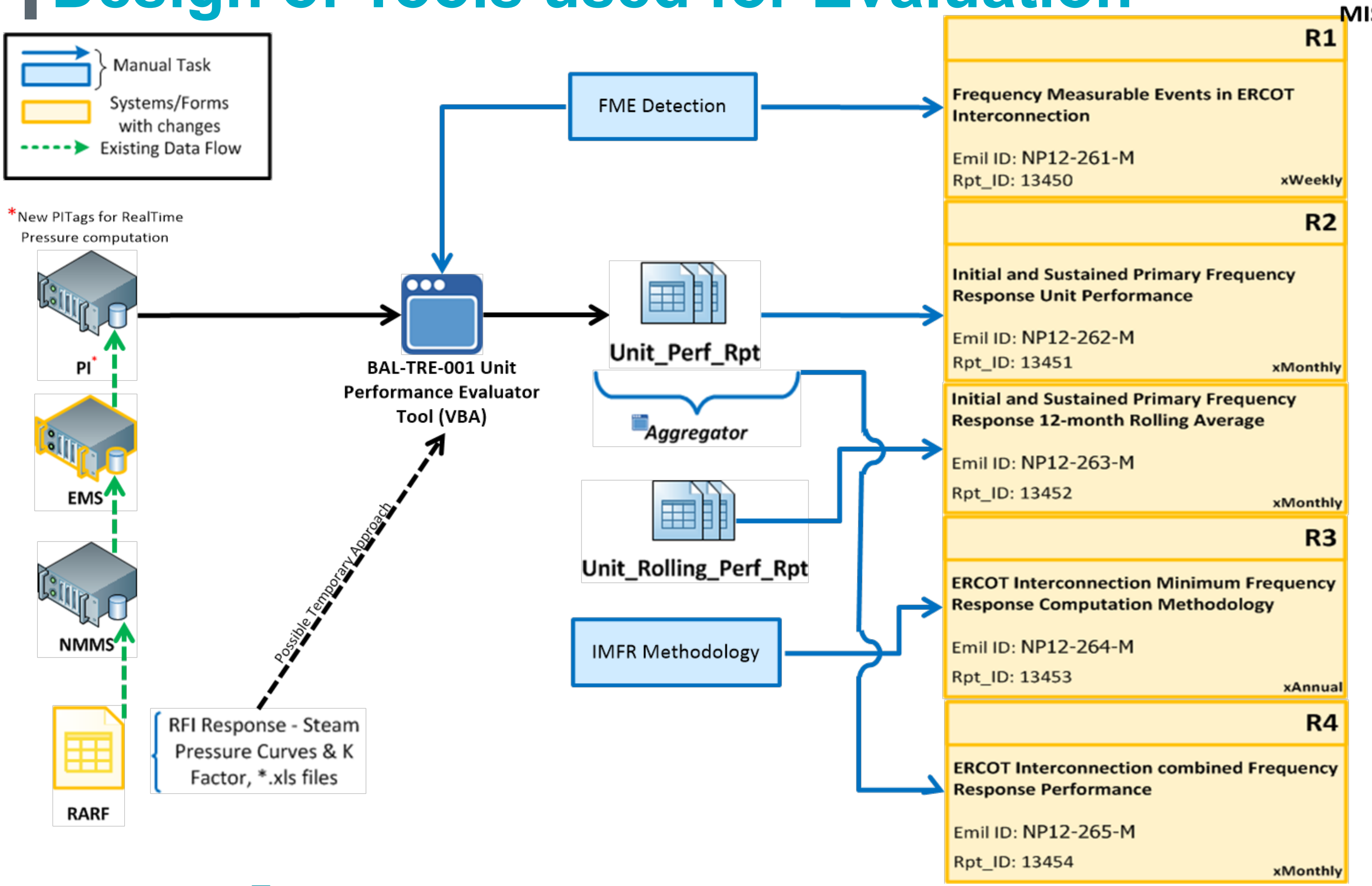
- Requirements for Generation Owners:
  - Specifies Droop and Deadband settings
  - Rolling 12-month performance requirements for generation resources

- Requirements for the Balancing Authority/ERCOT:
  - Reporting transparency and changes to measuring Frequency Measurable Events
  - Calculations for Frequency Response measurements (PFR and IMFR)
  - Calculation of 12-month rolling performance averages for each Generator

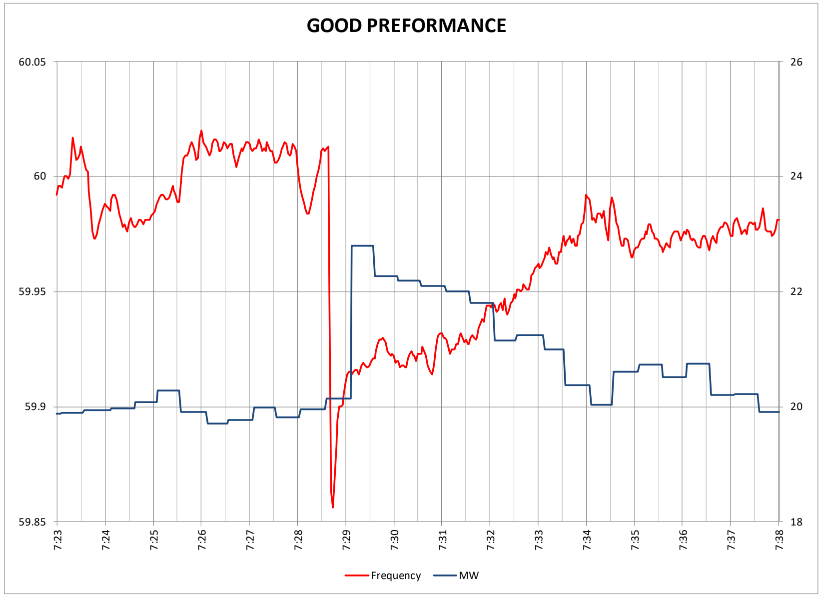
- Standard has been in effect since late 2015/early 2016.

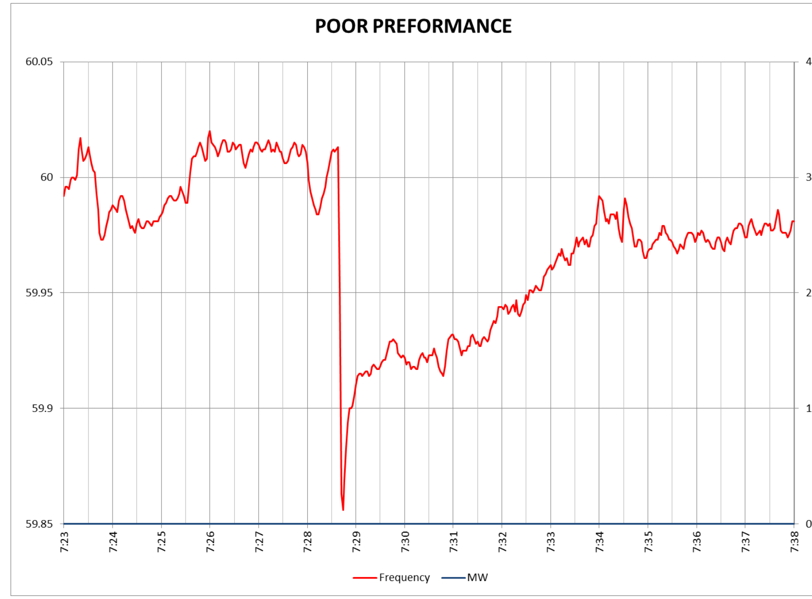
- Performance requirements in ERCOT protocols align with this standard

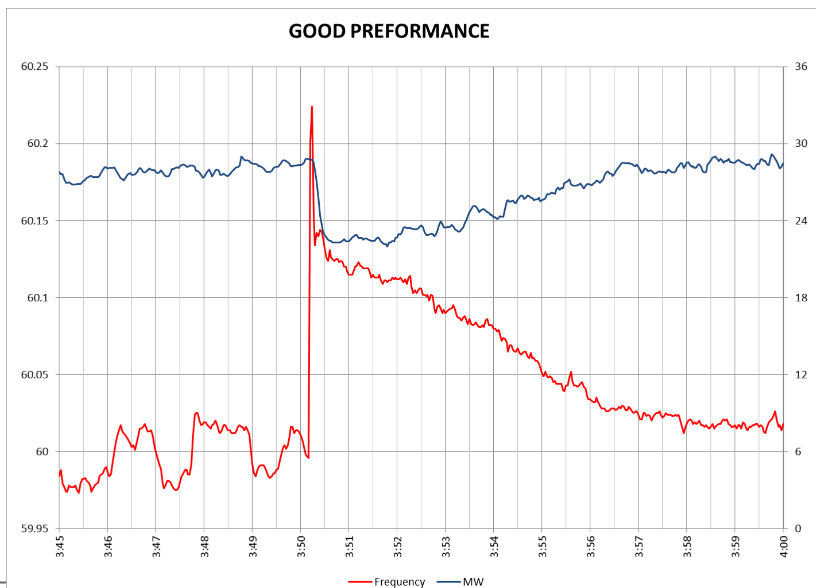
Design of Tools used for Evaluation

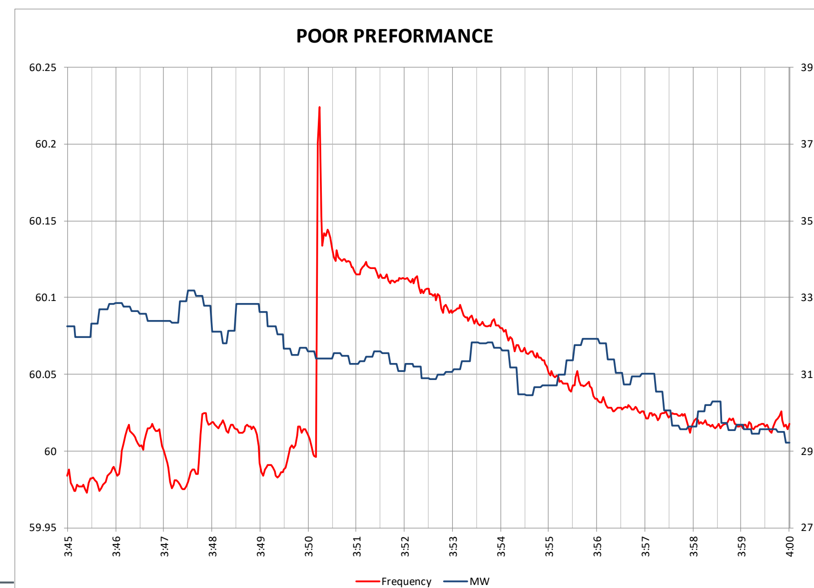


Performance Examples: Wind

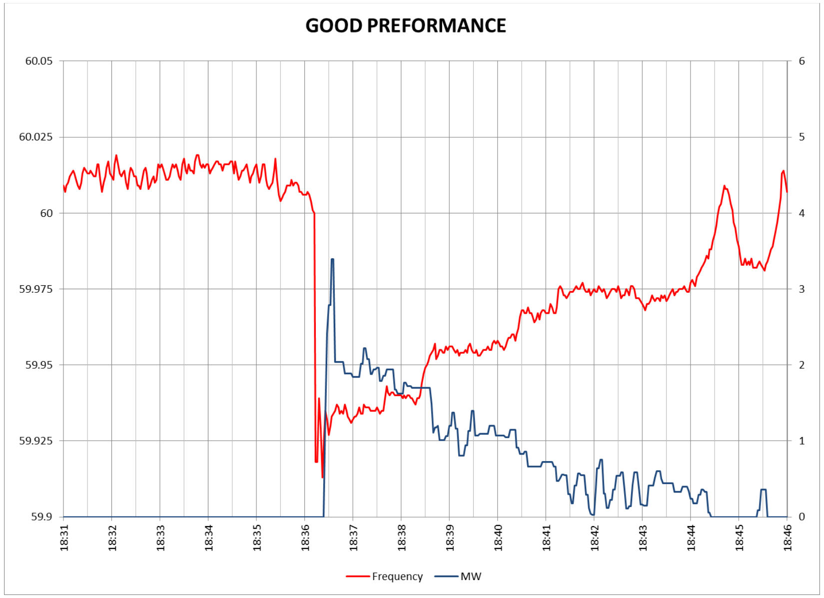


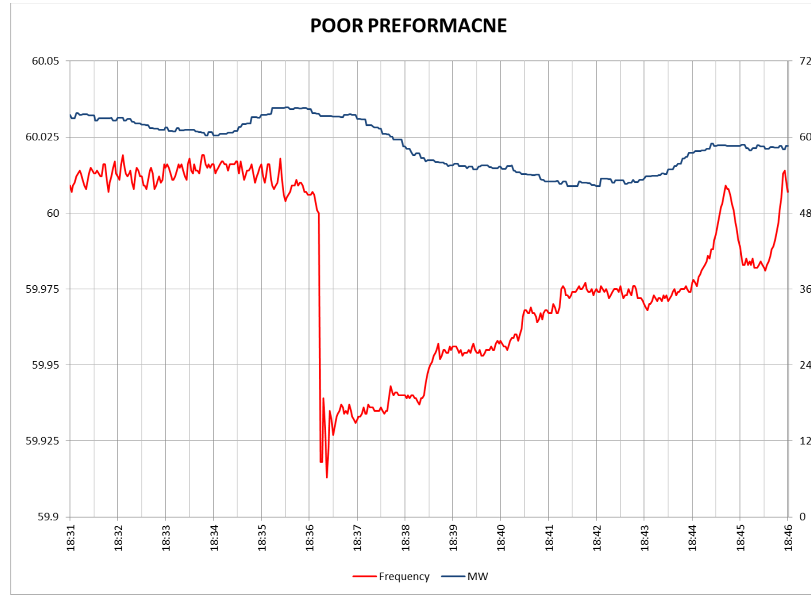


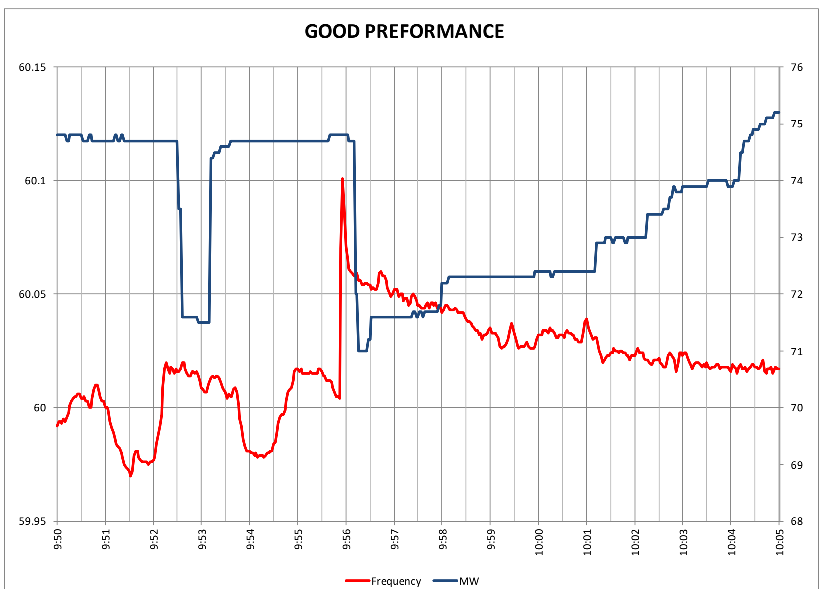


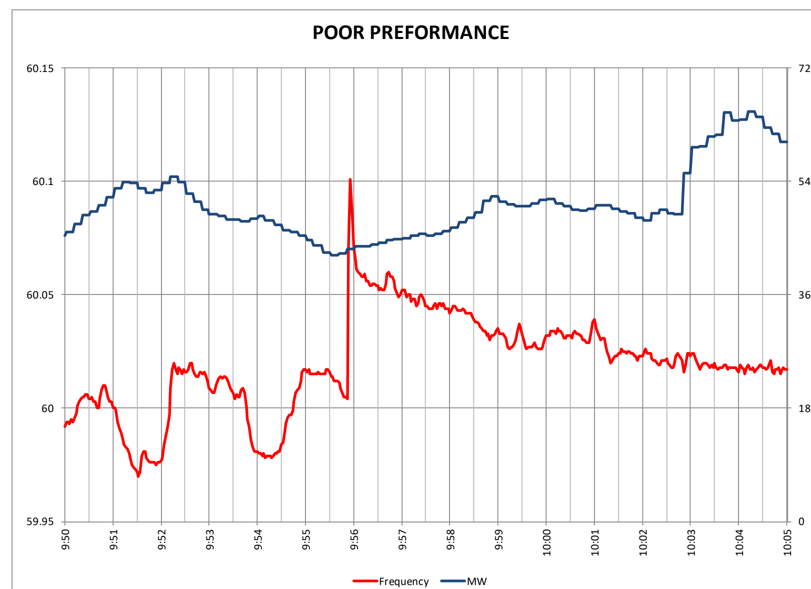


Performance Examples: Solar









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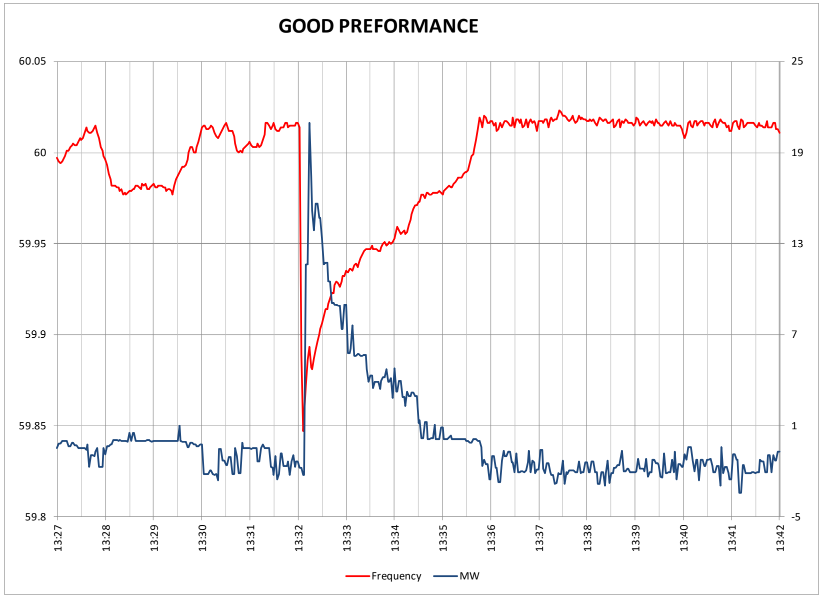
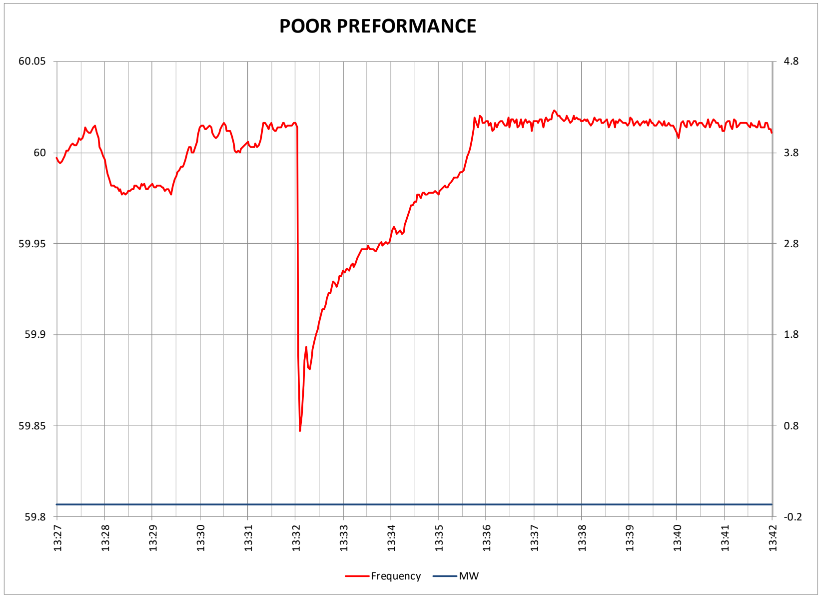
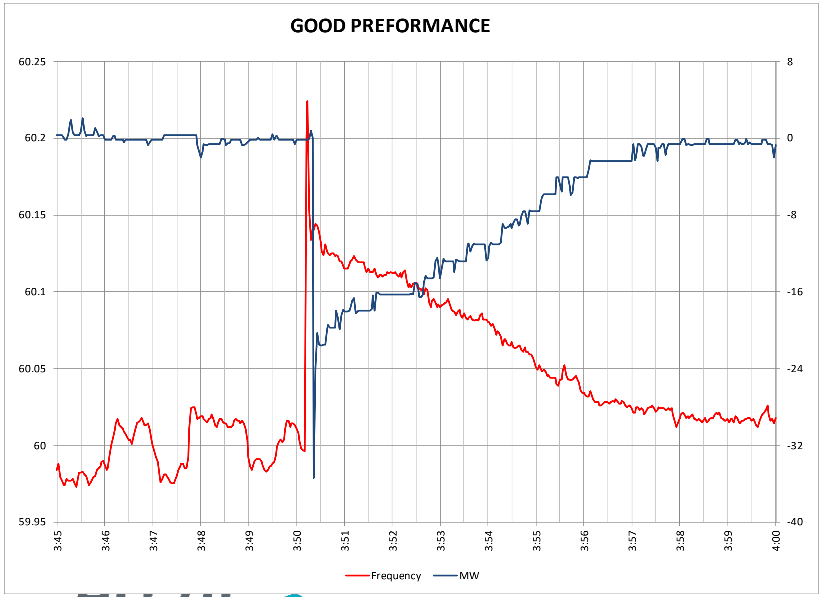
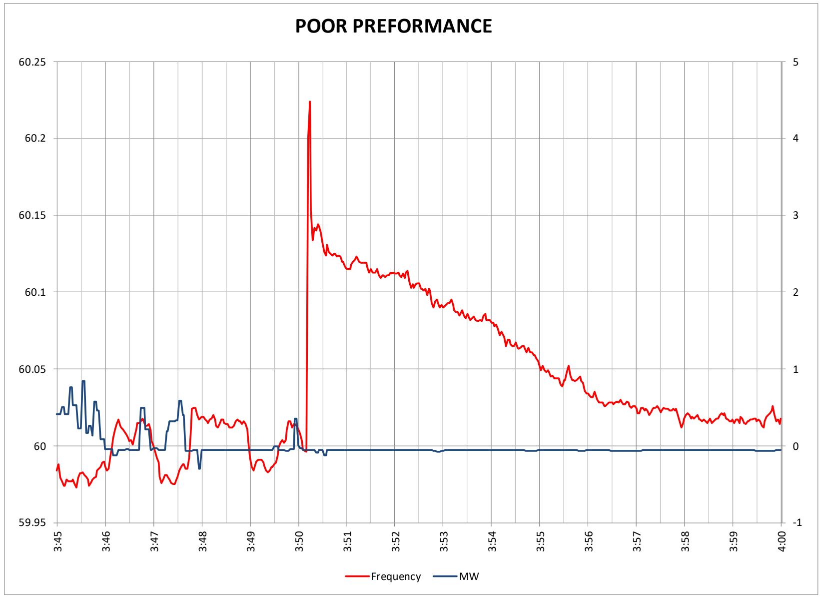
Performance Examples: Storage Resource

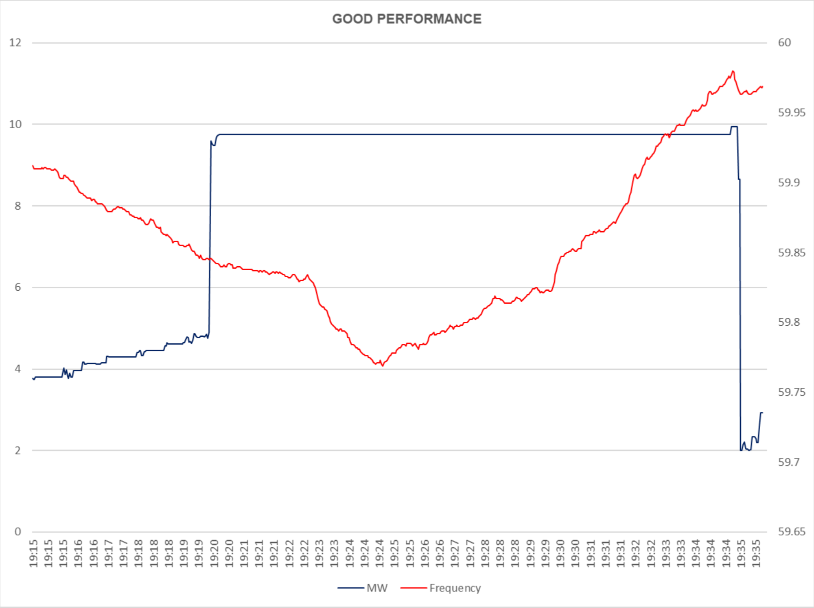


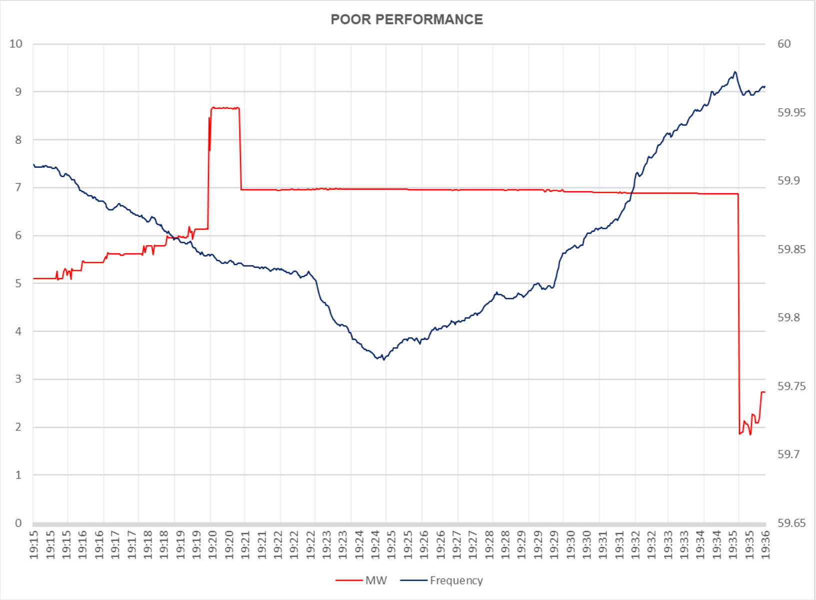






Performance Examples: FFR





Issues/Observations for Poor IRR PFR Performance

- Poor response from units that have been curtailed to low output which is below the design minimum operating limit. The resources will go to a standby/pause mode, and they have to go though the startup process before ramping up active power.

- Inactive PFR controls after a control system update

- Inaccurate calculation of available frequency response capacity.

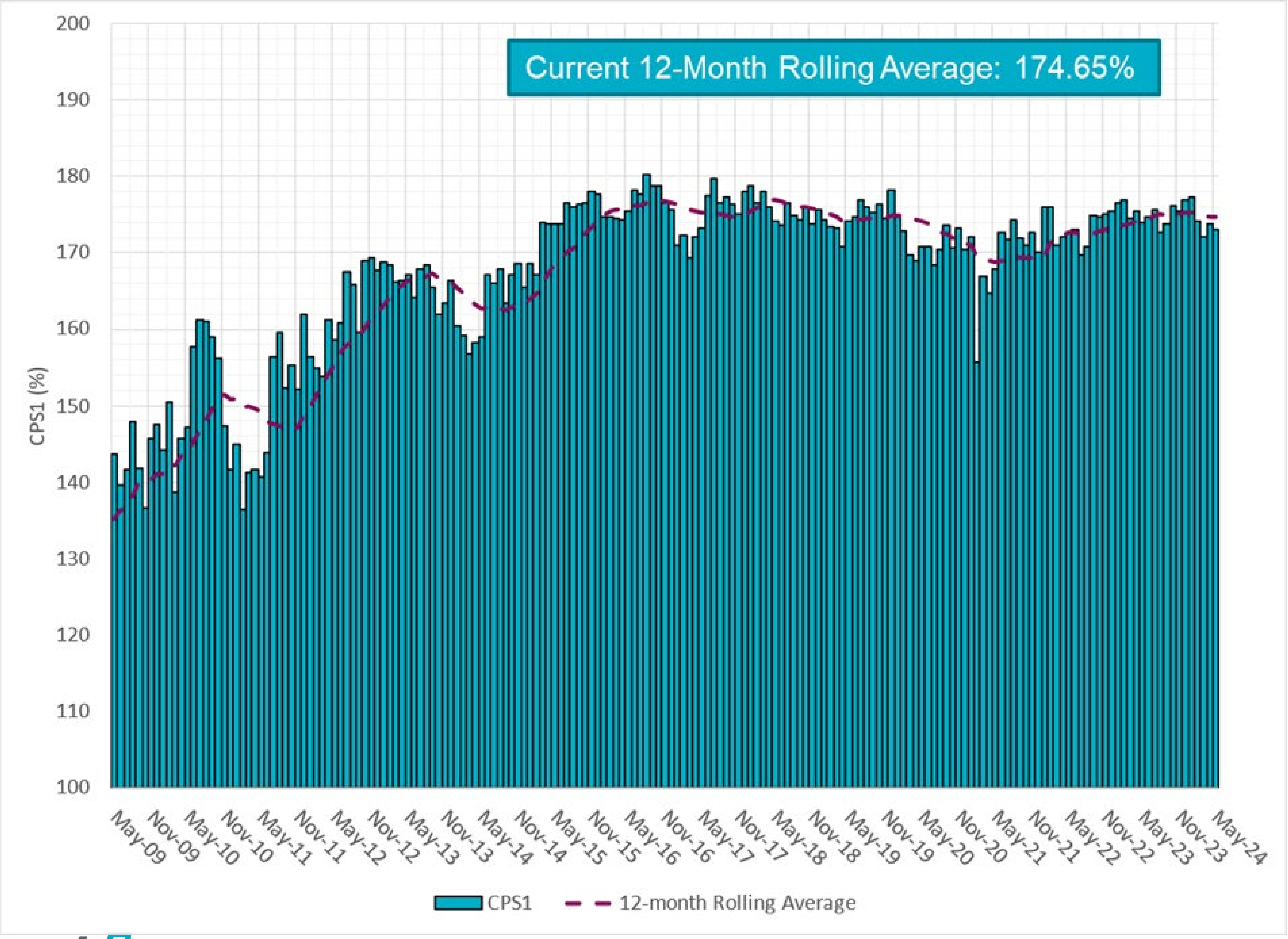
- For IRR groups, PPCs control the entire plant rather than individual units leading to potentially some units within the IRR group overresponding and no response from other units.

- Poor performance resulting from significant data latency.

- Poor performance from ESRs due to State of Charge being too high or too low and inaccurate HSL/LSL telemetry. Some ESRs have restrictions to charge from grid.

Effectiveness of Program: CPS1 Score

CPS1 measures how well a BA controls frequency. ERCOT's 12-month rolling average CPS1 score is below.



Effectiveness of Program: Frequency Nadir

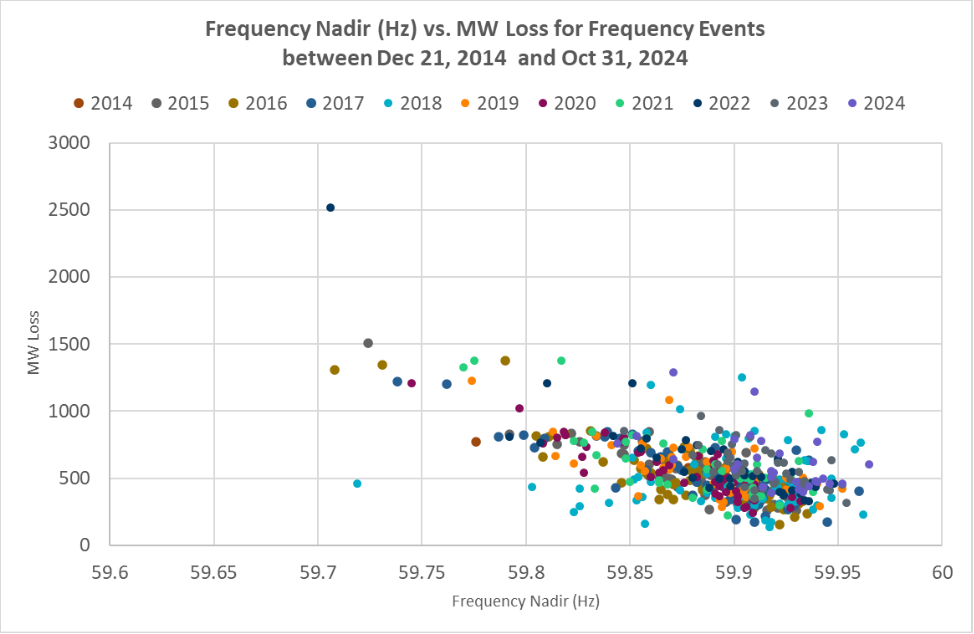
Using data from frequency events that occurred between December 1, 2014 and October 31, 2024

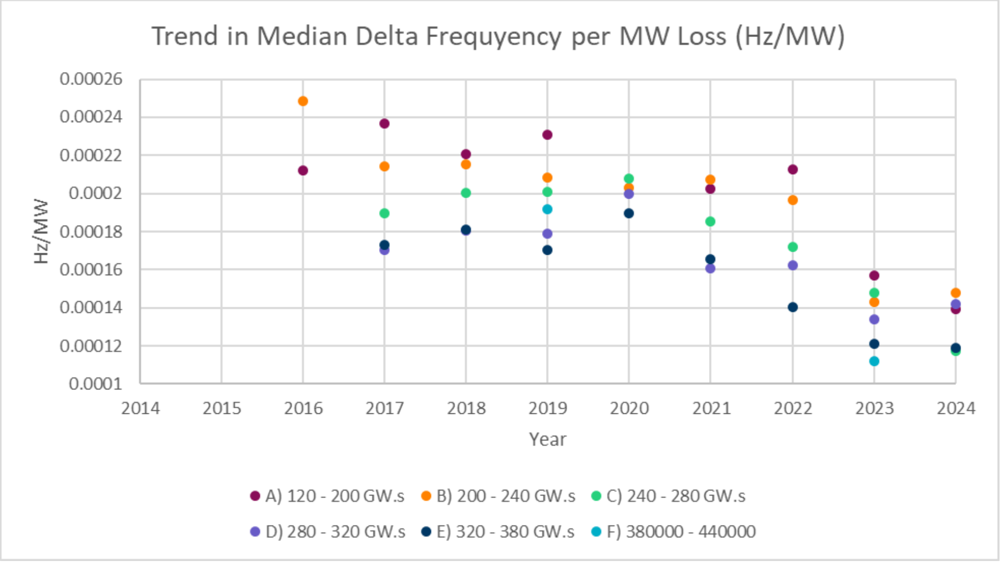
First image shows the frequency nadir (lowest point of frequency) vs MW Loss by Year

- Nadir has reached 59.7 Hz but no where close to 59.3 Hz (UFLS Stage 1 trigger)

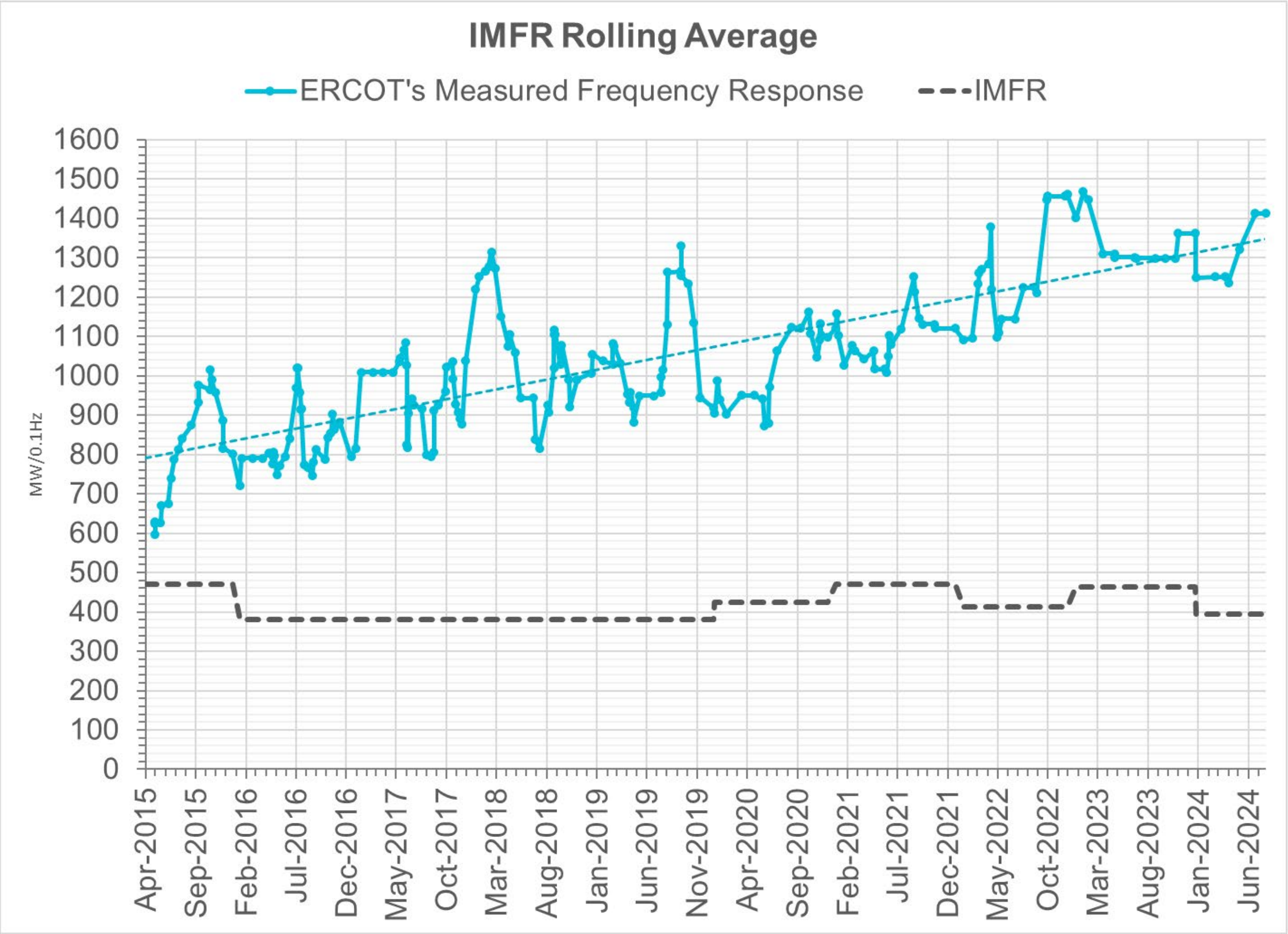
Second image shows the frequency nadir (lowest point of frequency) per MW loss during by Inertia

- In same inertia bin, nadir for similar MW loss is improving, i.e frequency is arrested at earlier than before.





Effectiveness of Program: Interconnection wide Frequency Response



Key Takeaways

- ERCOT is an islanded electrical grid in North America with a high penetration of utility scale wind and solar resources.

- Key Features that have helped ERCOT integrate large volumes of renewable resources include (a) strong Grid Code; (b) accounting for Renewable Forecasts in near Real Time and Real Time studies; (c) continually adapting Ancillary Services (both in product type and quantity determination); and (d) including enhanced Risk Assessment procedures near and in Real Time.

- ERCOT uses Responsive Reserve Ancillary Service to procure frequency responsive capability to meet ERCOT's obligations with NERC's BAL-003.

- ERCOT uses performance monitoring related requirements in NERC's BAL-001-TRE to monitor performance of all Resources during FME(s).

- ERCOT's 12-month rolling average CPS1 score is well above 170% - one of the best in North America.

Appendix

18

Ancillary Service (AS) Framework

AS - Frequency Response

RESPONSIVE RESERVE SERVICE (RRS)

2020

- Fast Frequency Response (FFR)
- Load Resources on Under Frequency Relay (UFR)
- Primary Frequency Response (PFR)

2,300 to 3,335 MW*

FFR
- Triggered at 59.85 Hz and full response in 15 cycles
- Once deployed, sustain for up to 15 mins. Once recalled, restore within 15 mins
- Maximum 450 MW of RRS may be provided by FFR Resources

PFR
- PFR capable capacity reserved on generators or Controllable Load Resources (CLR)
- Minimum 1,150 MW must be provided by resources capable of PFR
- Capacity that is used to provide RRS-PFR must be capable of being sustained for 1 hour

Load Resources with under frequency relay (UFR)
- Triggered at 59.70 Hz and full response in 30 cycles
- Sustain until recalled. Once recalled, restore within 3 hours
- Beyond the minimum PFR, up to 60% of total RRS can come from Load Resources on UFR or FFR

AS – Frequency Recovery and Net-Load Uncertainty/Variability

REGULATION -5MIN BALANCING

67 MW to 921 MW*

- Generators or Controllable Load Resources (CLRs) respond within 5 seconds to ERCOT LFC instructions
- FRRS providers respond within 60 cycles of either its receipt of ERCOT instruction or at 59.91 Hz; 65 MW maximum for FRRS-Up, 35 MW maximum for FRRS-Down
- Capacity that is used to provide conventional Regulation must be capable of being sustained for 1 hour

ERCOT CONTINGENCY RESERVE SERVICE (ECRS)

2023

- 10-minute ramp
- Load Resources may or may not be on UFR

1,098 MW to 3,038 MW*

Generation
- Online or offline capacity that can be converted to energy within 10 minutes
- Dispatched by SCED
- Capacity that is used to provide ECRS must be capable of being sustained for 2 hours.

Load Resources (UFR not required)
- Up to 50% of ECRS capacity can come from Load Resources with or without UFR
- Once deployed, must respond within 10 minutes. Sustain until recalled. Restoration within 3 hours

NON-SPINNING RESERVE SERVICE

1,688 MW to 5,633 MW*

- Online or offline capacity from generators and Load Resources that can be deployed within 30 minutes
- Online capacity (EOC floor $75/MWh) dispatched by SCED; Offline capacity dispatched by XML instruction
- Minimum 1,430 MW must be provided by SCED dispatchable Resources
- Non-Controllable Load Resources may provide Non-Spin; UFR if available, must be disarmed in Real Time
- Capacity that is used to provide Non-Spin must be capable of being sustained for 4 hours

Overall A/S: 6,133 to 11,622 MW*

*Quantities in this slide are posted as a part of 2023 Ancillary Service Methodology effort posted on Dec 5, 2022 TAC.
For Discussion Purposes Only. The intent of this slide is to represent Ancillary Service (AS) Framework after ECRS is implemented around mid 2023. Protocol language prevails to the extent of any inconsistency with this one-page summary.

ERCOT's Ancillary Services Overview

- Ancillary Service are procured in the Day-Ahead Market to ensure sufficient resource capacity is on-line, or able to be brought on-line in a timely manner, to balance the uncertainty that cannot be covered by the 5-minute energy market.

- Each Ancillary Service has its qualification requirements, performance obligation, and compliance rules if under performed.

- The need and quantity of each Ancillary Service are not static and can vary depend on the system conditions (hourly, daily, seasonally).

- ERCOT runs unit commitment studies on hourly basis to ensure sufficient resource capacity is on-line to cover the forecasted variability in wind and solar.

Ancillary Service Products

Regulation Service

– Reserved capacity that is deployed every 4 seconds to balance supply and demand and maintain frequency close to 60Hz between 5-minute SCED runs.

Responsive Reserve Service

– Reserved capacity that is procured to respond to low frequency events typically triggered by generating unit trips.

ERCOT Contingency Reserve Service *(Added in 2023)*

– Capacity that can respond in 10 minutes to recover frequency, cover forecast errors or ramps and replace deployed reserves. 2 hour duration requirement.

Non-Spin Reserve Service

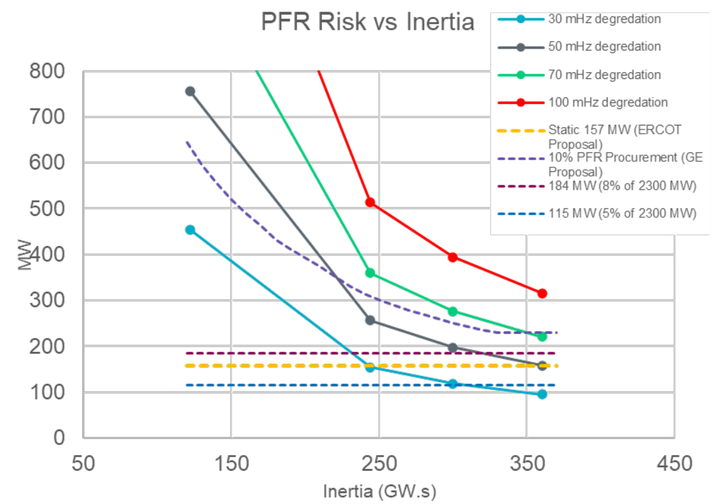
– Capacity that can be started in 30 minutes to cover forecast errors, ramps or forced outages and replace deployed reserves until additional resources can be committed. 4 hour duration requirement.

Common Mode Risk of PFR Failure

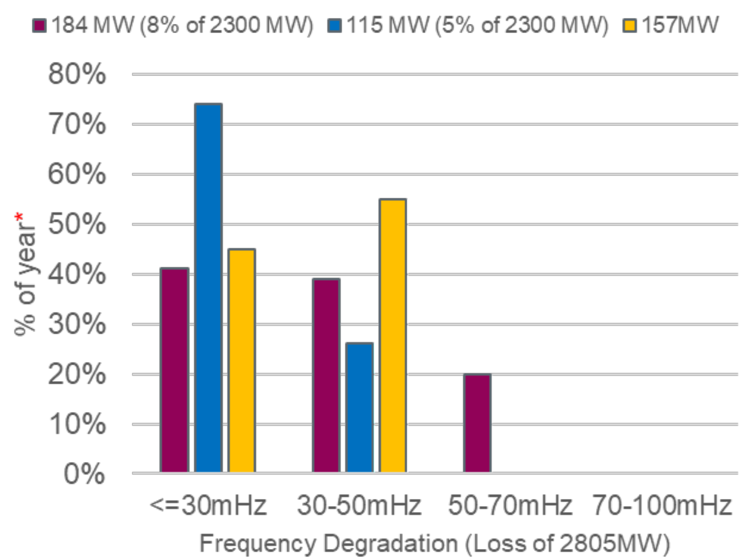
- Currently the maximum RRS-PFR a single resource may provide in ERCOT is established by its verified droop performance. Batteries are able to set 1% droop and provide 100% of capability as RRS-PFR.

- ERCOT builds a 100mHz margin in the studies used to establish RRS requirements. This margin helps in responding to differences between study setup/assumptions and Real Time that may affect response, such as:
  - Starting frequency in studies is 60 Hz but may be lower in Real Time,
  - Study models may not fully account for all of the non-linearities that may affect response in Real Time,
  - Some RRS-PFR resources may fail during an event, i.e. failing to perform or tripping.

- There is a concern that if too much RRS-PFR is being provided by one unit and that unit failing to perform, UFLS may get triggered, resulting in NERC compliance violation. To limit this exposure, going forward ERCOT is considering to include a limit on the maximum capacity a single resource can provide as RRS-PFR.



Frequency Degradation Profile (Based on 2022 Inertia)



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Wind Generation Frequency Response Capabilities

i2x FIRST Meeting

Miguel Campos

26 November 2024

Before we start…

Disclaimer:

- This presentation is designed as stand-alone material while trying to complement the broader industry knowledge already available. It is not necessary to refer to other presentations to gain full value, but relevant links can be found below .

Content :

- Focus on the turbine paused state: triggers, characteristics and implications

Topic: Physical basics of low power operation of wind turbines
Presenter: Nickholas Miller (ex GE)
Forum: ERCOT IBR Working Group – November 15, 2024
Link: ERCOT Low Power Wind Dynamics 11-15-24 v2.pptx

Topic: PFR from IBRs under "Deep" Curtailment
Presenter: Martin de Paz and Evelyn Hernandez (Nordex)
Forum: ERCOT IBR Working Group – November 15, 2024
Link: PowerPoint-Präsentation

Primary Frequency Reponse

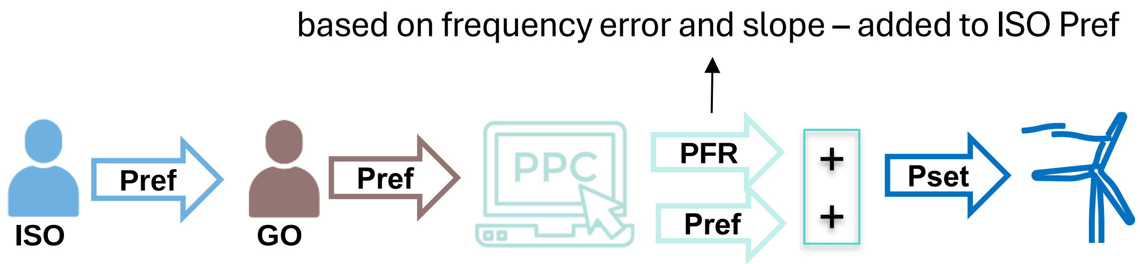


Table 6—Formula for frequency-droop (frequency-power) operation for low-frequency conditions and high-frequency conditions for *IBR plant*

Low frequency	$p = \min\{p_{avl}, p_{pre} + p_{PFR}\} = \min\left\{p_{avl}, p_{pre} + \max\left(0, \frac{f_{nom} - f - db_{UF}}{f_{nom} \times k_{UF}}\right)\right\}$ e.g., ICR = 100 MW, k_{UF} = 0.03 Hz/MW (0.05 p.u. droop), db_{UF} = 0.036 Hz p_{pre} = 50 MW = 0.50 p.u., p_{avl} = 51 MW = 0.51 p.u., f_{nom} = 60 Hz; f = 59.9 Hz, then $p = \min\{0.51, 0.50 + (60 - 59.9 - 0.036)/60/0.05\} = \min\{0.51, 0.5213\} = 0.51$ p.u. = 51 MW
High frequency	$p = \max\{p_{min}, p_{pre} + p_{PFR}\} = \max\left\{p_{min}, p_{pre} + \min\left(0, \frac{f_{nom} - f + db_{OF}}{f_{nom} \times k_{OF}}\right)\right\}$ e.g., ICR = 100 MW, k_{OF} = 0.024 Hz/MW (0.04 p.u. droop), db_{OF} = 0.036 Hz, p_{min} = 10 MW = 0.10 p.u. f = 60.1 Hz, p_{pre} = 50 MW = 0.50 p.u., then $p = \max\{0.10, 0.50 + (60 - 60.1 + 0.036)/60/0.04\} = \max\{0.10, 0.4598\} = 0.4598$ p.u. = 45.98 MW

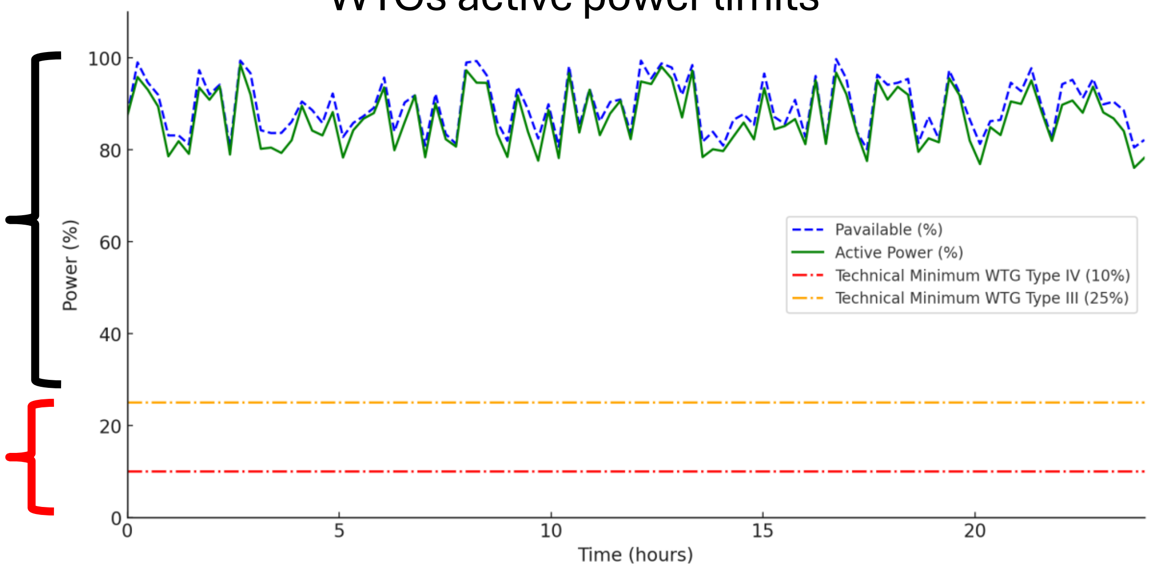
IEEE 2800 – Primary Frequency Response Requirement (section 6.1)

Where does Pset fall?

Between Pnom and Tech Min:
No need to pause WTGs

Below Tech Min:
Need to pause WTGs

WTGs active power limits



IEEE 2800 accounts for technical limits ✔

Compliant throughout operation ✔

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WTG **paused** vs **disconnected** state – Summary

PAUSED ⏸️

- Active power generation is not possible ❌ ⚡
- Can quickly resume operation ✔️ ▶️
- Switchgear closed ✔️ 🔌
- Reactive power generation might still be possible ✔️ ⚡Q
- Reported as available to ISO ✔️ 🖥️
- Some systems* might be de-energized ❔⚡

DISCONNECTED ❌

- Active power generation is not possible ❌ ⚡
- Cannot quickly resume operation ❌ ▶️
- Switchgear open ❌ 🔌
- Reactive power generation is not possible ❌ ⚡Q
- Reported as unavailable to ISO ❌ 🖥️
- All systems* de-energized ❌ ⚡

*Examples of systems: hydraulic, electric, safety (more in two slides)

WTG **paused** vs **disconnected** state – Typical Triggers

PAUSED

- Low wind speeds
  - Below cut-in threshold
  - Insufficient kinetic energy
- High wind speeds
  - Above cut-out speed
  - Prevents structural damage
- Grid curtailment
  - ISO setpoint
  - Balancing act (e.g. PFR)

DISCONNECTED

- Scheduled maintenance
  - Planned repairs, checkups
- Grid event and subsequent tripping
  - Voltage dips
  - Frequency instability
  - Islanding
- Emergency conditions
  - Unplanned equipment failure
  - Overheating
  - Internal faults
  - Environmental (e.g. bats/birds)

The WTG **paused** state

Key message:

Engaging and disengaging these components takes time…

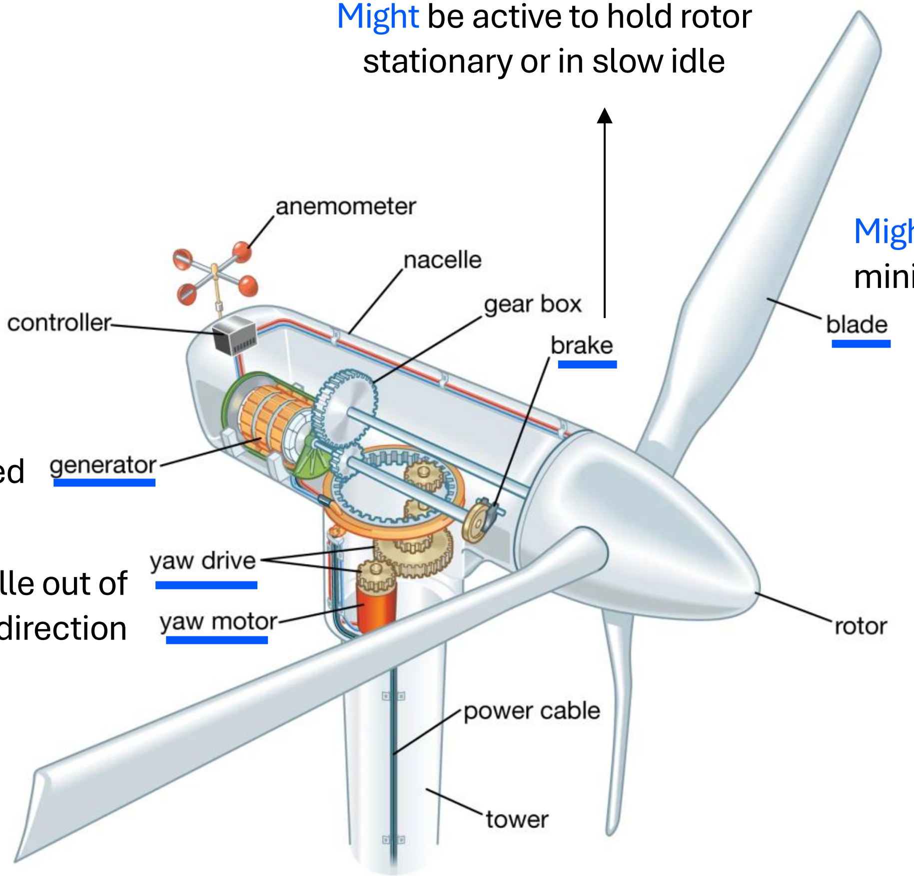
From approx. ~10s to several minutes…

Might be active to hold rotor stationary or in slow idle

Might be turned to minimize rotational force

Might be fully stopped

Might align nacelle out of wind direction



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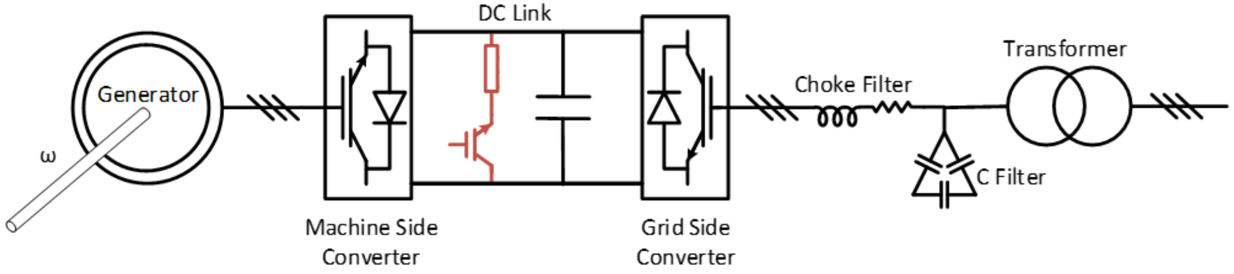
Might be discharged



Might be blocked

Classification: Public

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'Problematic' scenarios of pausing

Let us consider High Wind
Available in both scenarios

1) Under Frequency Event

Where turbines were previously paused

They need to be released first
<u>Uncertain reaction time or time frame</u>

At given moment:

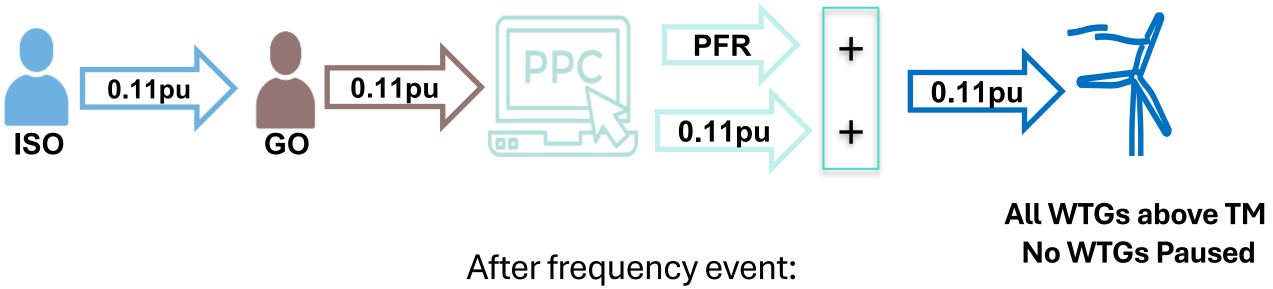
Available Power Wind Farm

≠

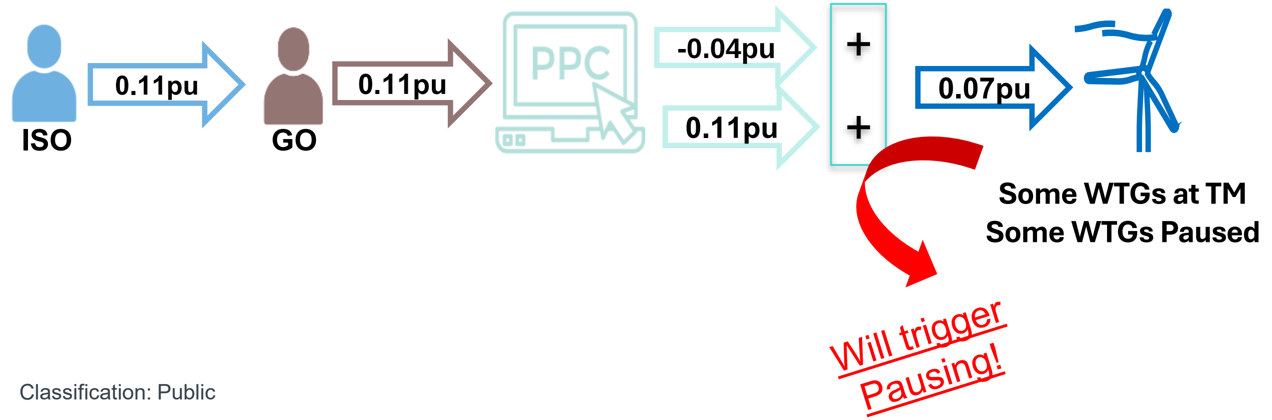
Available Power Wind Farm considering Pause

2) Over Frequency Event

Before frequency event:



After frequency event:



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But what if this happens **frequently!?**

Constant engagement & disengagement of mechanical components

High mechanical fatigue

➕

Lower electrical readiness

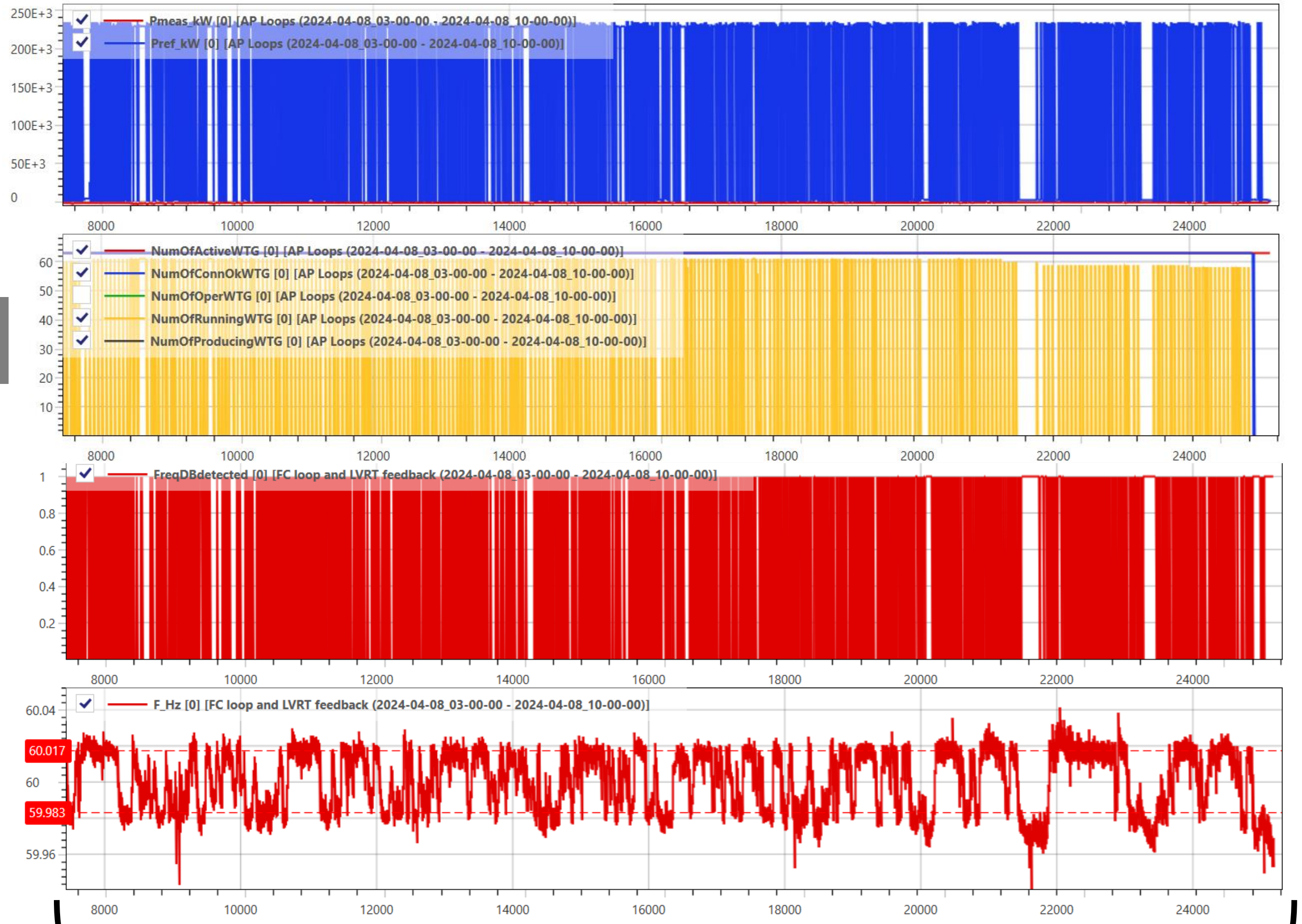
<u>Legend</u>:

PmeaskW (POI)
PrefkW (PPC to WTGs)

NumofRunningWTG (non paused)

Flag: Detection of Freq Deviation Outside Deadband

Measured Freq (deadband highlighted by horizontal bands)



Timescale is in seconds ~ 260h or 11days are plotted

Classification: Public

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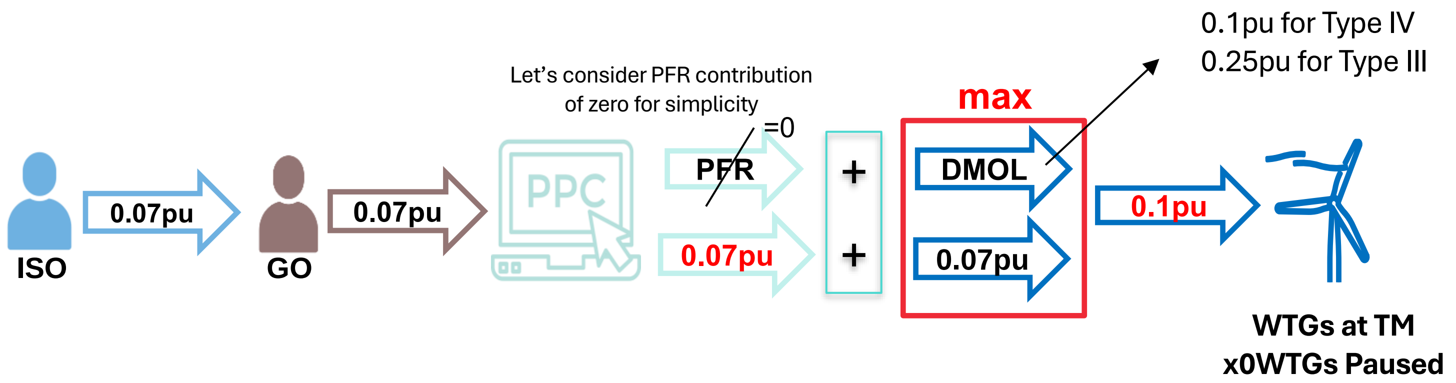
There are existing solutions…

Both solutions have been applied with good results in existing Vestas sites

1) DMOL – Defined Minimum Operating Limit



Pros:

- Avoids pausing
- Increases controllability and readiness

Cons:

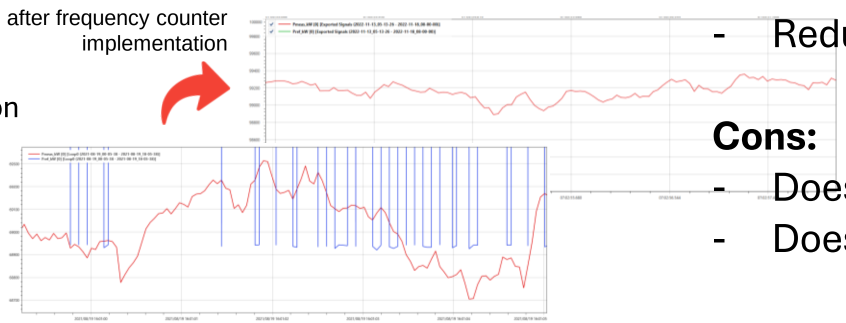
- Wind farm won't follow setpoints below DMOL*

*Note that for low wind with no available power, wind farm can go below DMOL

2) Introduce a filtered or delayed/counter frequency response

Couple of options…

1. Low pass filter for frequency variations
2. Introduce delays for control to act
   - Forces frequency to exist for a while to be acted upon
3. Counter aka integral gain on frequency deviations:
   - Small deviations for short time are ignored
   - Small deviations for long time are considered
   - Large deviations for short time are considered



Pros:

- Decreases number of pauses
- Reduces fatigue

Cons:

- Does not prevent pausing
- Does not address readiness problem

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Thank you

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