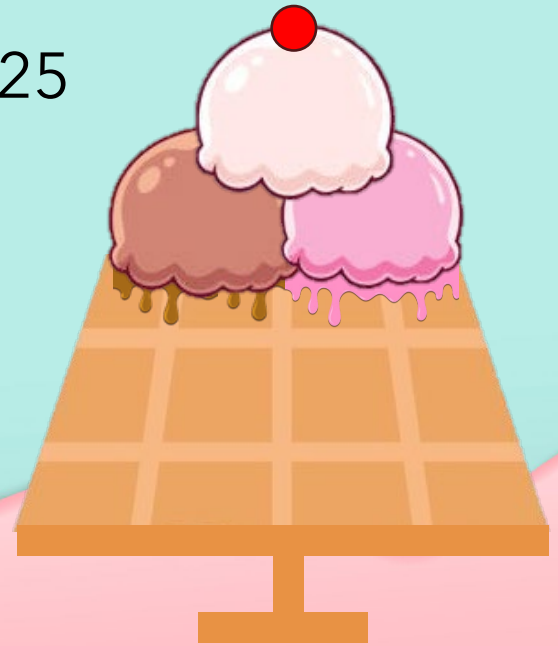
FORWARD TOGETHER RELIABILITYFIRST

WELCOME TO TECHNICAL TALK WITH RF

August 18, 2025



TECH TALK WITH RELIABILITY FIRST

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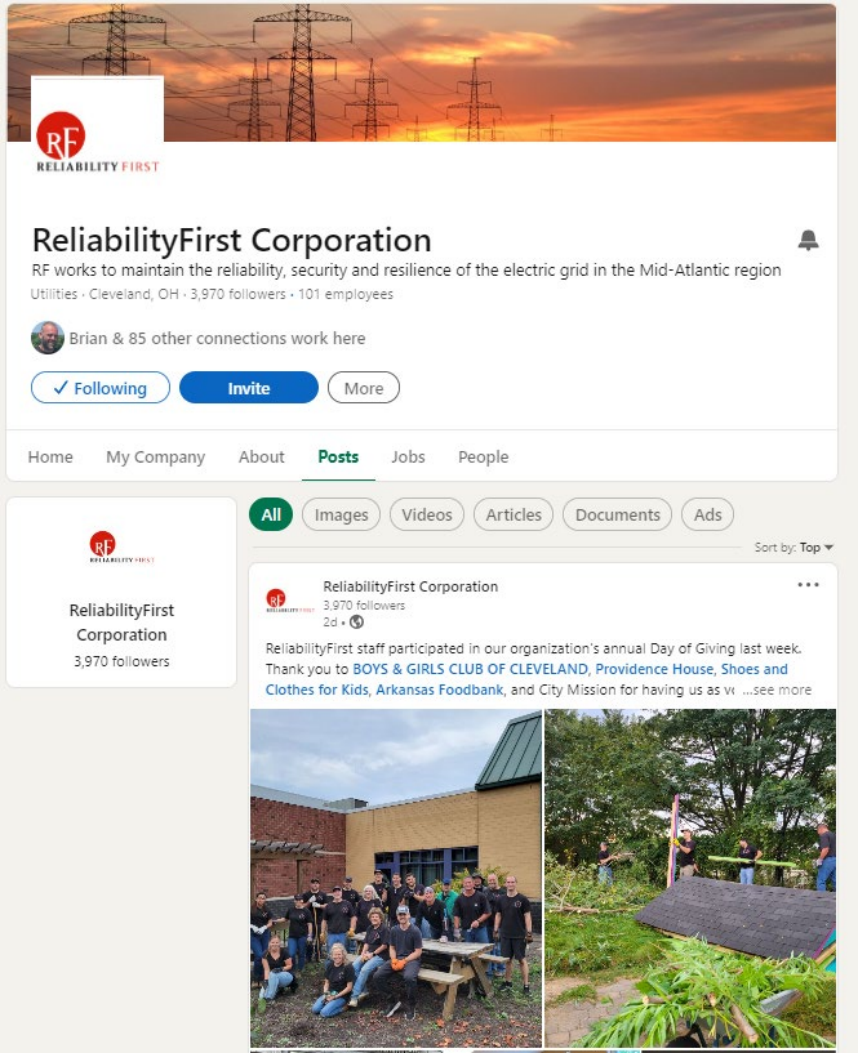


TECH TALK REMINDERS

Please keep your information up-to-date
- CORES and Generation Verification Forms

Following an event, send EOP-004 or OE-417 forms to disturbance@rfirst.org

CIP-008-6 incident reports are sent to the E-ISAC and the DHS CISA

Check our monthly CMEP update and newsletter:
- 2025 ERO Periodic Data Submittal schedule
- Timing of Standard effectiveness

BES Cyber System Categorization (CIP-002-5.1a)
- Assess categorization (low, medium, or high) regularly and notify us of changes

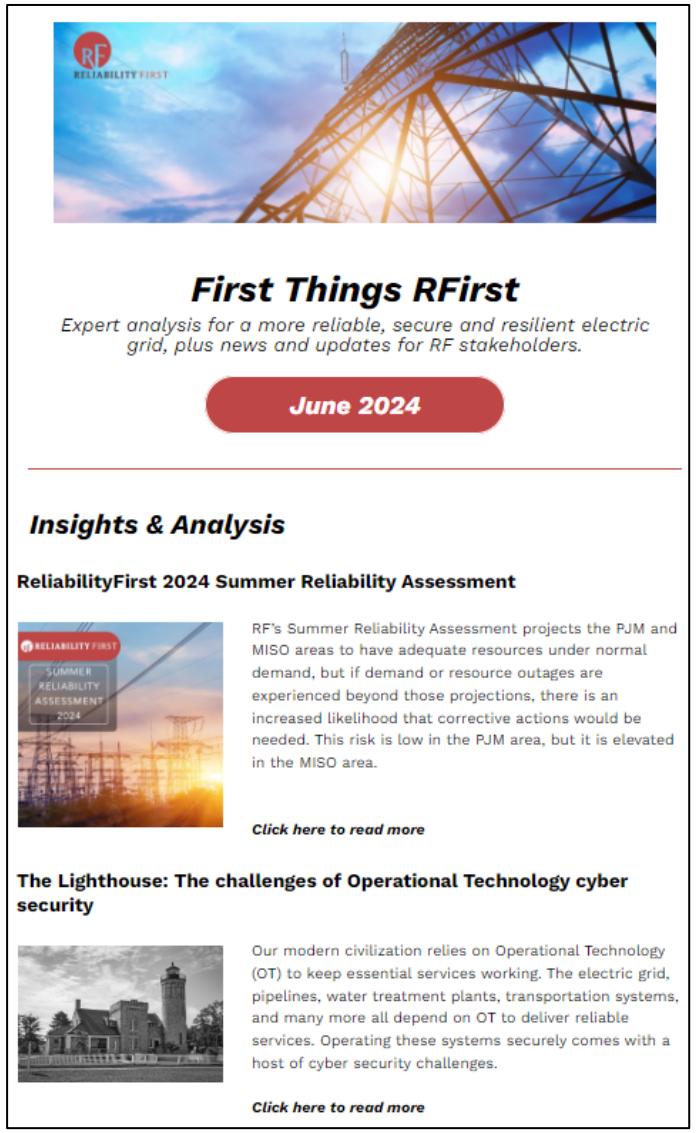
CIP Evidence Request Tool V9 was released and is on NERC's website

TECH TALK REMINDER

Are you getting our newsletter ***First Things RFirst?***

- Sign up today **here**

Also, make sure to check out our **2024 Impact Report** and **video**



RELIABILITY FIRST

First Things RFirst

Expert analysis for a more reliable, secure and resilient electric grid, plus news and updates for RF stakeholders.

June 2024

Insights & Analysis

ReliabilityFirst 2024 Summer Reliability Assessment

RF's Summer Reliability Assessment projects the PJM and MISO areas to have adequate resources under normal demand, but if demand or resource outages are experienced beyond those projections, there is an increased likelihood that corrective actions would be needed. This risk is low in the PJM area, but it is elevated in the MISO area.

Click here to read more

The Lighthouse: The challenges of Operational Technology cyber security

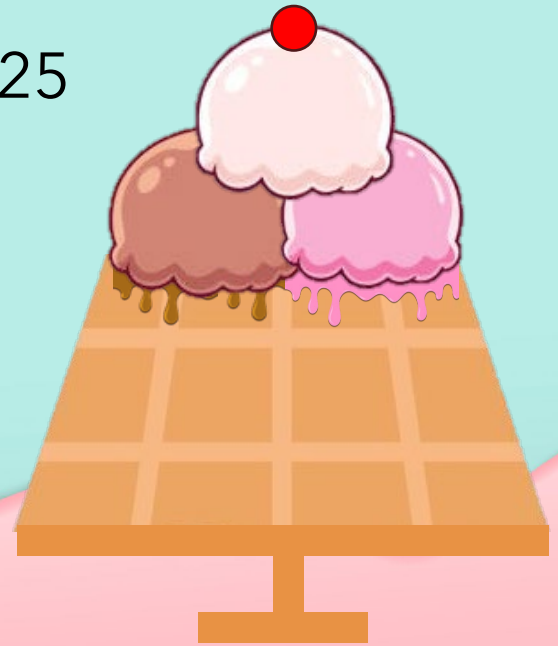
Our modern civilization relies on Operational Technology (OT) to keep essential services working. The electric grid, pipelines, water treatment plants, transportation systems, and many more all depend on OT to deliver reliable services. Operating these systems securely comes with a host of cyber security challenges.

Click here to read more

FORWARD TOGETHER RELIABILITYFIRST

WELCOME TO TECHNICAL TALK WITH RF

August 18, 2025



TECH TALK WITH RELIABILITY FIRST

TECH TALK ANNOUNCEMENT

RELIABILITYFIRST

Internal Controls Workshop 2026 Poll

What topics or NERC standards would you like the Compliance Team to cover during the February 2026 Internal Controls Workshop?

Please list any areas you're interested in learning more about, discussing with peers, or hearing examples from the audit perspective.

FORWARD TOGETHER RELIABILITYFIRST

TECH TALK ANNOUNCEMENT

Fall Reliability & Security Summit

(In-Person Only)

September 8-10th 2025

Register Now: Eventbrite

Event Details: rfirst.org

Join ReliabilityFirst at our annual Fall Reliability & Security Summit, hosted this year at the MGM National Harbor just outside of Washington, D.C.

We'll kick things off with an evening reception and our Reliability Recognition Awards Ceremony on Monday, Sept. 8, followed by an exciting agenda on Tuesday, Sept. 9. We'll be joined by key players from across the electric industry, including executives from FERC, NERC, PJM, AEP, LS Power, and more for a panel discussion as well as presentations on FERC Orders, RF Compliance and Enforcement, and more. Registration is limited, so be sure to sign up early!

MGM National Harbor, Oxon Hill, MD
September 8-10, 2025
Free to attend, Registration is Limited!
Details and Registration:
https://www.eventbrite.com/e/2025-fall-reliability-security-summit-tickets-1438521599829?aff=oddtdtcreator

TECH TALK ANNOUNCEMENT

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Standards Quarterly Outlook Video Highlights Key Order No. 901 Milestone 3 Activity

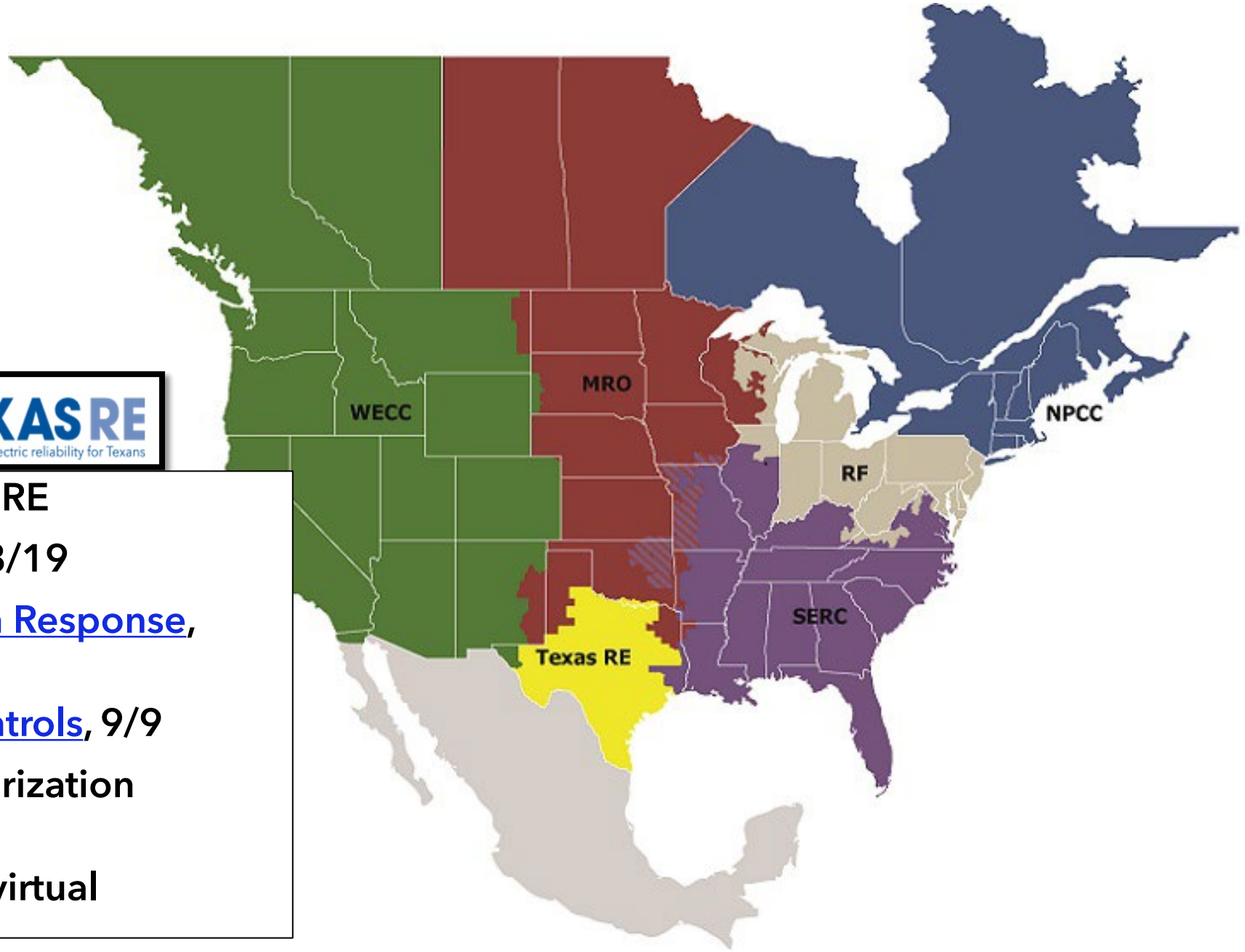
Full Announcement | **Video**

NERC has launched a new video series—the Standards Quarterly Outlook—designed to highlight key priorities and upcoming activities in the Standards space at the beginning of each quarter. This brief, accessible update is part of our ongoing efforts to increase awareness of ongoing projects and the Standards development process.

In this inaugural **Q3 2025 edition**, you'll hear directly from the Standards team about FERC Order No. 901 and Milestone 3 efforts, including the history of the order and a breakdown of the three associated projects as well as how you can get involved.

More details about the Milestone 3 project can be found in the **Milestone 3 Summary.** For more information on NERC's activities related to Order No. 901, please visit the **Standards Under Development page**.

Check out the video on NERC's YouTube Channel!



TEXAS RE
Ensuring electric reliability for Texans

Talk with Texas RE

- CIP-008-3, 8/19
- Data Breach Response, 8/26
- Internal Controls, 9/9

Winter Weatherization Workshop

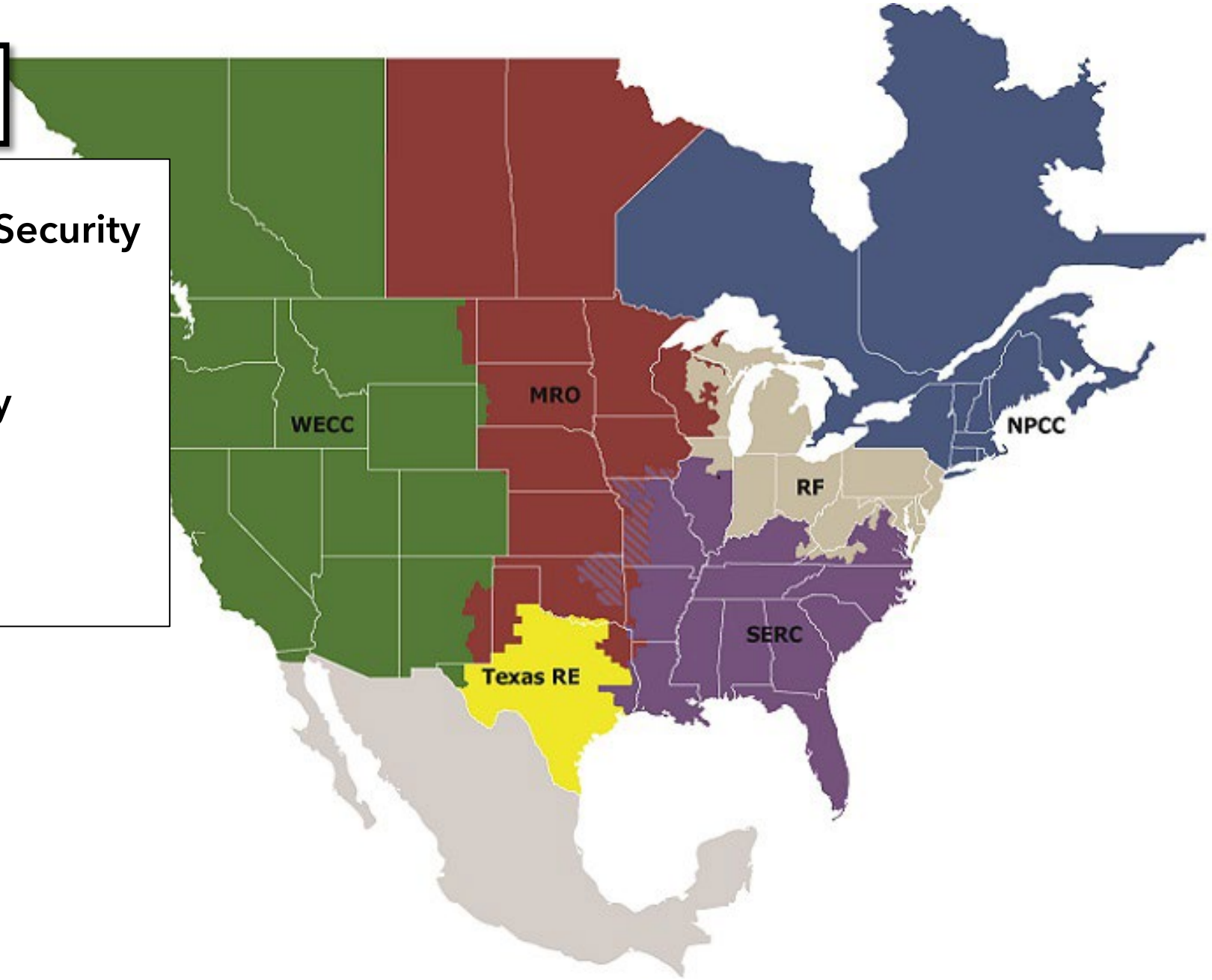
- October 1, virtual

WECC Reliability & Security Workshop

- October 14-15

Reliability & Security Oversight Update

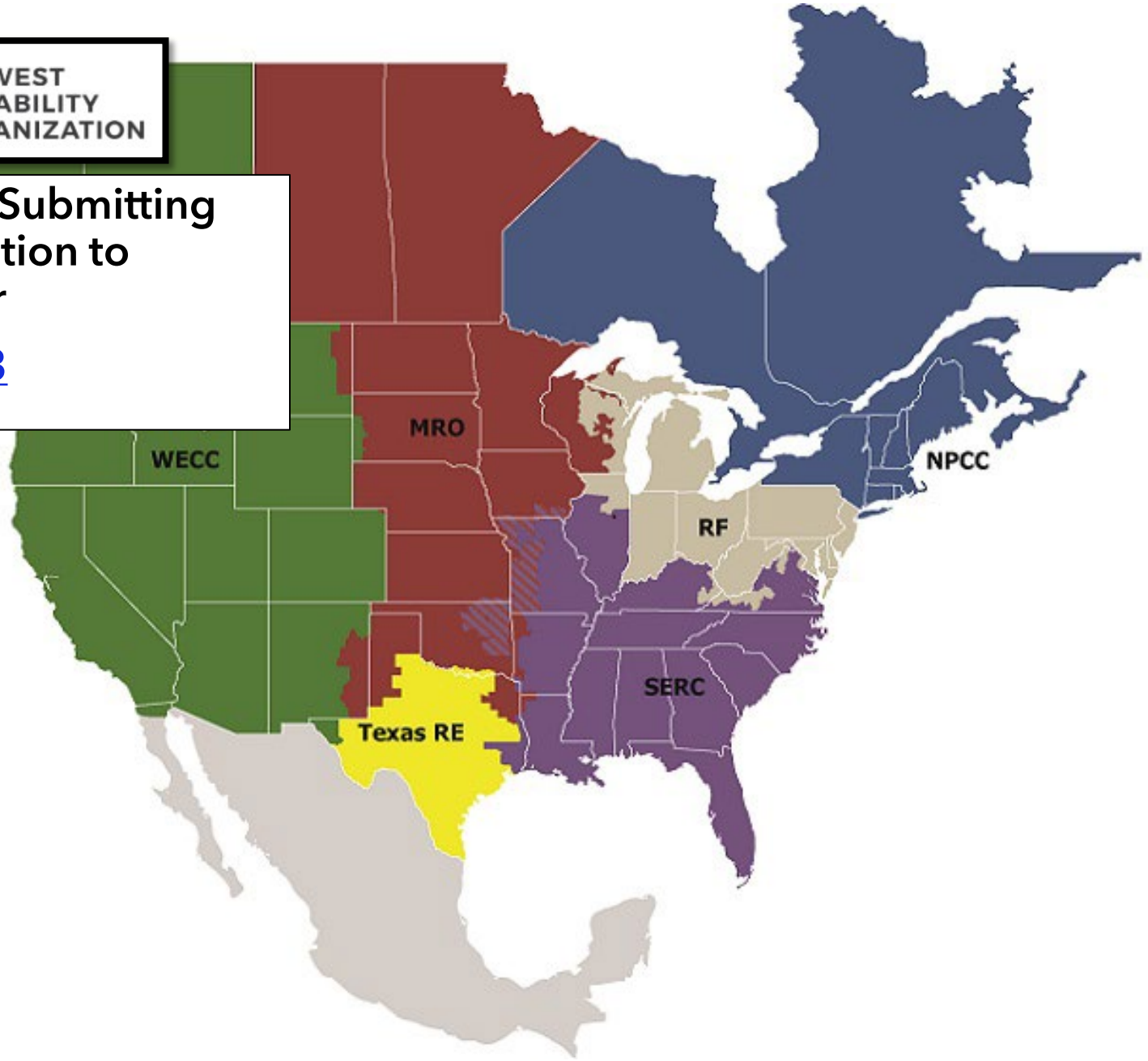
- August 21
- September 18

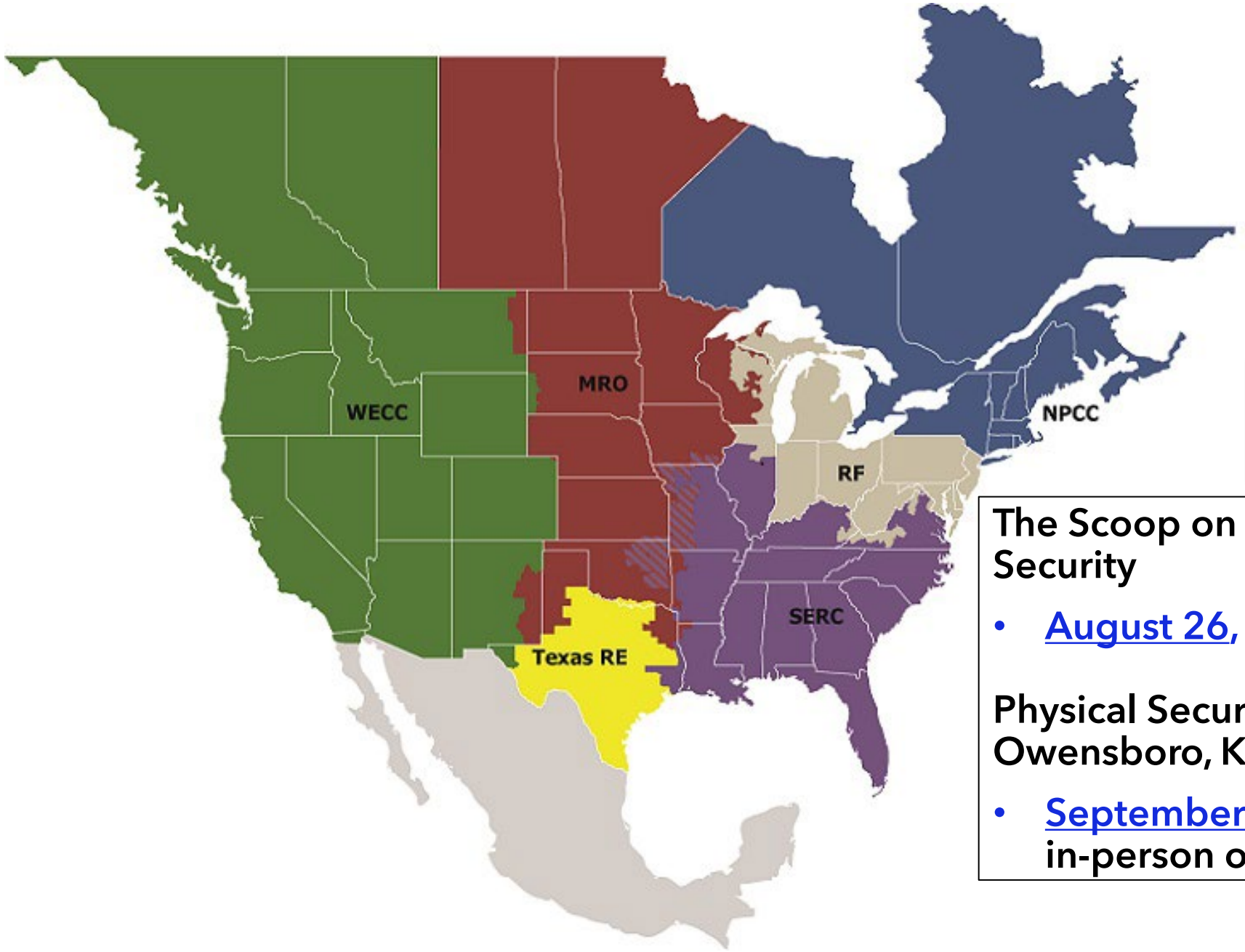


MIDWEST RELIABILITY ORGANIZATION

Misoperations: Submitting Quality Information to MIDAS Webinar

- [September 3]





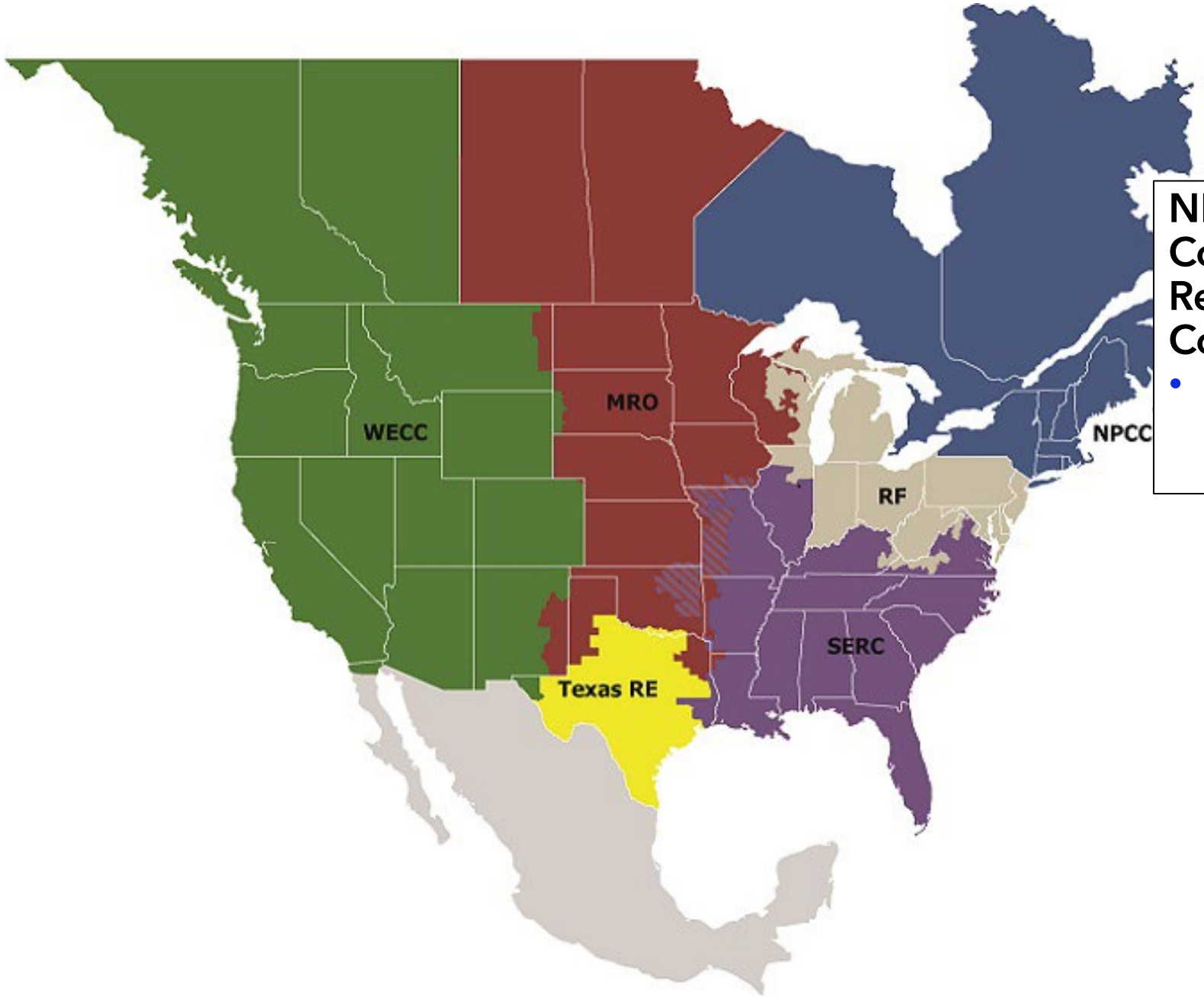
SERC Reliability Corporation

The Scoop on Cloud Security

- August 26, virtual

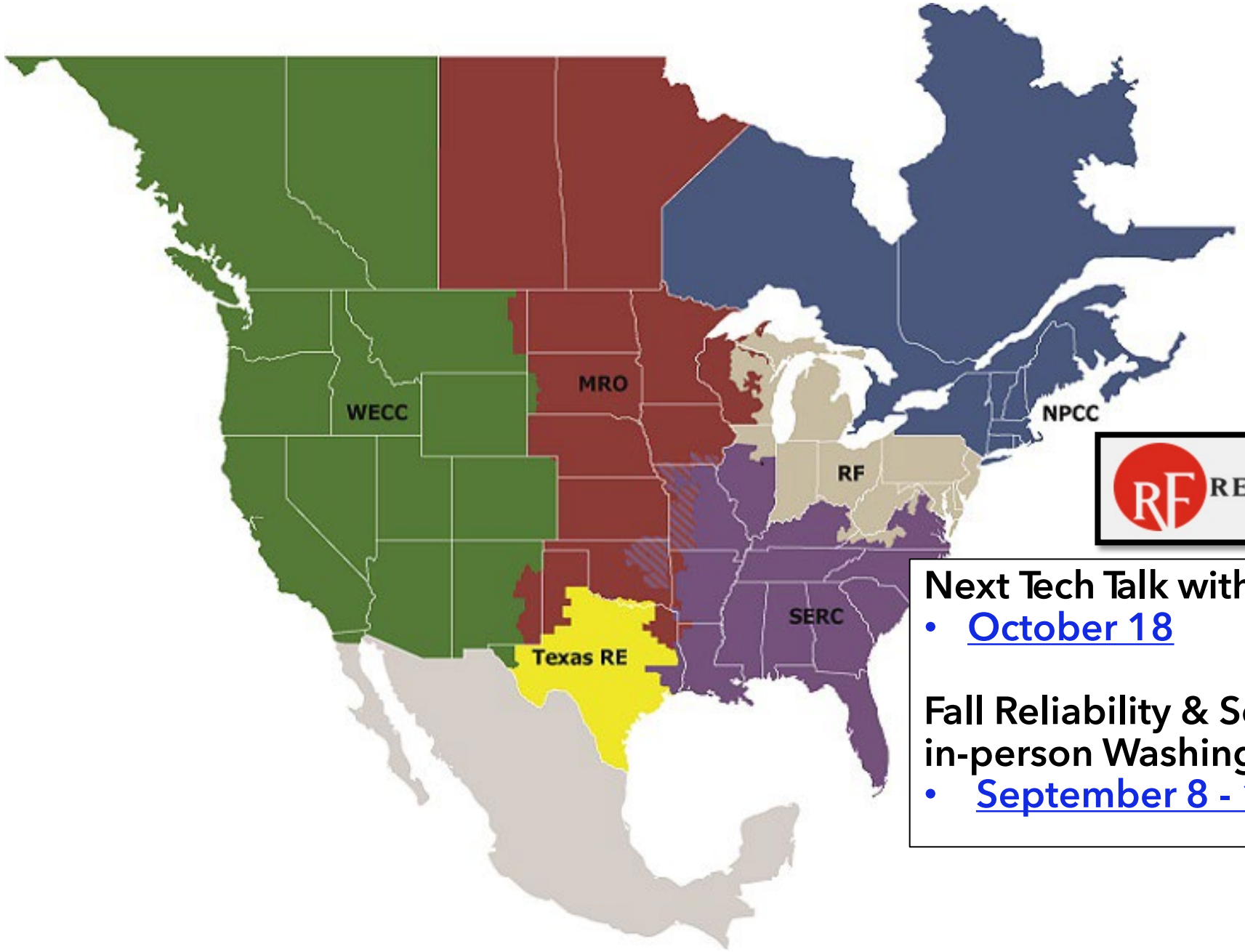
Physical Security Workshop, Owensboro, KY

- September 9 - 11, in-person only



NPCC Fall 2025 Compliance and Reliability Conference

- November 5 - 6 hybrid



RELIABILITY FIRST

Next Tech Talk with RF

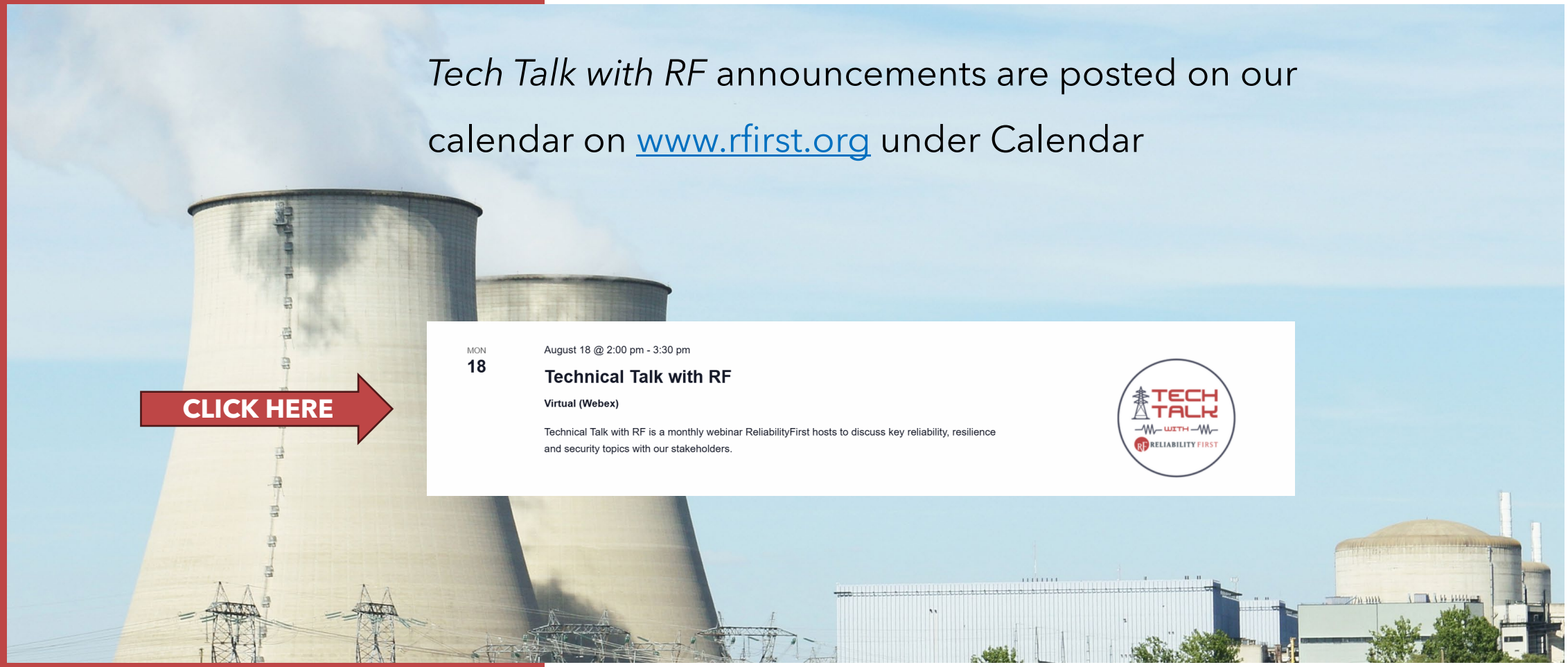
- October 18

Fall Reliability & Security Summit in-person Washington, D.C.

- September 8 - 10

TECH TALK REMINDER

FORWARD TOGETHER RELIABILITYFIRST



TECHNICAL TALK WITH RF

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Join the conversation at

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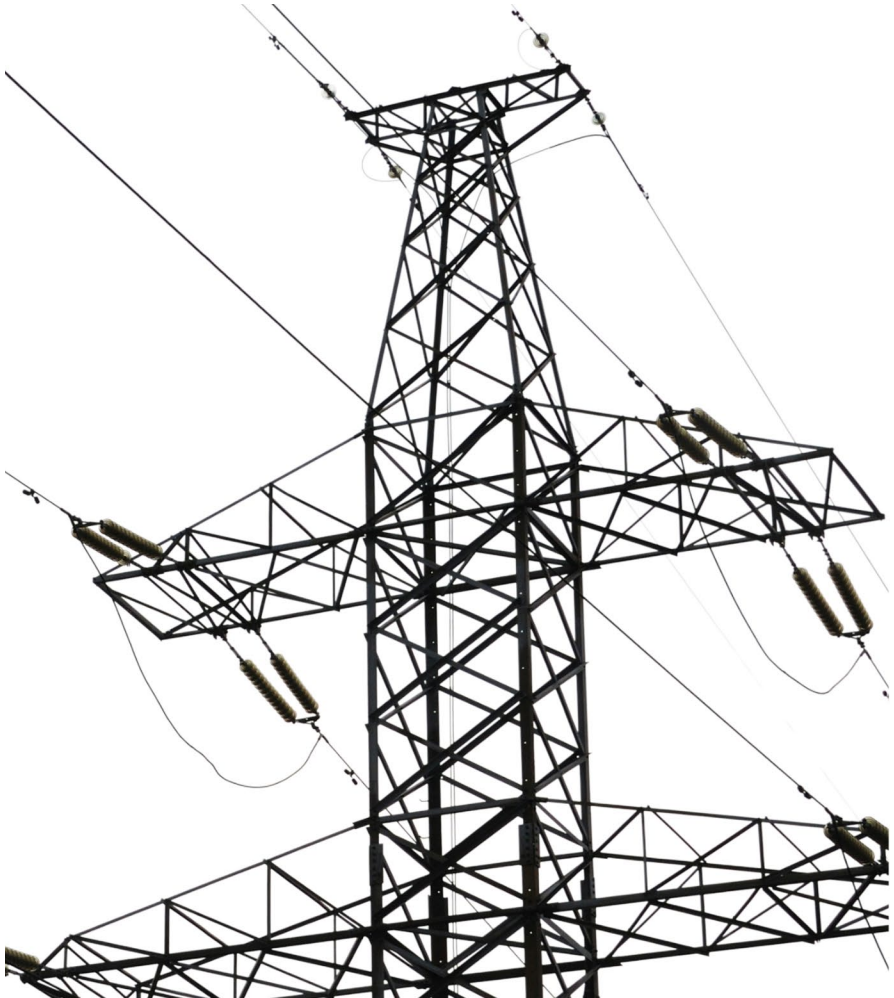
#TechTalkRF

Anti-Trust Statement

It is ReliabilityFirst's policy and practice to obey the antitrust laws and to avoid all conduct that unreasonably restrains competition. This policy requires the avoidance of any conduct which violates, or which might appear to violate, the antitrust laws. Among other things, the antitrust laws forbid any agreement between or among competitors regarding prices, availability of service, product design, terms of sale, division of markets, allocation of customers or any other activity that unreasonably restrains competition.

It is the responsibility of every ReliabilityFirst participant and employee who may in any way affect ReliabilityFirst's compliance with the antitrust laws to carry out this policy.



AGENDA

WHAT TO KNOW ABOUT DRAFT NERC RELIABILITY STANDARD PRC-029-1 AND HOW IT WILL IMPACT INVERTER-BASED RESOURCES (IBRS)

- **DAN RANSOM,** SENIOR CONSULTING, TECHNICAL APPLICATION ENGINEER, GE VERNOVA

RATE OF CHANGE OF FREQUENCY AND UNDERFREQUENCY LOAD SHEDDING

- **JOHN "JP" SKEATH,** SENIOR ENGINEER, NERC

ESSENTIALS OF RENEWABLE ENERGY PROTECTION AND MONITORING

Daniel L. Ransom, PE
GE Vernova

Our discussion

Increase in renewables

Nature of IBR response

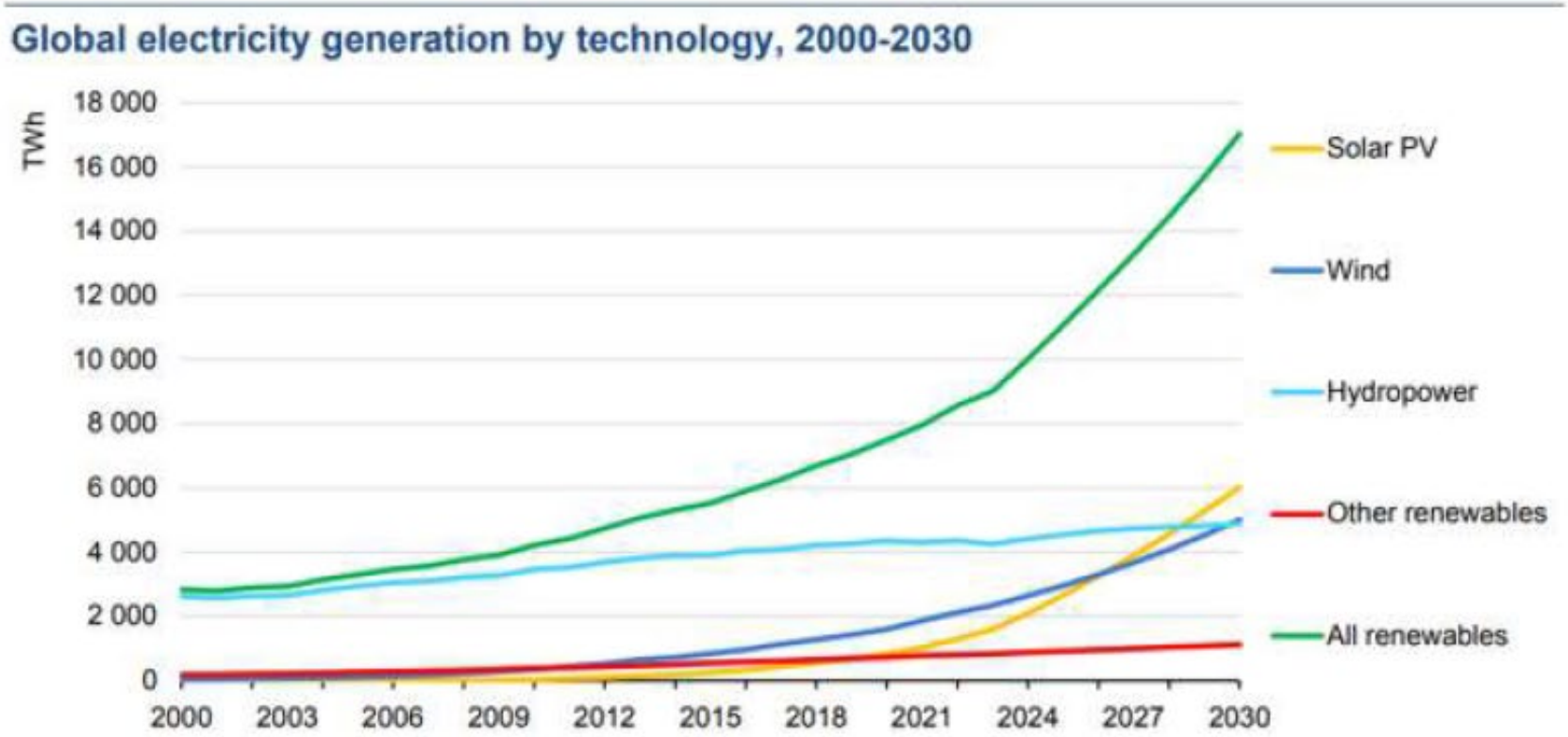
Improving IBR operation during events

- Voltage ride-through
- Frequency / power ride-through

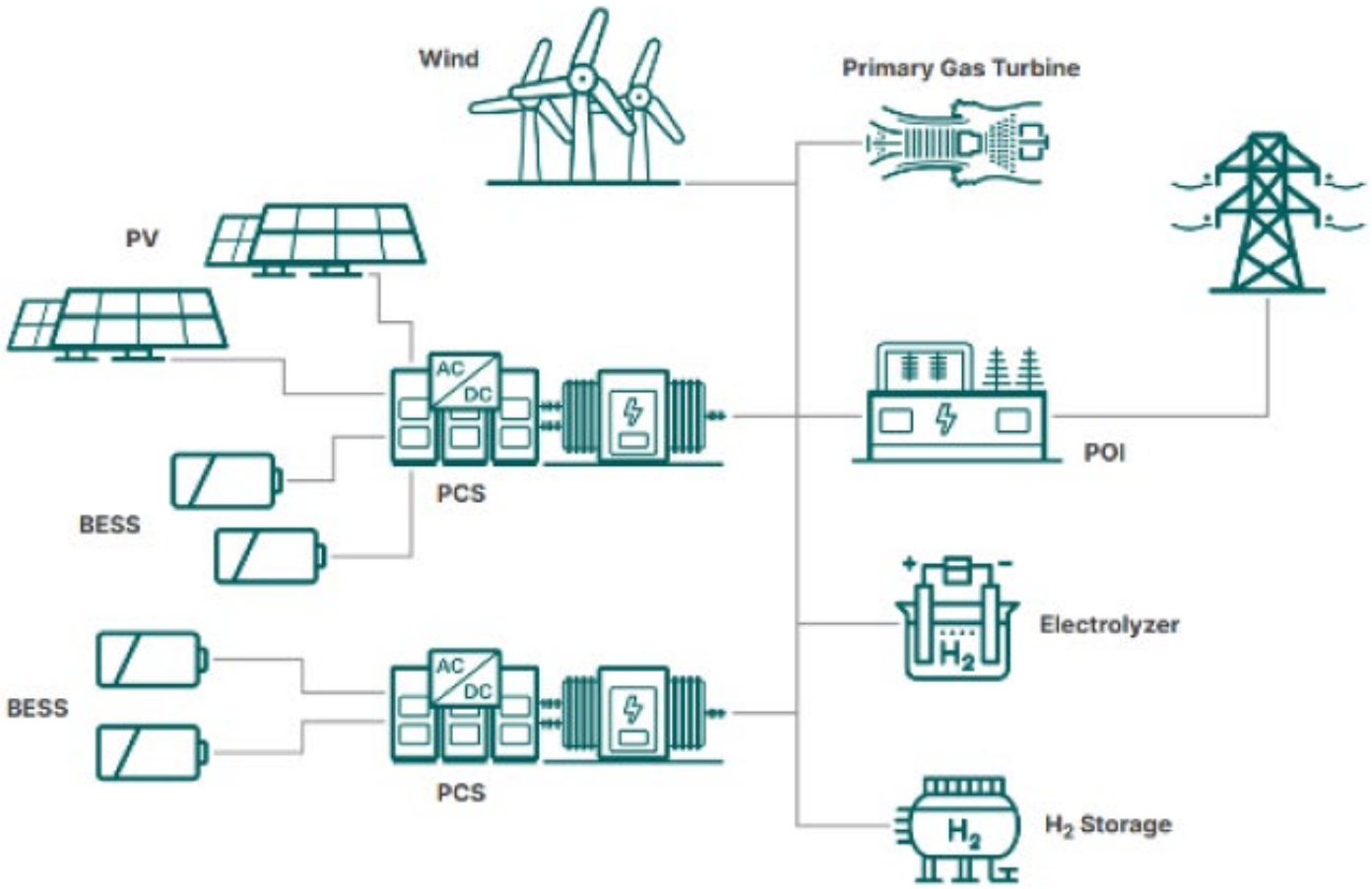
Monitoring and protection assistance in maintaining power-system stability

Increase in renewables

Global renewable electricity generation increases to 17,000 TWh by 2030



Modern grid with IBR, gas and hydrogen resources



Nature of IBR response

Semiconductor switching devices

Limit fault contributions to 1.1–1.5 pu

Not same as synchronous generators

- 3 pu
- Sub-transient, transient and steady state

IBR control systems cannot determine events well

- Faults
- Sudden load variations
- Inrush currents

Protective relays are confounded by IBR uncontrolled outputs

IEEE Standard 1547

IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems

Original, 2003

- Not interfere with distribution system
- Tight tolerances for voltage and frequency
- Quick suspension of DER operation
- No active voltage regulation

Amendment 1, 2014

- Relaxed some voltage and frequency targets
- DER may actively regulate voltage
- May ride through abnormal voltage / frequency
- May provide frequency response (droop compensation)
- Protective relays responded better

IEEE Standard 1547-2018 extends online operation

IBRs must stay online depending on severity of voltage and frequency excursions

- Category I meets minimum Bulk EPS reliability; applies to all DERs, including rotating machines
- Category II aligns with NERC PRC-024-2 (Generator Frequency and Voltage Protective Relay Settings)
- Category III is for low-inertia systems and large concentration of IBRs. Supports Hawaii Rule 14 and California Rule 21

Ride-through times for deviations from nominal voltage and frequency

	2003 level (pu)	2003 (s)	2018 level (pu)	2018-I (s)	2018-II (s)	2018-III (s)
Voltage						
OV2	1.2	0.16	1.2	0.16	0.16	0.16
OV1	1.1	1	1.1	2	2	13
UV1	0.88	2	0.88	2	10	21
UV2	0.5	0.16	0.5	0.16	0.16	2
	2003 Hz	2003 (s)	2018 Hz	2018-I (s)	2018-II (s)	2018-III (s)
Frequency						
OF2	n/a	n/a	61.8	0.16	0.16	0.16
OF1	60.5	0.16	61	300	300	300
UF1	59.3	0.16	59	300	300	300
UF2	n/a	n/a	57	0.16	0.16	0.16

Protective relays assist IBR plant in meeting standards

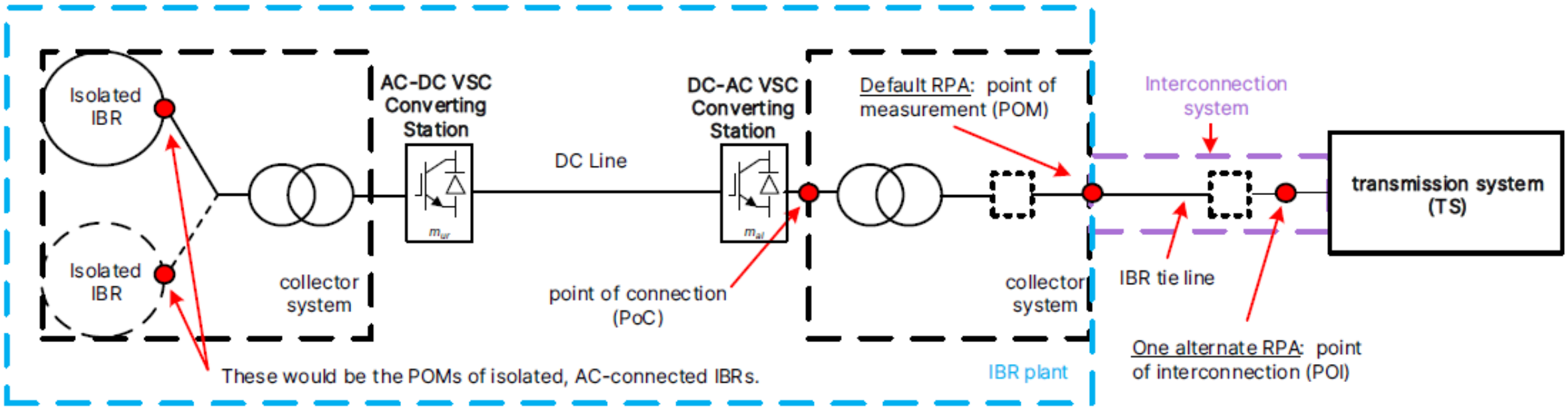
Monitoring at RPA (reference point of application)

- Voltage
- Frequency

Relays monitor Continuous, Mandatory, and Permissive Operation regions

Notify IBR plant controller via contacts or IEC 61850 GOOSE

Provide protection tripping or IBR plant curtailment

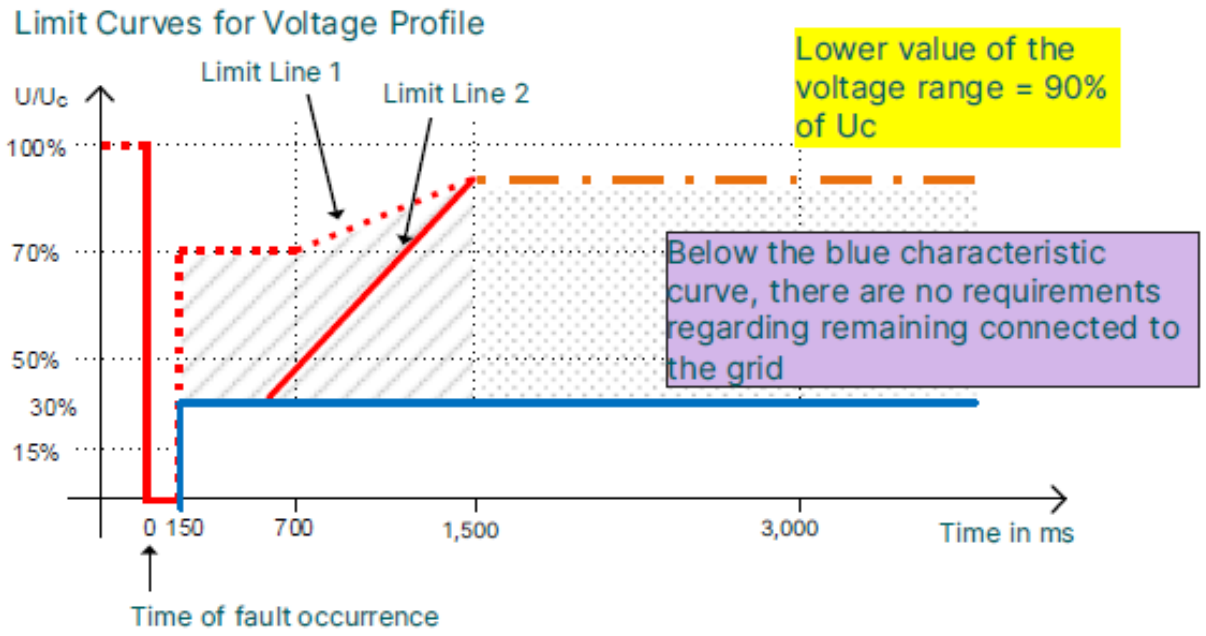


From IEEE 2800-2022

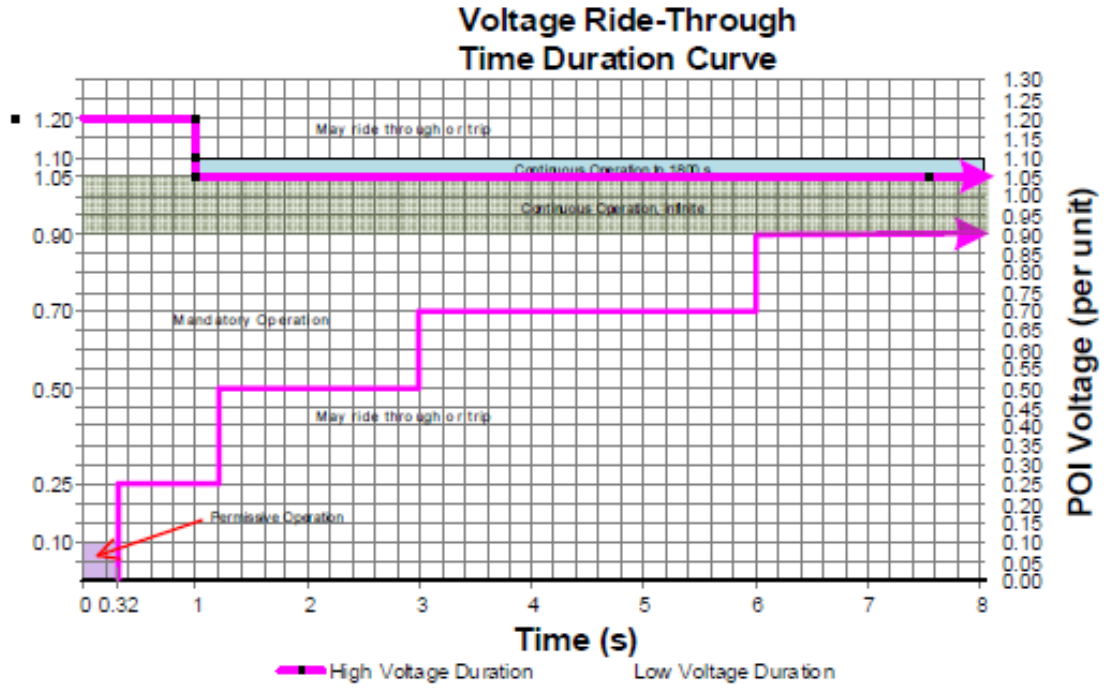
Improving IBR operation during events

Older IBRs suspended operation momentarily, with large variations in voltage, current, and frequency

Recent standards and grid codes are improving ability of IBRs to ride through load/generation changes and faults



German Grid Code, BDEW



NERC PRC-029-1

IEEE Standard 2800-2022 works towards consistency

Expands on previous work

Emphasizes areas for improvement and standardization, for grid stability

Consistent response from IBR plant connected to transmission system

- Voltage and frequency ride through
- Active and reactive power control
- Dynamic active power support

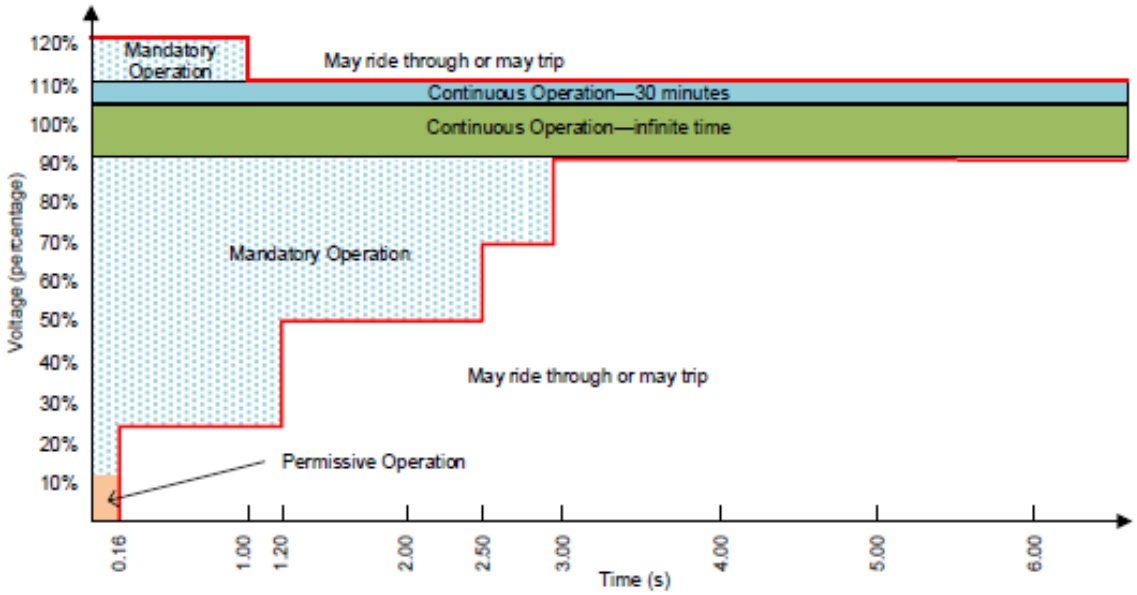
Covers IBRs with and without auxiliary equipment

Updated PRC-024-3 (IBRs with auxiliary equipment including synchronous generation and most newer wind plants)

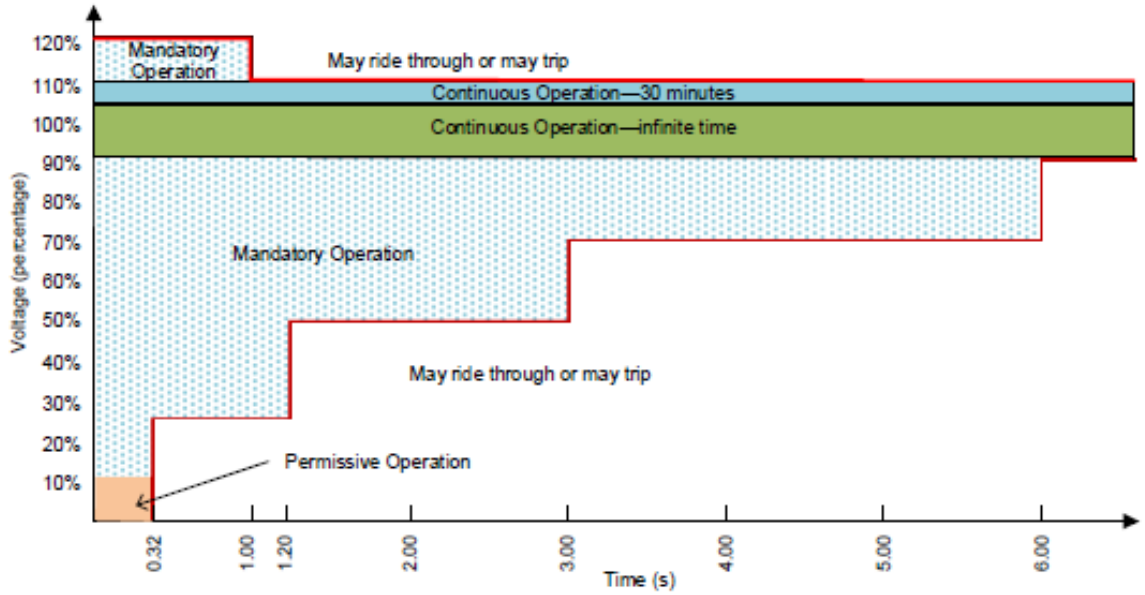
NERC PRC-029-1 has similar voltage and frequency requirements for IBRs without auxiliary equipment

IEEE 2800 voltage ride-through requirements

Mandatory, Continuous, and Permissive Operation regions

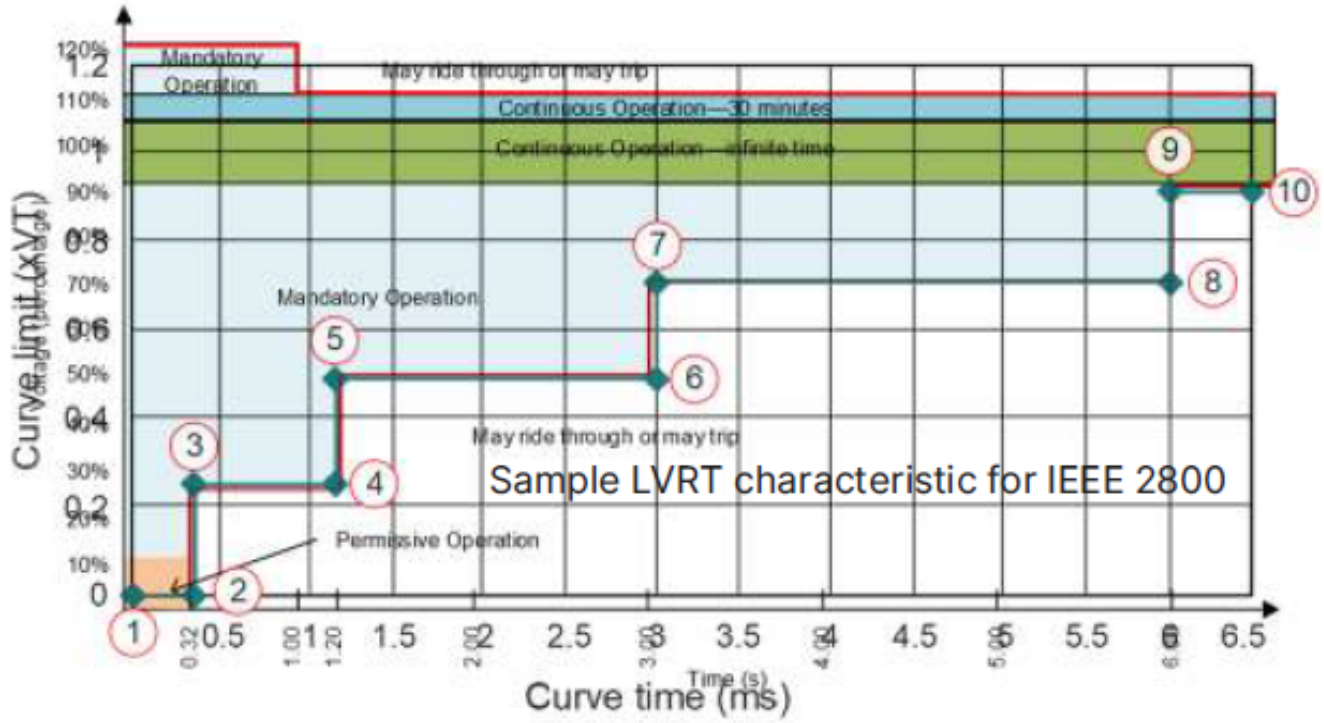


IBRs equipped with auxiliary equipment (wind plants)



IBRs without auxiliary equipment (PV and BESS)

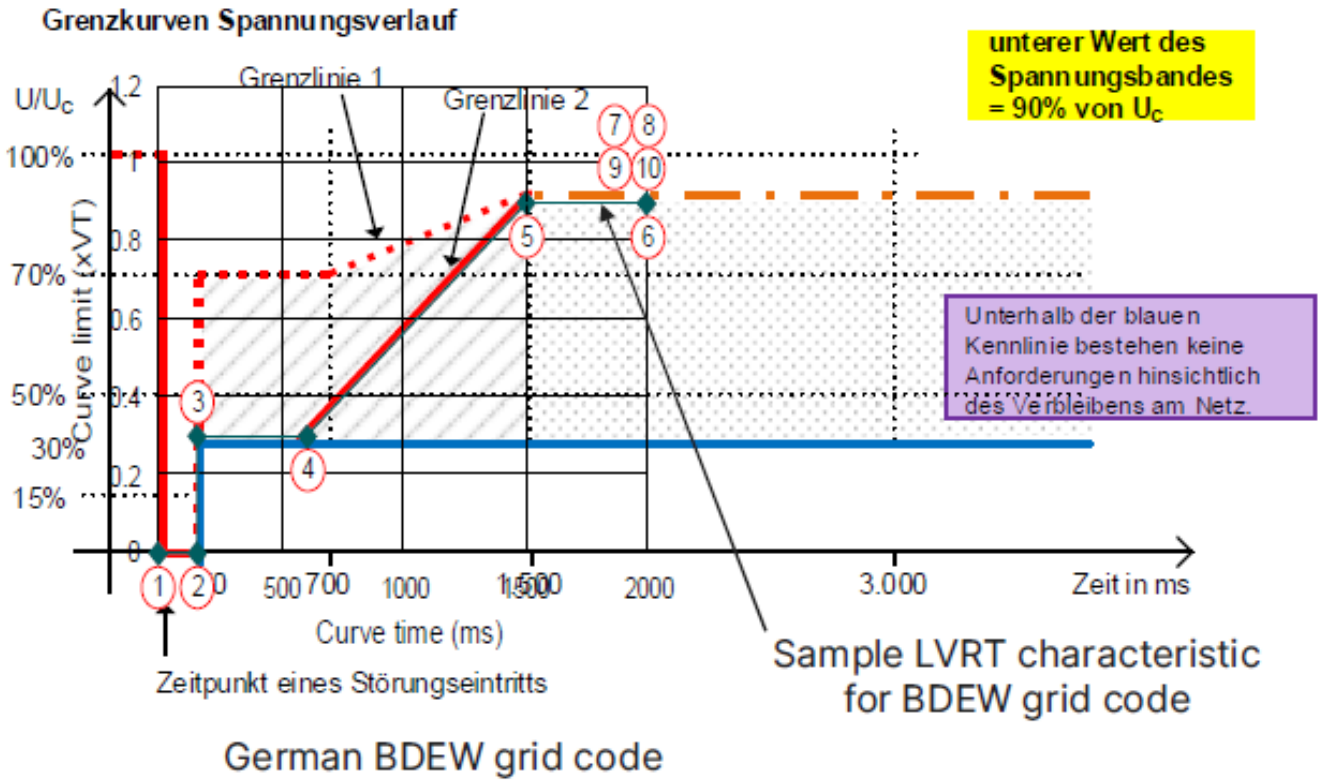
Timed Undervoltage, 27T, follows V vs. t curves



IEEE 2800-2022 IBRs without Auxiliary Equipment (PV and BESS)

	IEEE 2800 / PRC-029-1
Curve Limit 1 (x VT)	0
Curve Time 1 (s)	0
Curve Limit 2 (x VT)	0
Curve Time 2 (s)	0.32
Curve Limit 3 (x VT)	0.25
Curve Time 3 (s)	0.32
Curve Limit 4 (x VT)	0.25
Curve Time 4 (s)	1.2
Curve Limit 5 (x VT)	0.5
Curve Time 5 (s)	1.2
Curve Limit 6 (x VT)	0.5
Curve Time 6 (s)	3
Curve Limit 7 (x VT)	0.7
Curve Time 7 (s)	3
Curve Limit 8 (x VT)	0.7
Curve Time 8 (s)	6
Curve Limit 9 (x VT)	0.9
Curve Time 9 (s)	6
Curve Limit 10 (x VT)	0.9
Curve Time 10 (s)	6.5

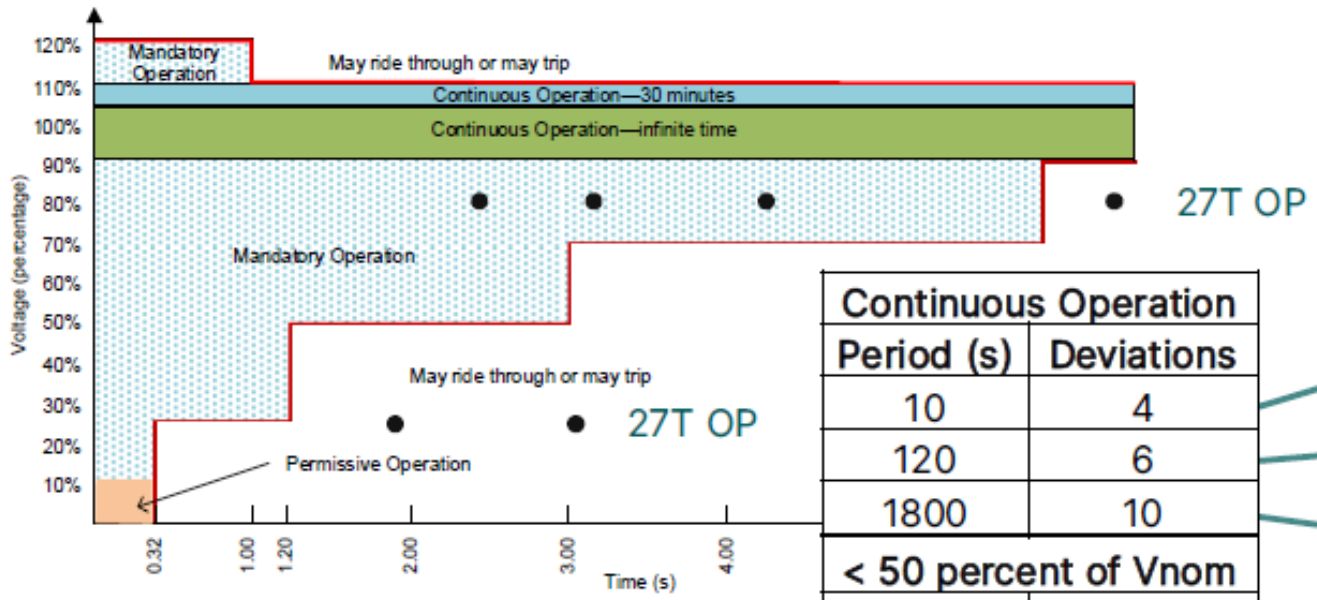
Timed Undervoltage, 27T, follows V vs. t curves



German BDEW grid code

	German BDEW
Curve Limit 1 (x VT)	0
Curve Time 1 (s)	0
Curve Limit 2 (x VT)	0
Curve Time 2 (s)	0.15
Curve Limit 3 (x VT)	0.3
Curve Time 3 (s)	0.15
Curve Limit 4 (x VT)	0.3
Curve Time 4 (s)	0.6
Curve Limit 5 (x VT)	0.9
Curve Time 5 (s)	1.5
Curve Limit 6 (x VT)	0.9
Curve Time 6 (s)	2
Curve Limit 7 (x VT)	0.9
Curve Time 7 (s)	2
Curve Limit 8 (x VT)	0.9
Curve Time 8 (s)	2
Curve Limit 9 (x VT)	0.9
Curve Time 9 (s)	2
Curve Limit 10 (x VT)	0.9
Curve Time 10 (s)	2

Consecutive voltage deviations



Continuous Operation	
Period (s)	**Deviations**
10	4
120	6
1800	10
< 50 percent of Vnom	
Period (s)	**Deviations**
10	2
120	3

IEEE 2800-2022

Timed UV1	
Pickup (xVT)	0.9
Counter Mode	Enabled
Voltage Drops	4
Time for Voltage Drops (s)	10
Timed UV2	
Pickup (xVT)	0.9
Counter Mode	Enabled
Voltage Drops	6
Time for Voltage Drops (s)	120
Timed UV3	
Pickup (xVT)	0.9
Counter Mode	Enabled
Voltage Drops	10
Time for Voltage Drops (s)	1800
Timed UV4	
Pickup (xVT)	0.5
Counter Mode	Enabled
Voltage Drops	2
Time for Voltage Drops (s)	10
Timed UV5	
Pickup (xVT)	0.5
Counter Mode	Enabled
Voltage Drops	3
Time for Voltage Drops (s)	120

Undervoltage reactive power, 27Q supports grid

Bus voltage drops

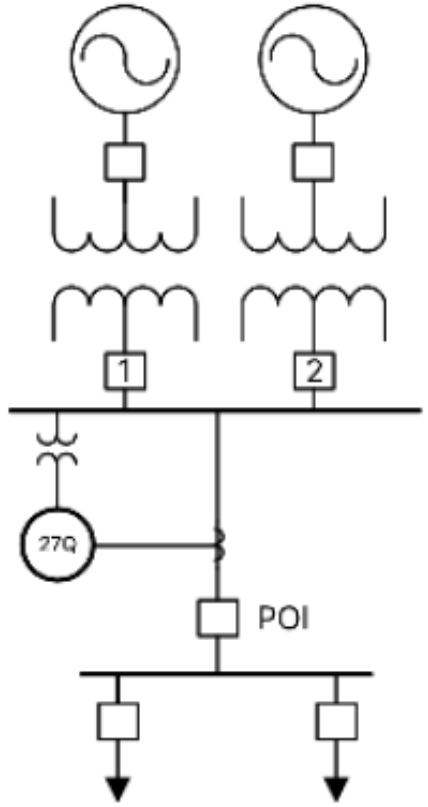
Reactive power flows toward generators (reverse)

Set Pickup to avoid excessive VArs into IBR

Restoration function

- Healthy voltage returns
- Grid frequency within programmed settings
- Close with sync check

Also monitors IBR consumed VArs when absorbing reactive, Q, power for voltage reduction



UV Reactive Power	
Pickup Voltage	0.85 x VT
Pickup Vars	25 kVAr
Curr Superv Level	0.1 x CT
Var Direction	Reverse
Pickup Delay	0.5 s
Dropout Delay	0.5 s
Restore Function	Configurable
Min Voltage	0.95 x VT
Min Frequency	59.00 Hz
Max Frequency	60.50 Hz
Min Current	0.1 x CT
Restore Initiate	programmable
27Q Initiate	On

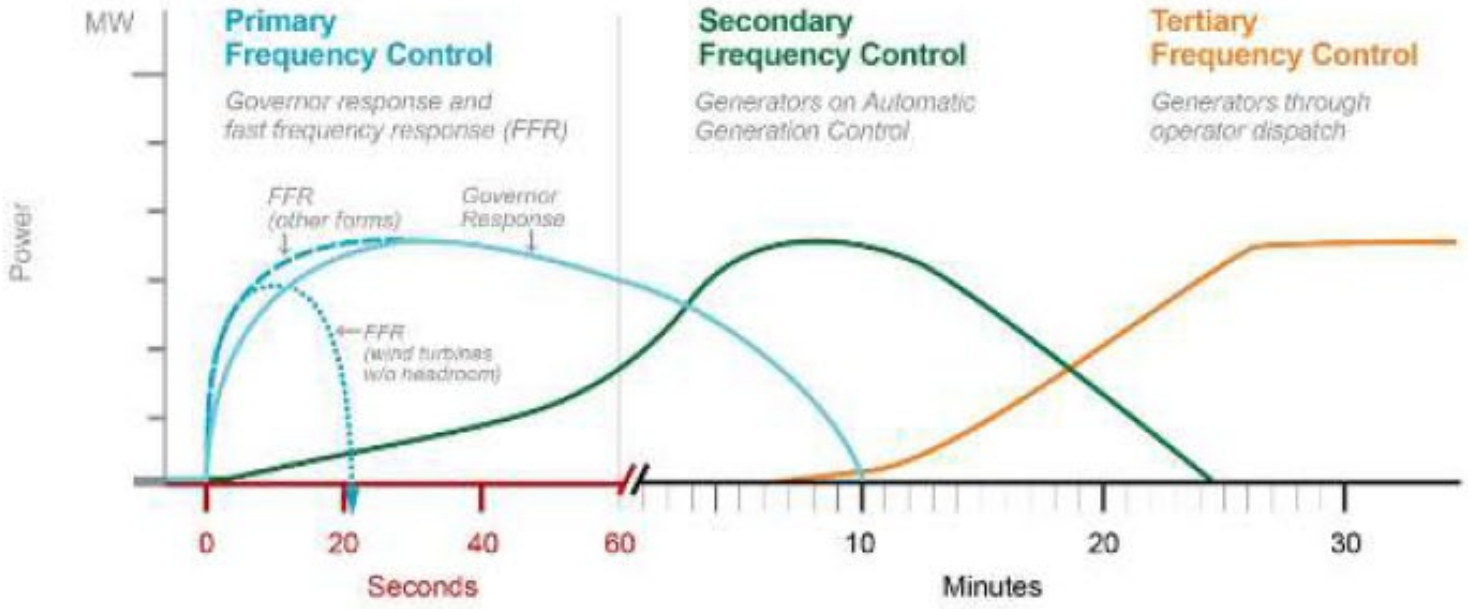
IEEE 2800 frequency response

IBR plant must ride through frequency disturbances

PFR—Primary Frequency Response

FFR—Fast Frequency Response

NERC PRC-024-3 responses based on region



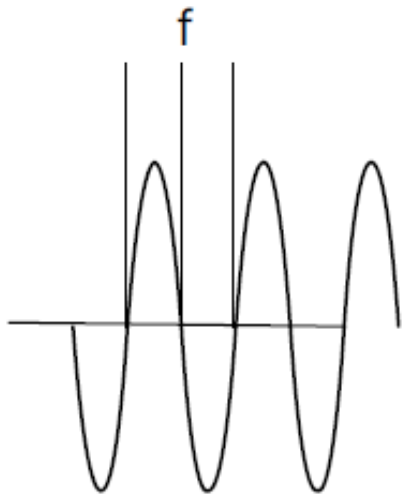
Employ fast frequency estimation

High-speed frequency checks time between two consecutive zero-crossing

One measurement available every half cycle

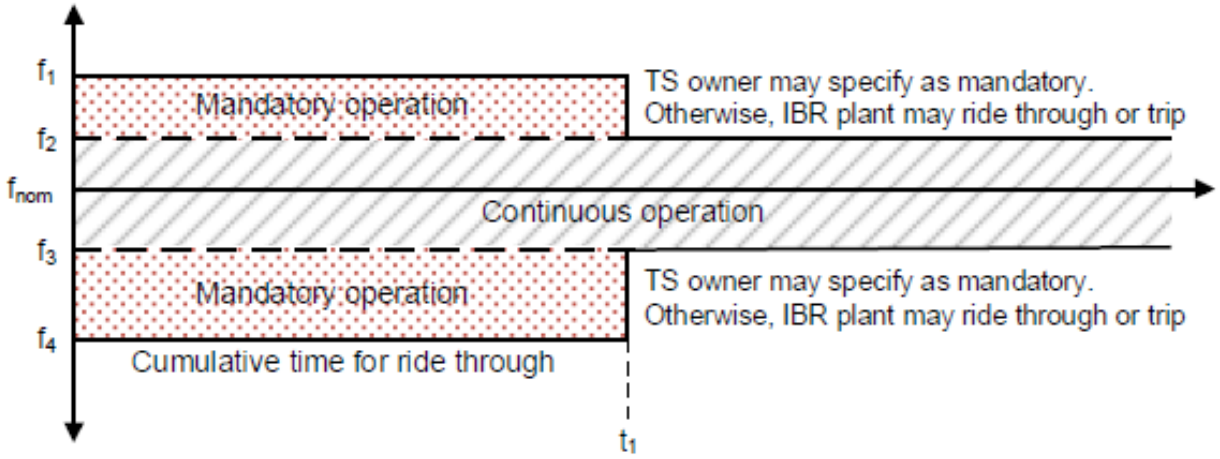
Operate times less than half of traditional methods

High-Speed Frequency	Enabled
Freq Set # Semi-cycles	5
Freq Reset # Semi-cycles	3



Frequency response to faults

IBR shall ride through and maintain synchronism



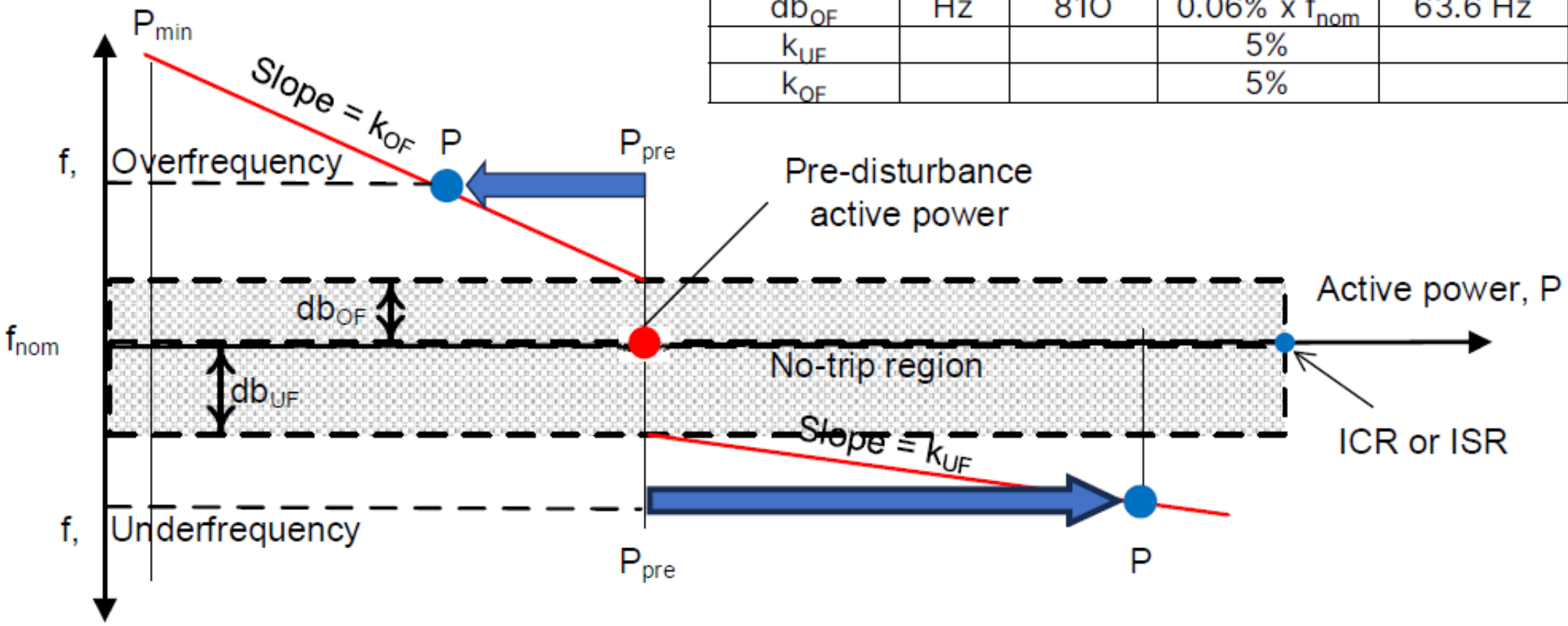
Frequency range (Hz)	Protect-ion Element	IEEE 2800 (Hz)	NERC PRC-029-1 Freq (Hz)	t1 Min. time (s)	Operation
f1	81O	51.5 / 61.8	61.8	299	Mandatory
f2	81O	51 / 61.2	61.2	—	Continuous
f3	81U	49 / 58.8	58.8	—	Continuous
f4	81U	47.5 / 57	57	299	Mandatory

Frequency monitoring IBR plant—Primary Frequency Response, PFR

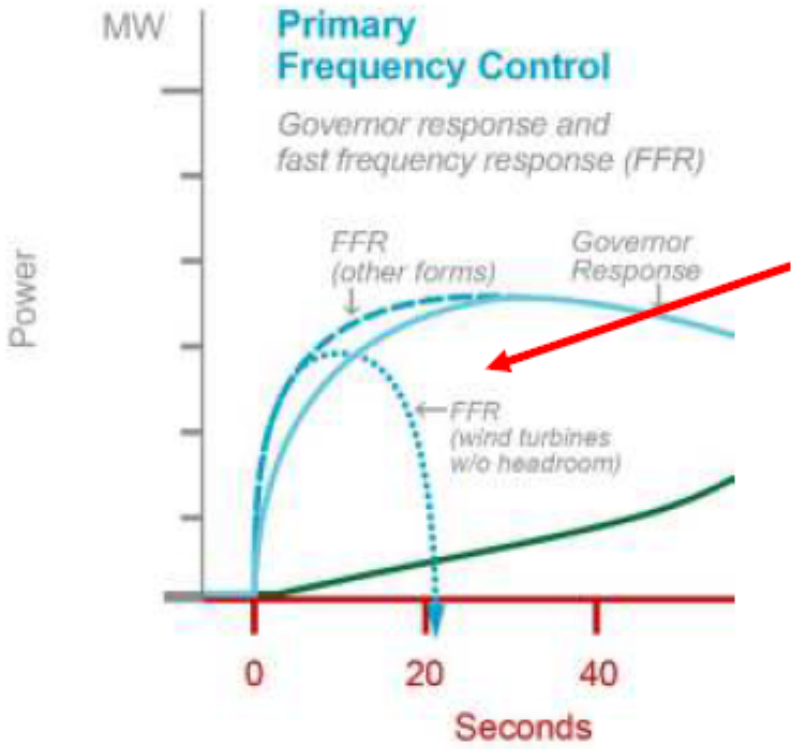
IBR plant operates in frequency “no-trip” region

Plant adjusts active power as required

IEEE 2800 Parameter	Units	Prot. Element	IEEE 2800 Default value	Protection Setting, 60 Hz	Protection Setting, 50 Hz
db_{UF}	Hz	81U	0.06% x f_{nom}	56.4 Hz	47.0 Hz
db_{OF}	Hz	81O	0.06% x f_{nom}	63.6 Hz	53.0 Hz
k_{UF}			5%		
k_{OF}			5%		



Fast Frequency Response, FFR, complements PFR



IEEE 2800-2022

$$p_{FFR1} = \min\left\{p_{avl},\ p_{pre} + \max\left(0,\ \frac{f_{UF,FFR1} - f}{f_{nom} \cdot k_{UF,FFR1}}\right)\right\}$$

$$p_{FFR2} = \begin{cases} 0, & f > f_{UF,FFR2} \\ -k_{UF,FFR2} \cdot \dfrac{df}{dt}, & f \le f_{UF,FFR2} \end{cases}$$

"$-k_{UF}$" is constant gain for underfrequency events in per unit of ICR in Hz/s

$$p_{FFR3} = \begin{cases} 0, & f > f_{UF,FFR3} \\ p_{T3,UF}, & f \le f_{UF,FFR3} \end{cases}$$

$p_{T3,UF}$ is constant active power target for underfrequency events in per unit of ICR

$$p_{FFR4} = \begin{cases} 0, & \dfrac{df}{dt} < dtrig_{UF,FFR4} \\ p_{T4,UF} \cdot \dfrac{df}{dt}, & \dfrac{df}{dt} \ge dtrig_{UF,FFR4} \end{cases}$$

$p_{T4,UF}$ is constant active power target for underfrequency events in per unit of ICR

FFR and PFR start independently and complement each other in power output: $p = \min\ \{p_{avl},\ p_{pre} + p_{PFR} + p_{FFR1} + p_{FFR2} + p_{FFR3} + p_{FFR4}\}$

Conclusions

IBR plants contributing more to overall generation mix on bulk power system

Must meet recent standards operation and ride-through requirements; voltage and frequency

- IEEE 1547-2018, IEEE 2800-2022
- NERC PRC-029-1 and NERC PRC-024-3

Protective relay elements assist IBR plant

Voltage

- Continuous, Mandatory, and Permissive Operation regions—27T, timed undervoltage
- Reactive power control—27Q voltage-controlled reactive power

Frequency

- Primary Frequency Response, PFR, Continuous and Mandatory Operation regions—81O, overfrequency, 81U, underfrequency
- Fast Frequency Response, FFR—81O, overfrequency, 81U, underfrequency, and 81R, rate of change of frequency

GE VERNOVA

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

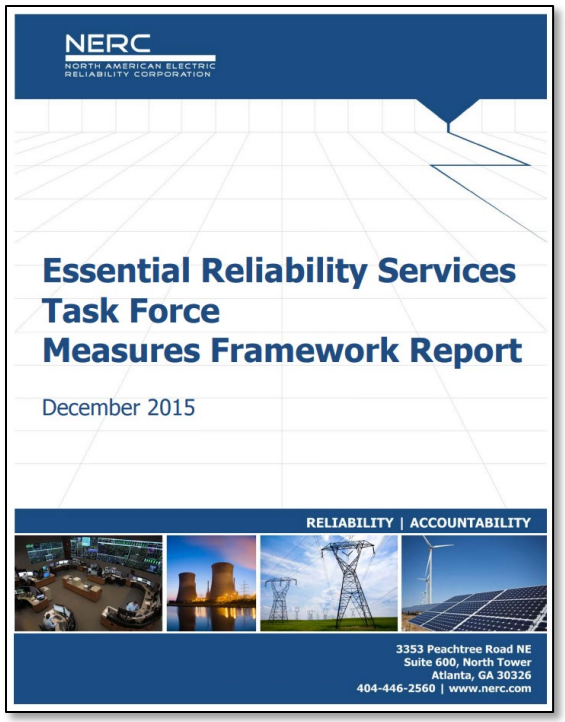
Fast Frequency Response

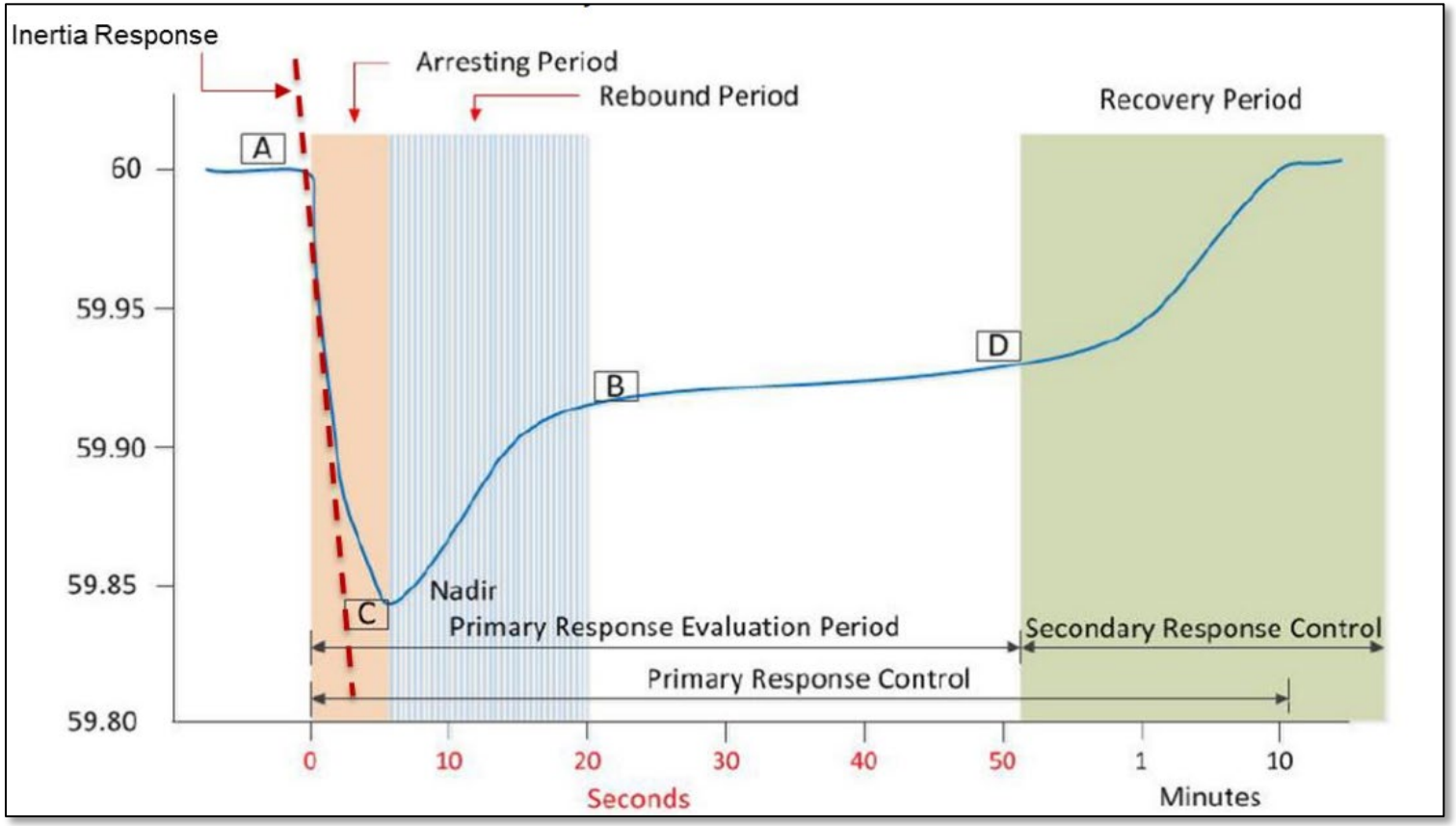
Rate of Change of Frequency and Underfrequency Load Shedding

JP Skeath, Manager of Engineering and Security Integration
RF Technical Talk
August 18th, 2025

Frequency Response Overview

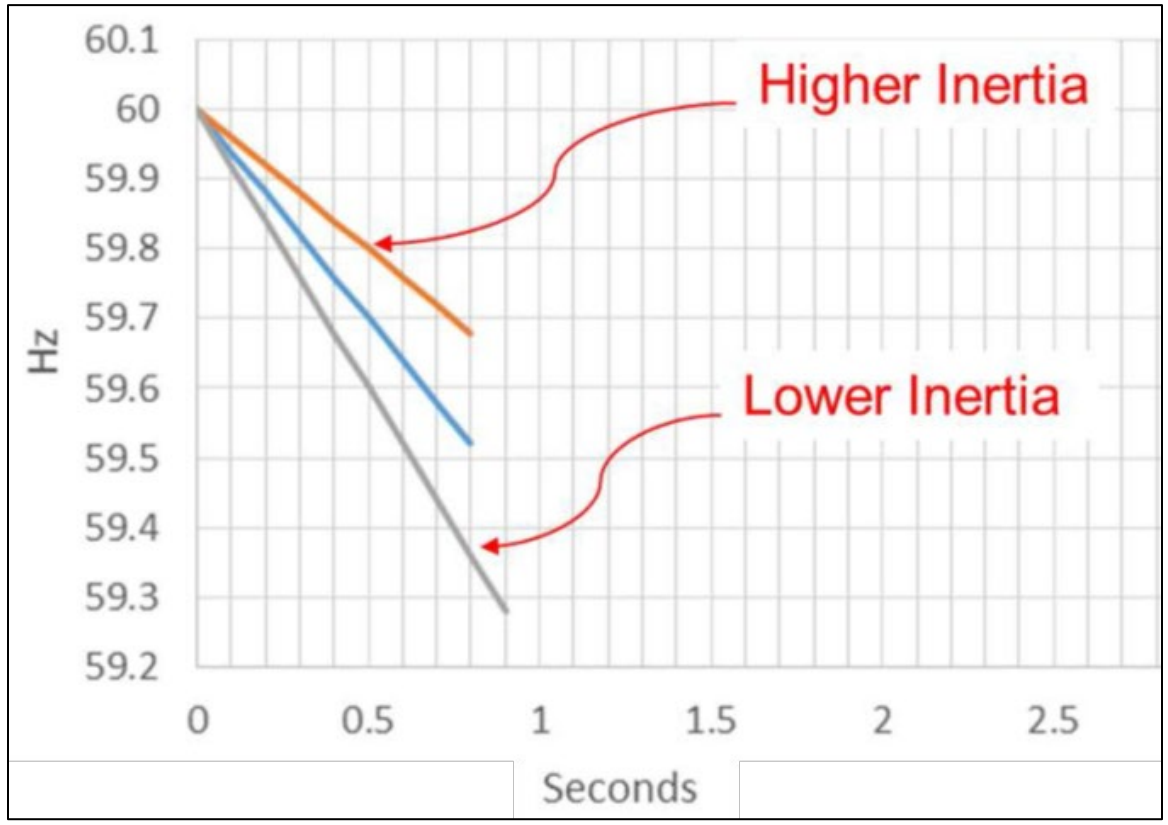
- Essential Reliability Services
  - Voltage Support
  - Net Demand Ramping
  - **Frequency Response**





https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/ERSTF%20Framework%20Report%20-%20Final.pdf

Quantifying ROCOF

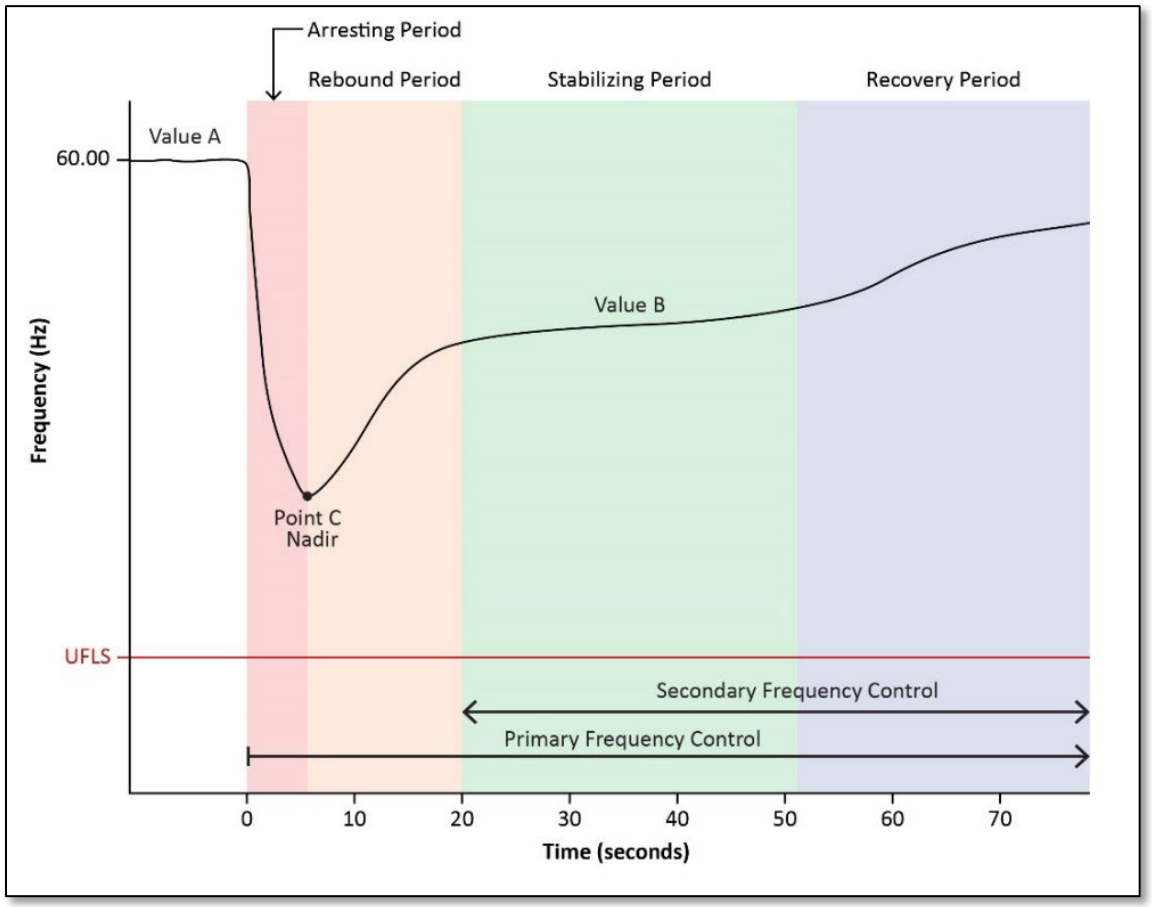


- ROCOF =/= Inertia
  - Similar but distinct
- NERC measures ROCOF post-event
  - Time of Point A
  - Time of Point A + 0.5 seconds

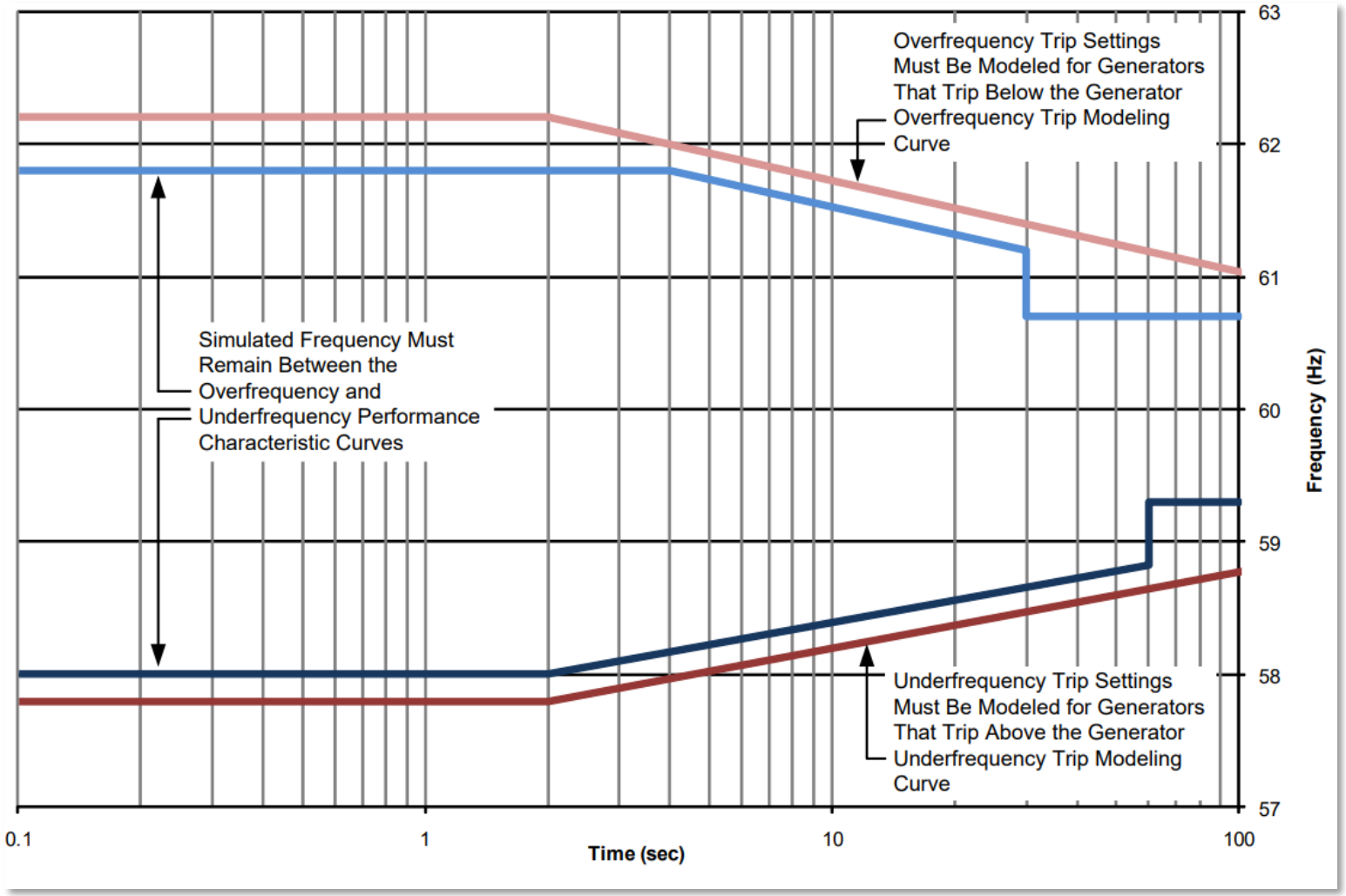
$$ROCOF = \frac{\Delta P_{loss}}{2 * \left(KE_{sys} - KE_{loss}\right)} * 60$$

Frequency Response and UFLS

- Arresting Period
  - Stops the decline
- Rebound Period
  - Initial fast recovery
- Stabilizing Period
  - Off nominal frequency holding steady
- Recovery Period
  - Return to normal operating bands
  - Secondary controls e.g., AGC



Underfrequency Load Shedding (UFLS)



Must Model

Time (s)	Frequency (Hz)
<= 2	57.8
>2	0.575log(t)+57.63

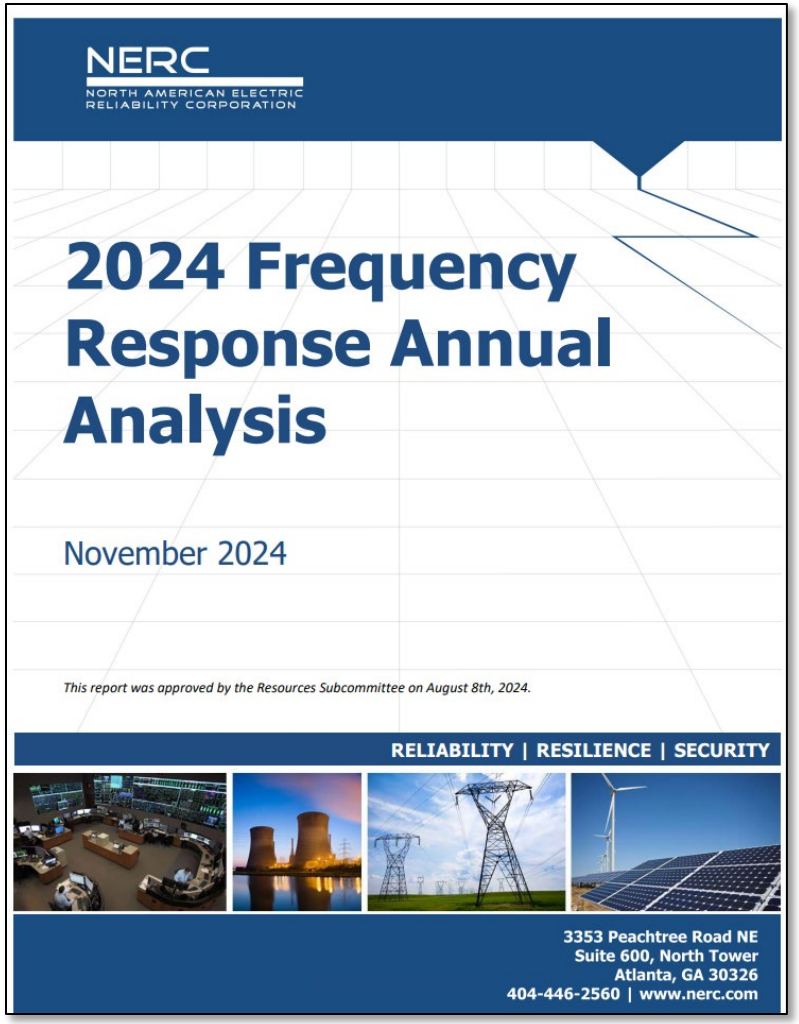
Performance

Time (s)	Frequency (Hz)
<= 2	58.0
> 2 and <=60	0.575log(t)+57.83
> 60	59.3

NERC's Role in Addressing Frequency

5-Year Statistical Trend				
Interconnection	**M-4 Interconnection Frequency Response**	**M4.1 Inertia and Rate-of-Change-of-Frequency**	**Margin-C-UFLS**	**Comment**
Eastern	neither decreasing nor increasing	neither decreasing nor increasing	neither decreasing nor increasing	No M4 events with FR below IFRO
Texas	increasing	increasing	increasing	No M4 events with FR below IFRO
Québec	neither decreasing nor increasing	decreasing	neither decreasing nor increasing	No M4 events with FR below IFRO
Western	neither decreasing nor increasing	neither decreasing nor increasing	neither decreasing nor increasing	Two M4 events with FR below IFRO

https://www.nerc.com/pa/RAPA/ri/Pages/InterconnectionFrequencyResponse.aspx



https://www.nerc.com/comm/OC/Documents/2024_FRAA_Report_Final_Draft.pdf

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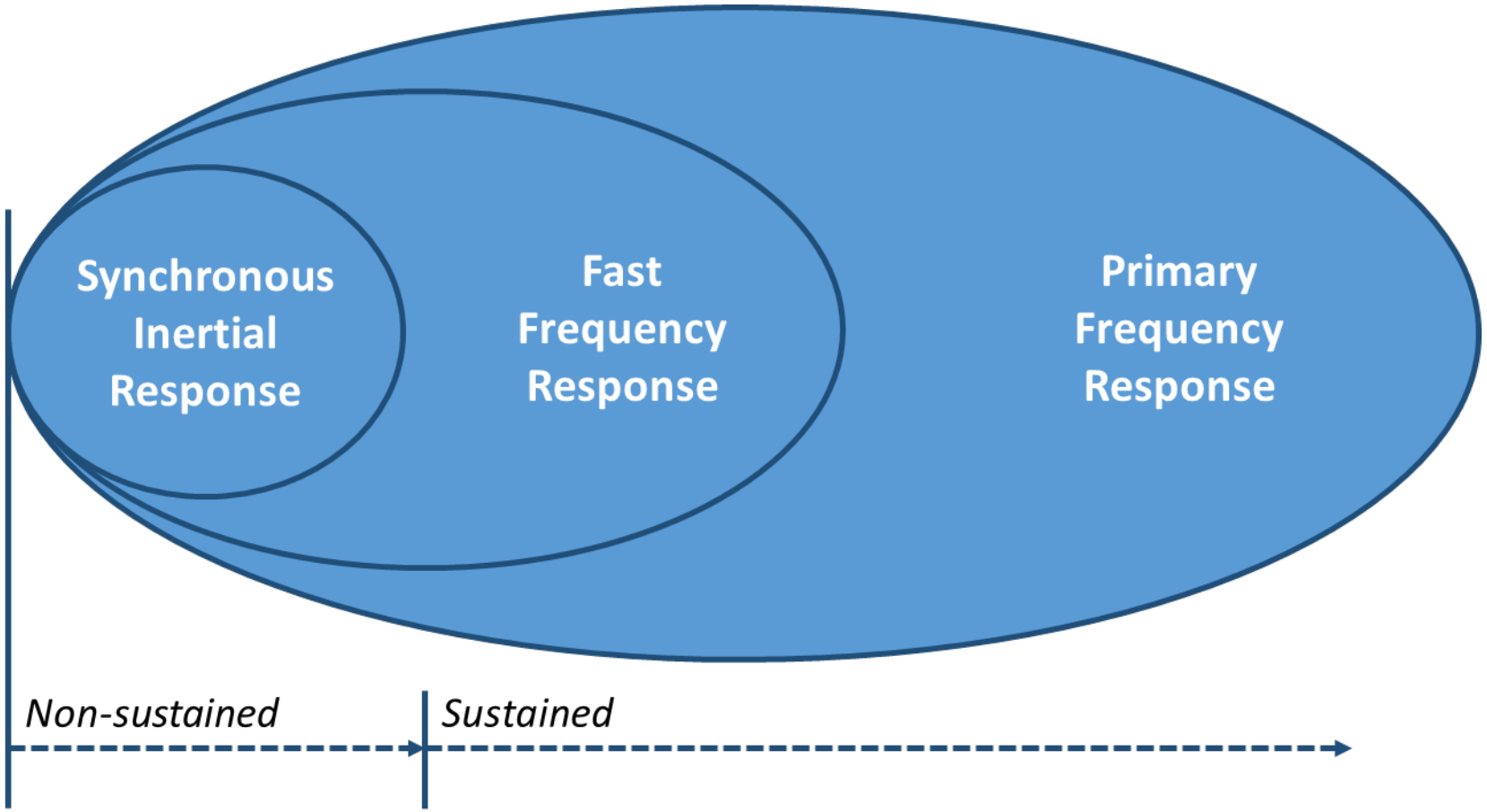
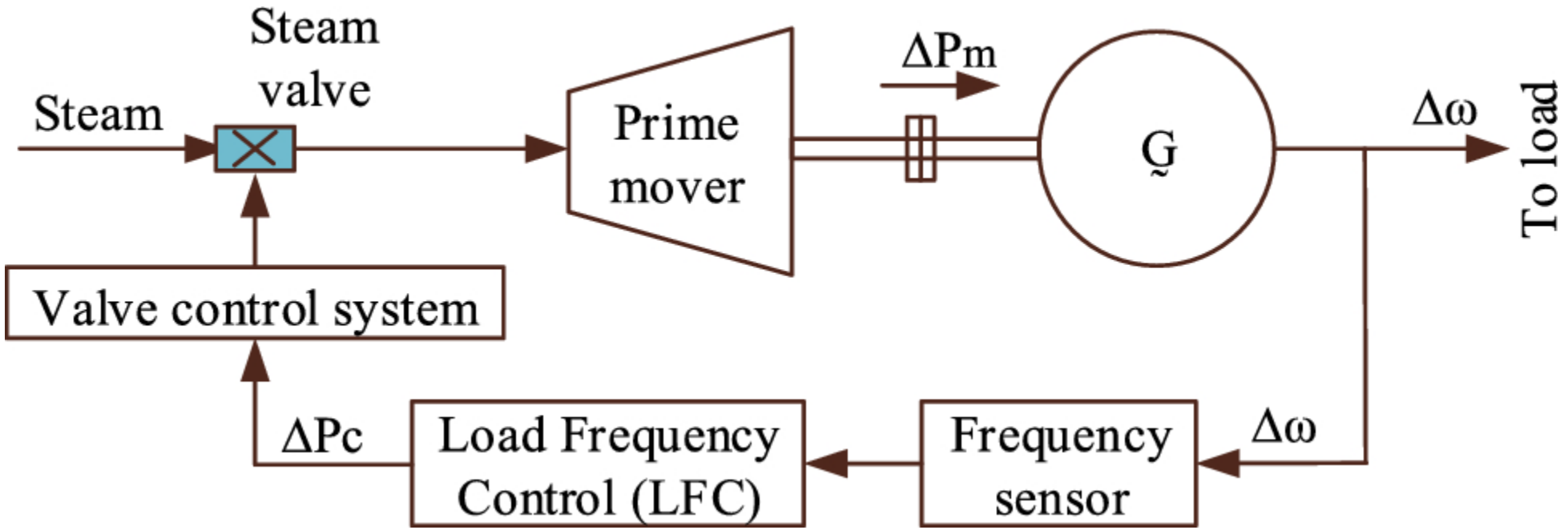
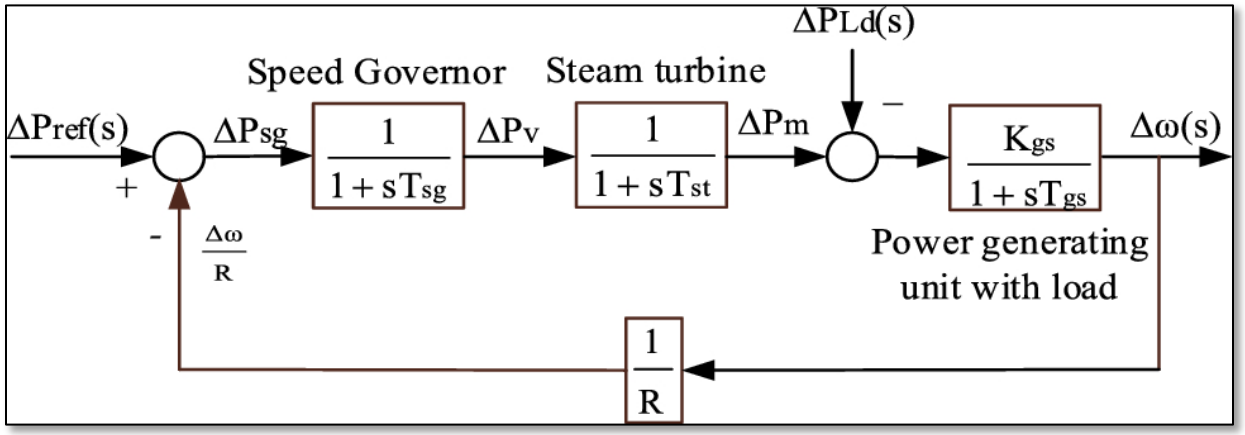
How is FFR Related to Frequency Response?

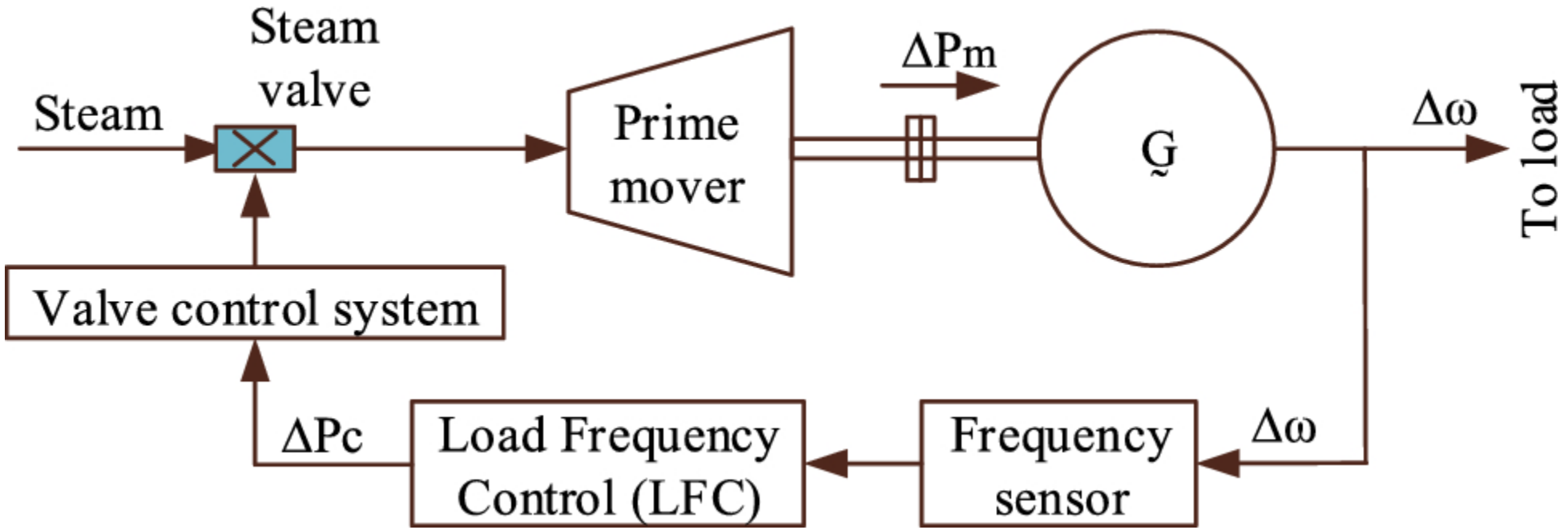


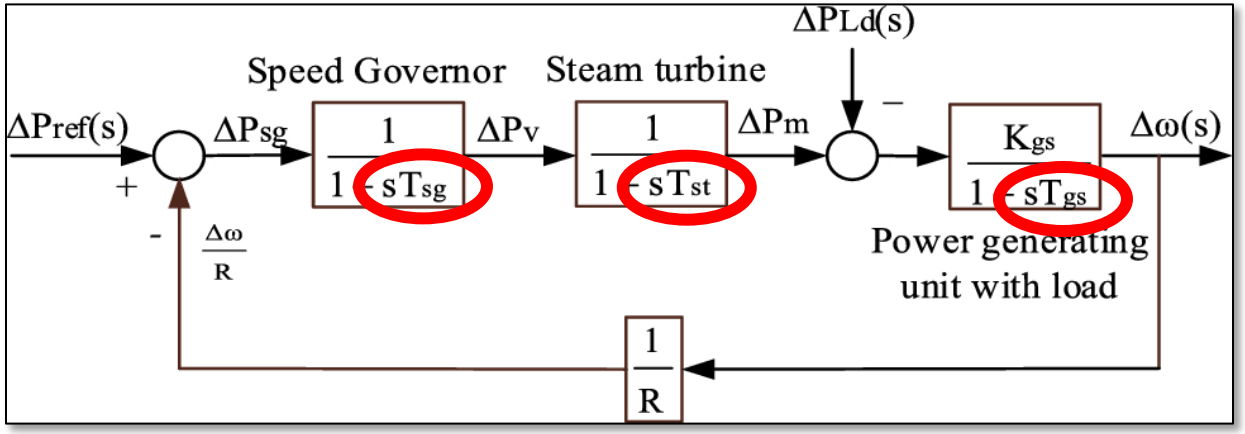




 https://www.nature.com/articles/s41598-024-66007-y

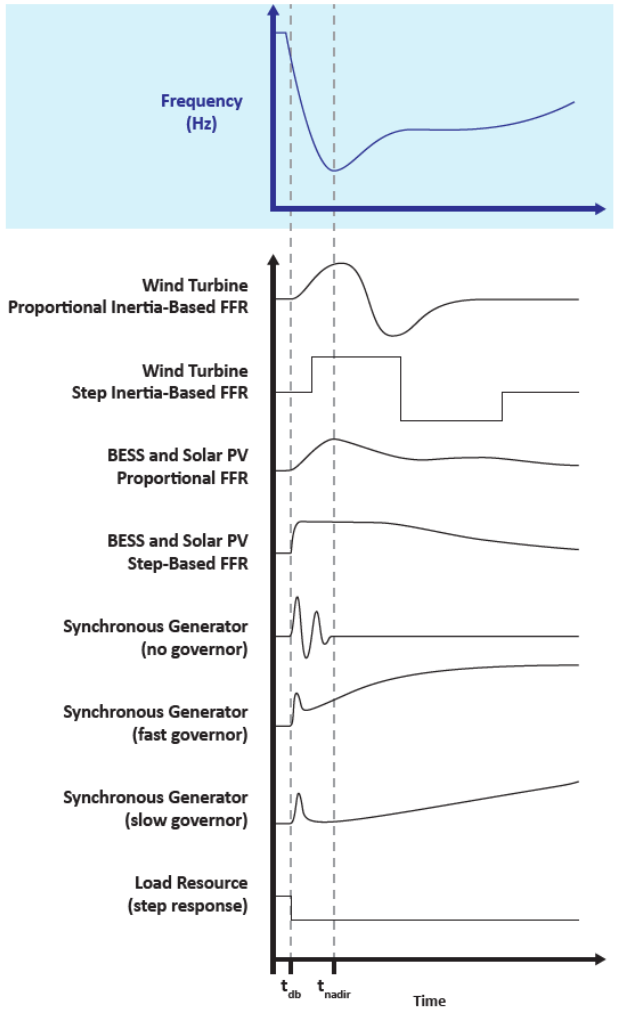
Sustained versus Fast Response

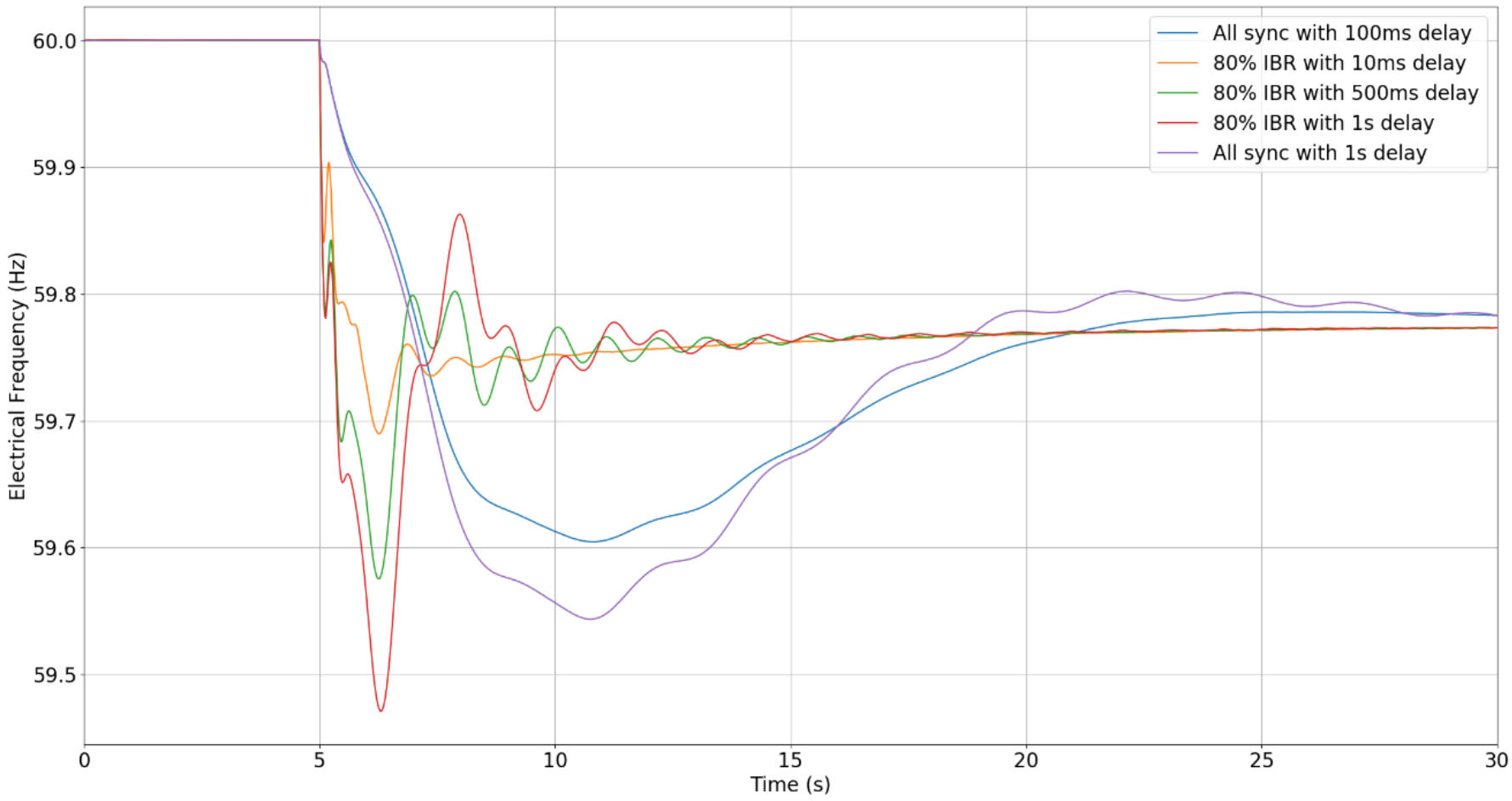




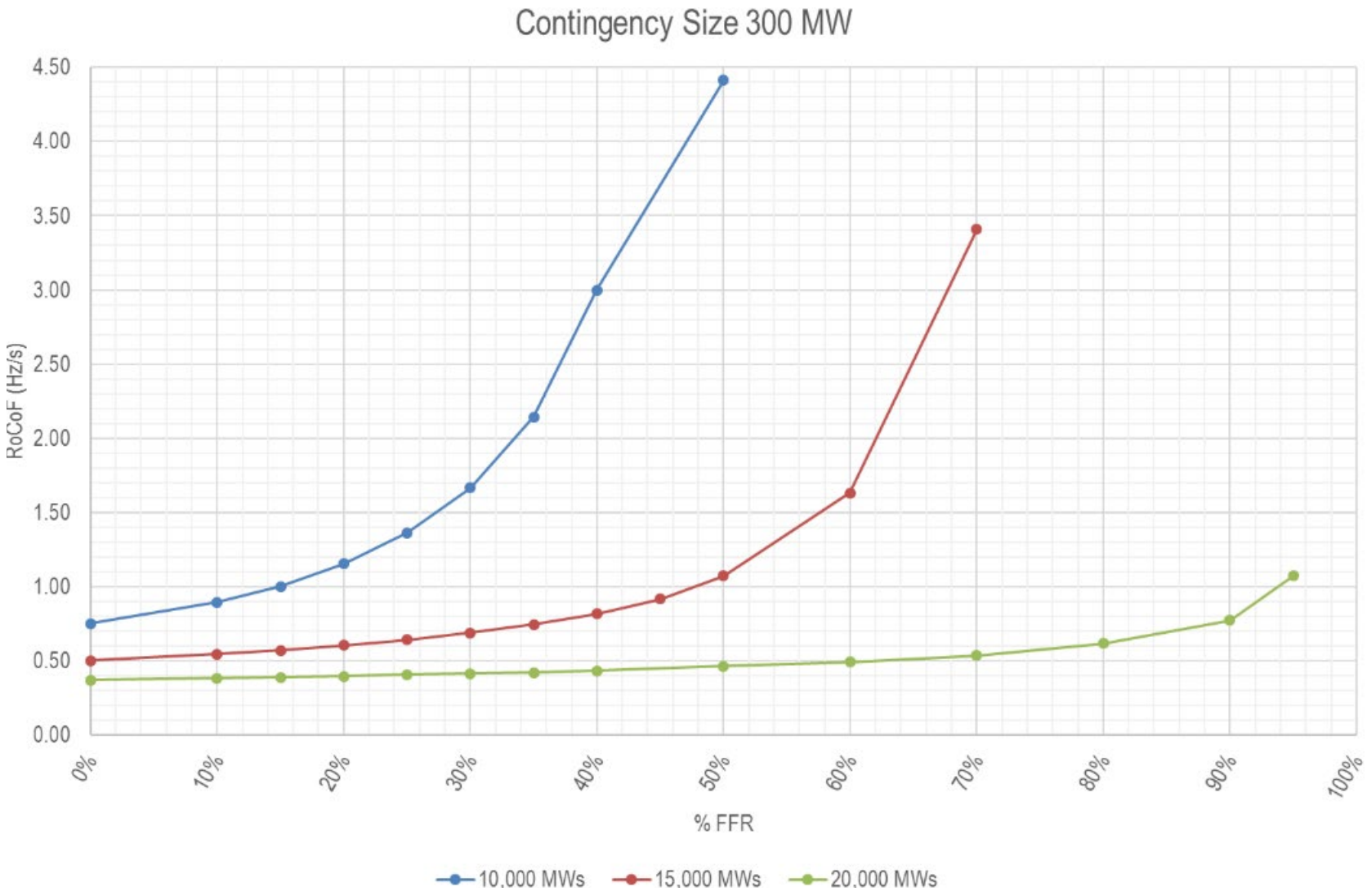
 https://www.nature.com/articles/s41598-024-66007-y

Type of FFR and the Benefit of Enabled FFR





How does FFR Impact the Inertia and ROCOF?



Increased FFR capabilities reduce need for Inertial Response

ROCOF still impacted by lower inertia

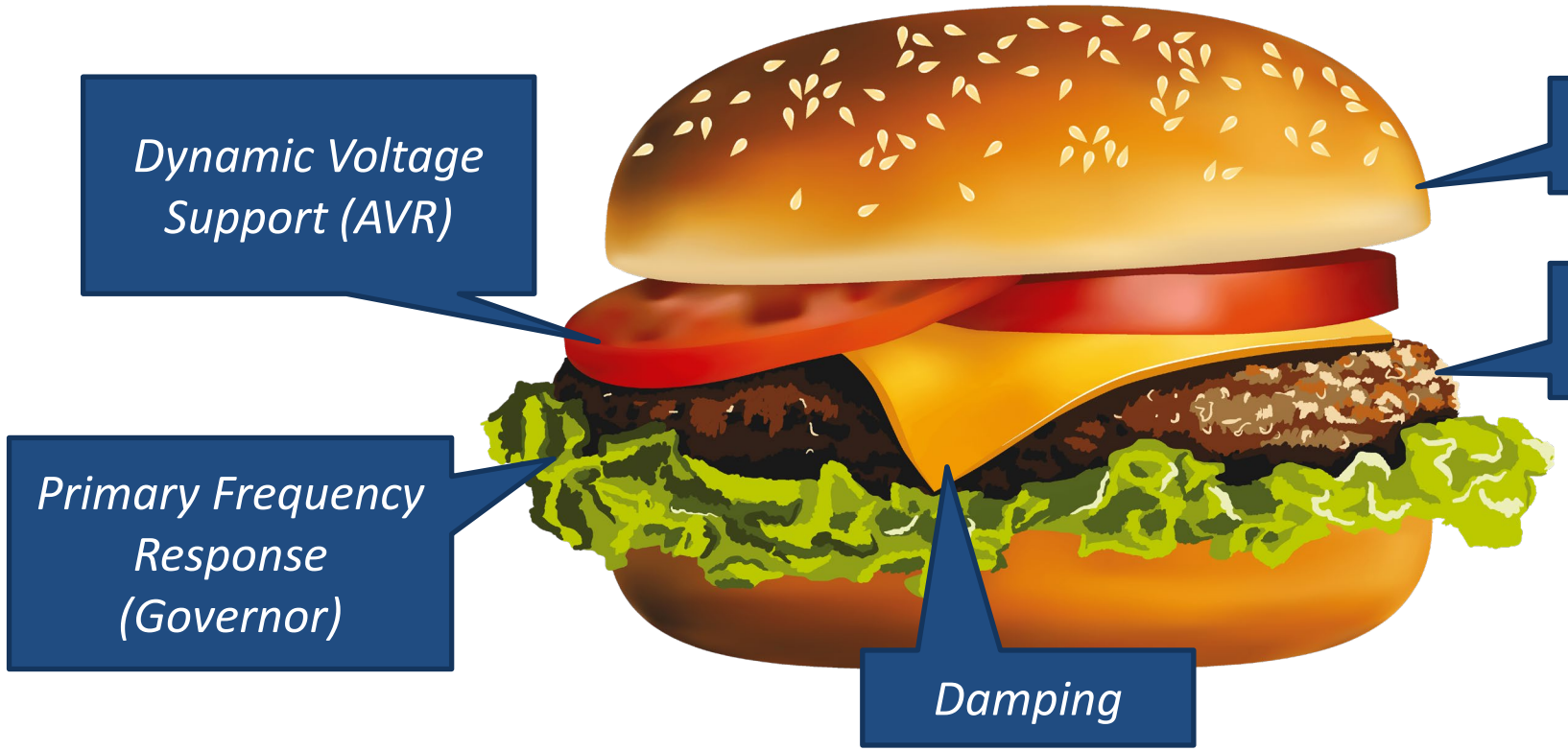
The Impact of the Changing Grid

Reduction of Inertia and Frequency damping reduce FR

FFR Capabilities improve FR

What Synchronous Generator Brings

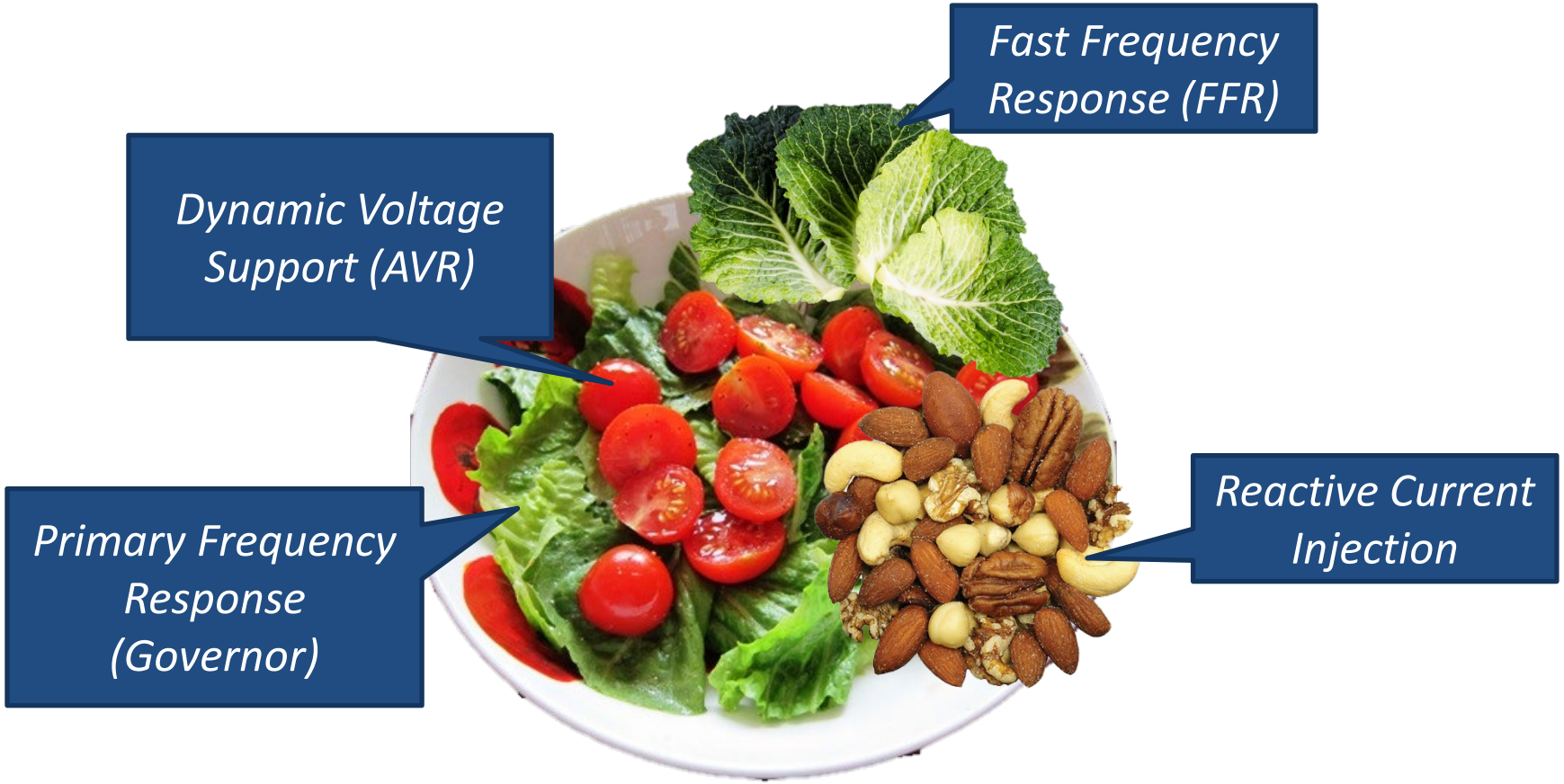
Providing essential services without explicit requirements



Sub-cycle voltage and phase angle response

What Grid Following IBR Brings

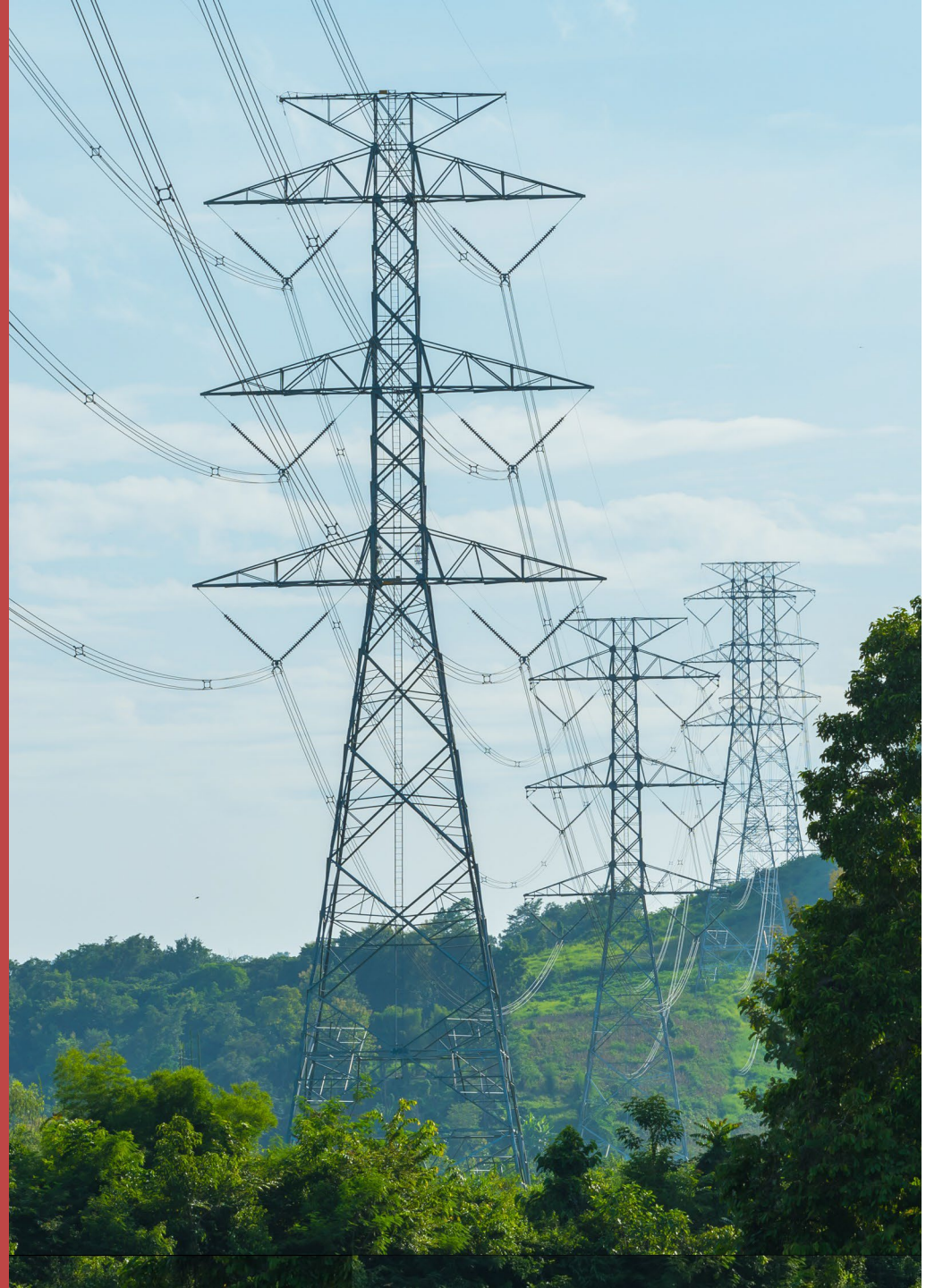
Providing *some* essential services when explicitly required



Key Takeaways

- Fast Frequency Response is an important part of ensuring Frequency excursions do not engage 1st stag of UFLS
  - Normal Operations <25% imbalance
- Increasing penetration of IBR serves as a potential double-edged sword
  - Increases FR through fast injection of power
  - Reduces FR due to a lack of inertia
- Strong Systems with FFR are possible with emerging technologies
  - Grid Forming Inverters
  - Battery Energy Storage Systems (BESS)
- NERC continues to monitor and mitigate threats to frequency stability due to its essential need for interconnected AC systems.

Questions and Answers



THANK YOU

Join us for our next Tech Talk – October 13th 2-3:30 pm EST

Webinar Link

Join the conversation at SLIDO.com

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