GE Energy Consulting

ERCOT RRS-PFR Study
Stakeholder presentation

April 2023
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GE Reservoir Solutions
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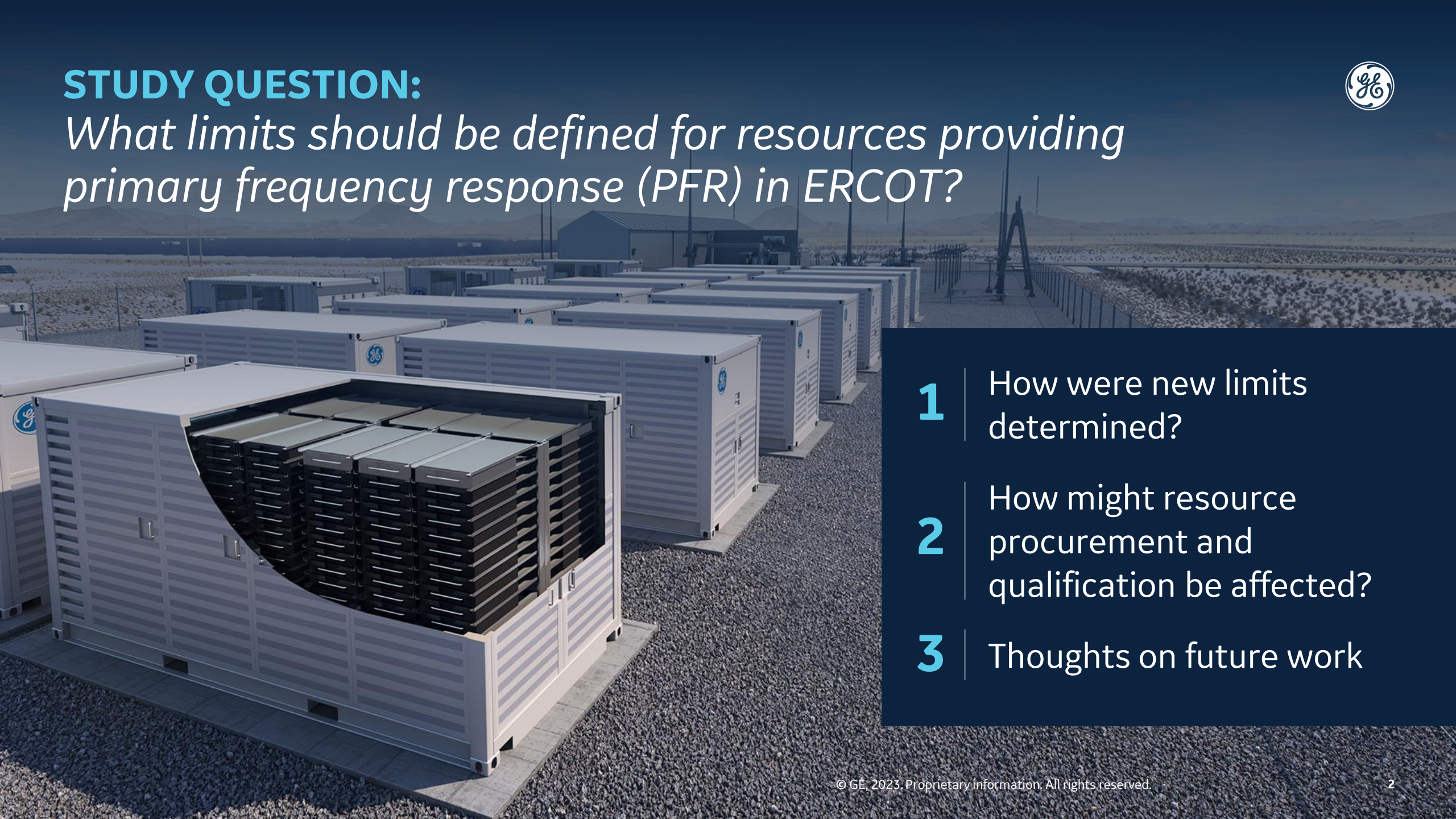
STUDY QUESTION:

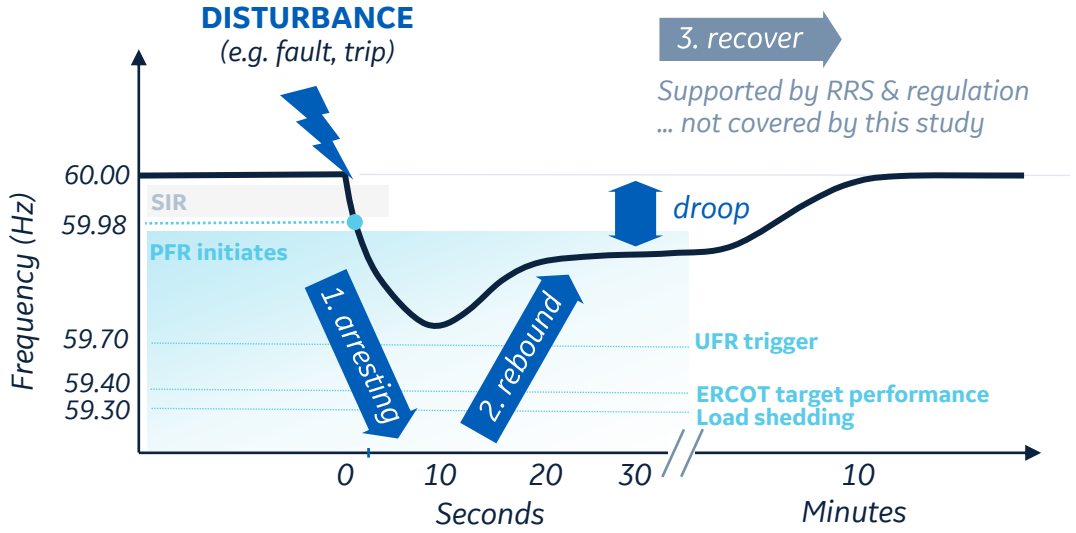
What limits should be defined for resources providing primary frequency response (PFR) in ERCOT?



1. How were new limits determined?
2. How might resource procurement and qualification be affected?
3. Thoughts on future work

Coordination across resources required for stable frequency

Study question: As 1% droop resources displace 5% droop resources, what reliability risks emerge?



ERCOT performance		SMs	BESS	Loads	Wind & PV
Non-market	SIR	X			
	PFR	X			X
	Voltage support	X	X		X
Responsive reserve services (RRS)	FFR (out of scope)		X		X
	PFR	X	X	X	X*
	UFR			X	

Modeled as negative loads: no frequency or voltage support

SIR=synchronous inertial response
SM=Synchronous Machine
BESS=Battery Energy Storage System
* Wind & PV typically don't provide underfrequency response due to zero headroom

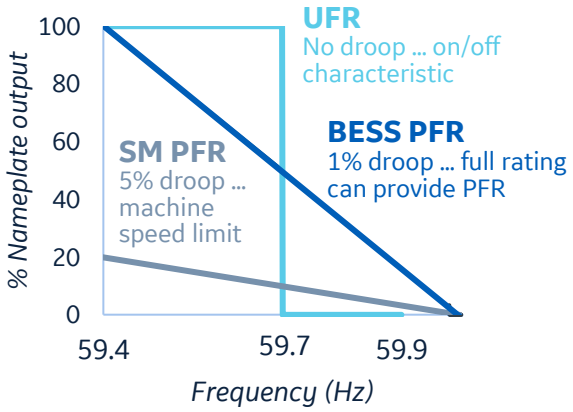
SM INERTIA SETS RATE OF INITIAL FREQUENCY DROP

INERTIA: Focus on worst case of 122 GW-s ... sensitivity at 244 GW-s

FAST FREQ RESPONSE (FFR): Assumed inactive as conservative measure but brief proof-of-concept test performed

PFR + UFR RESOURCES ARREST AND REBOUND FREQUENCY BASED ON SPEED AND DROOP

Study recommendation allows for degree of non-linearity in droop response



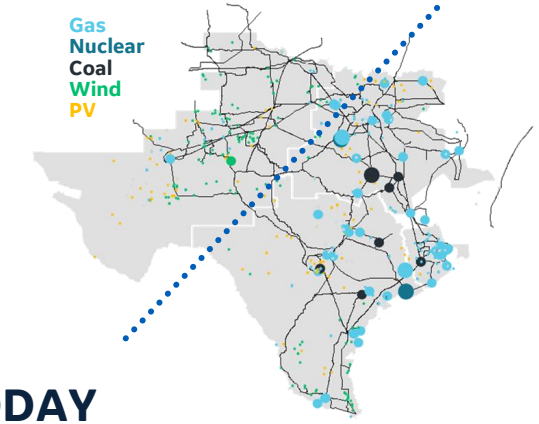
PRIMARY FREQ RESPONSE (PFR)

- PFR_{RRS} req't. = 3695MW @122 GW-s inertia
- PFR_{SM} non-market ~ 891MW (inherent w/commitment)

UNDER FREQ RESPONSE (UFR)

RRS req't. = 2744MW (PFR equiv.) @122 GW-s inertia

Evaluations based on a hypothesis of potential risks

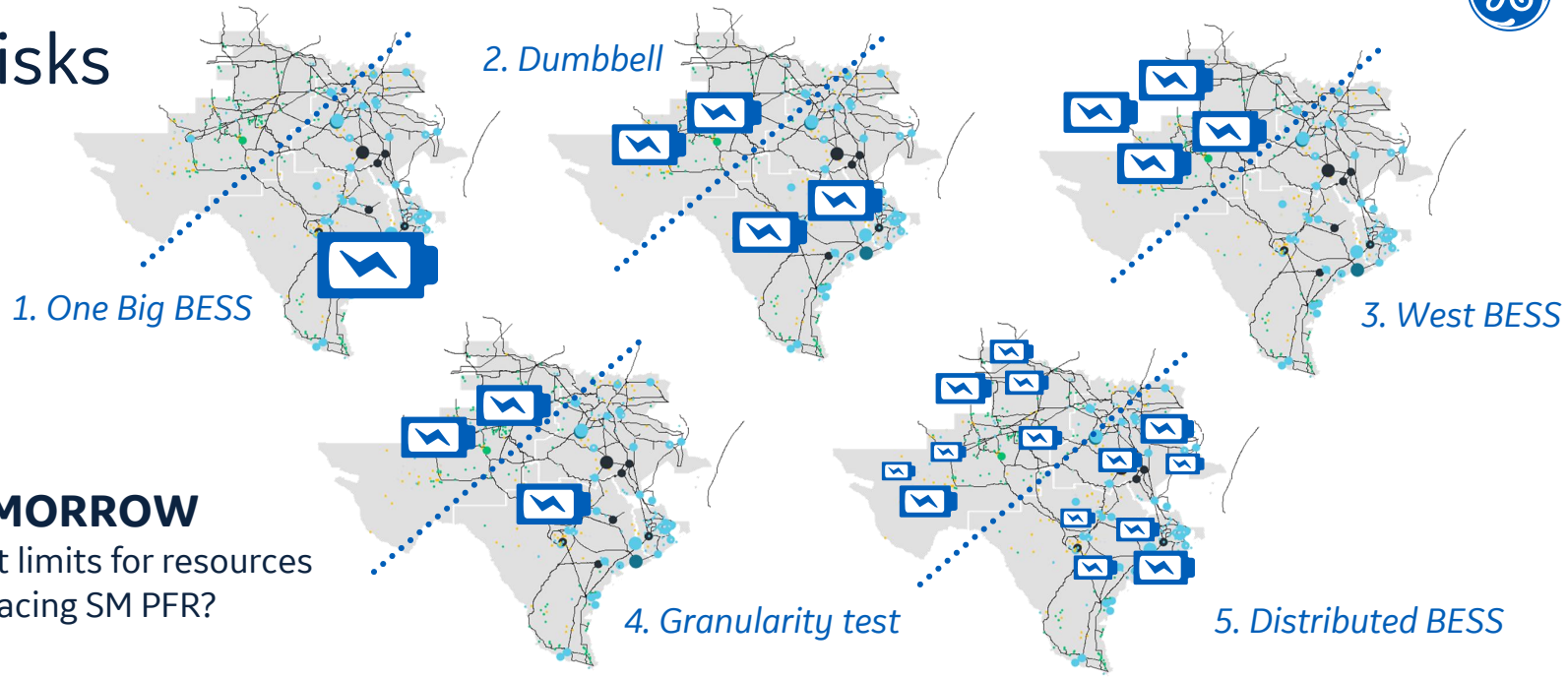


TODAY

PFR from East and South SMs
Grid weakness w/IBRs in west

TOMORROW

What limits for resources displacing SM PFR?



COMPLIANCE RISK

1. **Frequency compliance:** FRO met, nadir>UFLS

RELIABILITY RISKS

2. **Voltage** collapse
3. **Freq stability:** overshoot, backlash
4. **Small signal:** locational or regional
5. **Controls** instabilities/dysfunction
6. **Transient** instability
7. **Common mode** failure

EVALUATIONS: DESIGNED TO TEST RISKS VS PLANNING STUDY

BESS LOCATIONS

1. **One big** BESS
2. **Dumbbell**
3. **West** BESS
4. **Granularity** test
5. **Distributed** BESS (most similar to queue)

X

DISTURBANCES

A. Trip 2xSTP: 2804 MW equiv.
B. Just under UFR trigger
C. Fault & trip **most stressed** line
D. Local fault tests
E. Fault & trip 2xSTP: 2804 MW equiv.

X

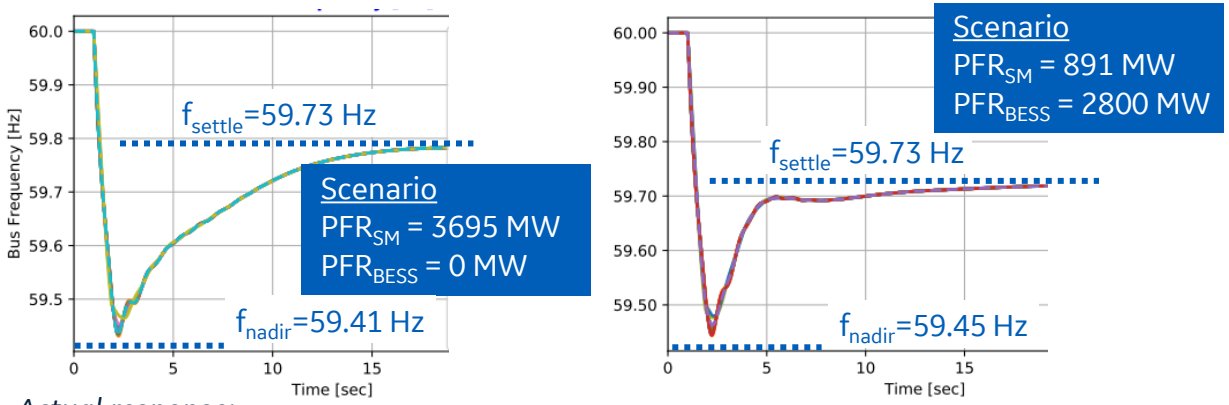
RRS CONFIGURATIONS

a) SM displacement: No BESS PFR -> Full BESS PFR
b) Load response (yes/no)
c) BESS droop = 1%, 0.5% (50% headroom)
d) BESS failure test: Steps of 700MW

Most cases resulted in low risks …

*E.g. One big BESS case, 2*STP trip (UFR triggered)*

ALL SM PFR vs. **ALL BESS PFR**



Actual response:

PFR_{SM}	1519MW	322MW
PFR_{BESS}	0	1181
PFR_{TOTAL}	**1519**	**1503**

Similar response despite droop difference!

RISK ASSESSMENT

Frequency compliance	✓ **Total FR > FRO** ✓ **f_{nadir} >59.4 Hz**
Voltage stability	✓ Stable voltage
Freq stability	✓ f_{settle} > 59.7 Hz ✓ Stable settling
Small signal stability	✓ Damped oscillations
Control stability	✓ No instabilities
Transient stability	✓ No loss of synchronism
Common mode failure	✓ No issue if 10% limit

TOP CONCLUSIONS

1. **Reliance**: ERCOT can fully rely on 1% droop resources for PFR
2. **Equivalency**: 1 MW PFR of 1% resources is equivalent to 1 MW PFR of 5% resources
3. Nadir results were **linear** w/BESS displacement

RELIABILITY DEPENDS ON PERFORMANCE EXPECTATIONS

1. **PFR response:** quick enough to support frequency but not so quick it's unstable
2. **IEEE 2800** compliance: PFR resources tuned towards fast end of compliance to best support frequency recovery
3. Individual resources **qualified** based on rating, location and performance

Informs qualification recommendations

Integration of new PFR resources depends on ensuring reliable performance from each resource

Current processes:
RELIABILITY vs PFR PERFORMANCE RISKS

1) *Interconnection:* **Assesses individual reliability impact** vs PFR performance risks (incl. Model Quality Tests)

2) *Quarterly stability assessment:* **Assesses reliability impact of groups of resources** vs PFR performance risks

Changes may also require re-qualification

Recommendation: **Revisit existing individual resource interconnection & RRS-PFR qualification process to address the following framework**

SIMULATE INDIVIDUAL RESOURCE BEHAVIOR → **ASSESS PERFORMANCE RISK** → **RESOURCES PASS/FAIL**

1. **Valid model** in appropriate tools (TSAT, PSS/e, or PSCAD)
2. **Risk areas** to study:
   a) PFR response
   b) Voltage static/dynamic
   c) Transient stability
   d) Relay behavior
   e) Torsional interaction
   f) Controls interaction
3. Cases designed to **test each risk under max stress**
4. **Operational constraints** must be modeled

✓ **Well-behaved POI impact**: Satisfies constraints, coordinates w/ relays/grid equipment

✓ **Good control response**: quick enough to support frequency but not so quick it's unstable

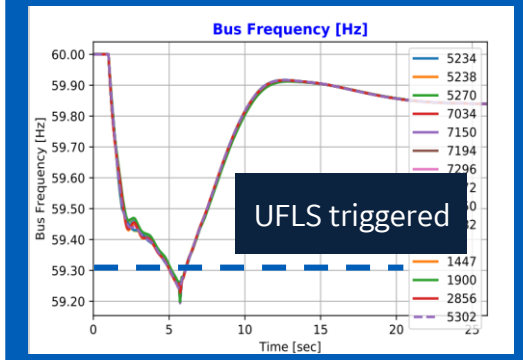
✓ **Well-behaved resource interactions**: no unacceptable torsional stress, oscillations, or dysfunction

✓ **IEEE 2800 compliant:** minimum capability to provide PFR

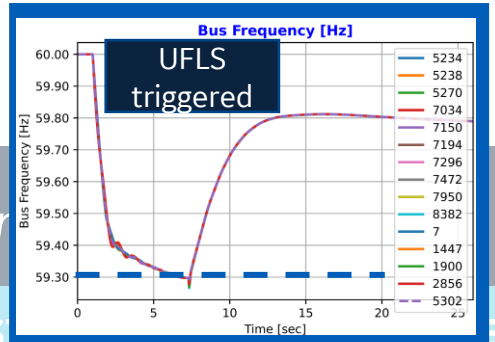
✓ **Passing resources can bid** into market

× **Failing resources can mitigate** risks until qualified:
- Control modifications
- Model improvements
- Communication improvements

Examples of poor frequency response when qualification is not met



Inadequate models resulted in simulated voltage collapse, impeding delivery of PFR



Droop gains lower than expected results in inadequate recovery

Changes may also require re-qualification

Recommendation **qualification process**

SIMULATE HOLIS… PFR PERFORMAN…

1. **Valid model** in appropriat… tools (TSAT, PSS/e, or PSC…
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…ESS …NCE RISK

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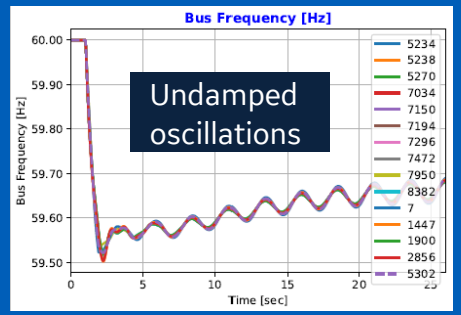
- ✓ **Good control response**: quick enough to support frequency but not so quick it's unstable
- ✓ **Well-behaved resource interactions**: no unacceptable torsional stress, oscillations, or dysfunction
- ✓ **IEEE 2800 compliant:** minimum capability to provide PFR

RESOURCES PASS/FAIL



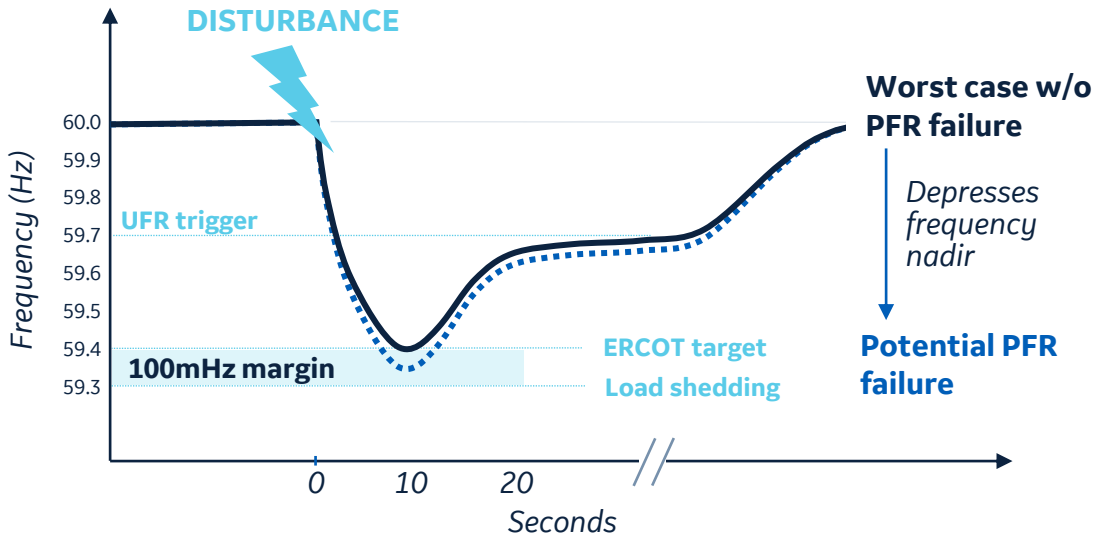
Undamped oscillations post-nadir when BESS tuned to be faster than IEEE 2800 reqt.

2) *Quarterly stability assessment:* **Assesses reliability impact of groups of resources** vs PFR performance risks

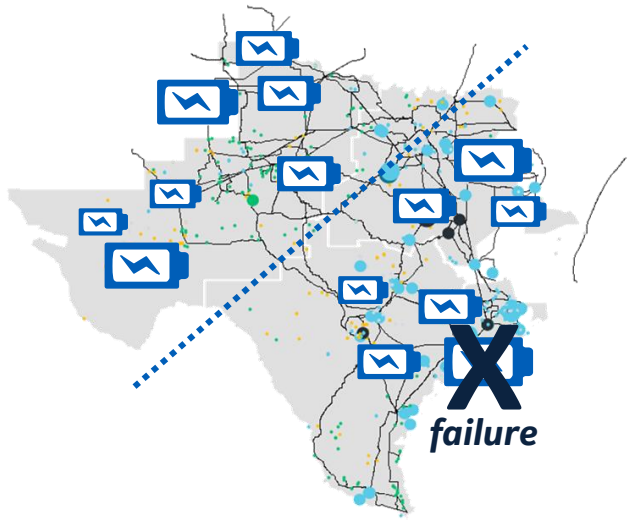
Common mode risk: Is there risk associated with too much PFR from one unit?

100mHz margin between ERCOT criteria and UFLS

… failure of one PFR resource may use margin



Initial recommendation: Individual unit PFR not to exceed 10% of total PFR requirement



Total PFR req't = 6425MW @122 GW-s (incl LR equiv)

10% rule => Largest single PFR unit = 643MW @122GW-s

Today, largest single SM PFR resource = 220MW (2-3 unit CCGT rated at ~1100 MVA)

Under PFR failure, what is acceptable margin usage?

- No established industry/NERC practice regarding PFR failures and meeting reliability criteria
- Exercising caution w/new resources
- Objective of simulations to determine a rule that
  - ✓ Retains reasonable margin
  - ✓ Is simple and implementable

MW limitation will decline with higher system inertia

- 10% rule => ~35mHz margin usage @122 GW-s inertia
- Allows ERCOT to satisfy reliability criteria and move forward qualifying resources
- Further study may be required to fine-tune the requirement

How should PFR procurement evolve?

PLANT-LEVEL RECOMMENDATIONS

1) **All PFR resources need to be qualified** to be considered for procurement independent of droop or resource type … Considers location and physical distribution of PFR resources
2) **Effective Droop determines PFR capability** Total MW offered
3) **Energy capability**: Resources must have the energy necessary to provide PFR MW offered for the duration specified by the ERCOT standard

SYSTEM-LEVEL RECOMMENDATIONS

1) **10% rule needs to be integrated** into procurement based on forecasted grid conditions
2) Continue present practices for **quantifying total PFR procurement** based on inertia, FFR, and LFR
3) **Procured PFR resources must deliver** required PFR

Opportunity to optimize PFR scheduling?

RRS procured w/1 hr. scheduling interval. ***e.g.* 100MW BESS**

- 100MWH procured, 1 hr.
- <8.5MWH delivered, ~30s

Over-procurement? RRS delivery significantly less than required for scheduling interval

Operational considerations

1

Dispatch: Resources must be dispatched so that it is possible for the resource to deliver the full PFR MW offered.

2

State of charge needs to be managed so that the resource can provide the full procured PFR.

3

Energy delivery: PFR resources must be operated to provide PFR MW procured for the duration specified by the ERCOT standard.

Future work: Are there remaining risks w.r.t. BESS interactions?

ADDITIONAL BESS COORDINATION RISKS?

Is response well-behaved with respect to other IBRs & frequency response services?

DYSFUNTION

ARRESTING

RECOVERY

1. **Do wind and solar help/hurt stability w/BESS?**
   Does including wind & solar in models help: support voltage? Stabilize small & large signal behavior? Create negative interactions?

2. **Do FFR and inertia coordinate well w/BESS PFR?**
   - Does adding grid forming BESS into the system alter FFR performance requirements?
   - Does FFR cause misbehavior: proper tuning, interactions w/IBRs/SMS, proper hand-off w/PFR?

3. **Do regulation and redispatch coordinate well w/BESS PFR?**
   - Does adding grid forming BESS into the system alter recovery performance requirements? E.g. coordinate w/ECRS
   - Room to optimize procurement across RRS & ECRS products?

Conclusions

1. **Reliance**: ERCOT can fully rely on 1% droop resources for PFR

Relies on:

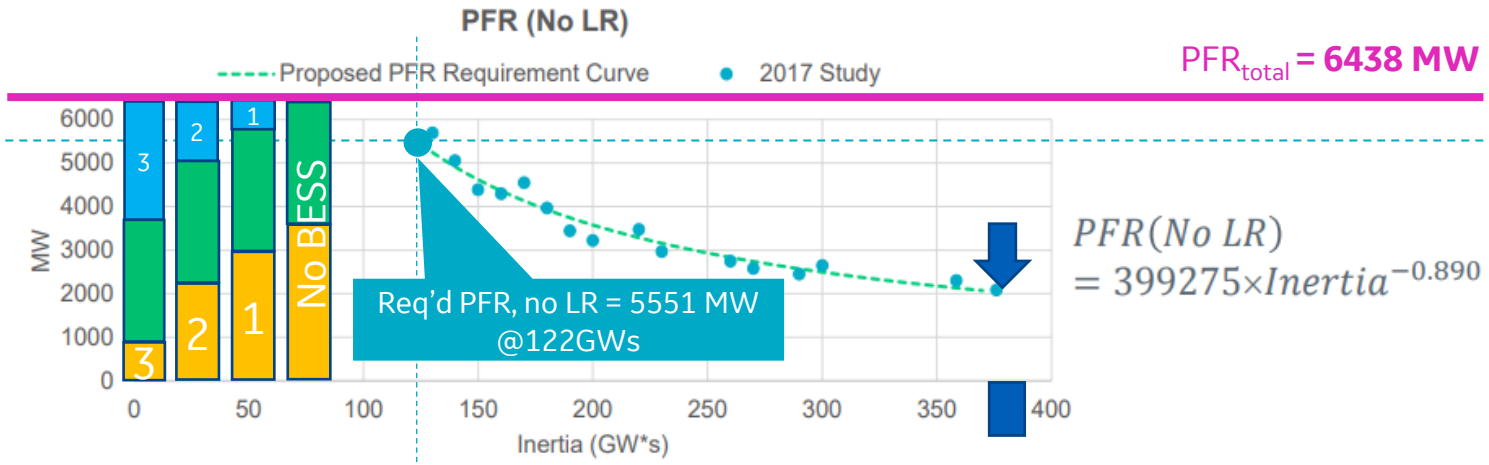
2. **All PFR resources to be qualified** to be considered for procurement independent of droop or resource type

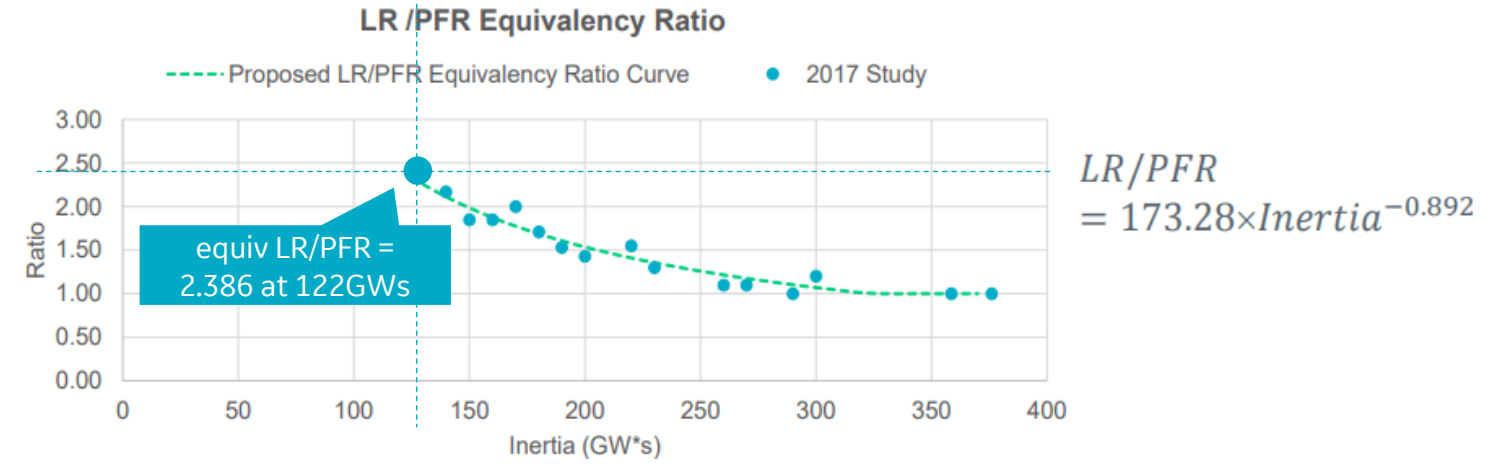
3. **Individual unit PFR not to exceed 10%** total PFR requirement

How much PFR_{BESS} reliably displaces PFR_{SM} + LR?

*Displacement cases in context of RRS req'ts (w/122 GW*s inertia)*

RRS Requirements and Equivalency Ratio





- Before summer 2015, ERCOT used to procure 2,800 MW of RRS for every hour of the year.
- Criteria: At each inertia level, RRS amount should be sufficient to avoid UFLS after 2,750 MW generation trip.

NO BESS (BASE CASE)

1150MW LR => **LR equiv PFR = 2744 MW**
+ 3695 MW PFR_{SM}
= **total of 6438 MW** equiv. PFR.

The base case is a good representation of ERCOT practice and **well suited as a starting point** for our investigation

ALL DISPLACEMENT SCENARIOS

PFR_{BESS} displaces PFR_{SM} 1:1 by turning off governors in our model

	LR equiv +	BESS rating +	Available PFR_{SM} =	Available PFR_{total}
0	2744 MW	0 MW	3695 MW	6438 MW
1	2744	700	2995	6438
2	2744	1400	2295	6438
3	2744	2800	891	6435

Govs turned off

GE Energy Consulting

Power system experts for >100 years

~120 grid experts
9 countries
>100 patents

1 INTEGRATED STUDIES

Economic analysis | grid value of technology

Network strategy | complex grid interconnection

Equipment integration | voltage and frequency performance

- System planning and strategy
- Financial modeling and forecasting

- Stability studies
- Network risk assessment
- Grid upgrades

- Interconnection support
- Grid code testing and compliance

2 MODELS

Planning years ⟷ **Transients** microseconds

3 SOFTWARE

Capacity GE MARS*

Energy GE MAPS*

Power flow GE PSLF*

GE technology | 1/3 earth's power | #1 clean energy fleet