CURRENT OVERUSE OF "NON-MARKET" PRIMARY FREQUENCY RESPONSE UNNECESSARY FOR FAIL-SAFE RELIABILITY AND UNDERMINES EFFICIENCY OF ERCOT COMPETITIVE MARKETS

MARCH 2018

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IMPROVE ERCOT MARKET EFFICIENCY WHILE MAINTAINING NON-MARKET PRIMARY FREQUENCY RESPONSE FOR FAIL-SAFE RELIABILITY

- BAL-001-TRE-1 mandated three key changes to Primary Frequency Response (PFR).[1]

    1. The frequency deadband for PFR governor activation was tightened from +/- 0.036 Hz to +/- 0.017 Hz in order to initiate deployment more frequently.

    2. Governor response was changed to a linear, proportional approach from a step function change in order to mitigate "frequency bounce", i.e., an over-correction of a frequency deviation.[2]

    3. All online generators and Controllable Load Resources with "head room" must provide PFR in order to expand PFR capacity.[3]

- These PFR changes dramatically increased the frequency of PFR deployments and enlarged the overall scale of PFR capability.

- Significantly, adoption of BAL-001-TRE-1 created a situation under which an important reliability service was mandated without merit-based commitment, without merit-based deployment, and without compensation – leading to demonstrable market inefficiencies.

- Given the significant support for mandating across-the-board generator frequency response at the FERC/NERC level (notwithstanding negative market impacts), Apex has investigated potential adjustments to the mandate, with the objective of reducing the magnitude of market distortion while maintaining compliance with all applicable reliability standards.

- A wider frequency deadband for resources NOT participating in the ERCOT Ancillary Service markets would optimize the role of non-market PFR by a) limiting unnecessary deployments during small frequency deviations, b) maintaining a practical, fail-safe service with deployments when large frequency deviations occur, and c) reducing the adverse market impacts from the large role that non-market PFR plays today.

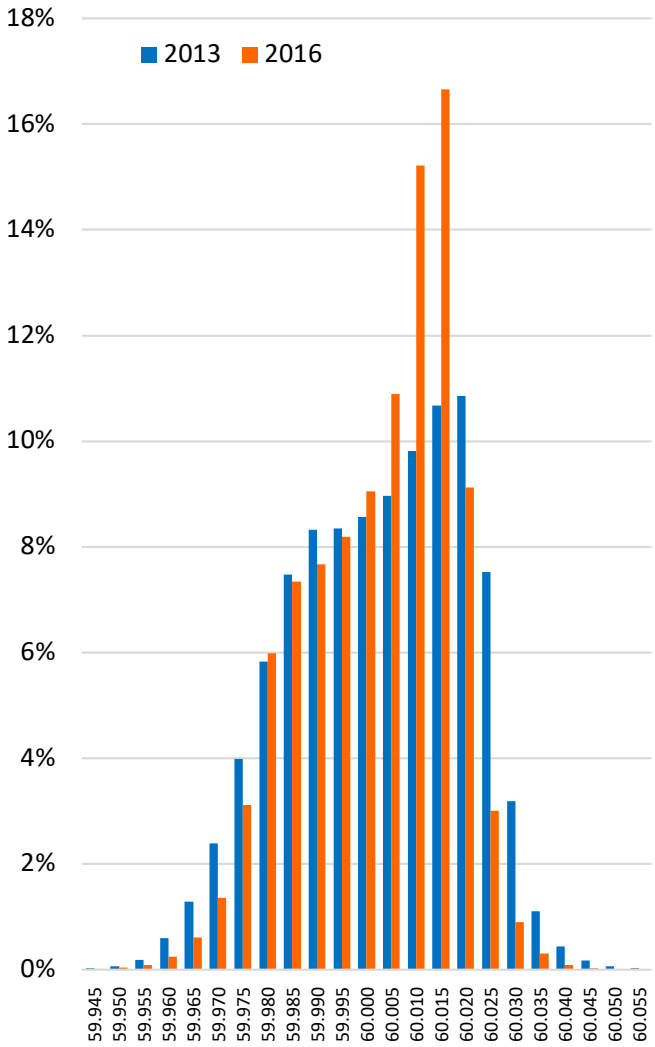
[1] In 2013, TRE requested approval from FERC to implement Regional Standard BAL-001-TRE-1 to improve frequency management in ERCOT, particularly in light of the growing wind supply. BAL-001-TRE-1 was approved by FERC in January 2014 with implementation to occur over the next several months.

[2] See appendix for further description of linear and step deployment approaches.

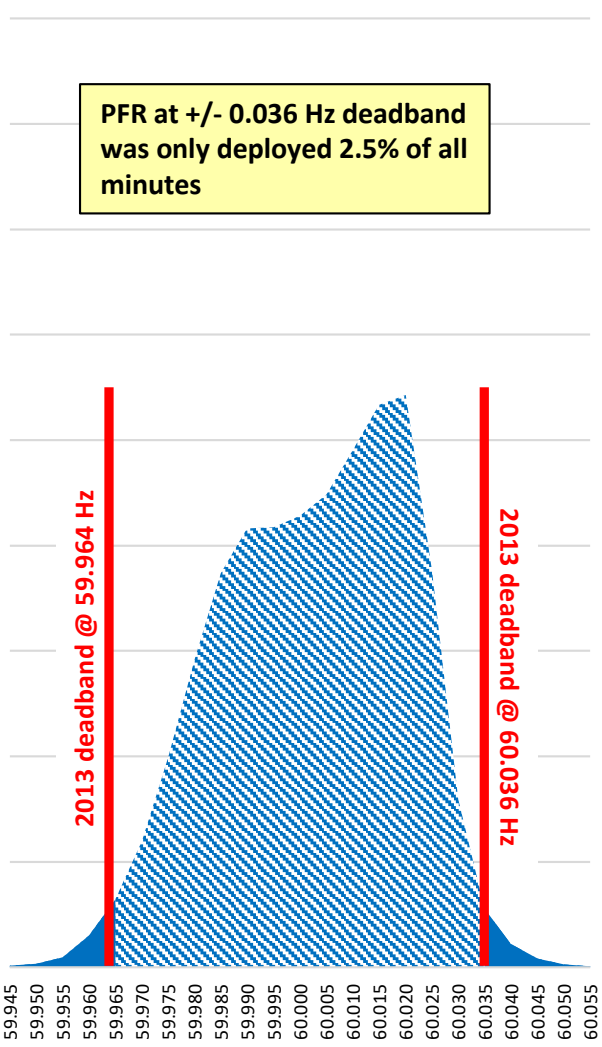
[3] Nuclear units, some older wind units, and units with mechanical governors are exempted from the PFR mandate. Headroom is available for PFR "up" deployment when a resource output level is below its High Sustained Limit, and PFR "down" deployment headroom is available when a resource output level is above its Low Sustained Limit.

ADOPTION OF TIGHTER FREQUENCY DEADBANDS RESULTS IN 10X GREATER PFR DEPLOYMENT – FROM 1-IN-40 TO 1-IN-4 MINUTES

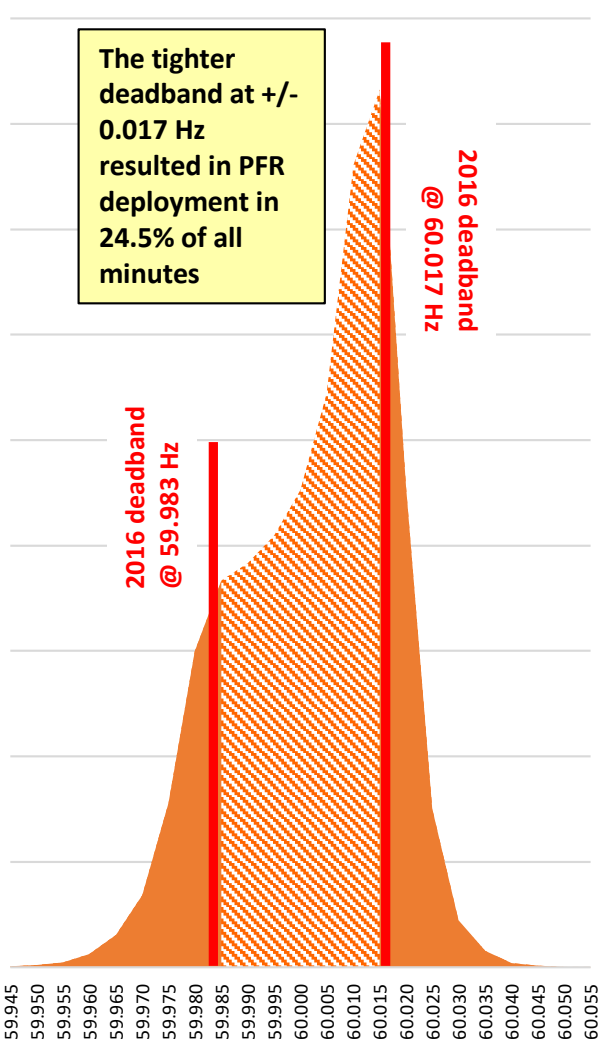
Distribution of 1-minute system frequency 2013 vs. 2016



Distribution of 2013 1-minute system frequency



Distribution of 2016 1-minute system frequency



Bin size = 0.005 Hz

Source: TRE 1-minute frequency data, 2013 & 2016

AVERAGE AVAILABILITY OF NON-MARKET PFR IS ~5X LARGER THAN PFR ACQUIRED THROUGH RRS PRODUCT

2016 average capacity available for market-based and non-market PFR, GW

Market-based PFR from RRS-Gen*

- Generators providing Responsive Reserve Service (RRS) must reserve unloaded capacity for under-frequency governor response "up" to reserved RRS volume
- RRS-Gen supplier not required to maintain output level greater than LSL to enable over-frequency governor response

Non-market PFR (average of up and down capacity)**

- Under-frequency response required by all online generators for unloaded capacity up to HSL at mandated droop setting
- Over-frequency response required by all online generators for loaded capacity greater than LSL
- Nuclear units not subject to requirement
- Generators are subject to penalties for non-compliance with mandated droop setting

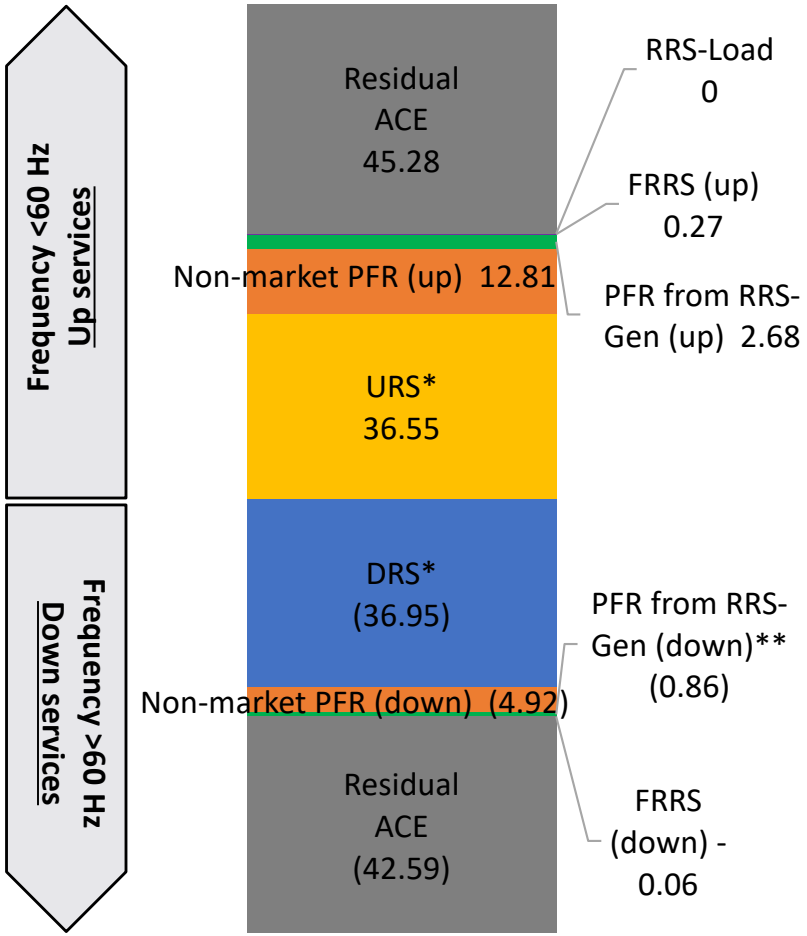
* Capacity available for market-based PFR based on 2016 RRS procurement volumes

** Capacity available for non-market PFR "up" deployment for under-frequency events is based on online natural gas, coal, and other capacity with deployment limited to "Total System-wide Capacity (excl. AS)"; capacity available for non-market PFR "down" deployment for over-frequency events is based on online natural gas, coal, wind, solar, and other production with deployment limited by LSL

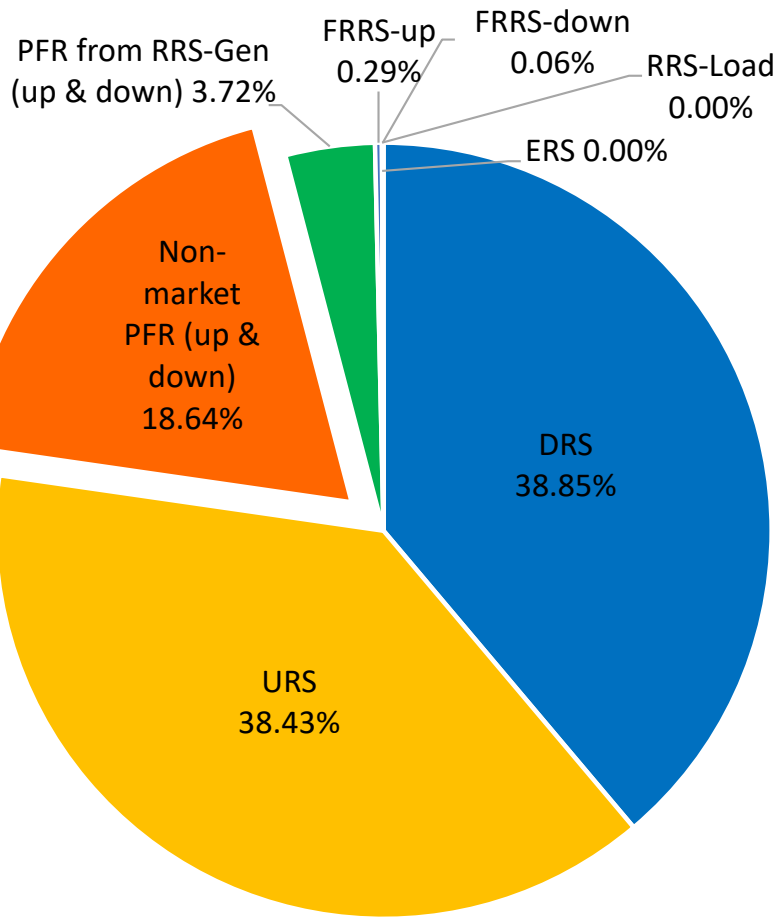
Source: 2016 monthly procurement volumes for RRS-Gen as reported by ERCOT; Apex analysis of 2016 average up and down capacity for non-market PFR deployment

NON-MARKET PFR DEPLOYMENTS PLAY A LARGE ROLE IN ERCOT FREQUENCY CONTROL

2016 net frequency correction, MW/minute



2016 net average 1-minute frequency correction
100% = 95.11 MW



* Net frequency error correction refers to the MW correction of frequency error only when the service is deployed in the direction of need (i.e. <60 Hz for Up-services and >60 Hz for Down-services) – this metric is used because regulation must un-deploy, and sometimes does so in a fashion that exacerbates AREA CONTROL ERROR (ACE)

** RRS-Gen down capacity always assumed available

COMPETITIVE MARKET INEFFICIENCIES CAUSED BY OVERUSE OF NON-MARKET PFR

	Issue	Example
Short-term market inefficiency	• Significant reliability services procured, committed, and deployed indiscriminately across all resources • No merit order for non-market PFR that reflects expected marginal costs • Unit with highest marginal cost (lowest opportunity cost) is natural resource to curtail first	• Wind/solar/CCGT curtailment for frequently occurring, over-frequency events is non-economic, increasing the cost of energy to retailers/customers

Long-term market inefficiency	• Non-market PFR interferes with the provision of an appropriate market signal for new investment in flexibility/ramping capability
	  • Lack of compensation
	  • Compliance risks and costs
		• Non-market PFR can displace Ancillary Service market procurement, reducing market revenue opportunity for supplying flexibility/ramping services

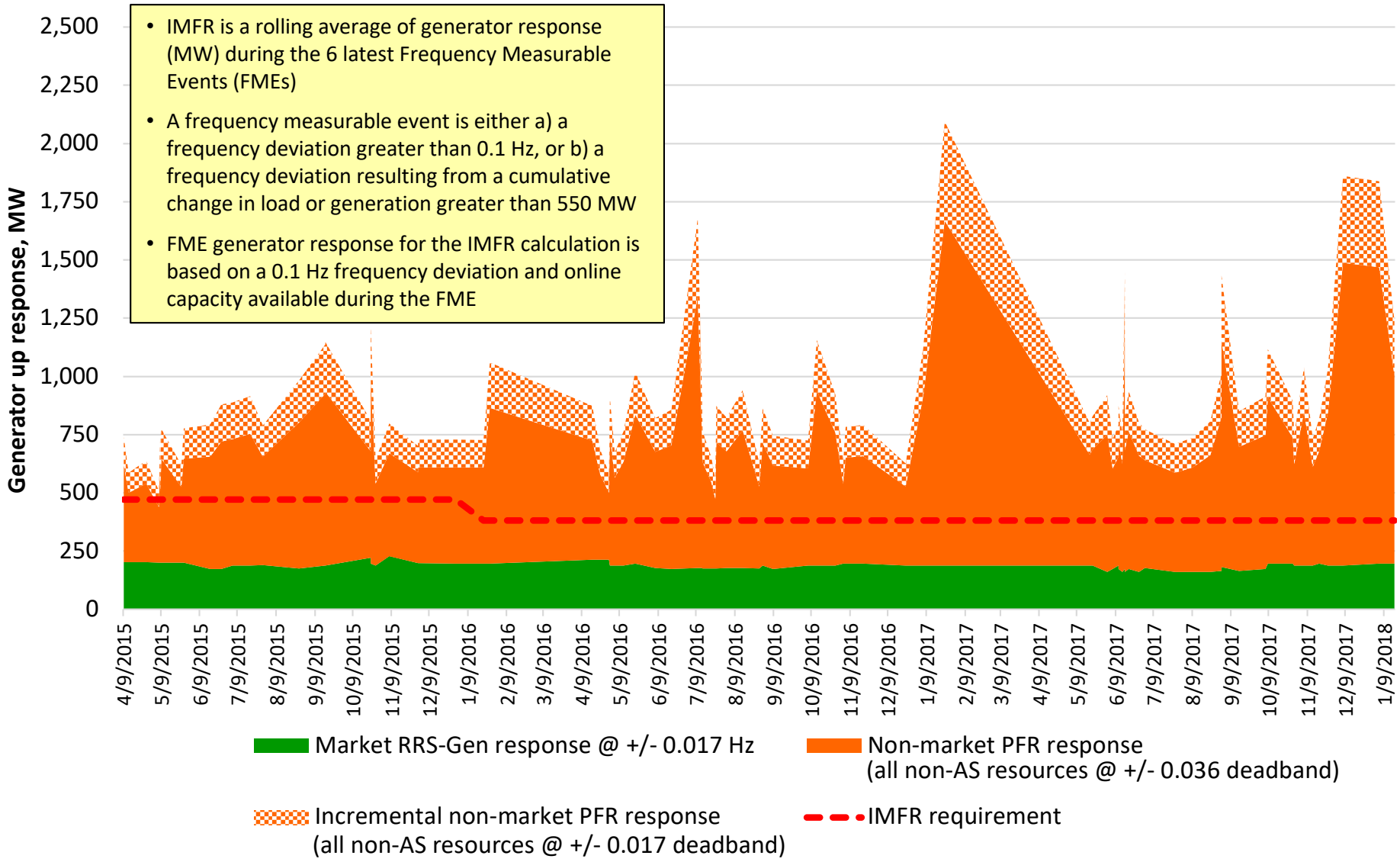
In a well-functioning real-time market, the market model will indicate the marginal cost of satisfying any requirement, which is the shadow price of the requirement. The shadow price is the most efficient clearing price for each of ERCOT's Ancillary Service requirements. Hence, we recommend that any new or updated Ancillary Services be priced on this basis.

- 2016 State of the Market Report for the ERCOT Electricity Markets, May 2017*

* Potomac Economics, *2016 State of the Market Report for the ERCOT Electricity Markets*. (Executive Summary, pp. xxv). Fairfax, VA.

FREQUENCY RESPONSE WITHOUT TIGHTER DEADBANDS WOULD HAVE COMPLIED WITH TRE RELIABILITY STANDARD IN 2016 AND 2017

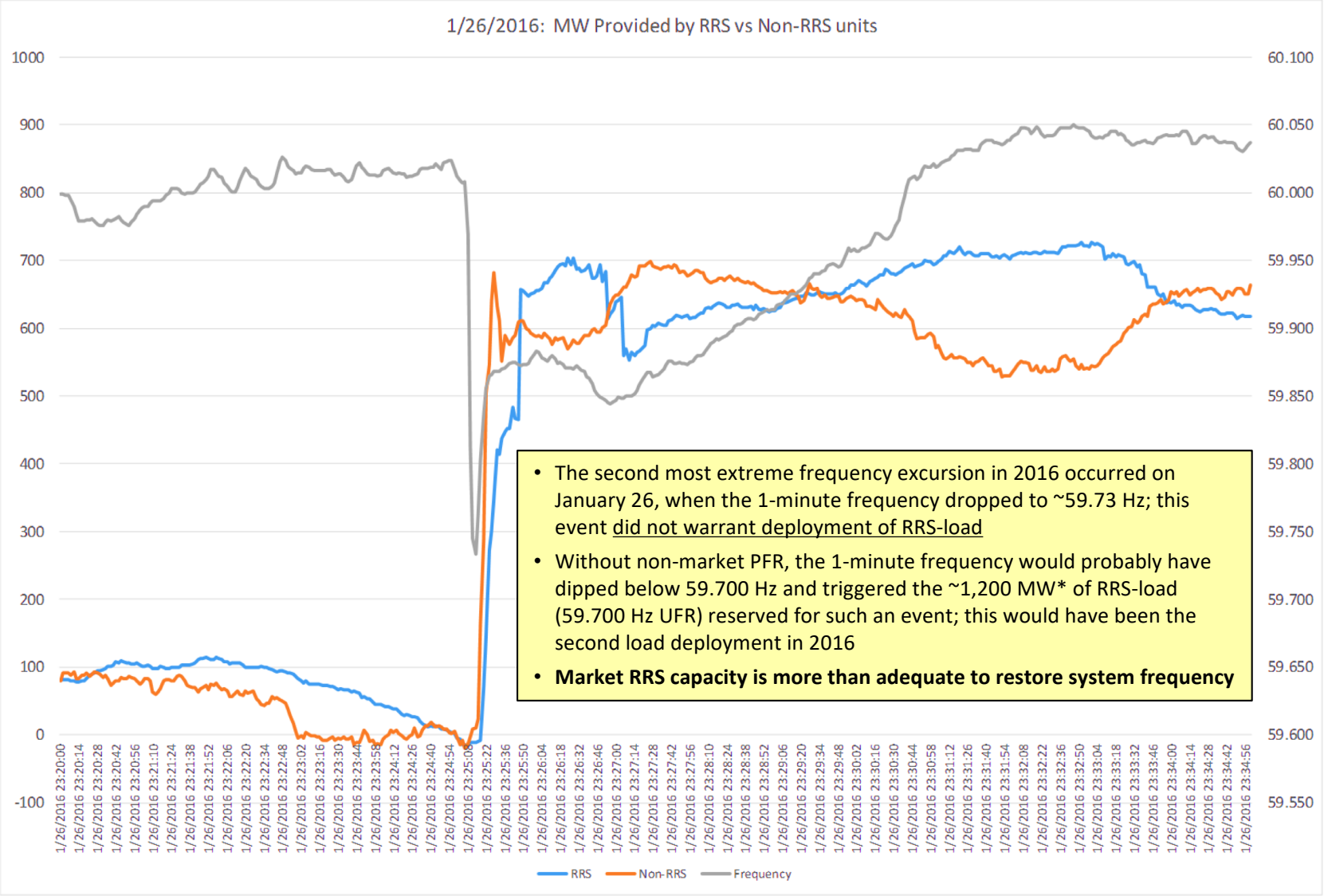
Market and non-market Interconnection Minimum Frequency Response (IMFR)



Source: IMFR Rolling Average Report as of 2/01/2018, ERCOT; Interconnection Minimum Frequency Response (IMFR) for ERCOT Balancing Authority, ERCOT, January 1, 2018; 2017 Frequency Response Annual Analysis, NERC, November 2017

MARKET AND NON-MARKET PFR DEPLOYMENT DURING SEVERE UNDER-FREQUENCY EVENT IN 2016

15-minute frequency management deployment on 1/26/2016

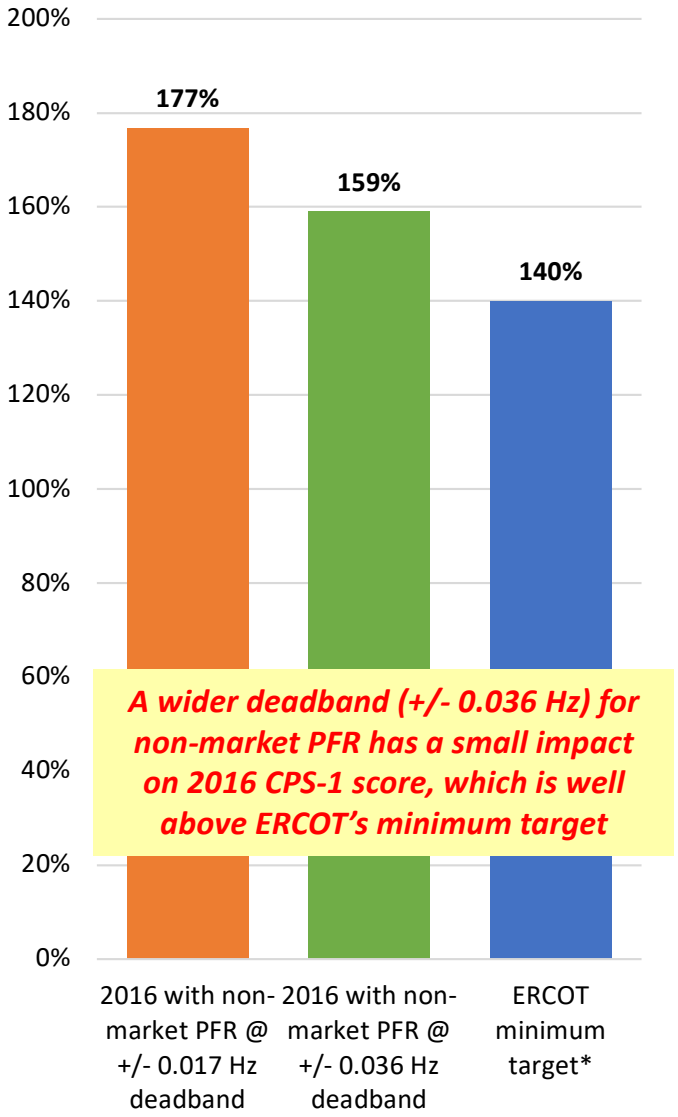


* TRE estimates 1,209 MW of hourly available load resources for January 2015 through December 2016

Source: TRE 2-second frequency data; 2017 Frequency Response Annual Analysis, NERC, November 2017

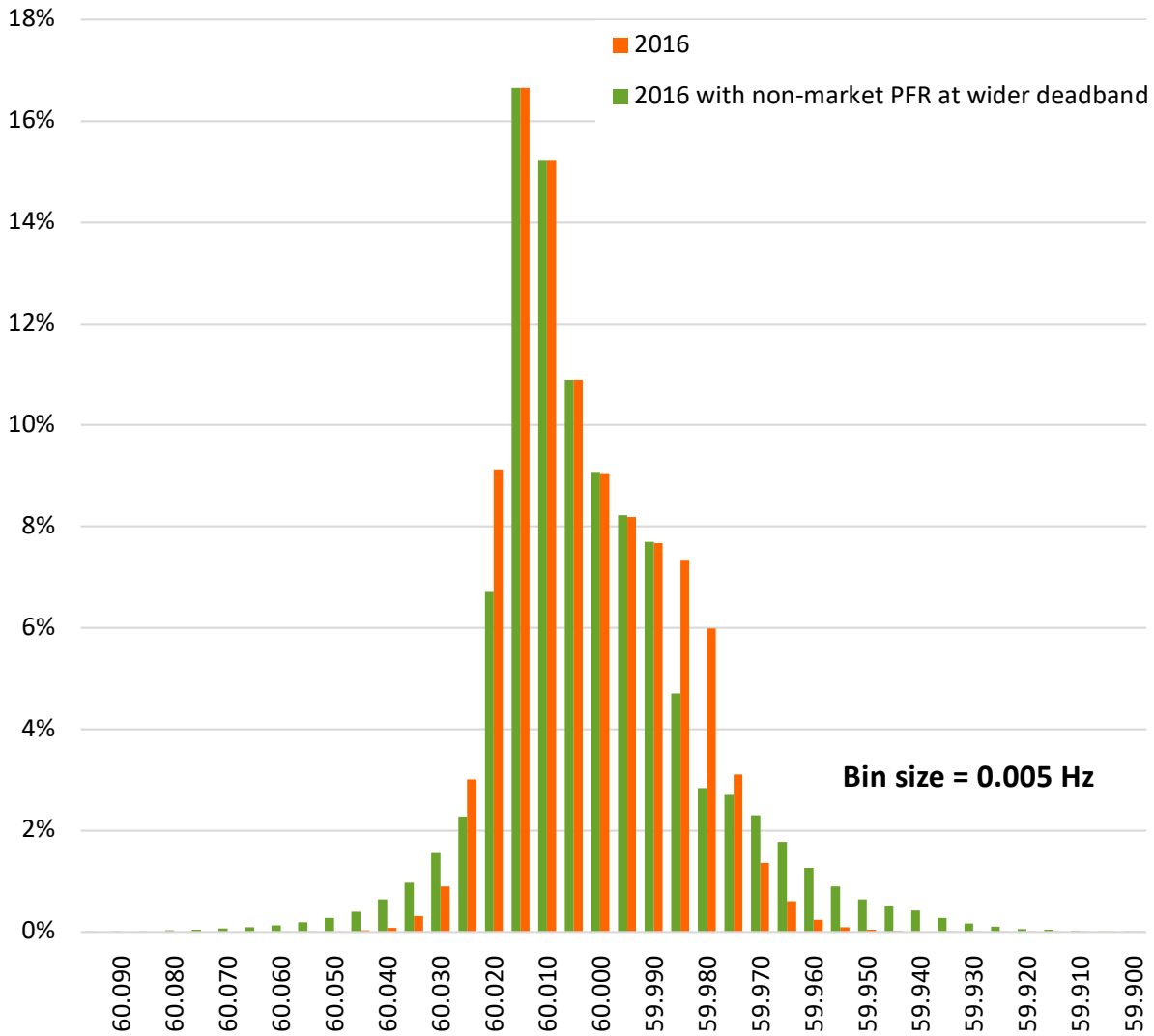
2016 FREQUENCY CONTROL WITH NON-MARKET PFR SET TO WIDER DEADBAND

2016 Control Performance Score 1



A wider deadband (+/- 0.036 Hz) for non-market PFR has a small impact on 2016 CPS-1 score, which is well above ERCOT's minimum target

2016 actual frequency distribution vs. 2016 frequency distribution with non-market PFR at wider deadband



* "ERCOT Methodology for Determining Minimum Ancillary Service Requirements" states that a CPS1 score of 140 or less (for a given month) warrants additional regulation procurement of 10% of the current volume, to be added in hours in which the CPS1 score was less than 140

RECOMMENDATION TO ADJUST PROTOCOLS TO LIMIT DEPLOYMENT TO PERIODS WITH LARGE FREQUENCY DEVIATIONS

Recommendation: A wider frequency deadband for resources NOT participating in the ERCOT Ancillary Service markets would optimize the role of non-market PFR by a) limiting unnecessary deployments during small frequency deviations, b) maintaining a practical, fail-safe service with deployments when large frequency deviations occur, and c) reducing the adverse market impacts from the large role that non-market PFR plays today.

Implementation:

1. Amend Table 1 of **Section 2.2.7 of Operating Guide** to add a new "Generator Type" called "Exempt Generator" with "+/- 0.036 Hz" for "Max. Deadband"
    - Gain concurrence of TRE to changes in operating guide and make similar amendments to TRE-BAL-001
2. Amend **ERCOT Protocol 3.18 (3) (a)** to disqualify resources with wider deadband from participating in RRS supply
    - (a) The full amount of RRS provided from a Online Generation Resource must be less than or equal to ~~20% of thermal unit HSL for an Ancillary Service Offer, and must be less than or equal to~~ the lesser of (i) ERCOT verified droop performance that is no greater than 5% and no less than 3% at dead-end setting of +/-0.017 Hz with linear deployment, or (ii) ten times the Emergency Ramp Rate~~, and must be frequency responsive~~;

Table 1, Section 2.2.7

Generator type	Maximum deadband
Steam turbines with mechanical governors	+/- 0.034 Hz
Hydro turbines with mechanical governors	+/- 0.034 Hz
All other generating units/generating facilities	+/- 0.017 Hz
Controllable Load Resources (CLEs)	+/- 0.036 Hz
Exempt Generator	+/- 0.036 Hz


Proposed

15-30 GW OF NG/COAL RESOURCES LIKELY TO MAINTAIN TIGHTER PFR DEADBAND, EVEN IF A WIDER DEADBAND OPTION IS AVAILABLE

2014 RRS/Regulation market participation by generation type, HSL GW

	RRS/Reg. supply >4% of HSL	RRS/Reg. supply = 0.1-4% of HSL	RRS/Reg. supply = 0% HSL	Total HSL
CCGT	10.1	5.7	13.3	29.2
COGEN	2.1	0.6	6.7	9.4
COAL	1.4	6.0	12.8	20.2
GAS STEAM	1	3.1	9.2	13.2
OCGT	0.1	0.1	3.9	4.2
WIND	0	0	12.5	12.5
SOLAR	0	0	0.1	0.1
NUCLEAR	0	0	5.1	5.1
	14.7	**15.5**	**63.3**	**93.9**
	16%	*16%*	*68%*	

In order to participate in the RRS market, 15-30 GW of natural gas & coal resources likely to maintain tighter frequency deadband on governor

Resources NOT participating in Ancillary Service market likely to request wider frequency deadband

* Includes resources announced for retirement

APPENDIX

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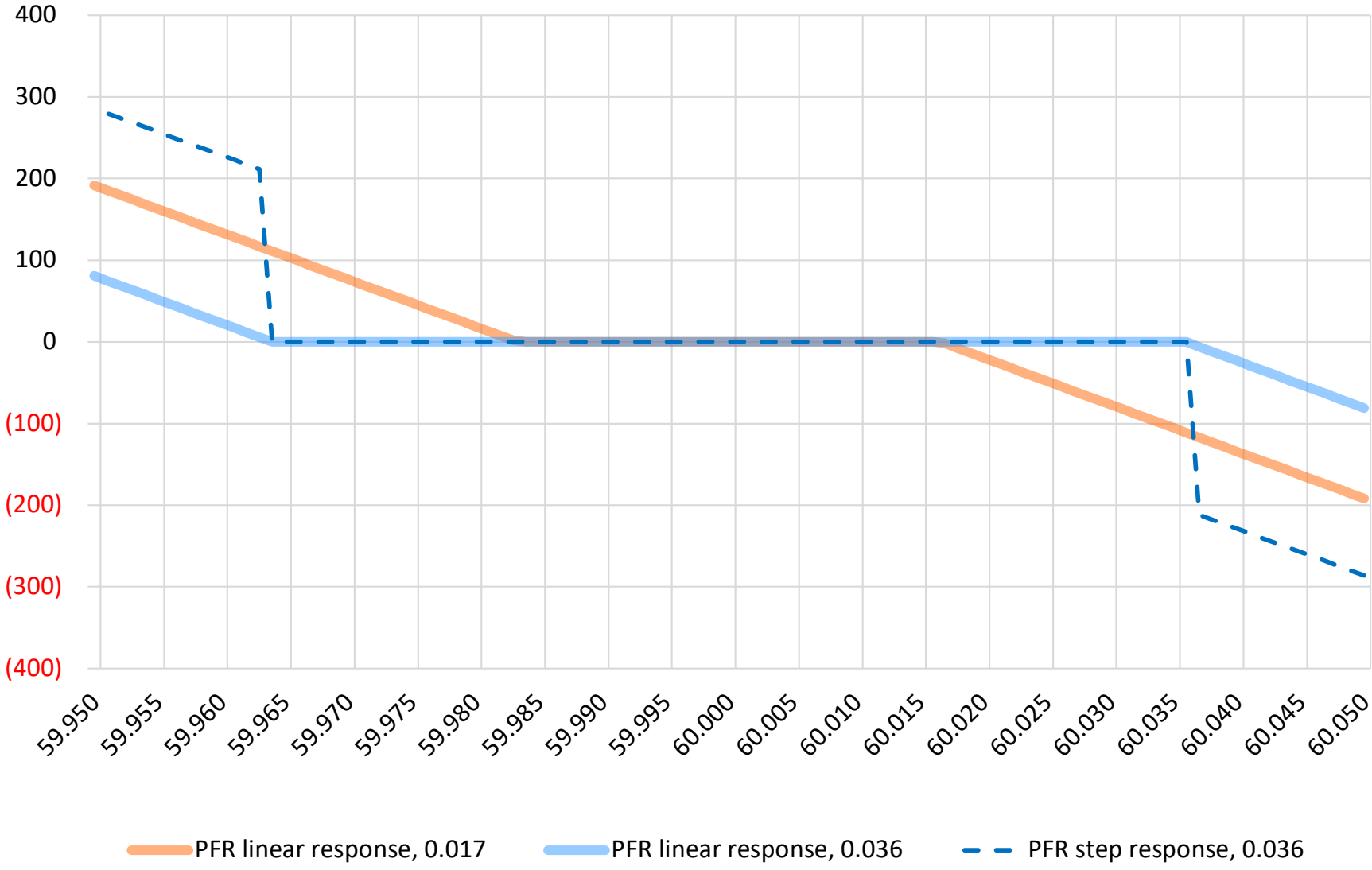
NON-MARKET PFR DEPLOYMENT: LINEAR VS. STEP FUNCTION

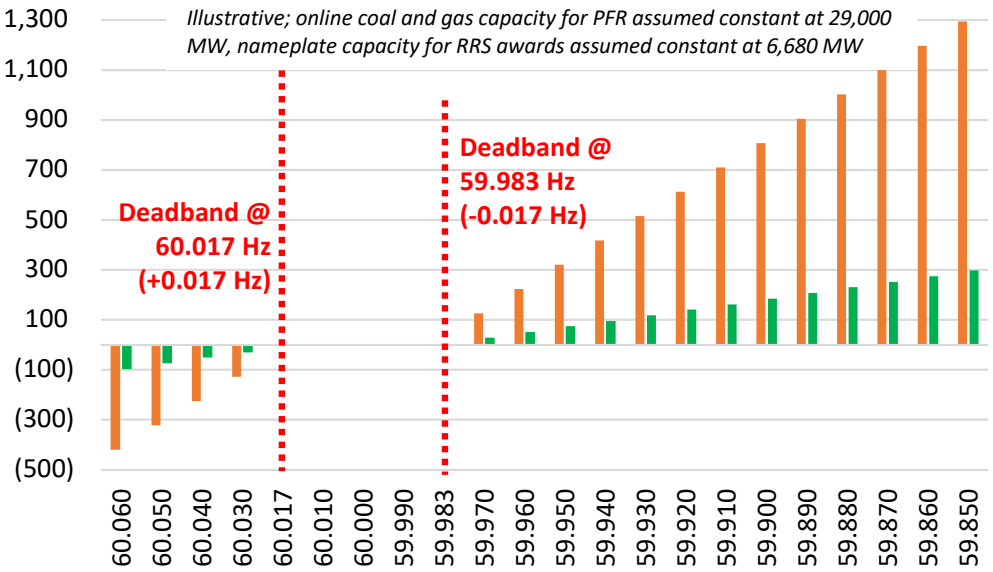
Illustrative deployment of non-market PFR under two governor deadband settings, MW



Source: Apex analysis using ERCOT Expected Primary Frequency Response formula, and illustrative non-market PFR capacity (NDC) of 17,160 MW

KEY FEATURES OF MARKET AND NON-MARKET PRIMARY FREQUENCY RESPONSE

Primary Frequency Response (PFR) deployment is a function of frequency level and available capacity



How is PFR deployed?

- Units are self-deployed by onsite governor, not via AGC signal
- PFR (up or down) deployment begins when system frequency deviates from 60.000 Hz by +/- 0.017 Hz*
- Magnitude of deployment depends on size of frequency deviation
- Deployment is limited to 20% of unit capacity**

What is PFR deployment speed?

- Initial response is required within ~30 seconds

How often is PFR utilized?

- Approximately 1-out-of-4 minutes in 2016

Market, remunerated PFR

- Remunerated PFR is delivered by Responsive Reserve Service (RRS) suppliers awarded based on co-optimization of hourly offers in the day-ahead market, i.e., merit-order procurement
- Market PFR is only supplied by generators (RRS-Gen), not Load Resources (though is provided by Controllable Load Resources, "CLRs")
- Generators providing RRS must reserve capacity to respond to under frequency signals ("PFR up"), but not required to reserve "down" capacity

Non-market, free PFR

- Mandated by BAL-001-TRE-1 with no remuneration; enforced with fines of up to $25k/event
- Up response mandated for all online coal and gas resources and CLRs not at maximum output (note: wind/solar are assumed to always be at maximum output, and are thus unable to provide "up" response; nuclear units are not subject to PFR mandate)
- Down response mandated for all online coal, gas, wind, and solar resources and CLRs not at minimum output***

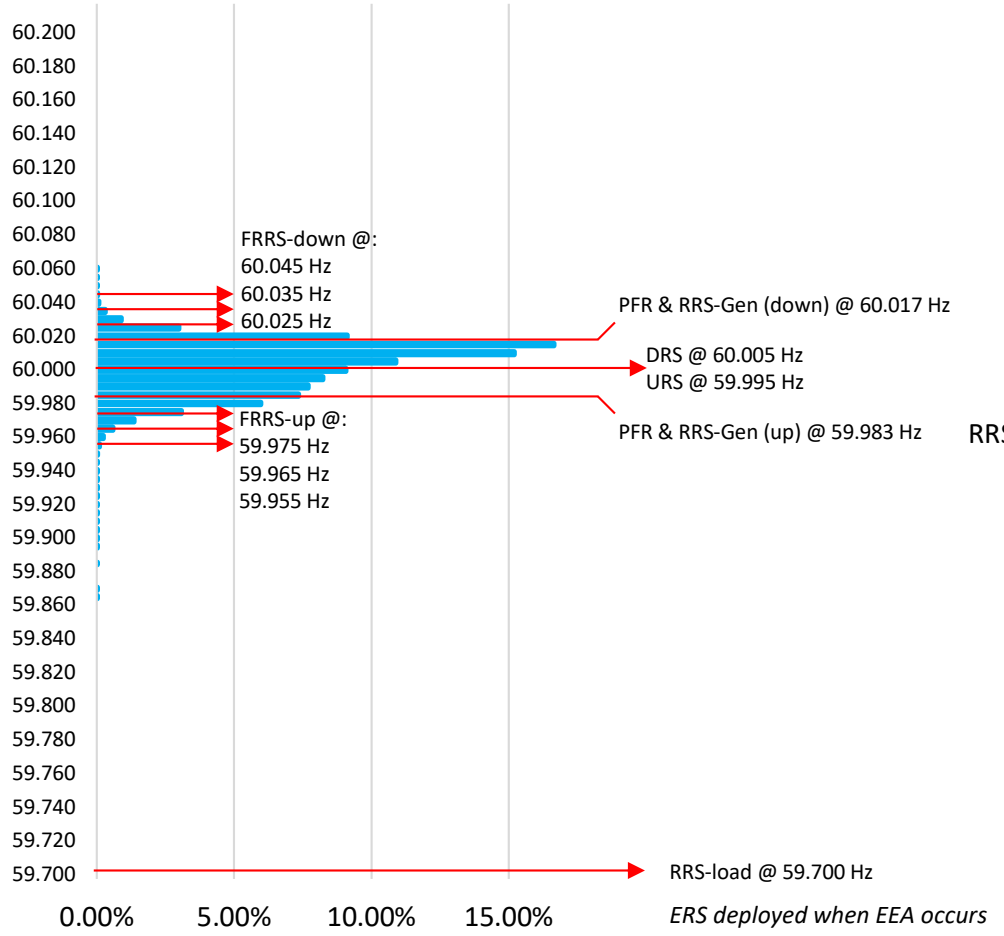
* Steam and hydro turbines with mechanical governors are subject to a deadband of +/- 0.034 Hz

** PFR deployment is limited to 20% of capacity at resource droop setting of 5%, which is most common setting

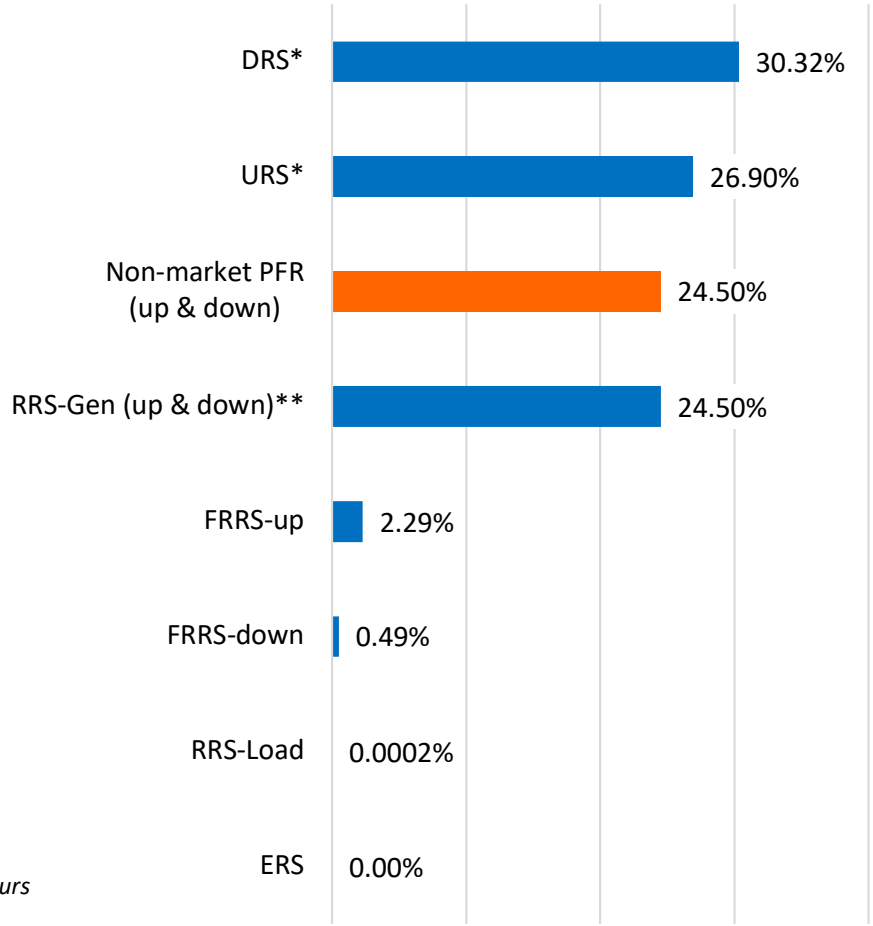
*** PFR capability requires that wind resources have an automatic generation control system; older turbines built without the system are either fitted with a control, or exempt from PFR provision if implementation of a generation control is not technically possible

PFR CONTRIBUTION TO FREQUENCY CORRECTION HAS HIGH PROBABILITY OF DEPLOYMENT – 25% OF ALL 1-MINUTE INTERVALS

2016 distribution of 1-minute average system frequency



2016 probability of deployment, % of 1-minute intervals



* Assumes URS deployments occur at frequencies below 59.995 Hz, and DRS deployments occur at frequencies above 60.005 Hz

** RRS-gen down capacity always assumed available, figures reflect up and down deployments

ERCOT FREQUENCY MANAGEMENT SERVICES

Product	Description	Deployment trigger	Deployment timing	Avg. hourly procurement size
Regulation services (Up-regulation, Down-regulation)	Provided by capacity that can respond to signals from ERCOT within five seconds, to respond to changes in system frequency by changing output as necessary	Based on proprietary Load Frequency Control algorithm; Up-service must be recalled prior to Down deployment, and vice versa	Upon instruction, URS/DRS is deployed within 5 seconds, reaching instructed level after five consecutive minutes – deployment duration is dependent on system needs but does not exceed the hour (after deployment URS/DRS must be un-deployed)	URS 326 MW (2016) DRS 301 MW (2016)
Fast Responding Regulation Services (Up-service)	A type of regulation service provided by resources able to respond to ERCOT dispatch instructions or detection of a trigger frequency within 30 cycles	Up: 40% @ 59.975 Hz 70% @ 59.965 Hz 100% @ 59.955 Hz Down: 40% @ 60.025 Hz 70% @ 60.035 Hz 100% @ 60.045 Hz	Upon instruction, FRRS is deployed instantaneously to reach instructed level within 30 cycles – deployment duration is at least 10 consecutive minutes and dependent on system needs	Hourly system total may not exceed: 65 MW for Up 35 MW for Down
Responsive Reserve Service-Gen (Up- and Down-services that include market-based PFR)	A type of operating reserves provided by generators able to adjust power output to assist in the arrest of system frequency decay within the first few seconds of a significant frequency deviation (market PFR), and thereafter provide/reduce energy to help restore system frequency; also provides backup regulation – capacity for Up deployment is reserved and capacity for Down deployment is as-available	59.983 Hz for Up 60.017 Hz for Down	At significant frequency deviation reaching the trigger, RRS-Gen is deployed instantaneously, reaching instructed level after 10 consecutive minutes – deployment duration is dependent on system needs, but does not exceed the hour	1,375 MW (2016) For both Up- and Down-services
Primary Frequency Response (non-market Up- and Down-services)	Provided by generators/load able to increase/decrease real power output in order to respond (proportionally, in the direction that stabilizes frequency) to system frequency deviations greater than +/- 0.017 Hz, as mandated by BAL-001-TRE-1	59.983 Hz for Up 60.017 Hz for Down	At a frequency deviation reaching the trigger, PFR is deployed instantaneously, reaching instructed level after 30 consecutive seconds – deployment duration is dependent on system needs	6,167 MW (2016) For both Up- and Down-services
Responsive Reserve Service-Load (Up-service)	A type of operating reserves provided by load resources that are able to provide energy or continued load interruption during the implementation of the Energy Emergency Alert	59.700 Hz	At a frequency deviation reaching the trigger, RRS-Load is deployed instantaneously, reaching instructed level after 10 consecutive minutes – deployment duration is up to 1 hour and dependent on system needs (loads must then return to 95% of Ancillary Service Resource Responsibility within 3 hours unless otherwise instructed)	1,364 MW (2016), limited to 50% of the RRS requirement for a given hour
ERS-10/30 (Up-services)	Emergency Response Service is used during an Energy Emergency Alert to assist in maintaining or resorting system frequency, though it is not an Ancillary Service; ERS is intended to reduce the probability of load-shedding	Dispatch instruction during an EEA period	Provided within a 10-minute/30-minute ramping period after dispatch instruction	Procured three times annually for a four-month ERS Standard Contract Term, in which procurement for six designated time periods takes place; procurement volumes for ERS-10 average ~200 MW, while procurement volumes for ERS-30 average ~650 MW per period
Involuntary load curtailment (Up-service)	Curtailment % of ERCOT system load, based on level of significant system frequency decay	5% @ 59.300 Hz 15% @58.900 Hz 25% @ 58.500 Hz	Upon ERCOT instruction	

Source: ERCOT Glossary and NPRR for Ancillary Services Enhancements, 2017