IMPROVE MARKET EFFICIENCY AND RELIABILITY PLANNING BY MINIMIZING NON-MARKET PRIMARY FREQUENCY RESPONSE

FEBRUARY 2018

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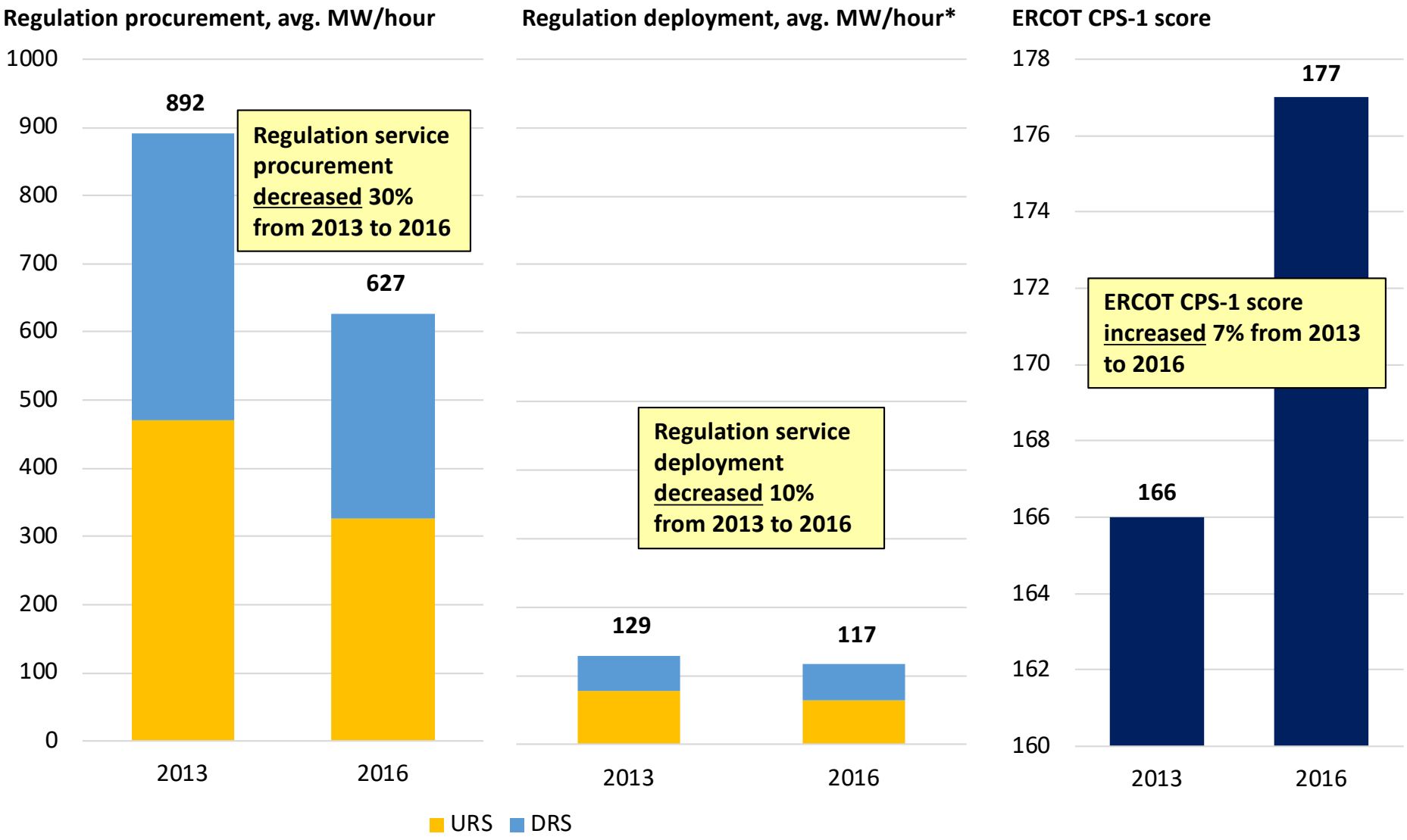
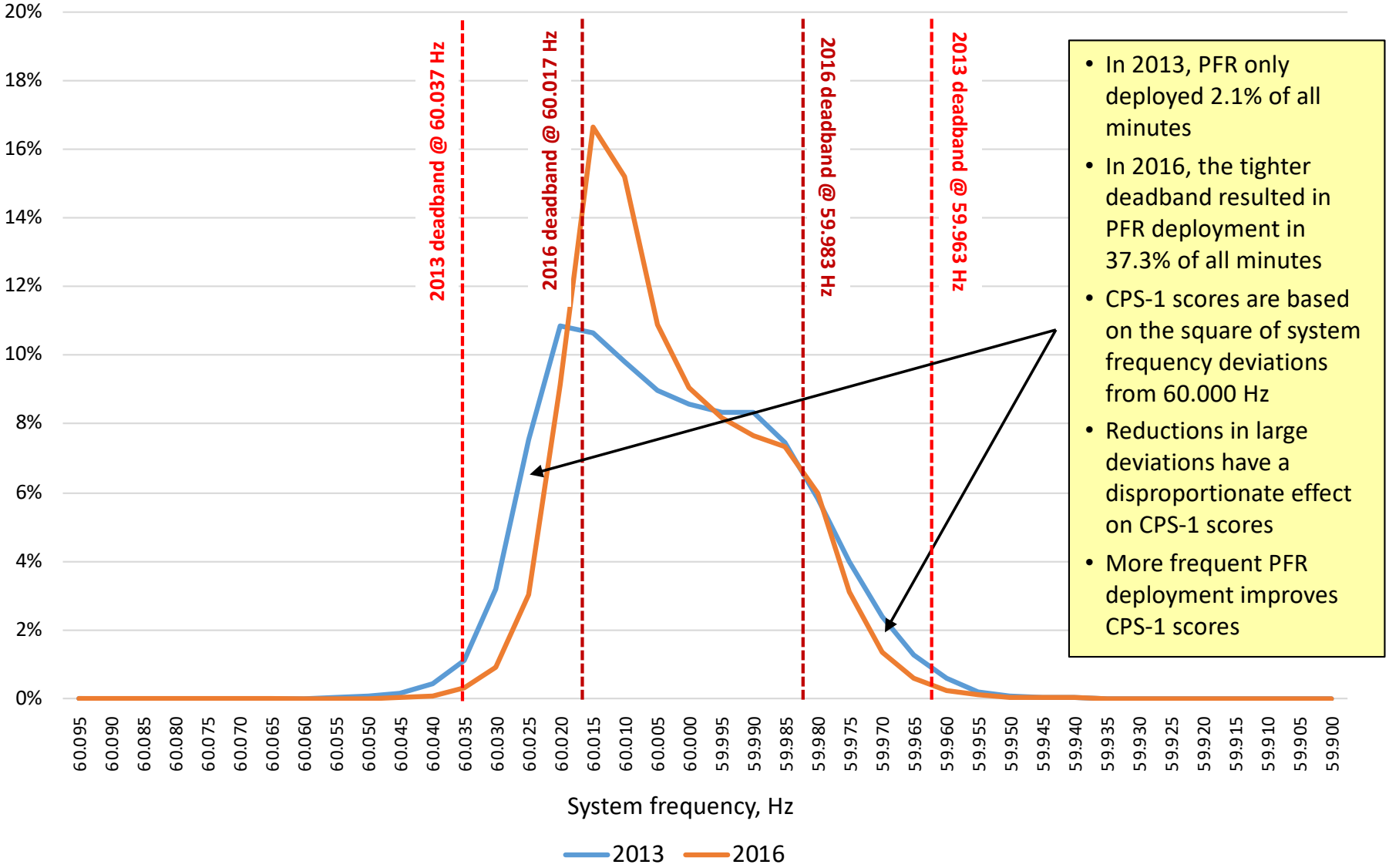
BETWEEN 2013 AND 2016, REGULATION PROCUREMENT AND DEPLOYMENT WERE REDUCED WHILE CPS-1 SCORES INCREASED



* Figure shows *total* deployment, regardless of system frequency

CPS-1 SCORES BOLSTERED BY PRIMARY FREQUENCY RESPONSE (PFR) DEPLOYMENTS, WHICH OCCUR SOONER WITH A STRICTER FREQUENCY DEADBAND

Distribution of 1-minute system frequency 2013 vs. 2016



- In 2013, PFR only deployed 2.1% of all minutes
- In 2016, the tighter deadband resulted in PFR deployment in 37.3% of all minutes
- CPS-1 scores are based on the square of system frequency deviations from 60.000 Hz
- Reductions in large deviations have a disproportionate effect on CPS-1 scores
- More frequent PFR deployment improves CPS-1 scores

MARKET-BASED VS. NON-MARKET PRIMARY FREQUENCY RESPONSE

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 for over-frequency governor response

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

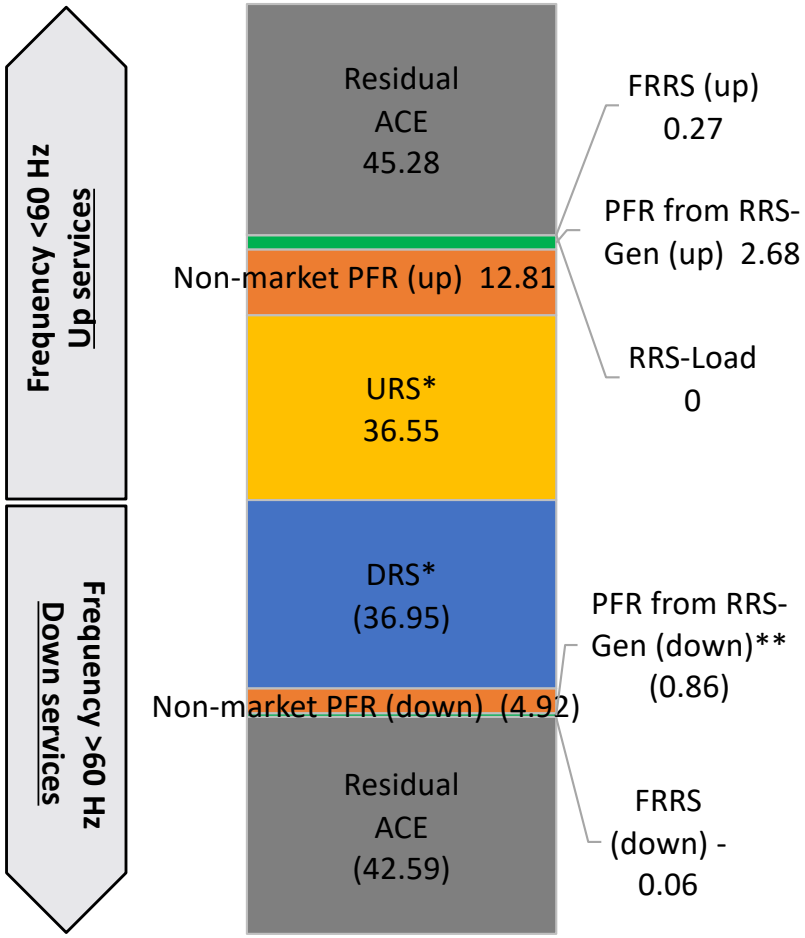
- Under-frequency response required by all online generators for unloaded capacity up to HSL as BAL-001-TRE droop setting
- Over-frequency response required by all online generators for loaded capacity greater than LSL
- Nuclear units not subject to requirement
- Generators are subject to penalties for non-compliance with mandated droop setting

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

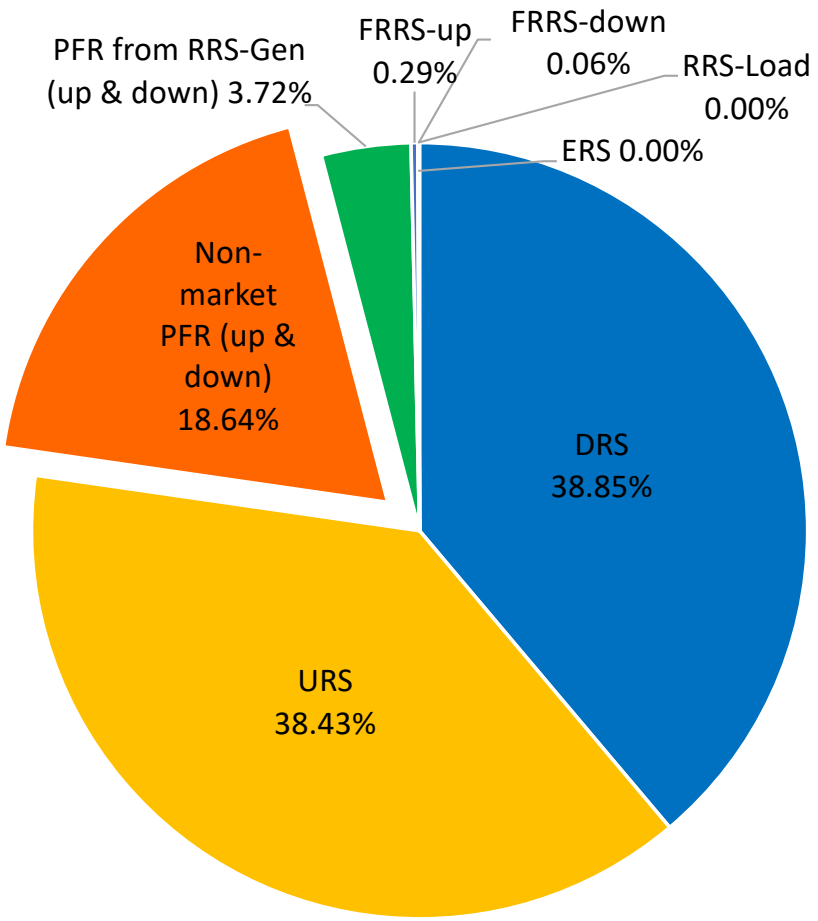
** Capacity available for non-market PFR "up" deployment for under-frequency events is based on online natural gas, coal, and other capacity with deployment limited to "Total System-wide Capacity (excl. AS)"; Capacity available for non-market PFR "down" deployment for over-frequency events is based on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

NON-MARKET PFR DISPLACES MARKET-BASED REGULATION SERVICE

2016 net frequency correction, MW/minute



2016 net average 1-minute frequency correction
100% = 93.32 MW

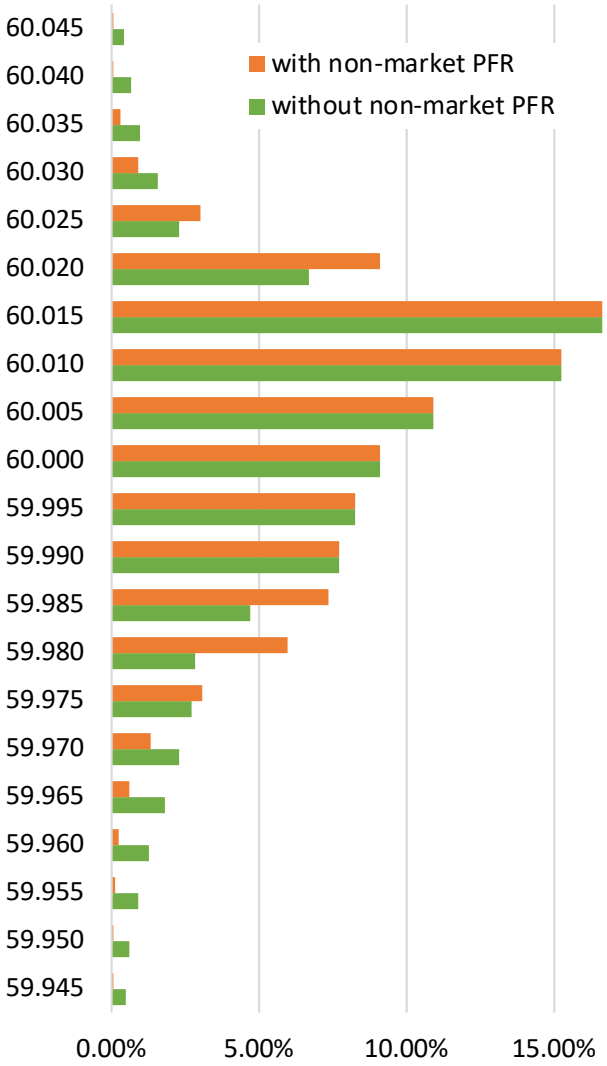


* Net frequency error correction refers to the MW correction of frequency error only when the service is deployed in the direction of need (i.e. <60 Hz for Up-services and >60 Hz for Down-services) – this metric is used because regulation must un-deploy, and sometimes does so in a fashion that exacerbates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

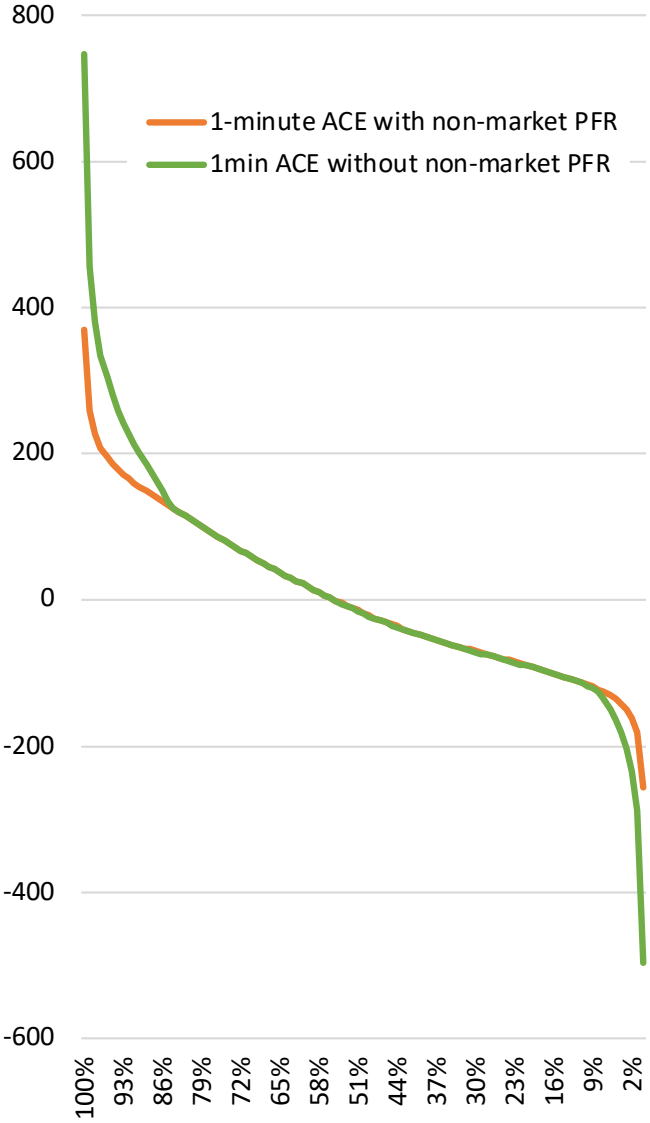
** RRS-Gen down capacity always assumed available

2016 FREQUENCY CONTROL WITH AND WITHOUT NON-MARKET PFR

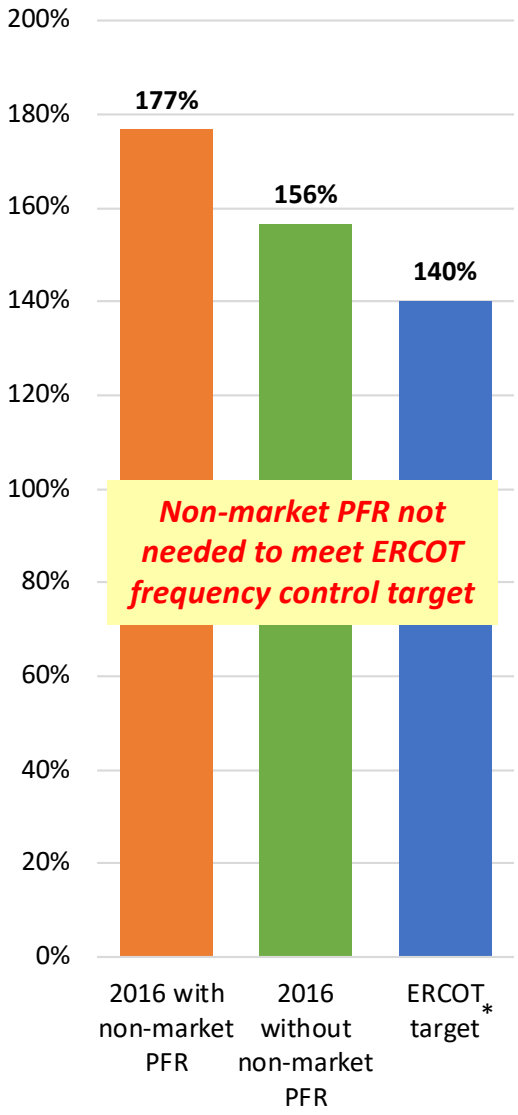
2016 distribution of 1-minute system frequency



2016 1-minute Area Control Error



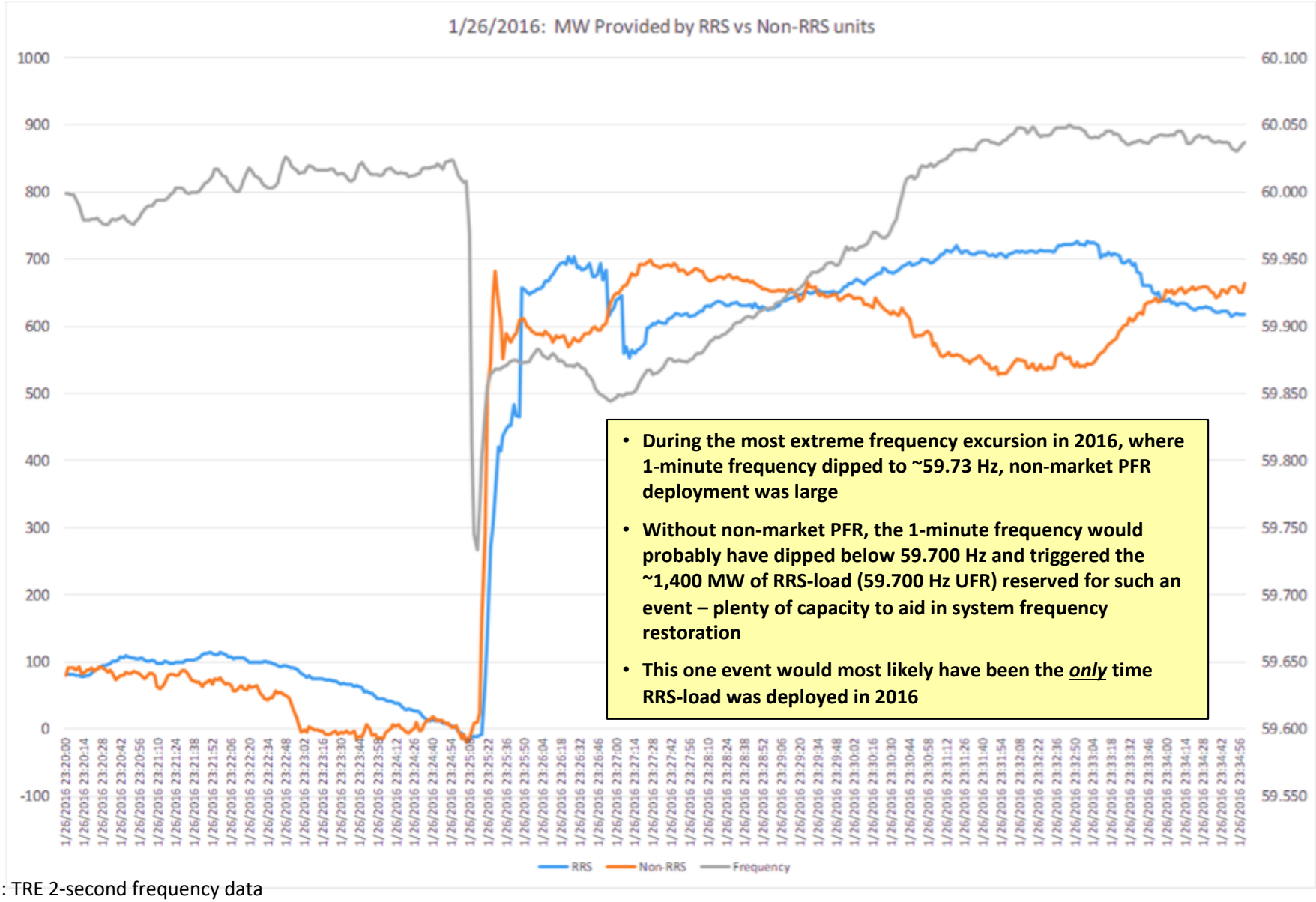
2016 Control Performance Score 1



* "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

NON-MARKET PFR DEPLOYMENT WAS LARGE DURING MOST SEVERE UNDER-FREQUENCY EVENT IN 2016

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



Source: TRE 2-second frequency data

POTENTIAL SOLUTIONS TO ADDRESS ALL STAKEHOLDER NEEDS

	Unbiased reliability planning Incorporates all frequency management services in future reliability plans/analysis	***Short-term* Market efficiency** Reliability services procured in merit order that reflect marginal costs	***Long-term* Market efficiency** Ensures appropriate market signal for new investment in flexibility	**Reliability** Maintains satisfactory system frequency control
Status quo BAL-001-TRE-1	X ***Ignoring non-market PFR usually underestimates actual reliability outcomes***	X ***Wind/solar/CCGT curtailment is non-economic***	X ***Non-market PFR displaces Ancillary Service procurement***	 ***Over-controlled***
For generators not providing RRS-Gen allow governor dead band at +/-0.037 Hz (old setting)	 ***Much smaller bias toward underestimation of reliability outcomes***	 ***Minimization of non-market PFR mitigates inefficiencies, yet leaves unresolved the challenge of appropriate compensation***	 ***Minimization of non-market PFR mitigates inefficiencies, yet leaves unresolved the challenge of appropriate compensation***	 ***Nearly optimal market-based control***
For generators not providing RRS-Gen allow governor block (same as nuclear) – no change for RRS-Gen suppliers	 ***Unbiased reliability planning/analysis***	 ***All A/S procured in merit order, results in lowest cost supply***	 ***A/S procurement sends investment signal***	 ***Optimal market-based control***

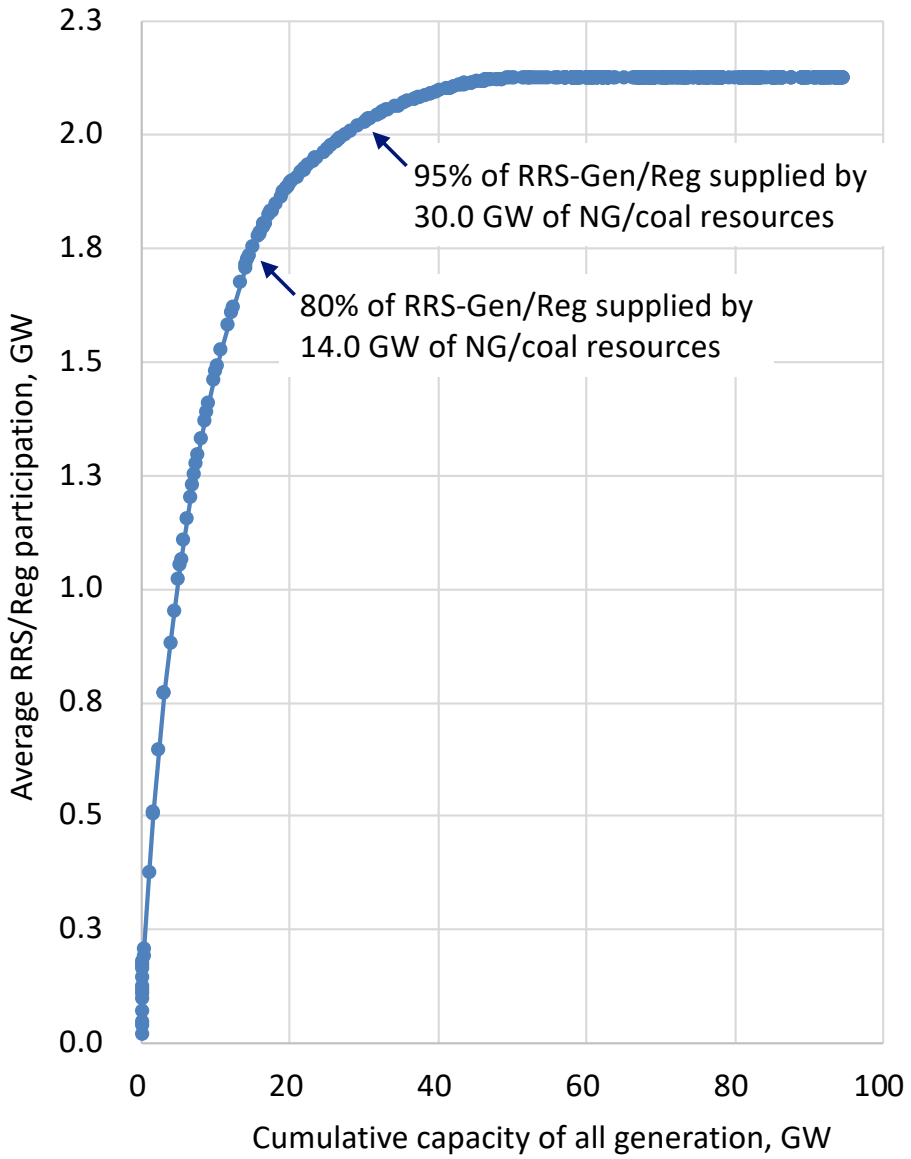
In a well-functioning real-time market, the market model will indicate the marginal cost of satisfying any requirement, which is the shadow price of the requirement. The shadow price is the most efficient clearing price for each of ERCOT's Ancillary Service requirements. Hence, we recommend that any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

15-30 GW OF NG/COAL RESOURCES LIKELY TO CONTINUE PROVIDING PFR SERVICE

2014 RRS-gen/Reg supply



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

	RRS/Reg supply >4% HSL	RRS/Reg supply 0.1-4% HSL	RRS/Reg supply 0% HSL	Total
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
NUKE	0	0	5.1	5.1
	14.7	**15.5**	**63.3**	**93.9**
	16%	*16%*	*68%*	

Estimated 2018 marked-based PFR supply:
15-30 GW of NG/coal resources

* Includes resources announced for retirement

RECOMMENDATION

Recommendation:

ERCOT stakeholders should minimize non-market, free PFR by either…

a) allowing generators not providing RRS an exemption to set governor to +/-0.036 Hz

b) allowing generators not providing RRS an exemption to block their governor

Implementation:

- Amend Table 1 or 2 of Section 2.2.7 of Operating Guide..

  a) To widen deadband, add new "Generator Type" to Table 1 called "Exempt Generator" with "+/- 0.036 Hz" for "Max. Deadband"

  b) To block governor response, add new "Generator Type" to Table called "Exempt Generator" with a "blocked" for "Max. Droop % Setting"

- Gain concurrence of TRE to changes in operating guide and make similar amendments to TRE-BAL-001

Table 1: Maximum Governor Dead-Band Settings

Generator 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	+/- 0.017 Hz
Controllable Load Resources (CLRs)	+/- 0.036 Hz

Table 2: Maximum Governor Droop Settings

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

APPENDIX

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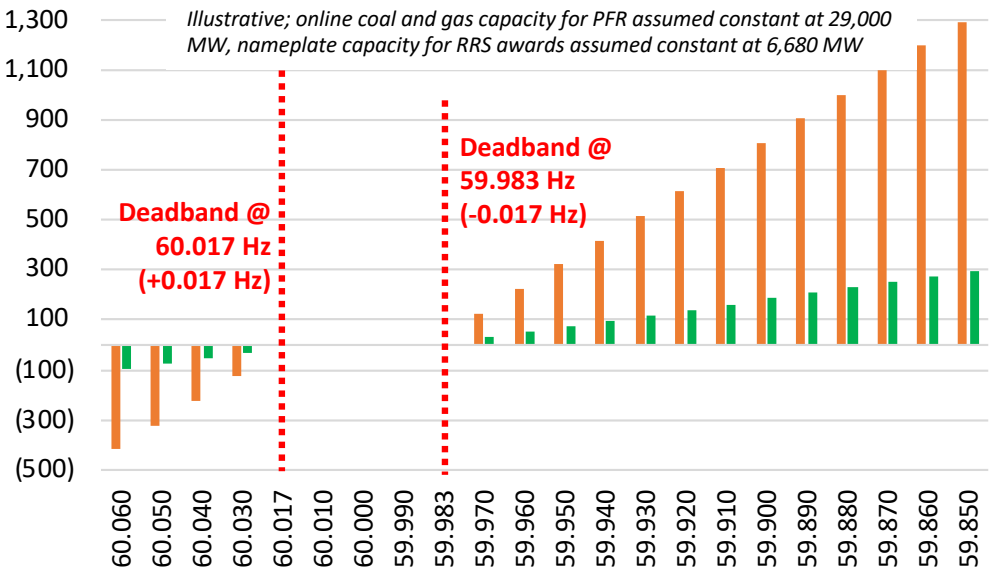
EVOLUTION OF NON-MARKET PFR MANDATE

- In 2013, TRE requested approval from FERC to implement Regional Standard BAL-001-TRE-1 in order to tighten the frequency deadband (the trigger points around 60.000 Hz at which Responsive Reserves and Primary Frequency Response are deployed) in the ERCOT market from +/- 0.037 Hz to +/- 0.017 Hz*, and mandate that all generators and Controllable Load Resources available to do so (except those allowed exemptions) provide PFR without compensation (ERCOT Protocol 8.5.1.1)
- The intent of the rule change was to improve frequency management, particularly in light of the growing wind supply in Texas, and was approved by FERC in January 2014 with implementation to occur over the next several months
- This uncompensated, "non-market" PFR is required in addition to the PFR provided to the system through Responsive Reserve Service supplied by generators (RRS-Gen), which is compensated via the RRS clearing price
- ERCOT is now the only interconnection where non-market PFR provision is required by NERC rule
- The stricter deadband for PFR/RRS-Gen deployment, and mandated non-market PFR provision, resulted in a much higher deployment of PFR, and improved CPS-1 scores
- However, greater non-market PFR deployment also displaced a significant amount of (market-based) Regulation Service procurement and deployment in favor of an uncompensated service
- Thus, the current PFR construct creates uncertainty and market inefficiencies inconsistent with ERCOT's competitive market framework – the following analysis provides a basis for Apex's recommendation that non-market PFR be eliminated

* Prior to BAL-001-TRE-1, PFR provision was determined using a step calculation; it is currently determined using a linear method

KEY FEATURES OF IN-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

In-market, remunerated PFR

- Remunerated PFR is delivered by Responsive Reserve Service suppliers awarded based on co-optimization of hourly offers in the day-ahead market, i.e., merit order procurement
- 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

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

COMPARISON OF ERCOT FREQUENCY MANAGEMENT SERVICES

Service	Up-service	Down-service	Deployment speed	2016 deployment potential, MW/hour (average)	2016 participation in frequency correction, % of minutes
Non-market PFR: Primary Frequency Response	✓	✓	~30 seconds	6,835 *	24.37%
RRS-Gen: Responsive Reserve Service from generators (includes market-based PFR)	✓	✓**	~30 seconds	1375	24.37%
RRS-Load: Responsive Reserve Service from loads	✓		<1 second	1364	0.00%
ERS: Emergency Response Service	✓		10 minutes / 30 minutes	865	0.00%
URS: Up-regulation service	✓		5 minutes	326	26.90%
DRS: Down-regulation service		✓	5 minutes	301	30.32%
FRRS-up: Fast Responding Regulation Service up* **	✓		<1 second	30	2.29%
FRRS-down: Fast Responding Regulation Service down* **		✓	<1 second	30	0.49%

Non-market PFR usually has the largest deployment potential, and deploys quickly and frequently

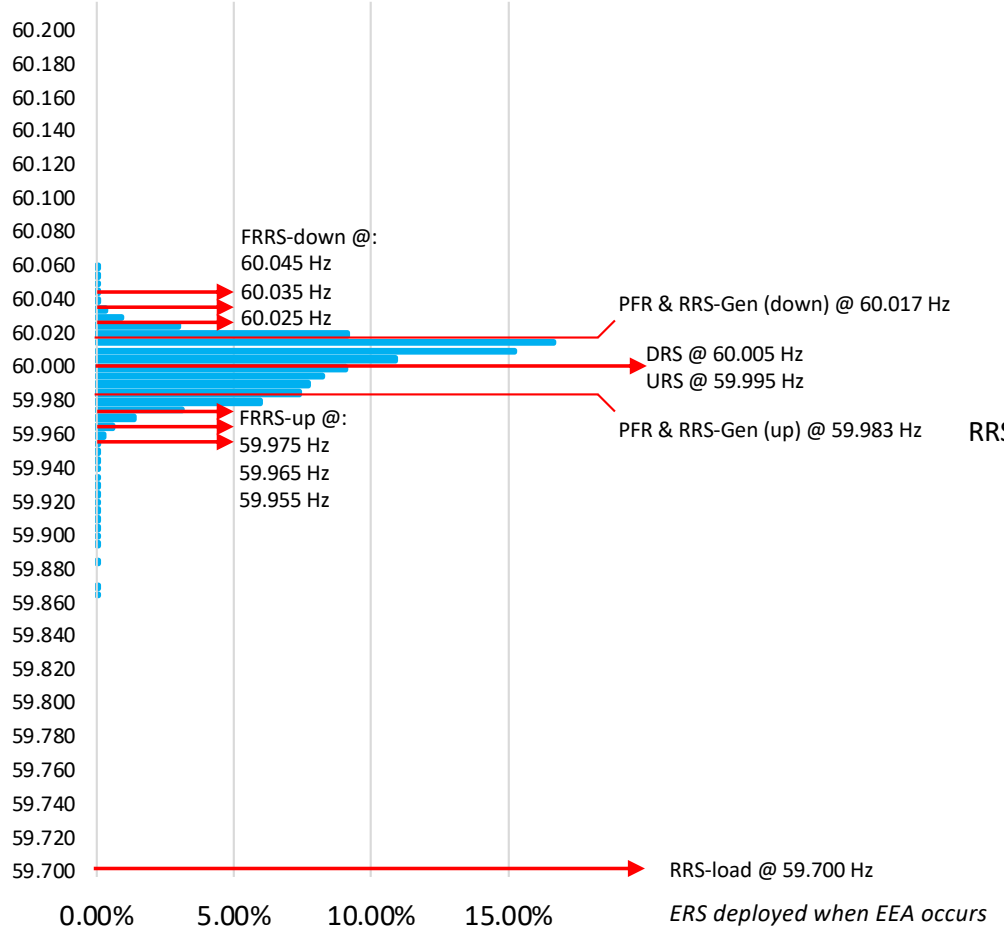
* Non-market PFR deployment potential is the average of PFR-up available and PFR-down available in 2016; PFR-up available is calculated as the lesser of: a) online capacity available less demand, or b) 20% of coal and gas capacity online, PFR-down available is calculated as the lesser of: a) gas and coal production less LSL (assumed to be 39% of gas and coal capacity online) and less DRS requirement, or b) 20% of gas, coal, wind, solar, and hydro capacity online

** RRS-Gen down is available when online capacity for a given generator exceeds LSL and DRS requirement; for this analysis, RRS-Gen down capacity is always assumed to be available

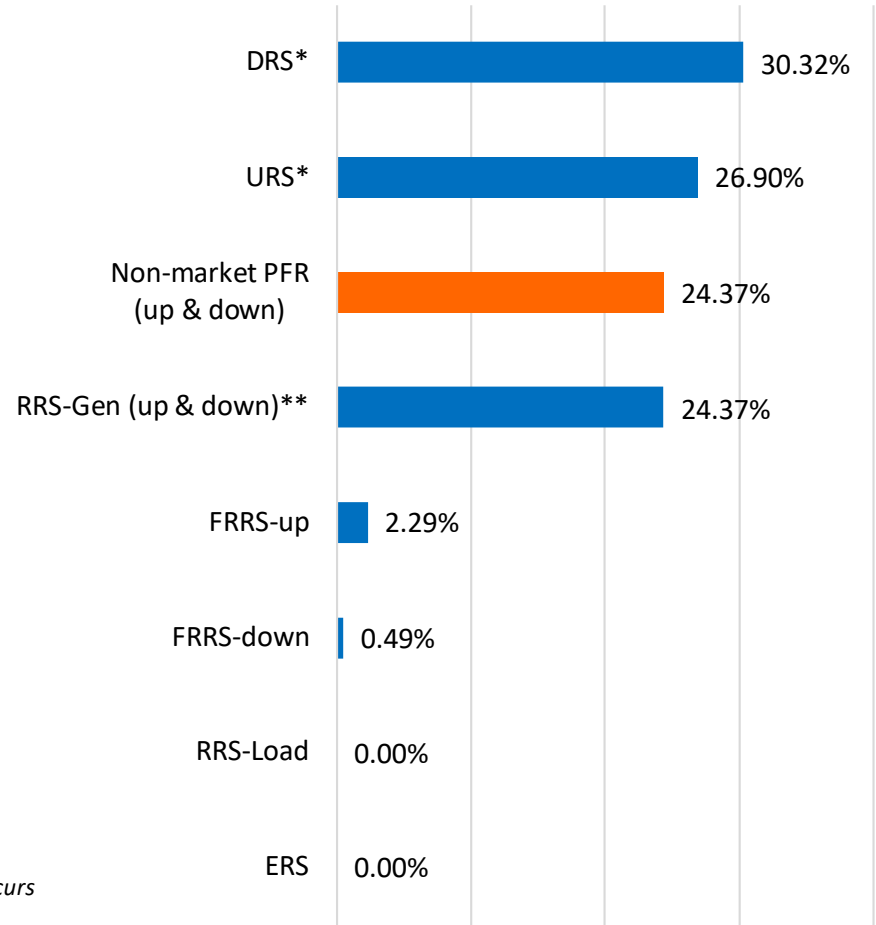
*** 2016 average size of FRRS-up and FRRS-down markets assumed to be 30 MW/hour

PFR CONTRIBUTION TO FREQUENCY CORRECTION HAS HIGH PROBABILITY OF DEPLOYMENT – 24% 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

REGULATION IS LOWEST COST ALTERNATIVE TO REPLACE NON-MARKET PFR, IF NEEDED

	2016 average price for procurement, $/MW	2016 average procurement volume, MW/hour	2016 average net contribution to frequency correction, MW/hour	Implied cost of frequency correction, $/MW
Up- services:				
URS	7.63	326	36.39	68
FRRS-up	7.63	30	0.27	833
RRS-Gen*	11.12	1375	3.54	4,318
RRS-Load	11.12	1365	0	∞
ERS*	6.49	865	0	∞
Down-services:				
DRS	5.69	301	37.11	46
FRRS-down	5.69	30	0.06	2,896

If CPS-1 scores were to drop below 140 due to wind/solar growth, ERCOT A/S methodology would prompt increased regulation procurement

Lowest cost Up-service

Lowest cost Down-service

* RRS-gen down capacity always assumed available, figures reflect up and down deployments; RRS-gen includes market-based PFR

** Based on procurement of ERS-10 and ERS-30 from Feb. 2016 through Jan. 2017

NON-MARKET PFR AVAILABILITY FOR REAL-TIME DEPLOYMENT IS HIGHLY UNCERTAIN

Maximum non-market PFR (up) capability:

- Capacity available for PFR (up) deployment is equal to online coal and gas-fired capacity less energy production and A/S commitment

Maximum non-market PFR (down) capability:

- Capacity available for PFR (down) deployment is equal to the sum of:
  - Lesser of 20% of online coal capacity or coal production less LSL and DRS commitment
  - Lesser of 20% of online gas-fired capacity or coal production less LSL and DRS commitment
  - Lesser of 20% of online wind capacity or wind production
  - Lesser of 20% of online solar capacity or solar production

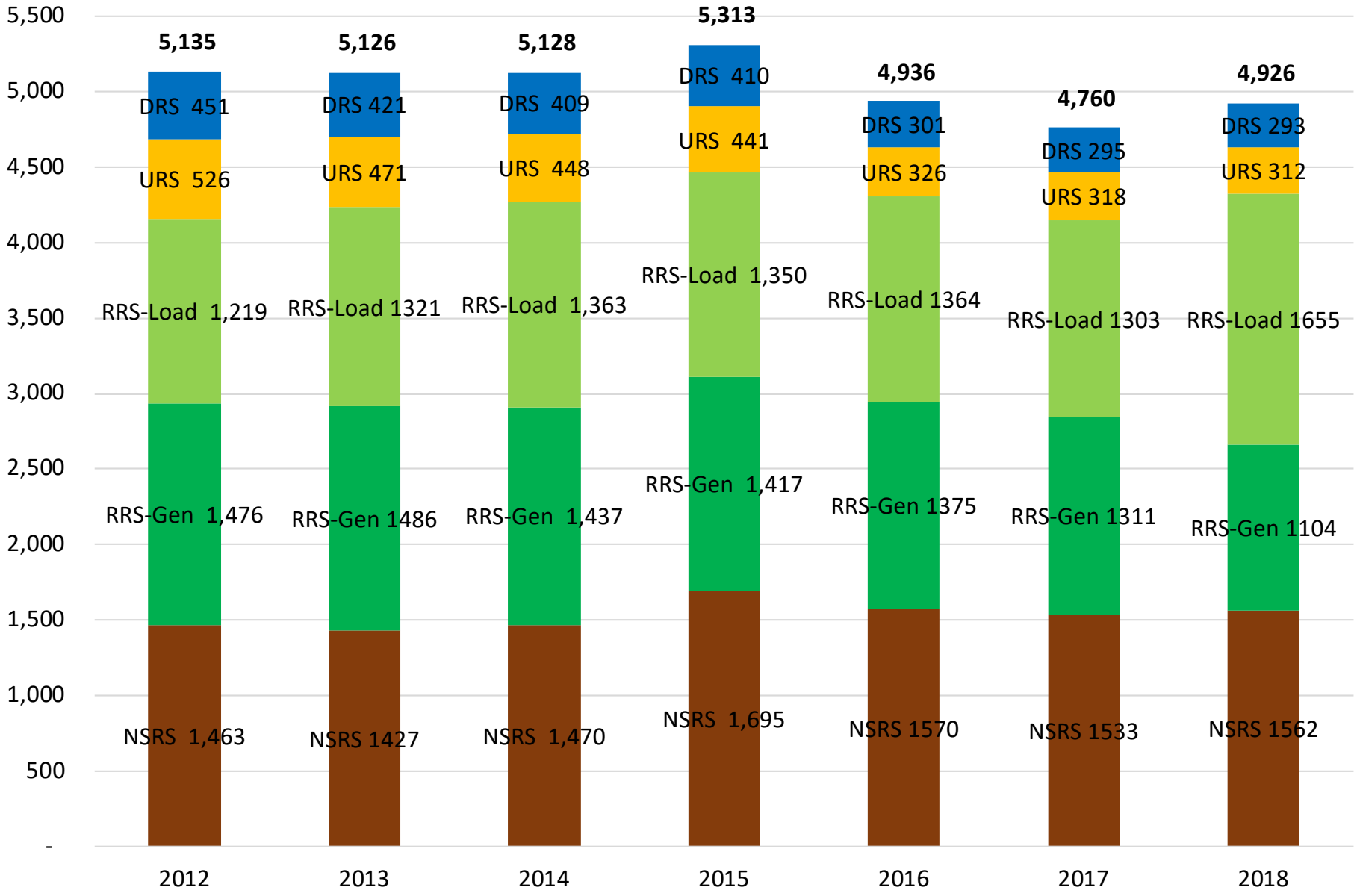
2016 capacity available for non-market PFR (up) by percentile and month

Percentile	1%	5%	50%	95%	99%
January	2,405	3,273	6,184	8,173	8,771
February	2,332	3,263	5,079	7,026	7,688
March	1,952	2,525	4,287	5,813	7,107
April	1,984	2,563	4,613	6,269	6,985
May	2,324	3,022	5,710	7,540	8,249
June	2,163	2,826	6,284	7,963	8,933
July	2,070	2,846	6,731	8,799	9,558
August	1,925	2,695	6,747	9,072	9,751
September	1,425	2,383	6,108	8,362	8,900
October	1,682	2,410	5,362	7,335	8,049
November	1,941	2,447	5,016	6,550	6,876
December	1,697	2,198	4,965	8,898	10,183

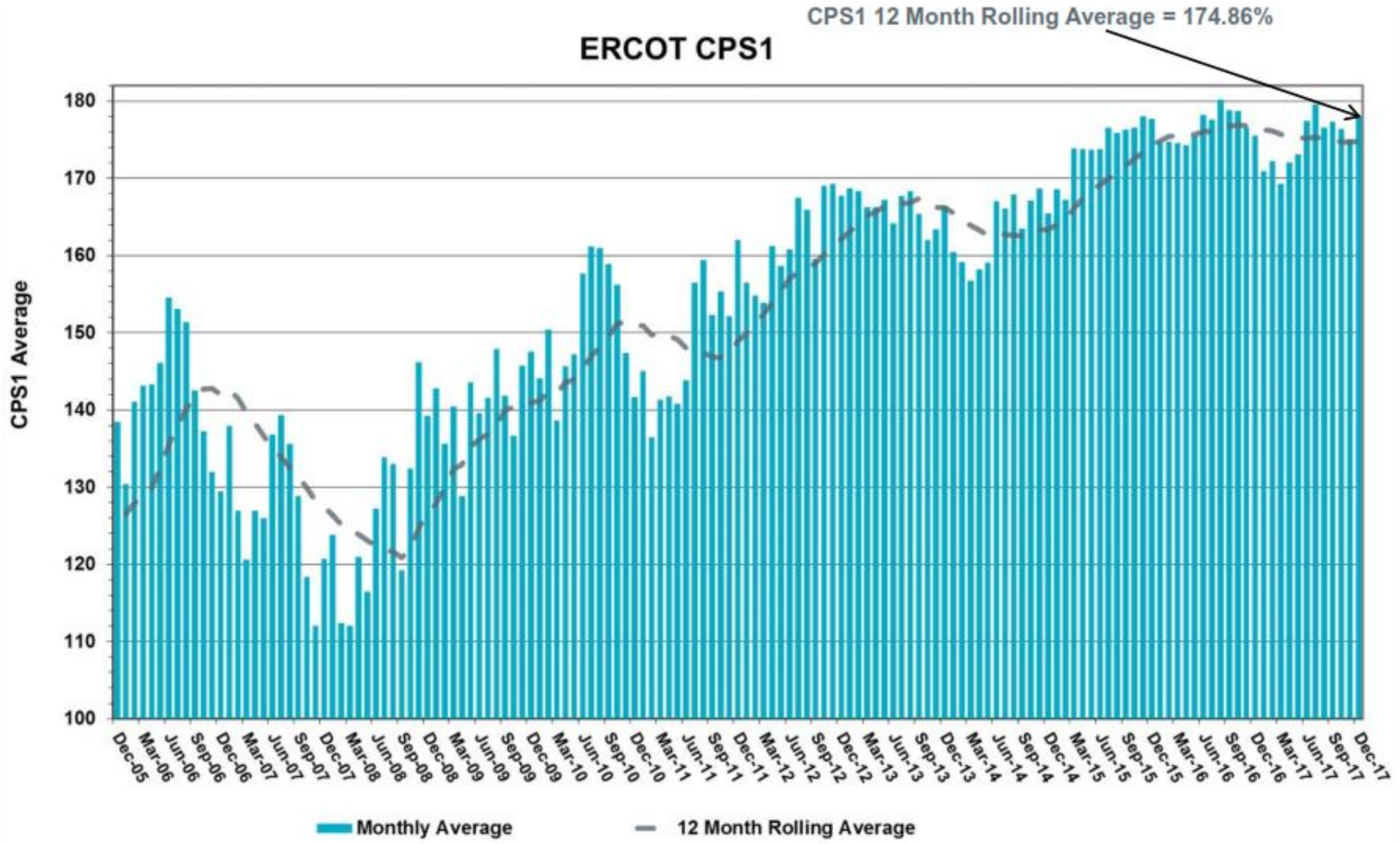
2016 capacity available for non-market PFR (down) by percentile and month

Percentile	1%	5%	50%	95%	99%
January	3,398	5,702	8,007	9,286	9,683
February	2,311	3,771	7,094	8,452	9,279
March	2,545	3,654	6,679	7,857	8,936
April	2,831	4,092	7,006	9,145	9,951
May	4,049	6,077	8,270	10,378	11,083
June	6,663	7,287	9,387	12,359	12,836
July	7,701	8,714	10,830	12,961	13,383
August	8,017	8,230	10,137	13,285	13,908
September	6,803	7,144	9,461	12,078	12,693
October	4,223	5,383	8,185	10,824	11,346
November	1,953	4,000	7,055	8,447	9,386
December	1,650	4,622	7,323	10,896	11,548

HISTORICAL VOLUME OF ANCILLARY SERVICES PRODUCTS



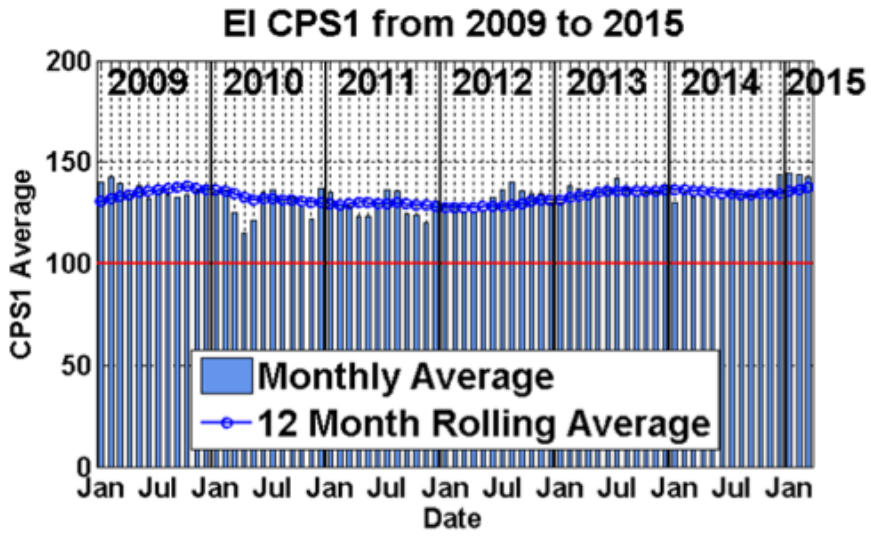
ERCOT's CPS1 Monthly Performance – December 2017

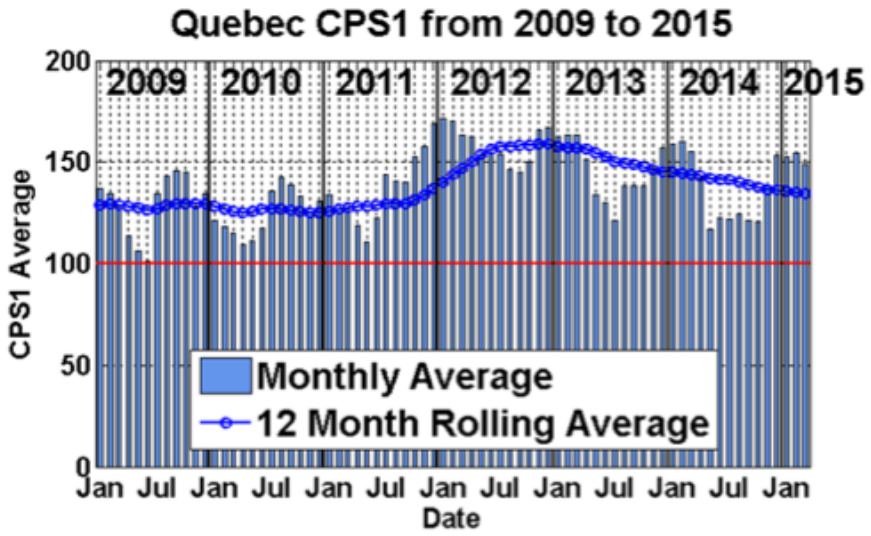


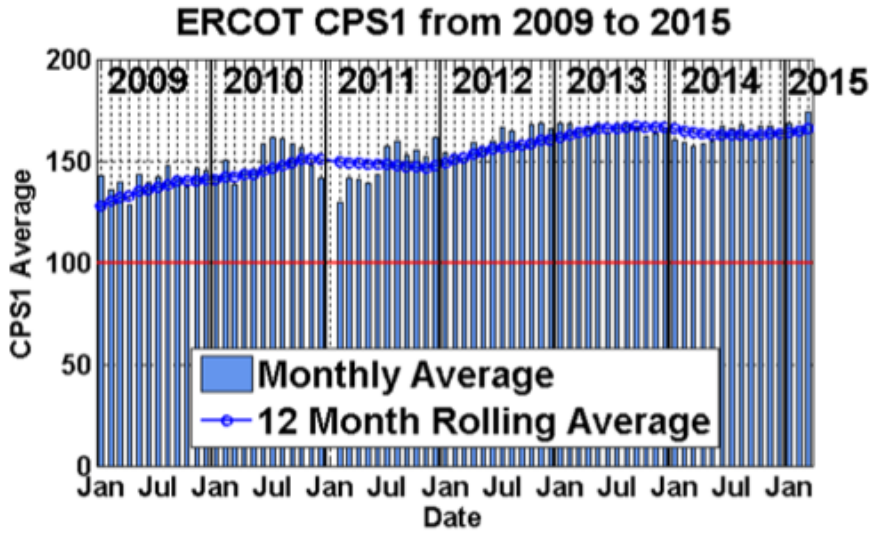
Source: ERCOT Monthly Operational Overview, December 2017

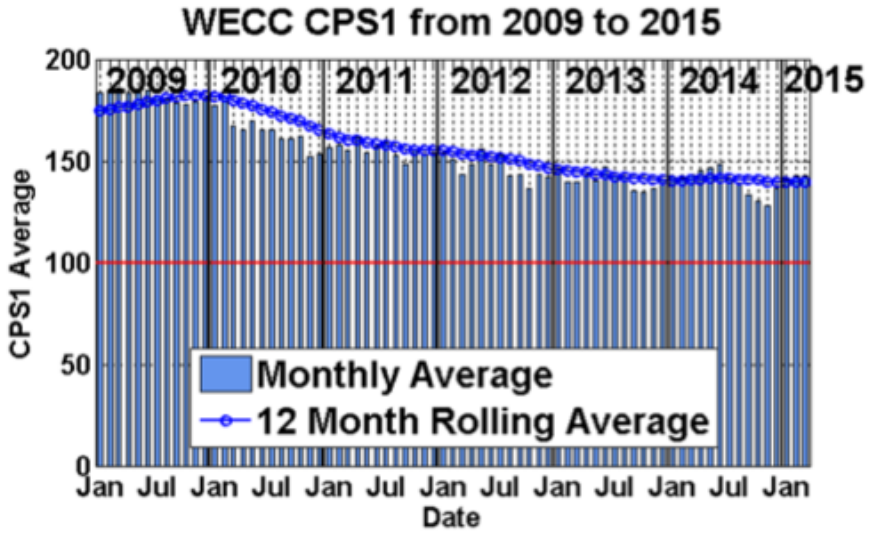
ERCOT CPS-1 SCORES ARE MUCH HIGHER THAN IN OTHER INTERCONNECTIONS

Monthly CPS1 through March 2015



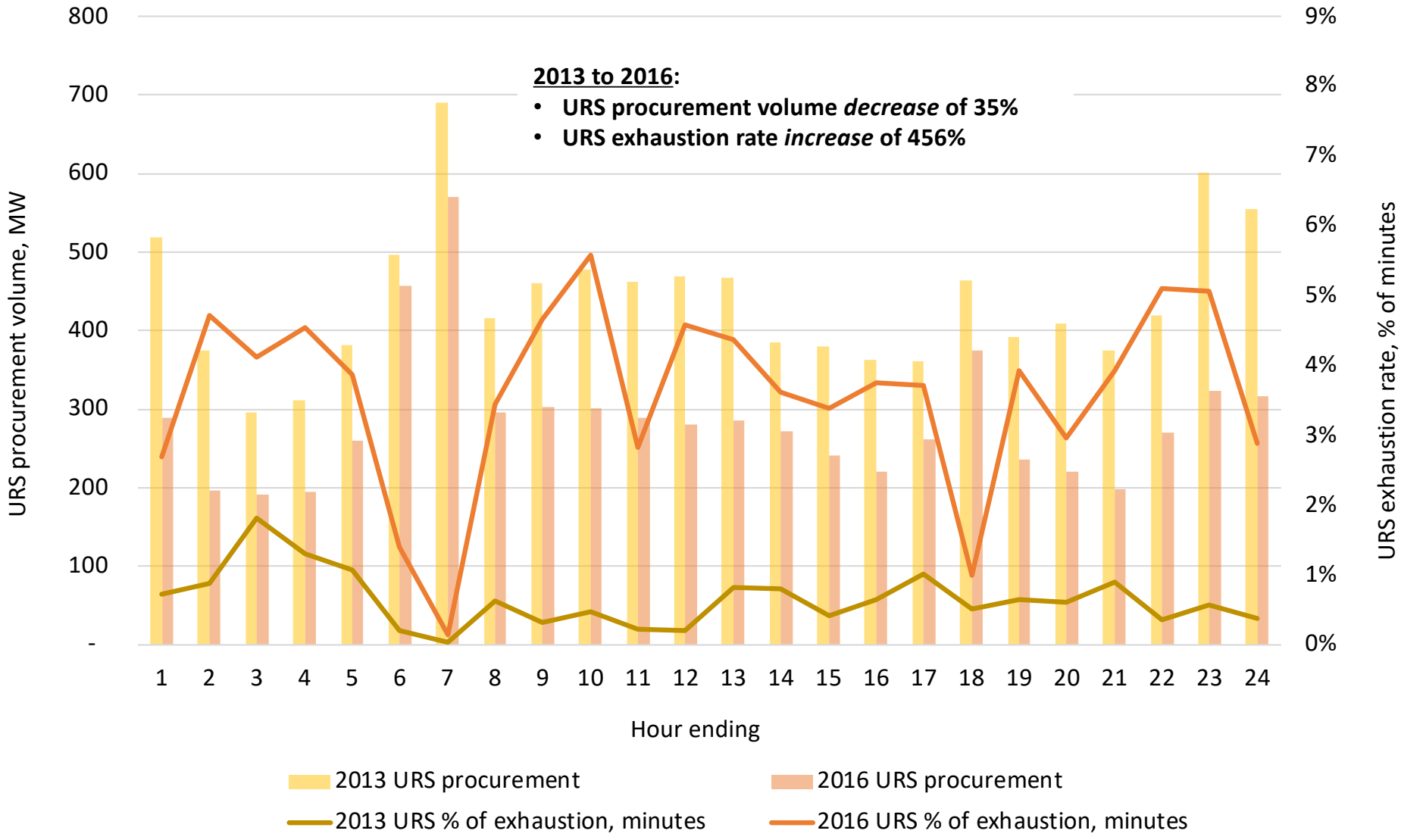






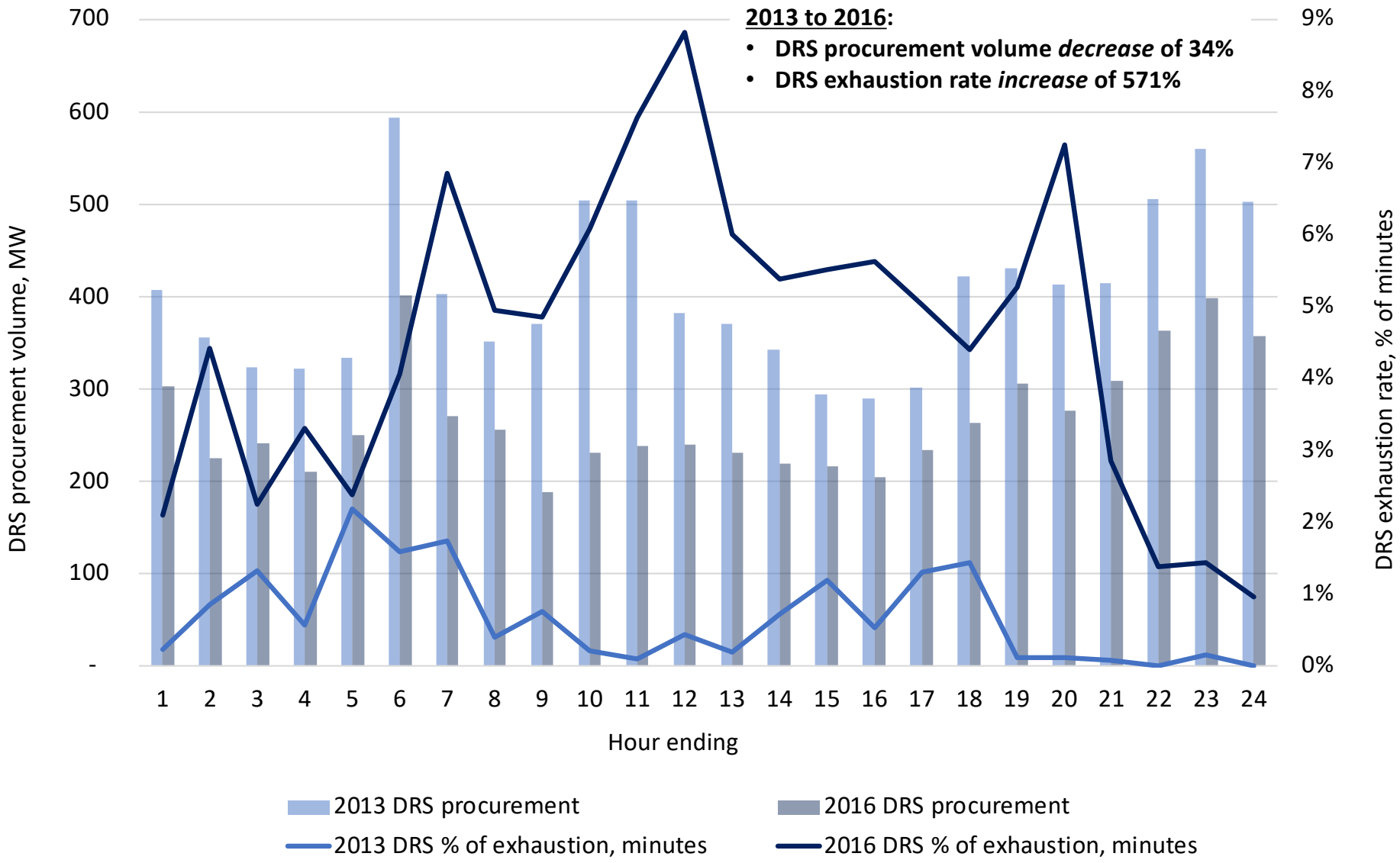
Source: TRE

URS PROCUREMENT AND EXHAUSTION OCT-DEC, 2013 VS. 2016*



* Exhaustion occurs when 1-minute deployment volume is at least 95% of hourly procurement volume; procurement volumes and exhaustion rates are calculated using 1-minute regulation deployment data for October-December, 2013 and 2016

DRS PROCUREMENT AND EXHAUSTION OCT-DEC, 2013 VS. 2016*



* Exhaustion occurs when 1-minute deployment volume is at least 95% of hourly procurement volume; procurement volumes and exhaustion rates are calculated using 1-minute regulation deployment data for October-December, 2013 and 2016