Demonstration of PFR Improvement
September 2017

ERCOT
Operations Planning

Agenda

- Overview
- BAL-001-TRE-1 Standard
- Applicability to Alternative Resources
- Ancillary Service Products & Dispatch
- Improvements & Changes
  - Frequency Profile Comparison
- Lessons Learned
- Questions

Overview

- ERCOT has implemented NERC Regional Standard BAL-001-TRE-1
  - Effective April 1st, 2015
  - Implemented governor dead-band and droop setting requirements for Generation Resources (GRs)
  - Implemented enforcement mechanisms for evaluating quality of Primary Frequency Response (PFR) from GRs
- Fast Responding Regulation Service (FRRS) being provided from storage resources (i.e. batteries).
- Improvements made to Generation to be Dispatched (GTBD) (load balance equation) and Regulation Deployment (LFC).

BAL-001-TRE-1

- Requirements of Note
  - 1: Identify Frequency Events as Frequency Measurable Events (FMEs)
  - 2 & 3: Calculate Initial & Sustained PFR for each FME and include into a Rolling Average for each GR of each GO
  - 6: Generation Resource governor dead-band and droop setting requirements:

Generator Type	Max. Deadband
Steam and Hydro Turbines with Mechanical Governors	+/- 0.034 Hz
All Other Generating Units/Generating Facilities	+/- 0.017 Hz

Generator Type	Max. Droop % Setting
Hydro	5%
Nuclear	5%
Coal and Lignite	5%
Combustion Turbine (Simple Cycle and Single-Shaft Combined Cycle)	5%
Combustion Turbine (Combined Cycle)	4%
Steam Turbine (Simple Cycle)	5%
Steam Turbine (Combined Cycle)*	5%
Diesel	5%
Wind Powered Generator	5%
DC Tie Providing Ancillary Services	5%
Renewable (Non-Hydro)	5%

Combined Cycle facilities get evaluated using a 5.78% droop setting to account for lack of PFR coming from Steam Turbine.

BAL-001-TRE-1

- Requirements of Note (cont'd.)
  - 7 & 8: Each GO must operate each GR with settings in R6 when it is online and available for dispatch, unless the GO has a valid reason not to. GO must inform ERCOT within 30mins if a governor is to be out of service.
  - 9 & 10: Each GO must maintain a 12-month rolling average PFR score of 0.75 (75%) or higher.
    - Opportunities for exemptions/re-evaluations

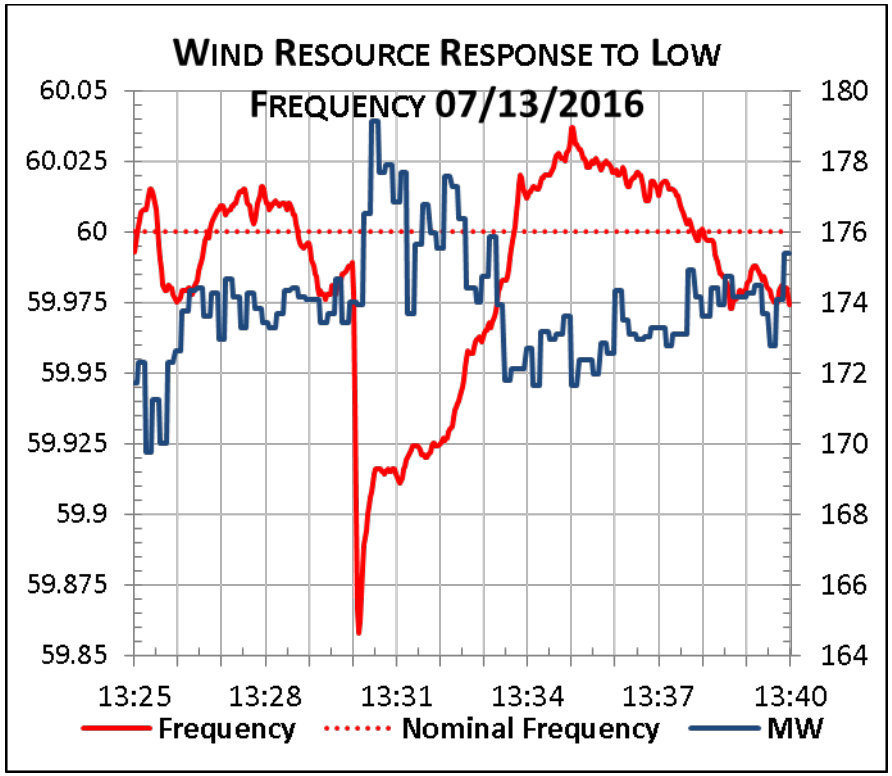
BAL-001-TRE-1

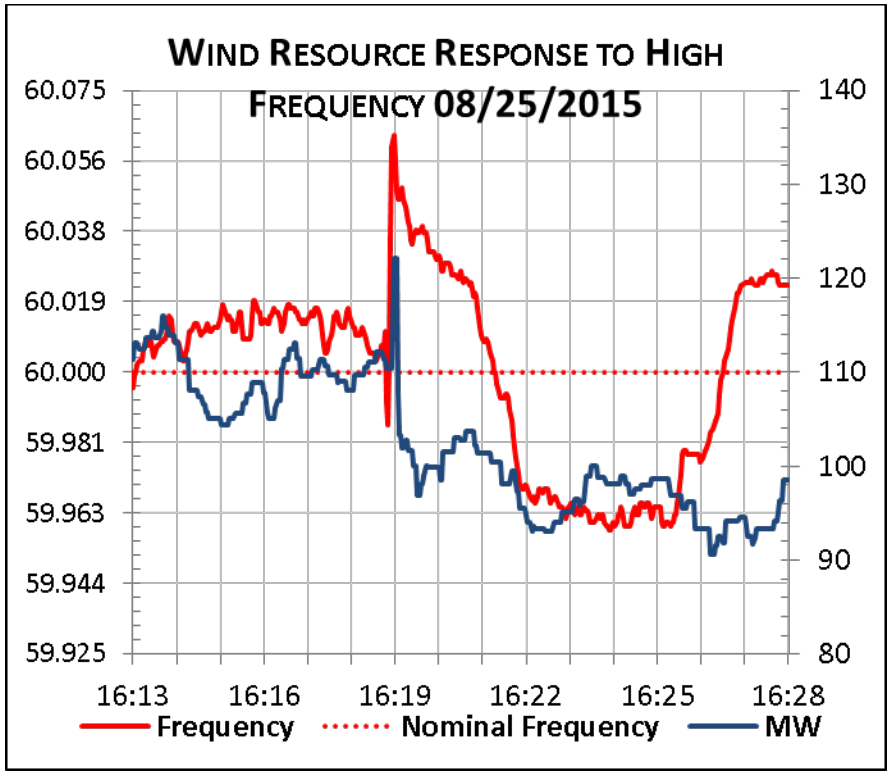
- Increases amount of governor action from GRs.
  - Improves frequency control performance (CPS1)
- Improves PFR during frequency events
  - Faster recovery times
  - Dampens initial excursion (governor dead-bands tighter)
  - Better Interconnection Combined Frequency Response Performance (R4 & R5)
- All GRs required to provide PFR with defined governor dead-band and droop settings.
  - Changed requirement from 36mHz to 17mHz on most GRs
  - Regardless if they are in Responsive Reserve (RRS) (contingency reserves) market
  - No current PFR market (no payment for providing PFR

Alternative Resources & PFR

- Storage Resources
  - Subject to BAL-001-TRE-1
  - Participate in FRRS market
- Wind & Solar Resources
  - Subject to BAL-001-TRE-1
  - Have required governor dead-band and droop settings.
    - Have had requirement since 2010. BAL-001-TRE-1 changed dead-band requirement from 36mHz to 17mHz.
  - All Resources only expected to provide PFR when they have enough headroom for low frequency events.
  - Wind & Solar typically dispatched to their Pmax (HSL), typically do not have headroom.
    - No headroom = not evaluated for PFR during FMEs.
  - PFR performance from Wind & Solar has thus far been satisfactory.

Alternative Resources & PFR





Ancillary Service Products & Dispatch

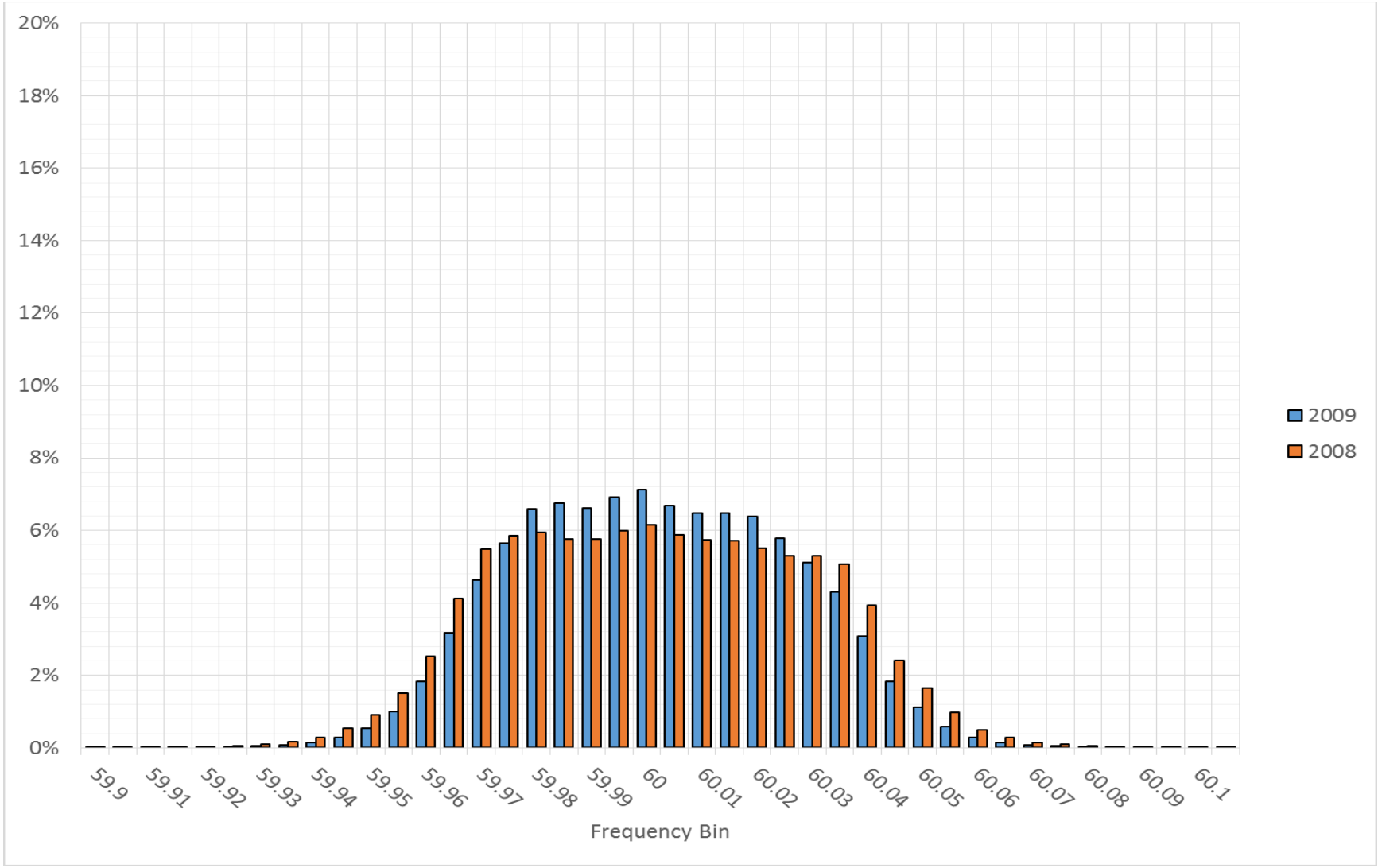
- Regulation (AGC)
  - Annually/seasonally tune AGC parameters for regulation deployment.
- FRRS
  - Typically carried by storage resources (batteries.)
  - Deployed on a step scale based on frequency.
  - Maximum deployment time typically around 5-minutes.
- Energy Dispatch
  - Include ACE Integral in load balance equation
    - Dispatches energy to recent frequency trends
  - Include regulation deployment in load balance equation
    - Helps recover regulation deployment

Improvements & Changes

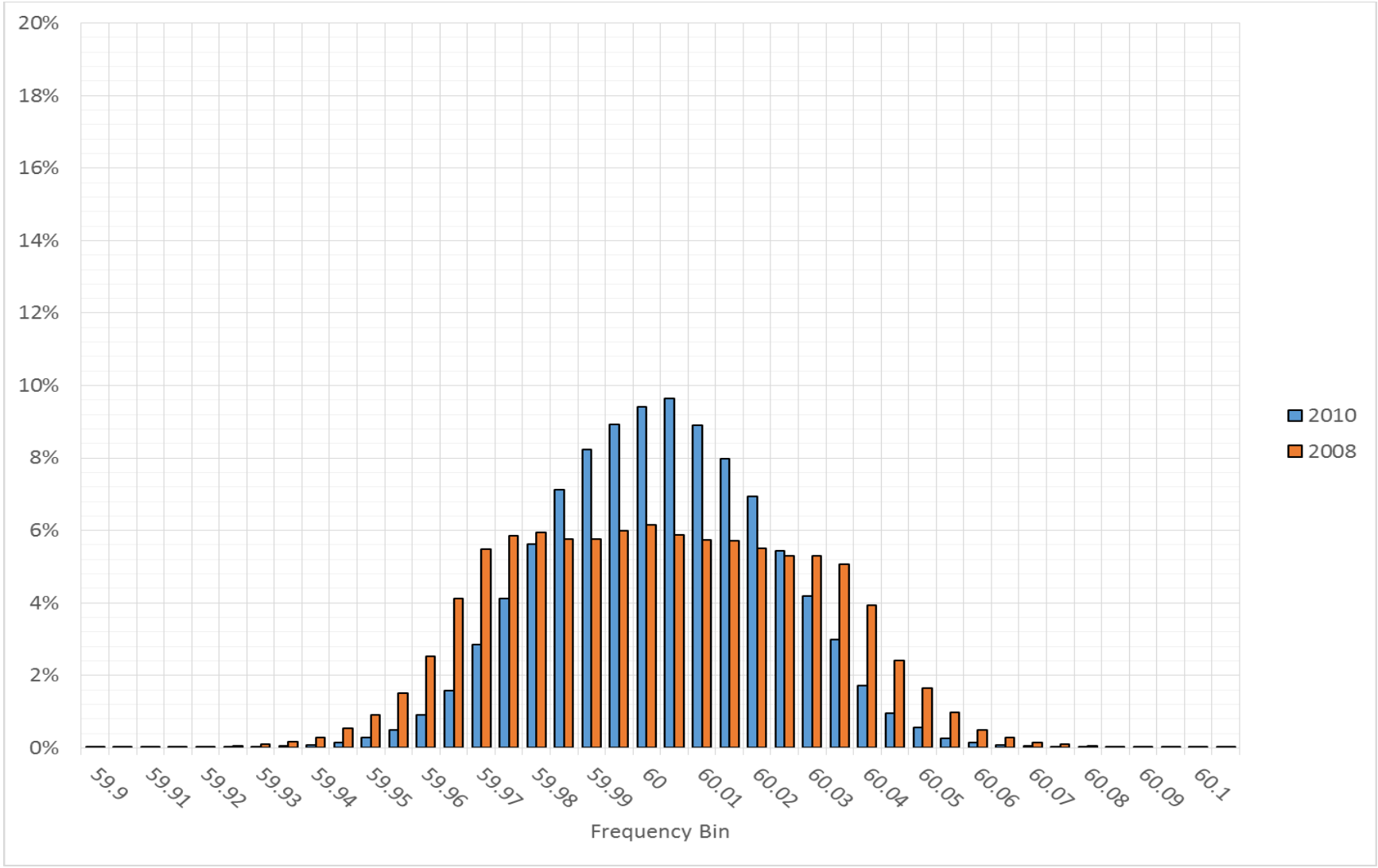
Frequency Profile Comparison, etc.

2008 - 2017

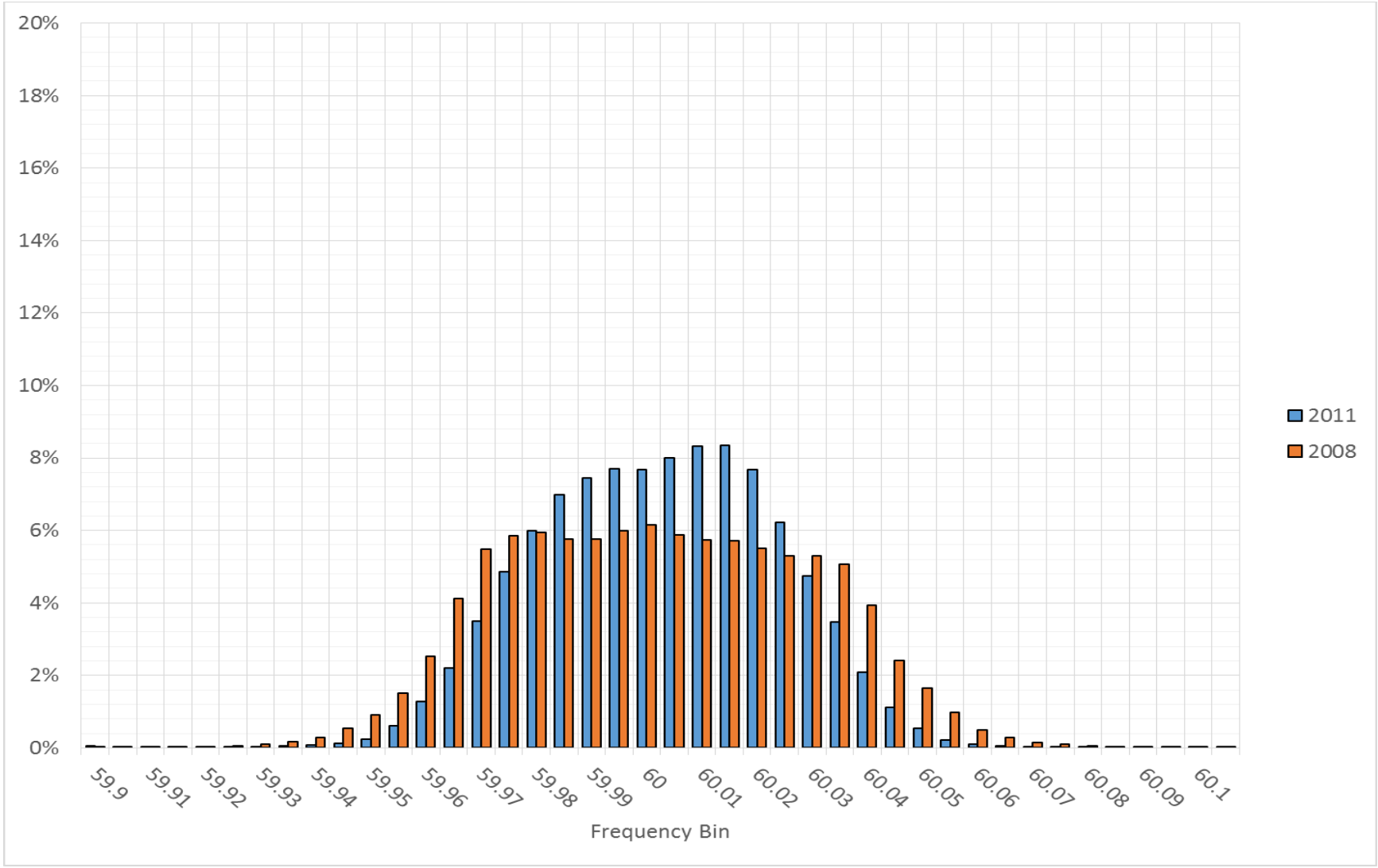
Comparing 2009 vs 2008 Frequency Profile in 5 mHz Bins



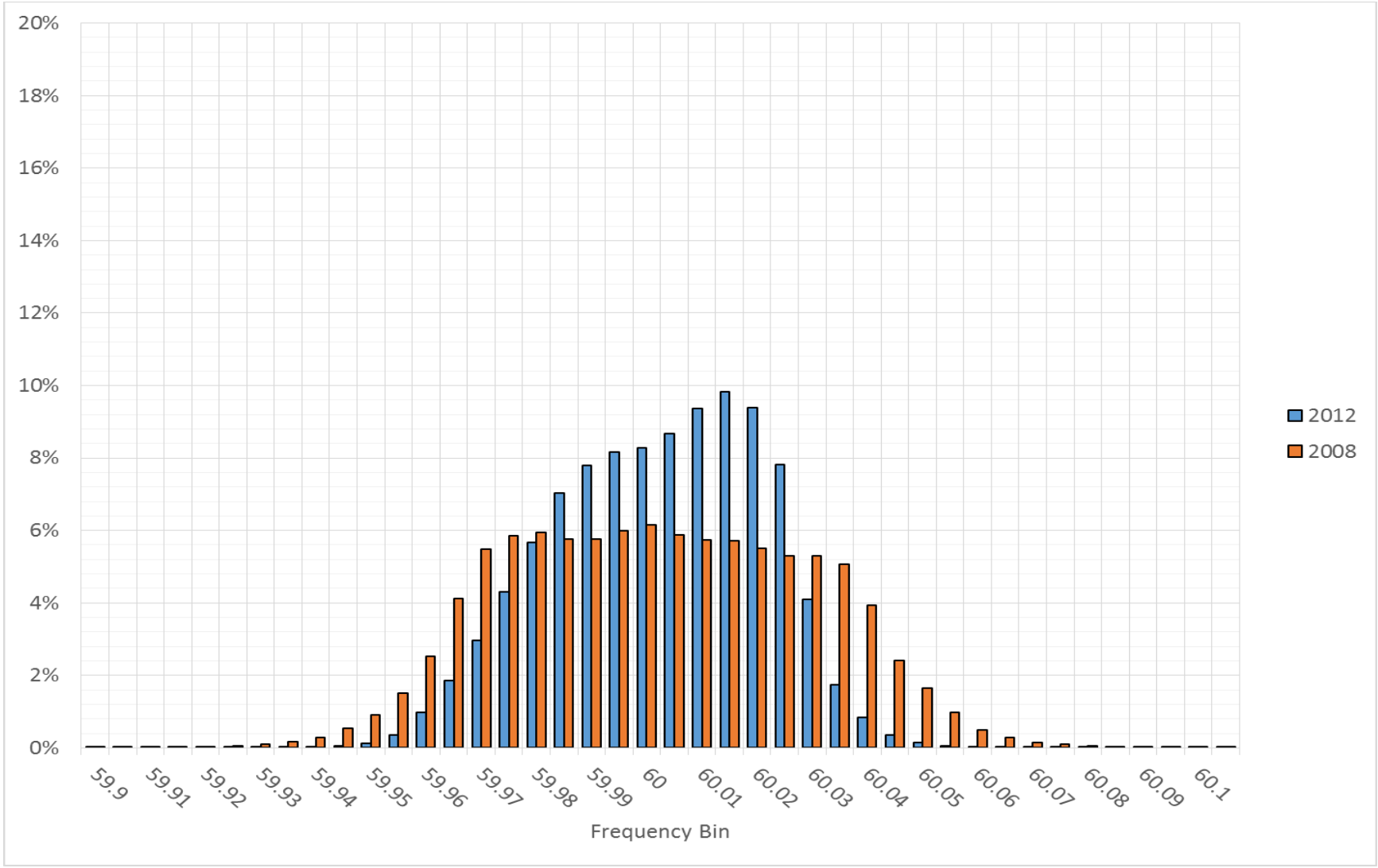
Comparing 2010 vs 2008 Frequency Profile in 5 mHz Bins



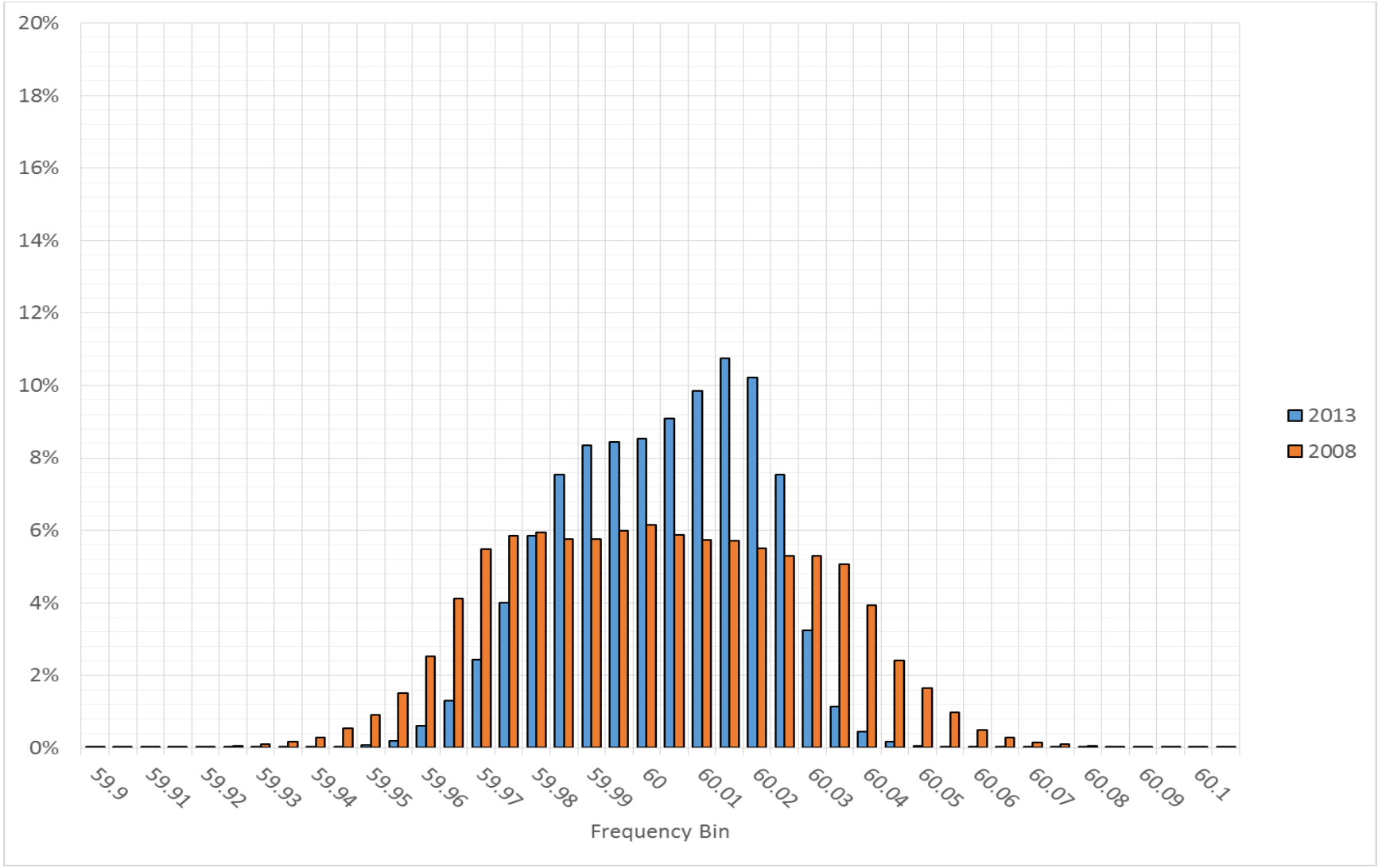
Comparing 2011 vs 2008 Frequency Profile in 5 mHz Bins



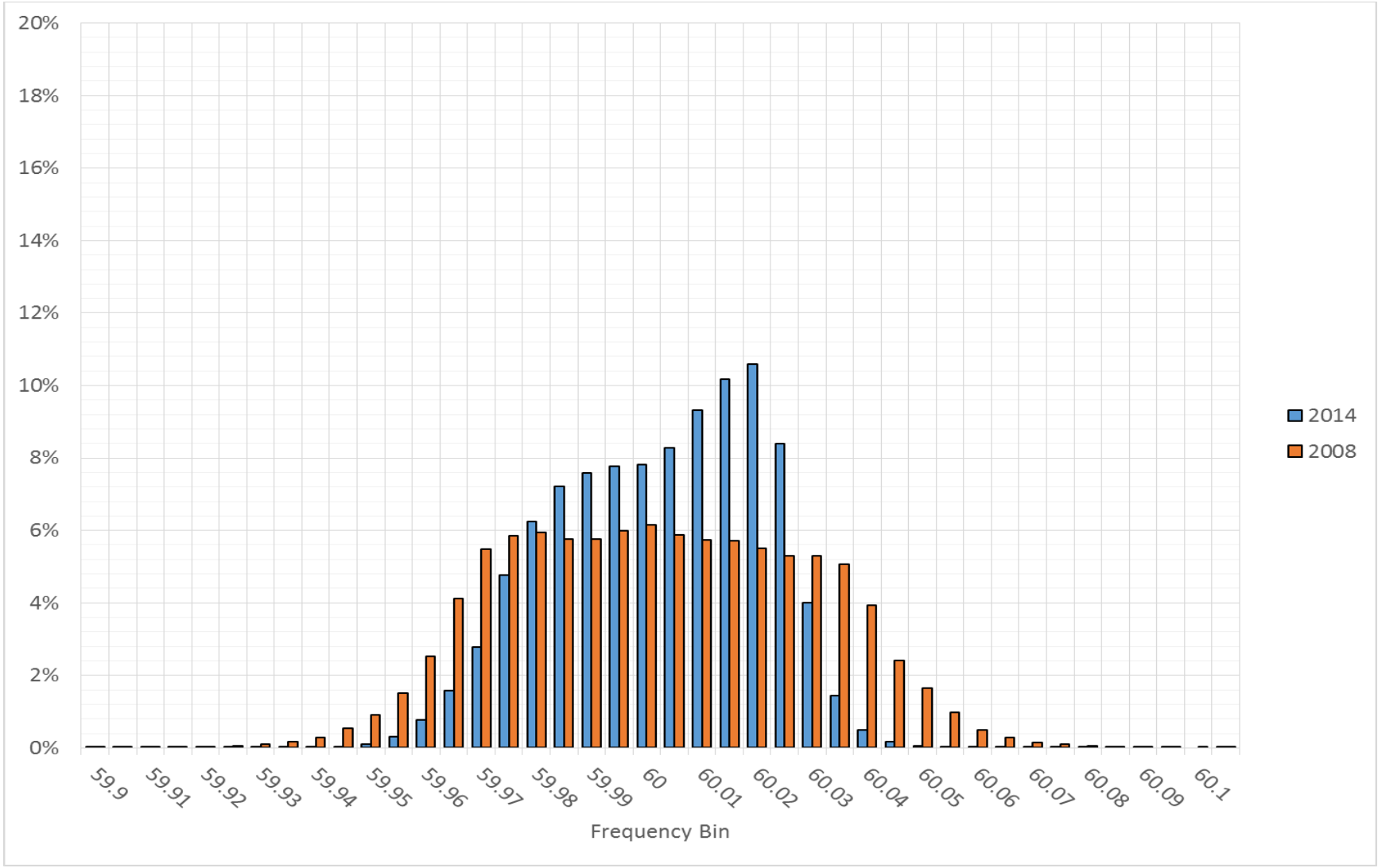
Comparing 2012 vs 2008 Frequency Profile in 5 mHz Bins



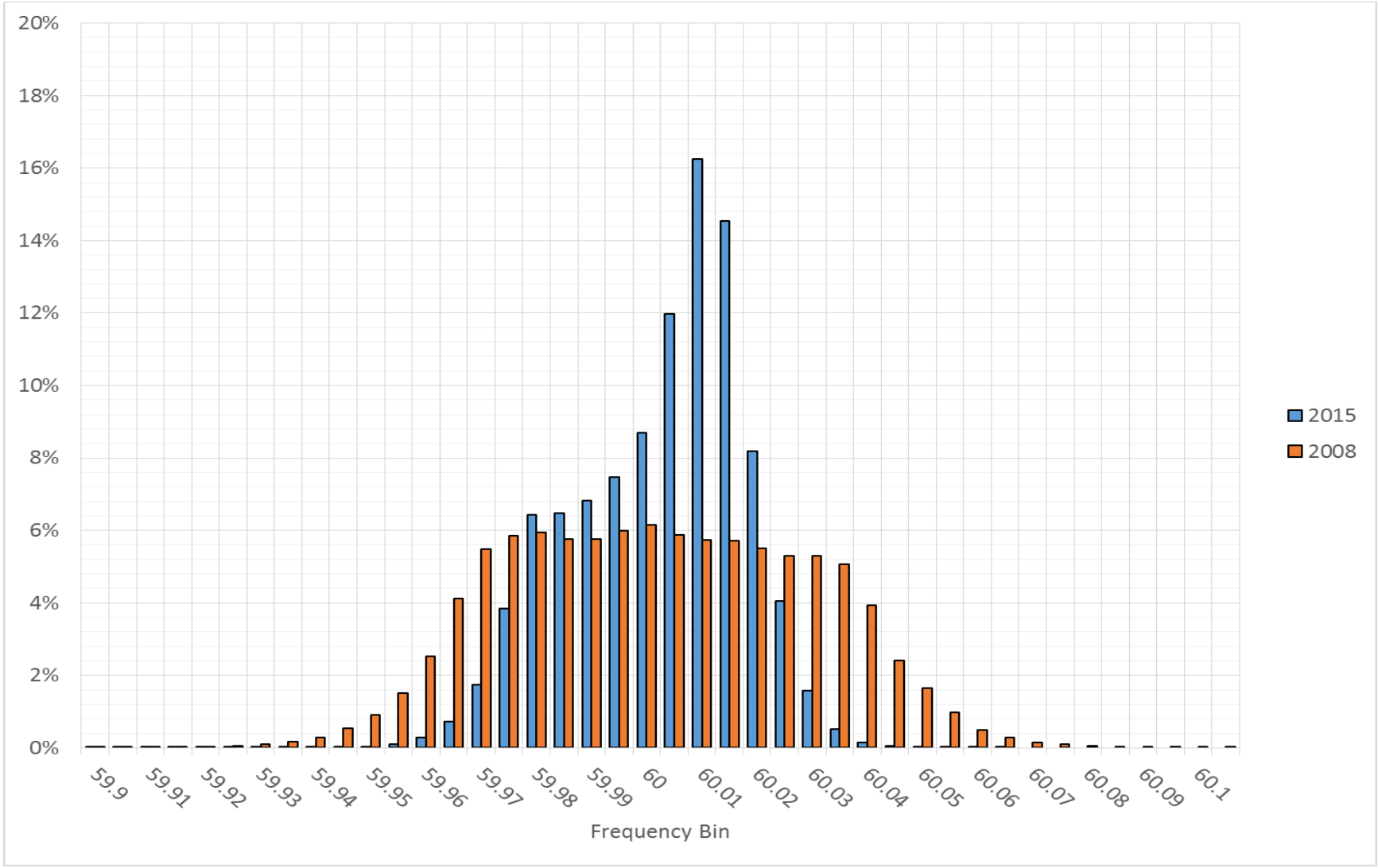
Comparing 2013 vs 2008 Frequency Profile in 5 mHz Bins



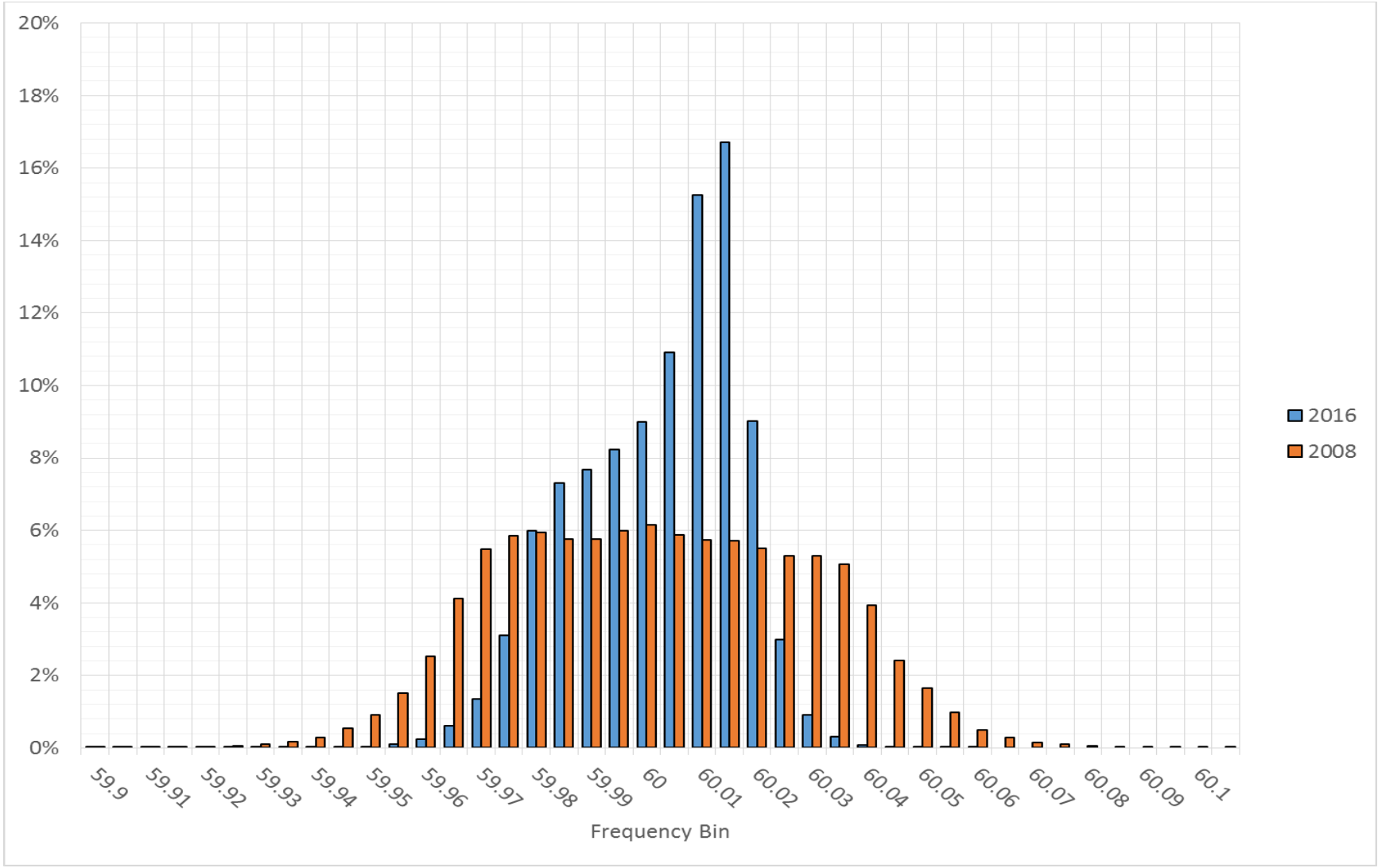
Comparing 2014 vs 2008 Frequency Profile in 5 mHz Bins



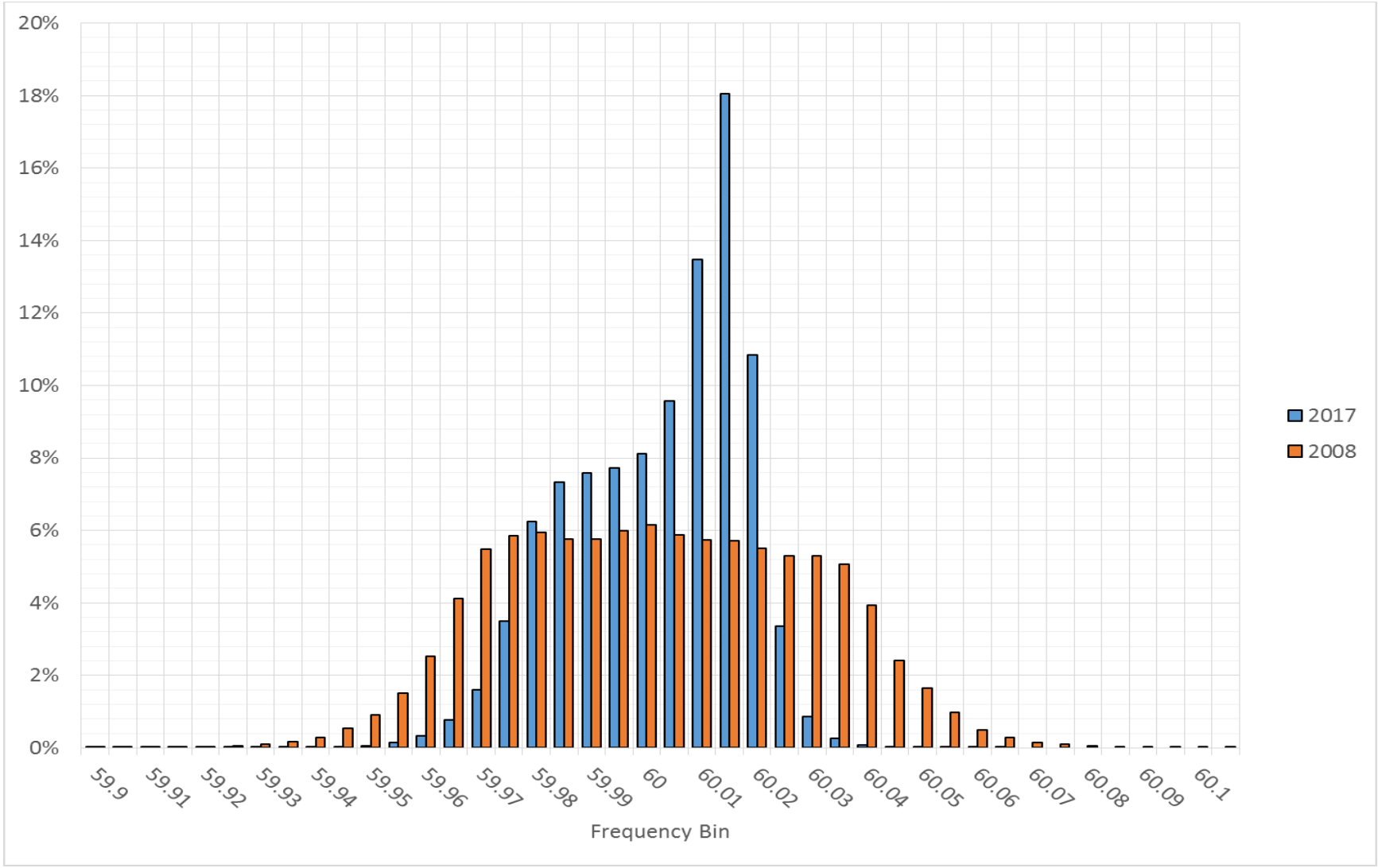
Comparing 2015 vs 2008 Frequency Profile in 5 mHz Bins



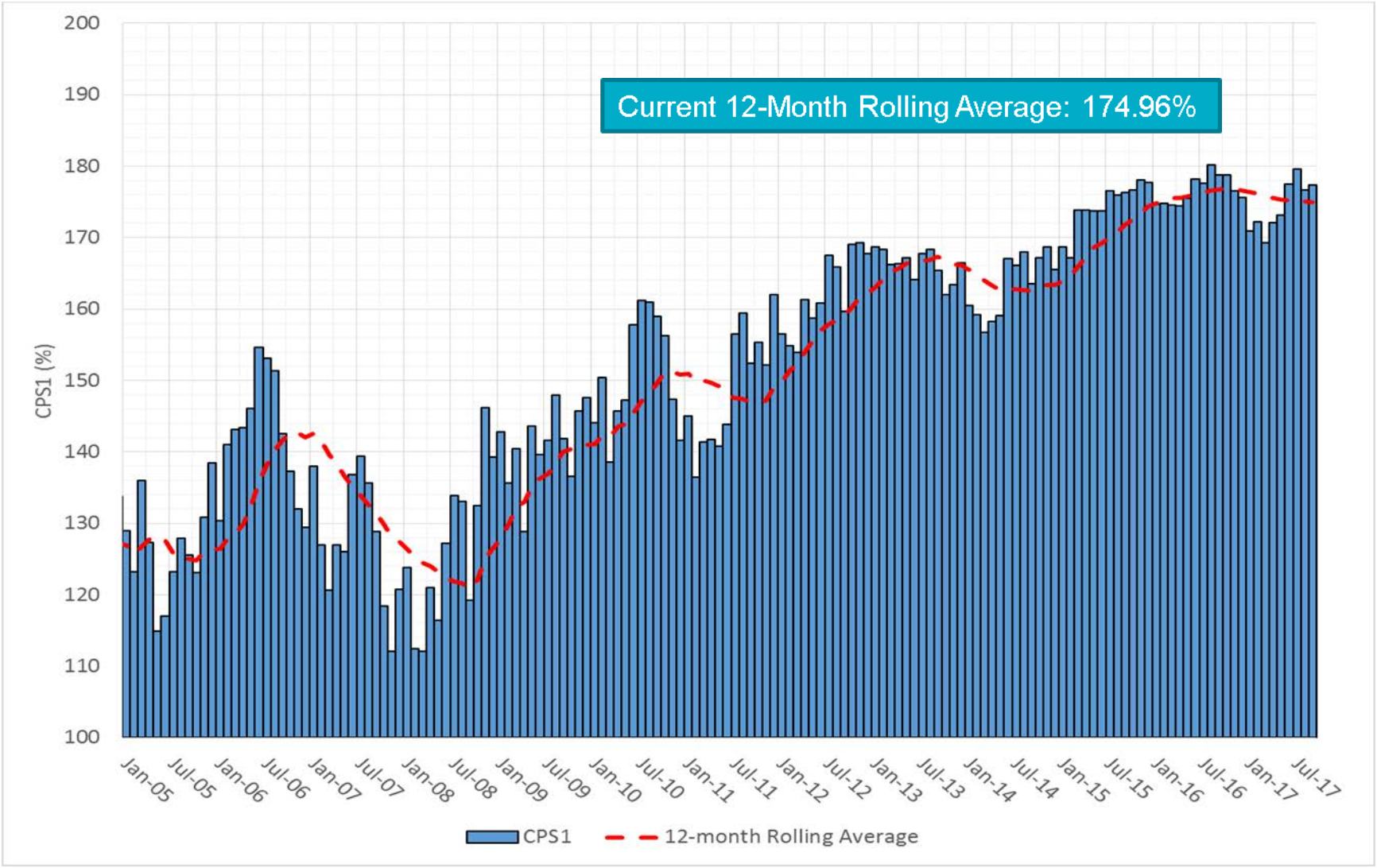
Comparing 2016 vs 2008 Frequency Profile in 5 mHz Bins



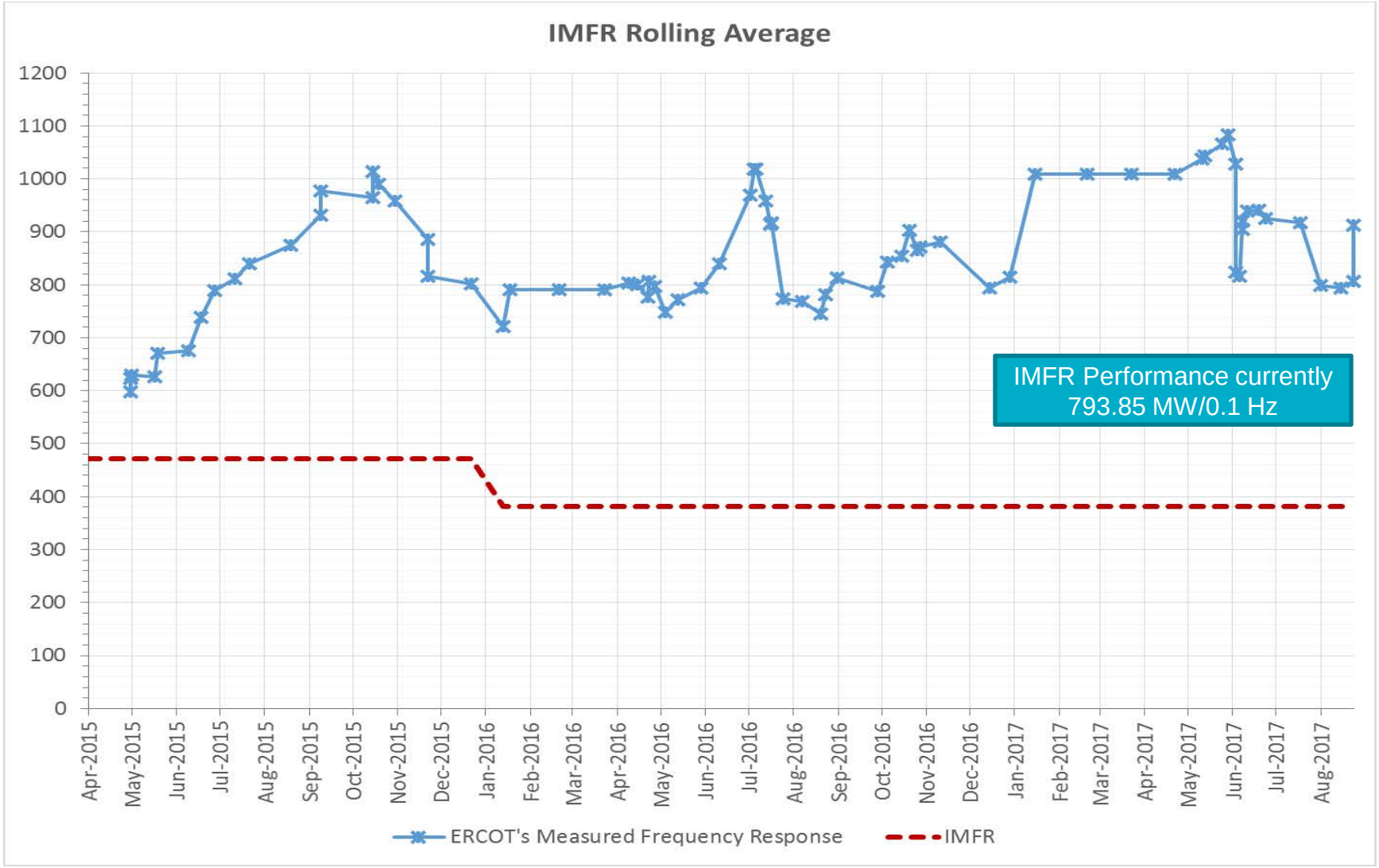
Comparing 2017 vs 2008 Frequency Profile in 5 mHz Bins



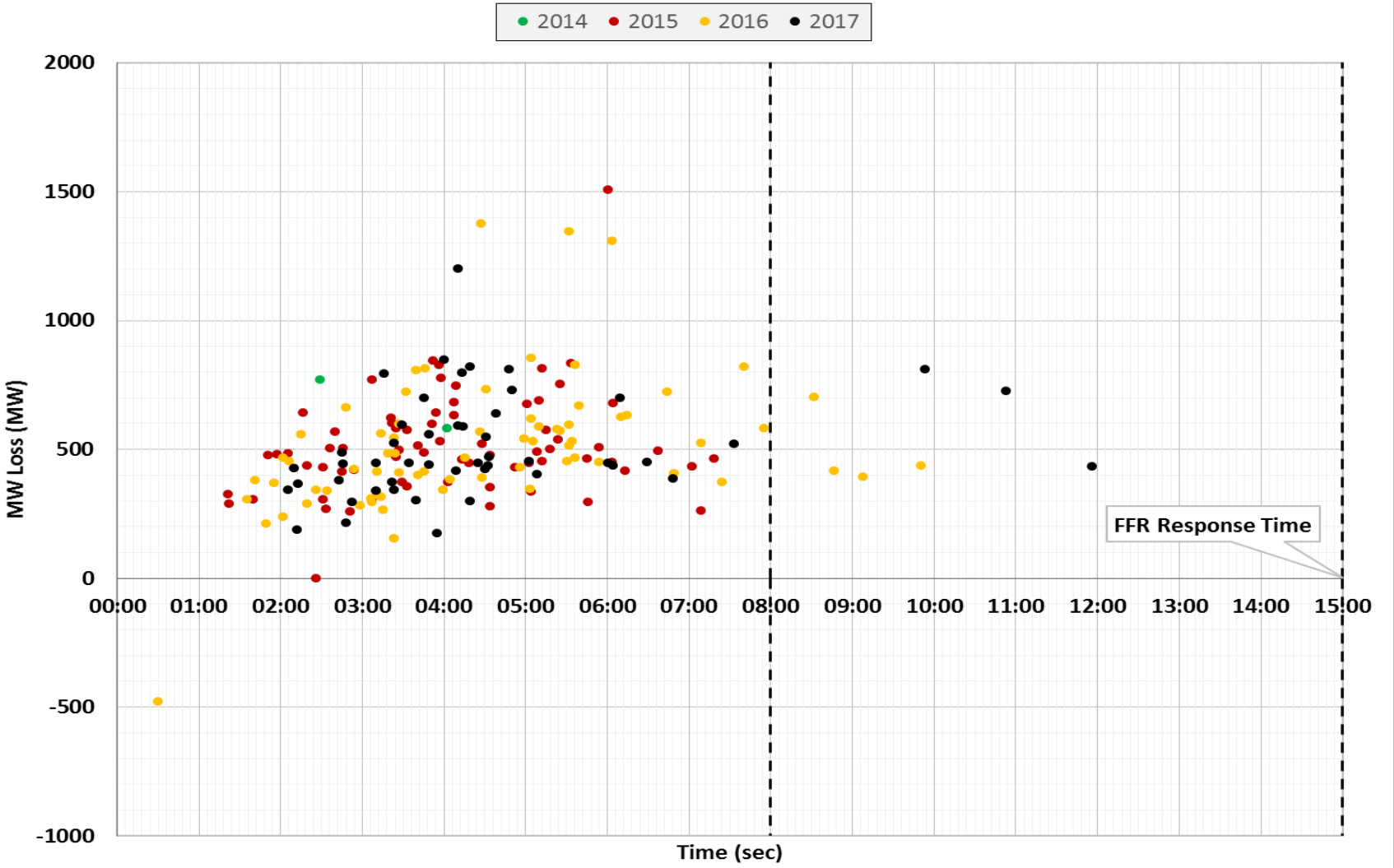
Rolling Average CPS1



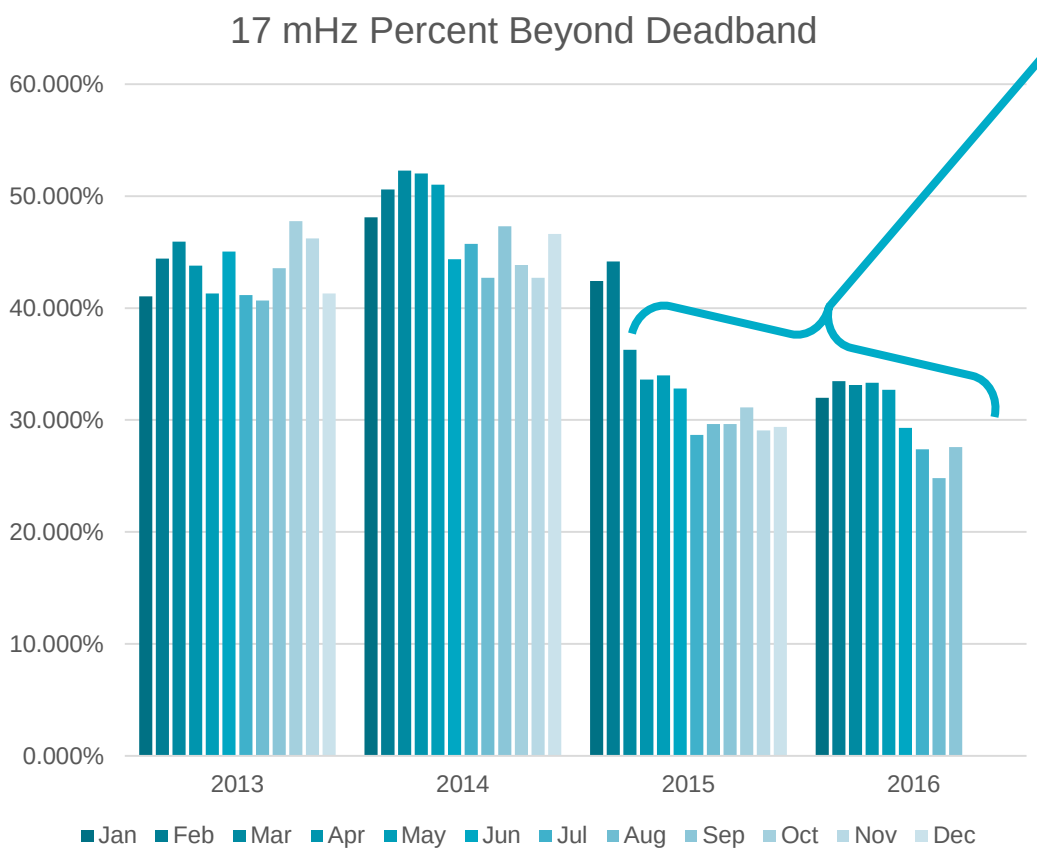
Interconnection Minimum Frequency Response (IMFR) Performance



MW Loss vs. Frequency Recovery Time



Percent Beyond Dead-band – 17mHz

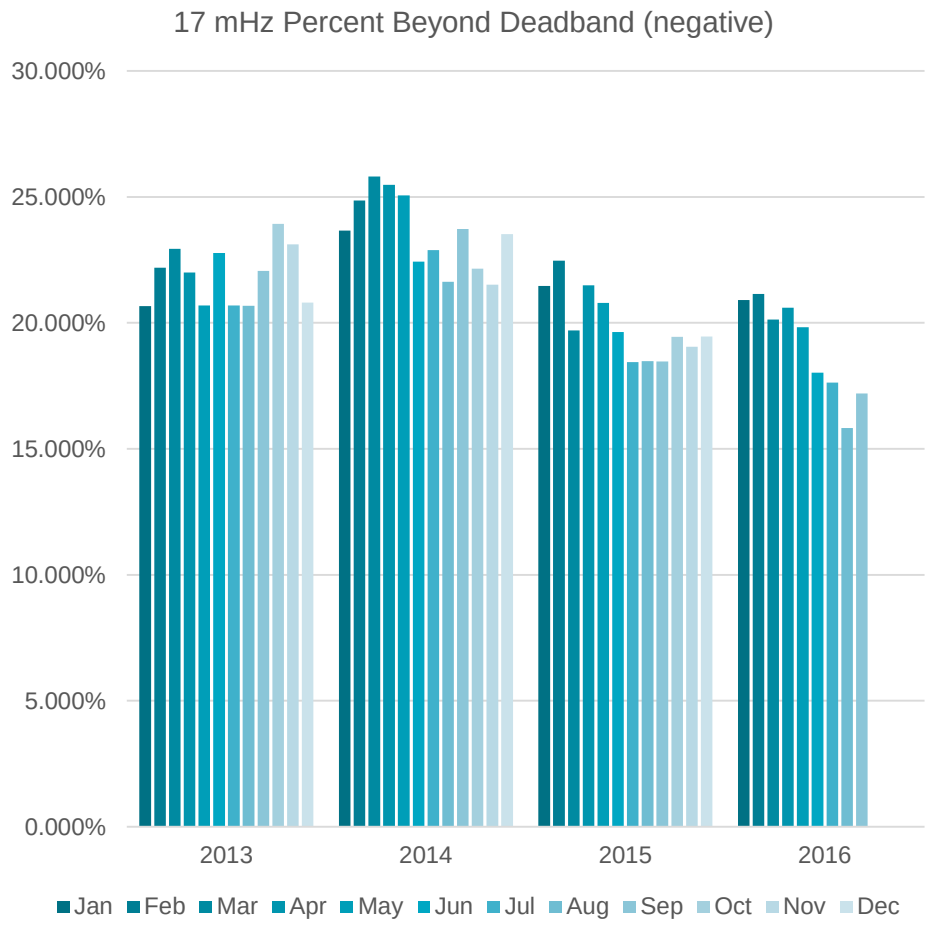


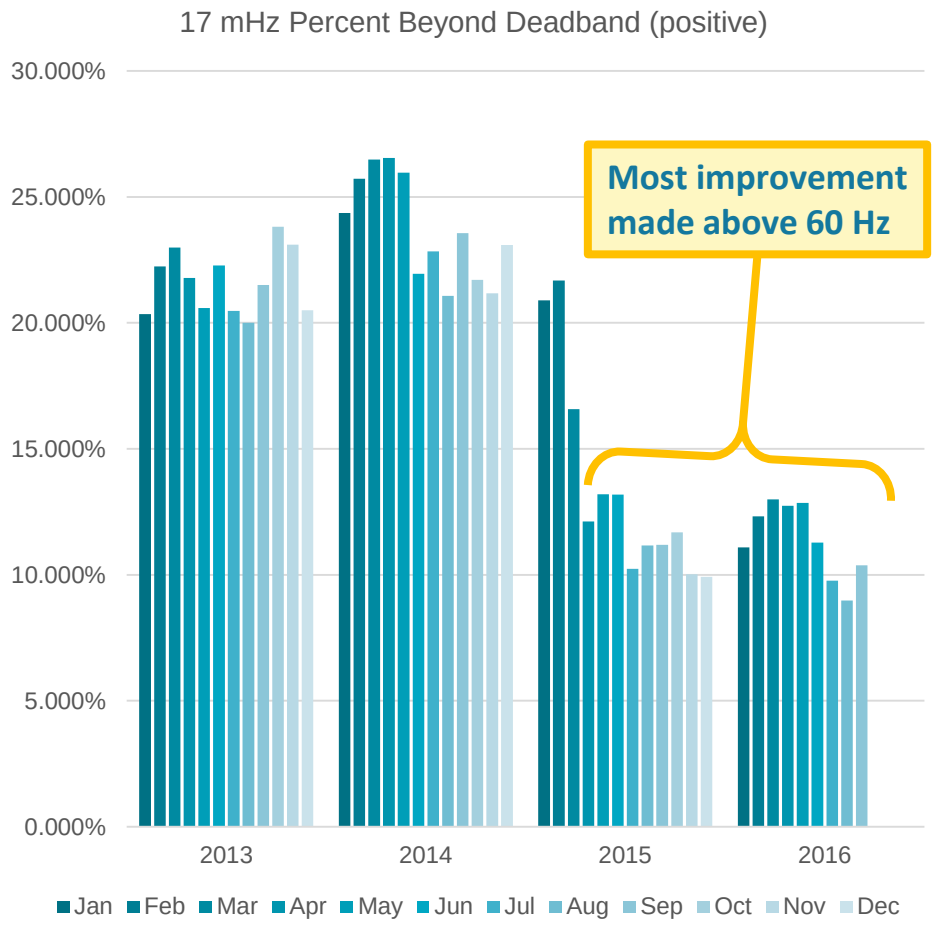
Significant improvement after March 2015

Percent Beyond Dead-band				
	2013	2014	2015	2016
Jan	41.051%	48.102%	42.429%	31.995%
Feb	44.427%	50.586%	44.148%	33.458%
Mar	45.921%	52.290%	36.276%	33.128%
Apr	43.779%	52.026%	33.607%	33.334%
May	41.289%	51.019%	33.985%	32.685%
Jun	45.053%	44.369%	32.814%	29.301%
Jul	41.170%	45.723%	28.677%	27.393%
Aug	40.682%	42.703%	29.639%	24.815%
Sep	43.564%	47.292%	29.652%	27.573%
Oct	47.753%	43.855%	31.120%	-
Nov	46.212%	42.698%	29.067%	-
Dec	41.306%	46.615%	29.385%	-

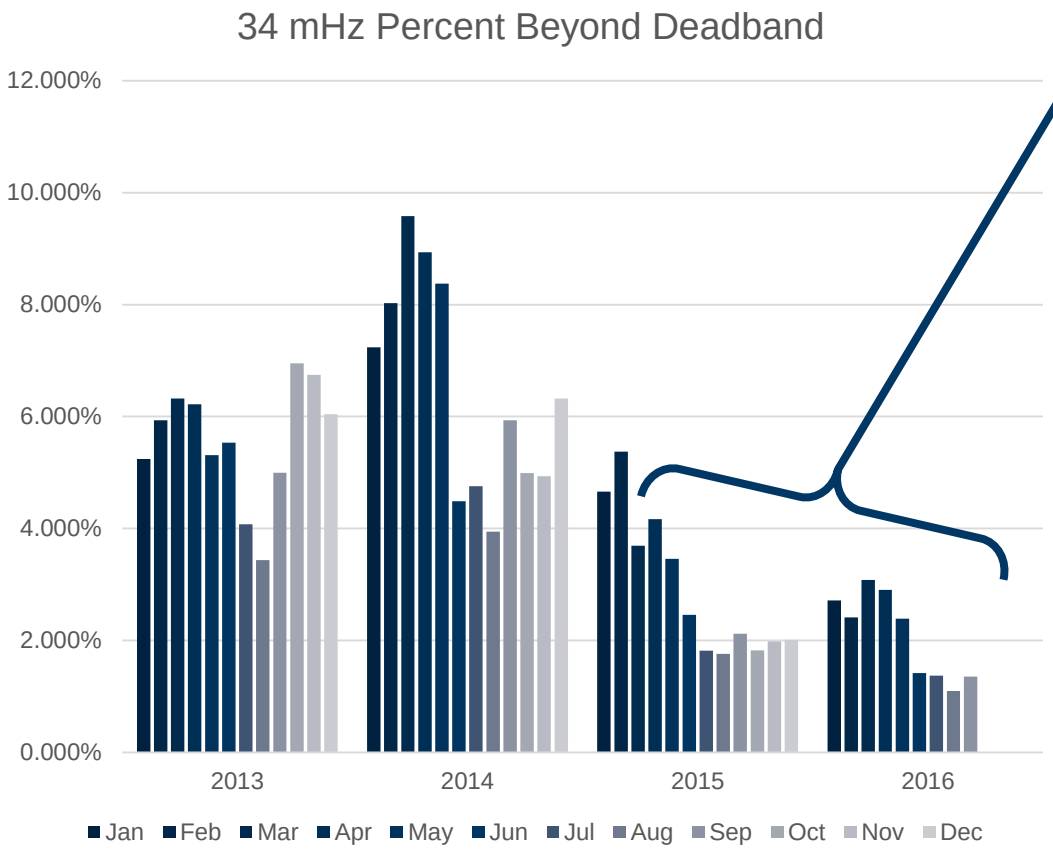
*Any interval outside deadband is counted.

17 mHz Below & Above Deadband Comparison





Percent Beyond Dead-band – 34mHz

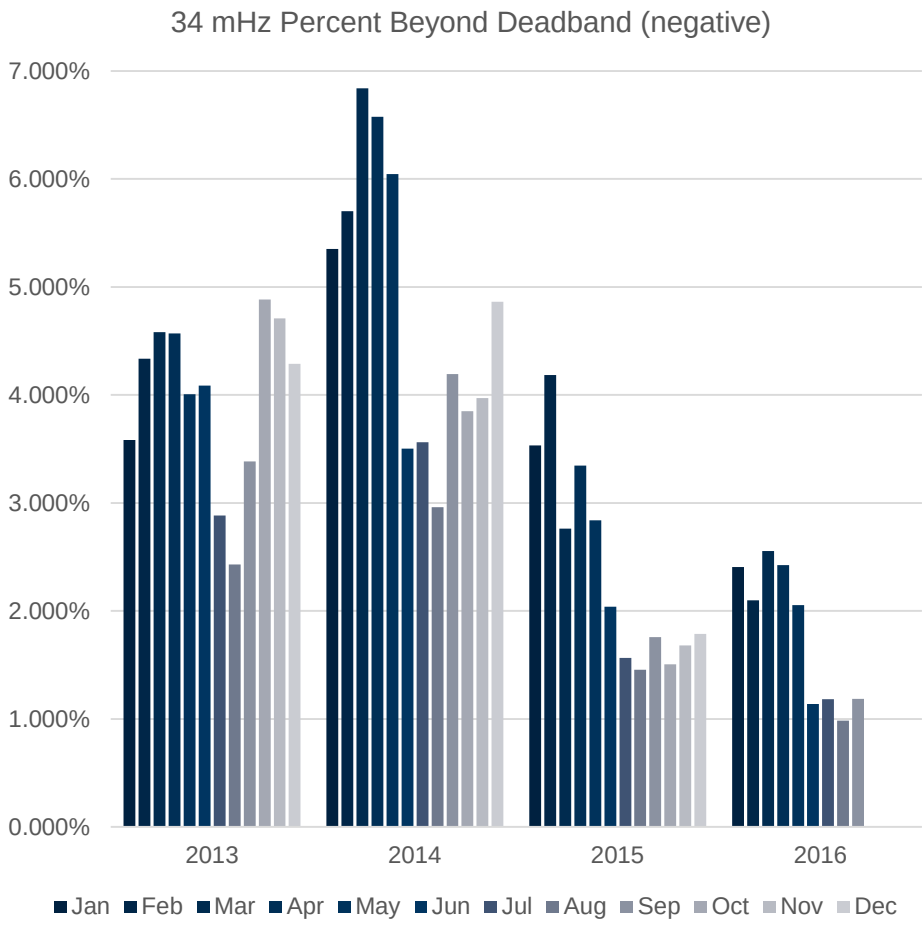


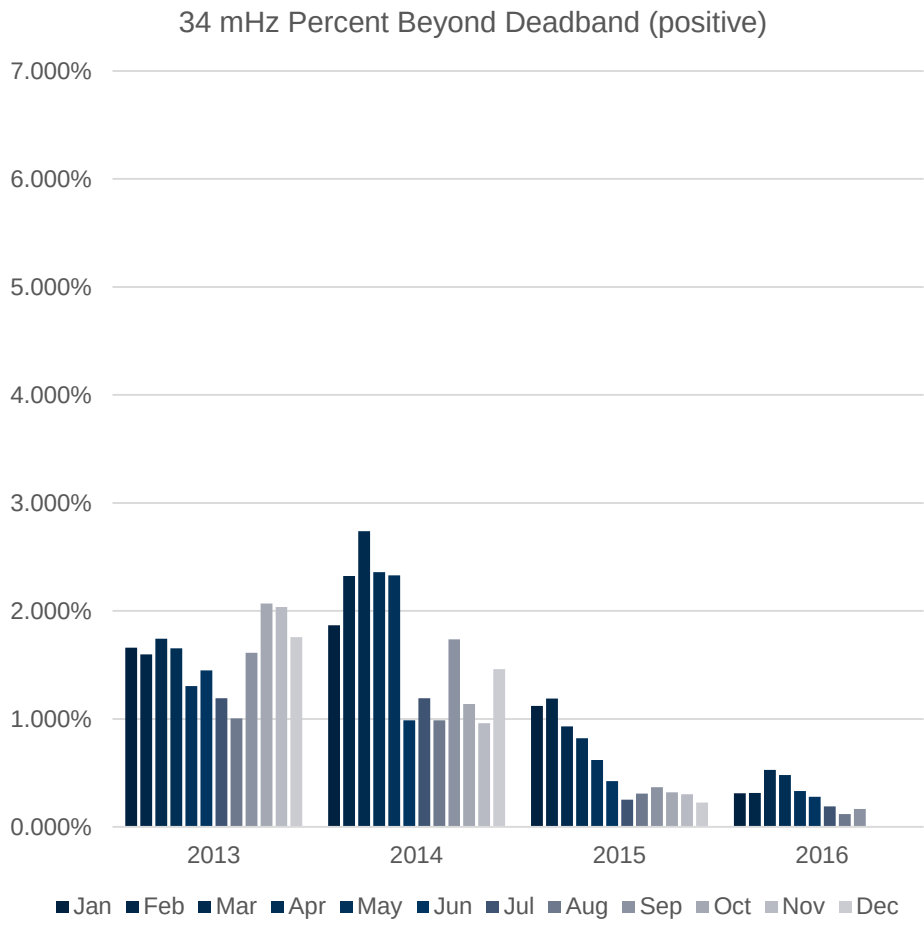
Significant improvement after March 2015

Percent Beyond Dead-band				
	2013	2014	2015	2016
Jan	1.661%	1.868%	1.121%	0.310%
Feb	1.598%	2.324%	1.187%	0.313%
Mar	1.742%	2.739%	0.931%	0.526%
Apr	1.652%	2.359%	0.819%	0.481%
May	1.303%	2.329%	0.619%	0.332%
Jun	1.450%	0.986%	0.422%	0.278%
Jul	1.190%	1.193%	0.253%	0.188%
Aug	1.006%	0.986%	0.307%	0.117%
Sep	1.611%	1.737%	0.366%	0.167%
Oct	2.068%	1.137%	0.319%	-
Nov	2.036%	0.959%	0.301%	-
Dec	1.756%	1.460%	0.225%	-

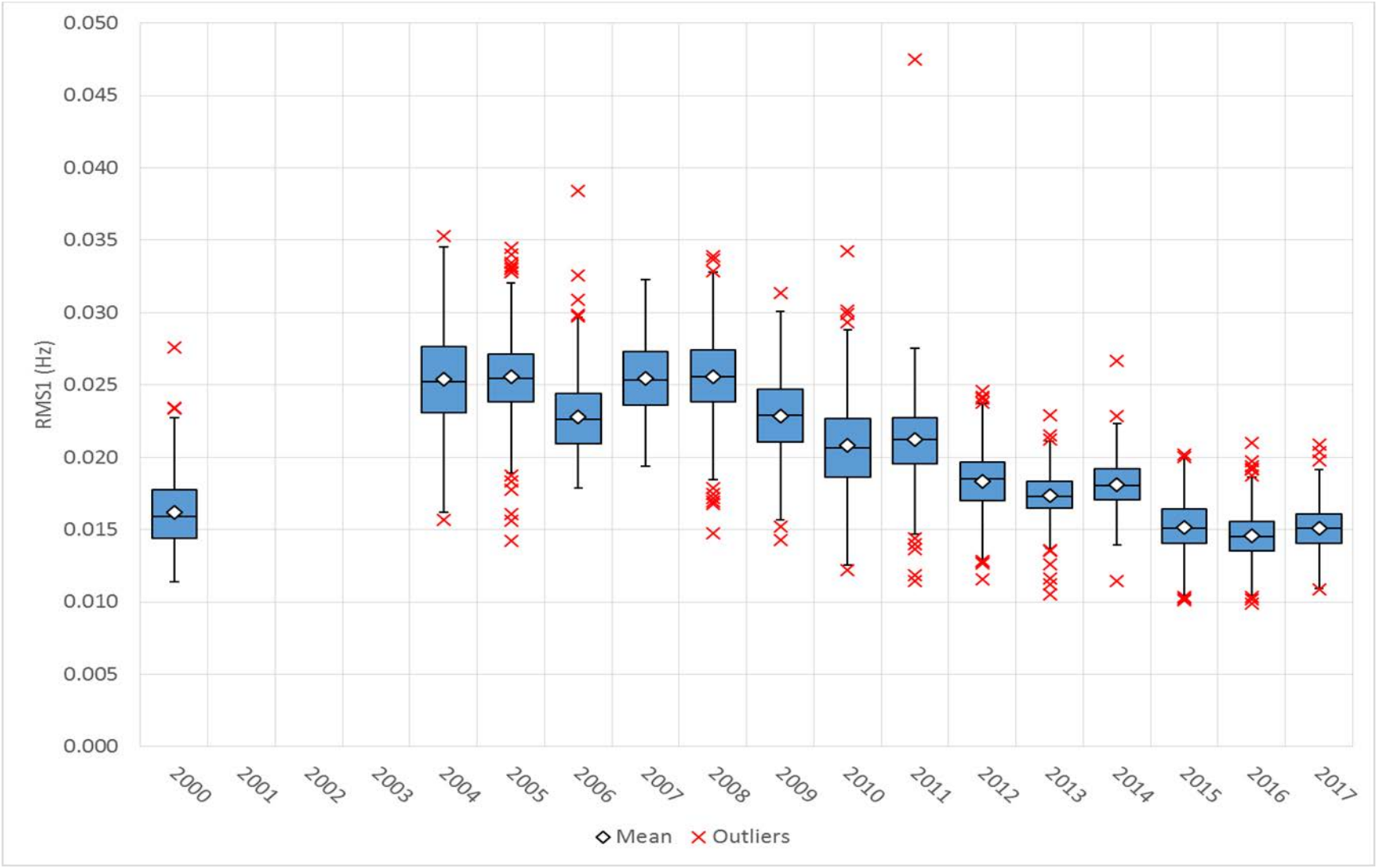
*Any interval outside deadband is counted.

34 mHz Below & Above Deadband Comparison

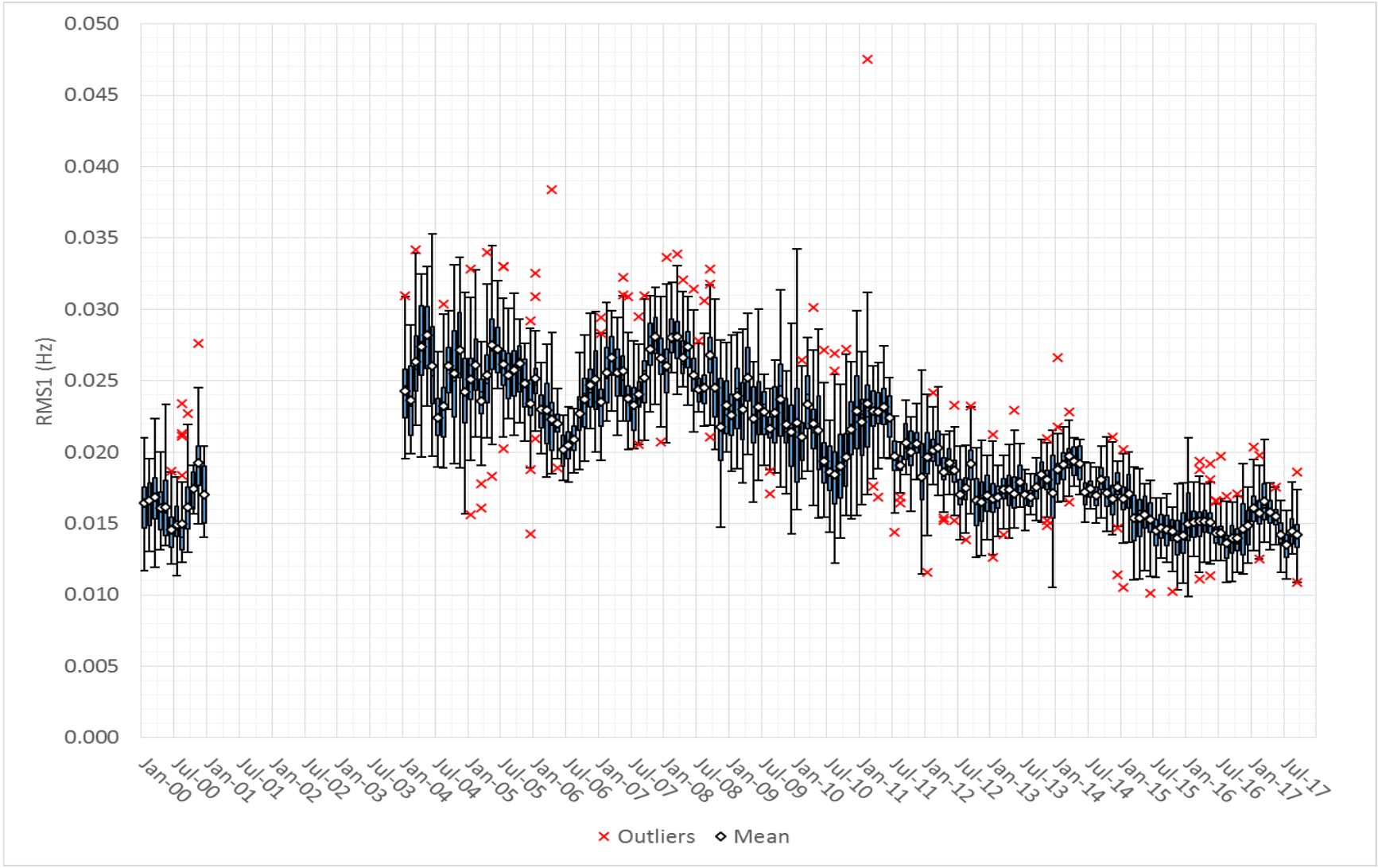




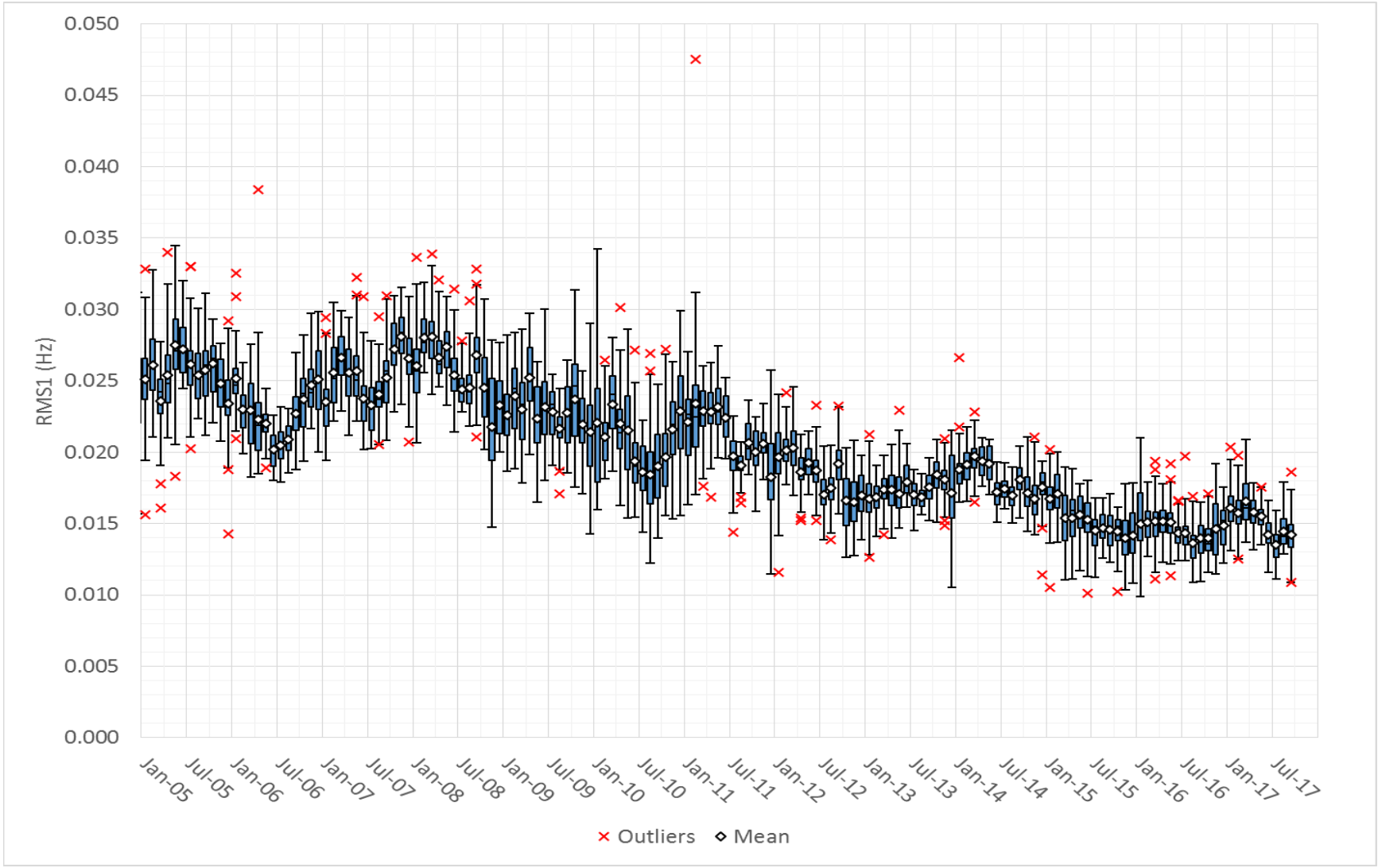
Daily RMS1 of ERCOT Frequency by Year



Daily RMS1 of ERCOT Frequency by Month



Daily RMS1 of ERCOT Frequency by Month



Improvements & Changes

- Improved CPS1 scores
- Improved frequency response during frequency events
  - Better IMFR performance
- Increased governor action
  - Can be burdensome on certain Generation Resources
- Distribution of frequency leans towards 60.017
  - More resources able to respond to frequency deviations of +0.017Hz (wind, base loaded resources, etc.)

Lessons Learned

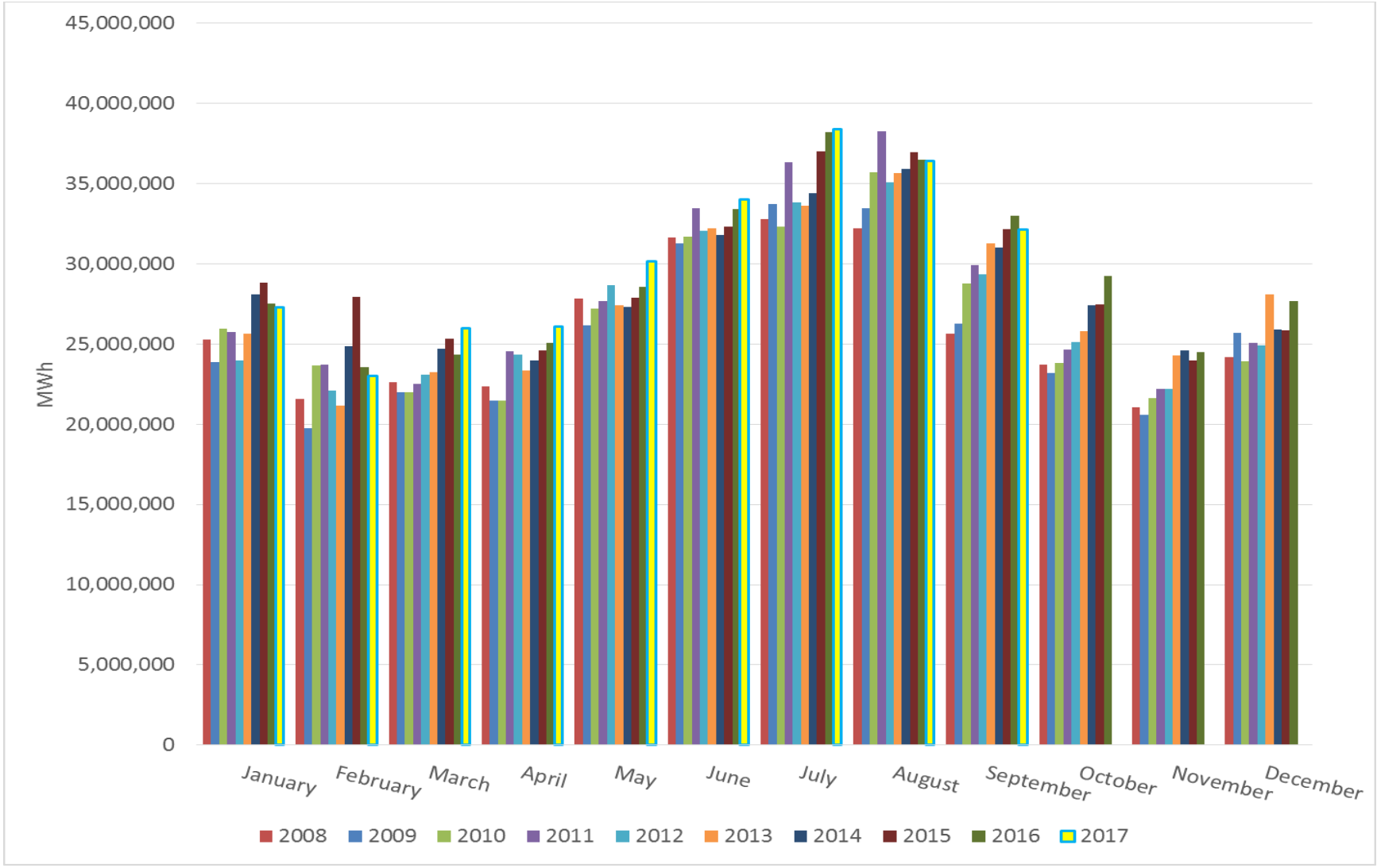
- Requires a lot of coordination with GOs
- Data quality from GRs is very important
- Evaluation of PFR scores per GR can be a strenuous process

Questions?

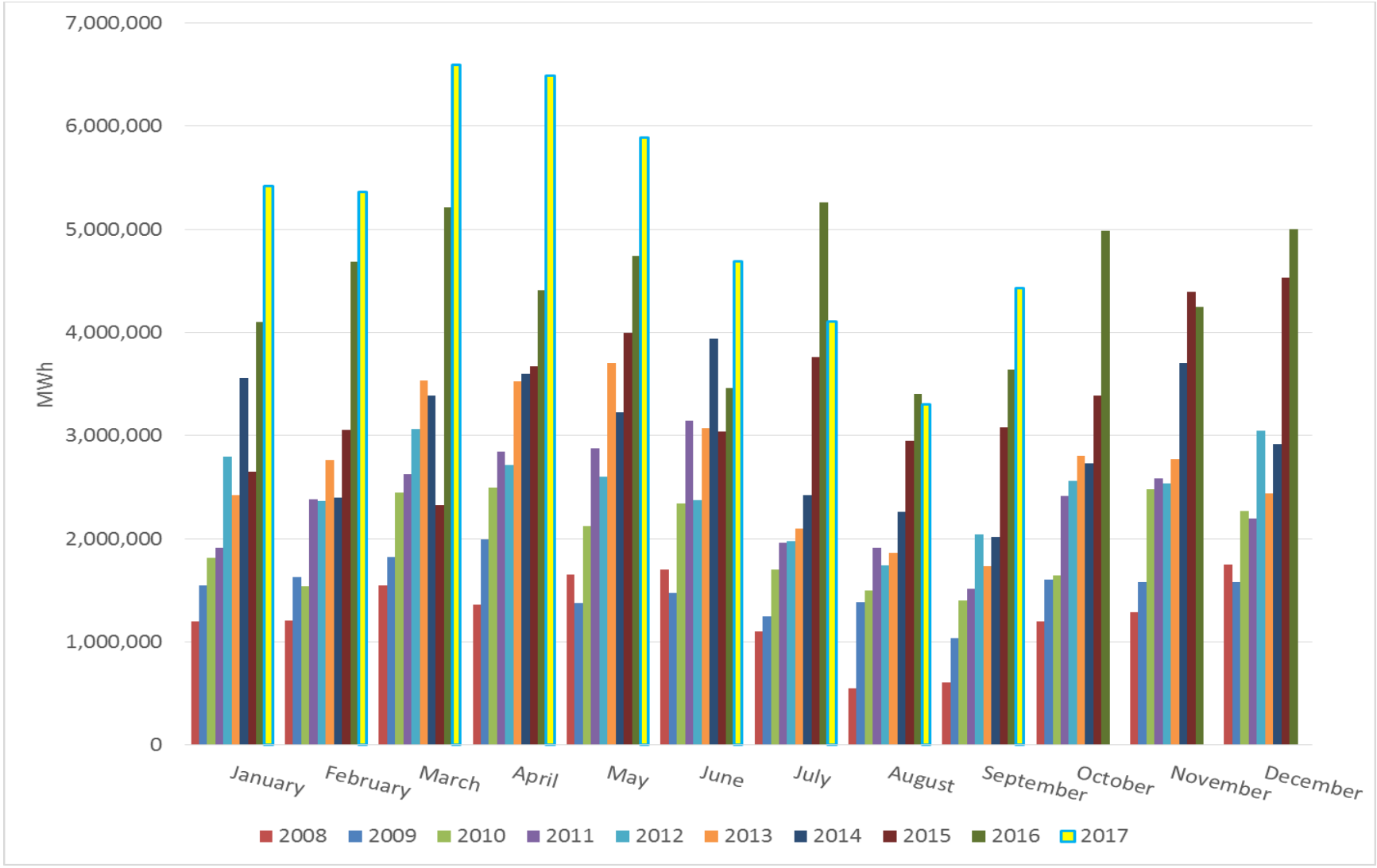
Thank you!!

Appendix

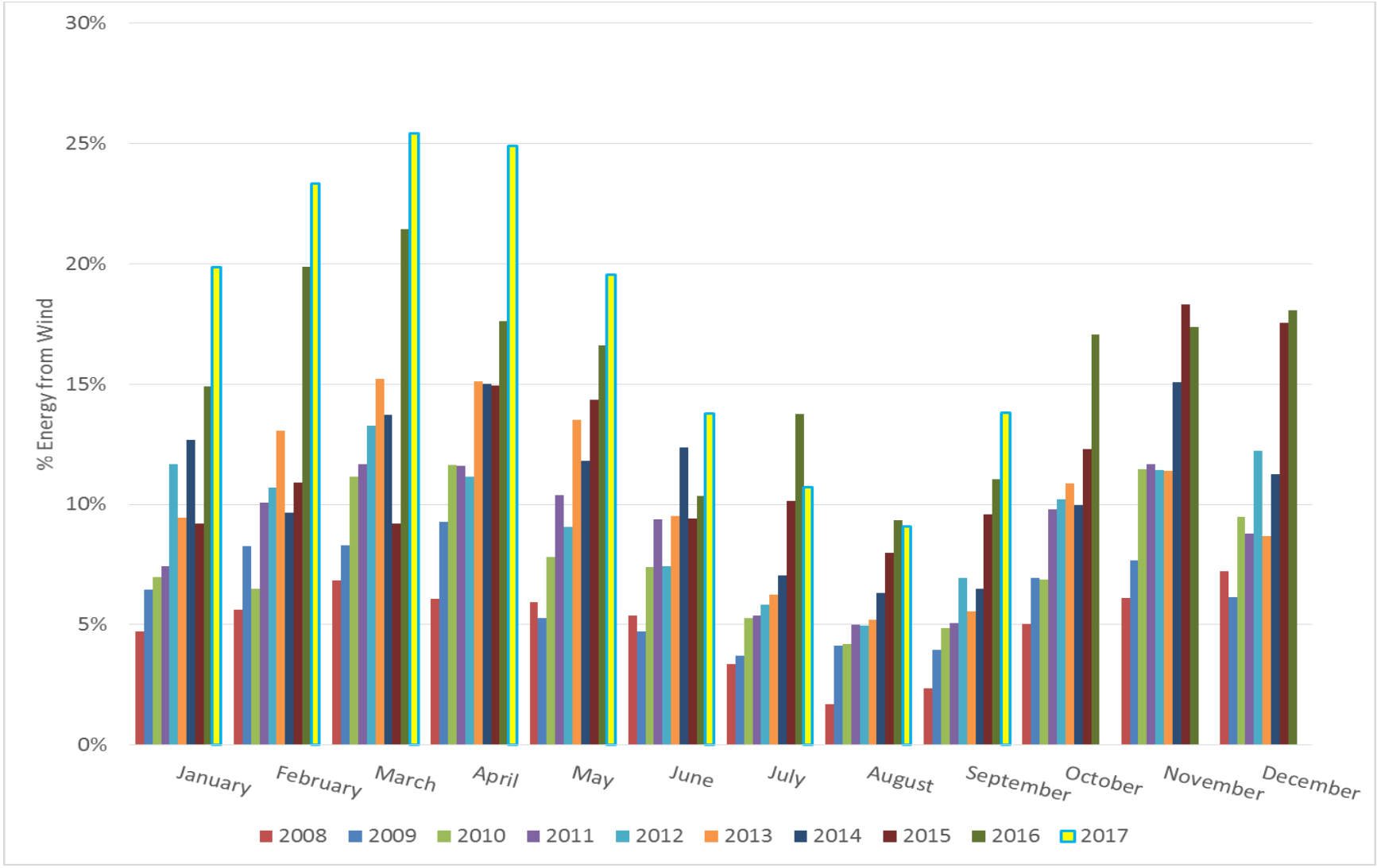
Total Energy



Total Energy from Wind Generation



% Energy from Wind Generation



Daily Minimum System Inertia