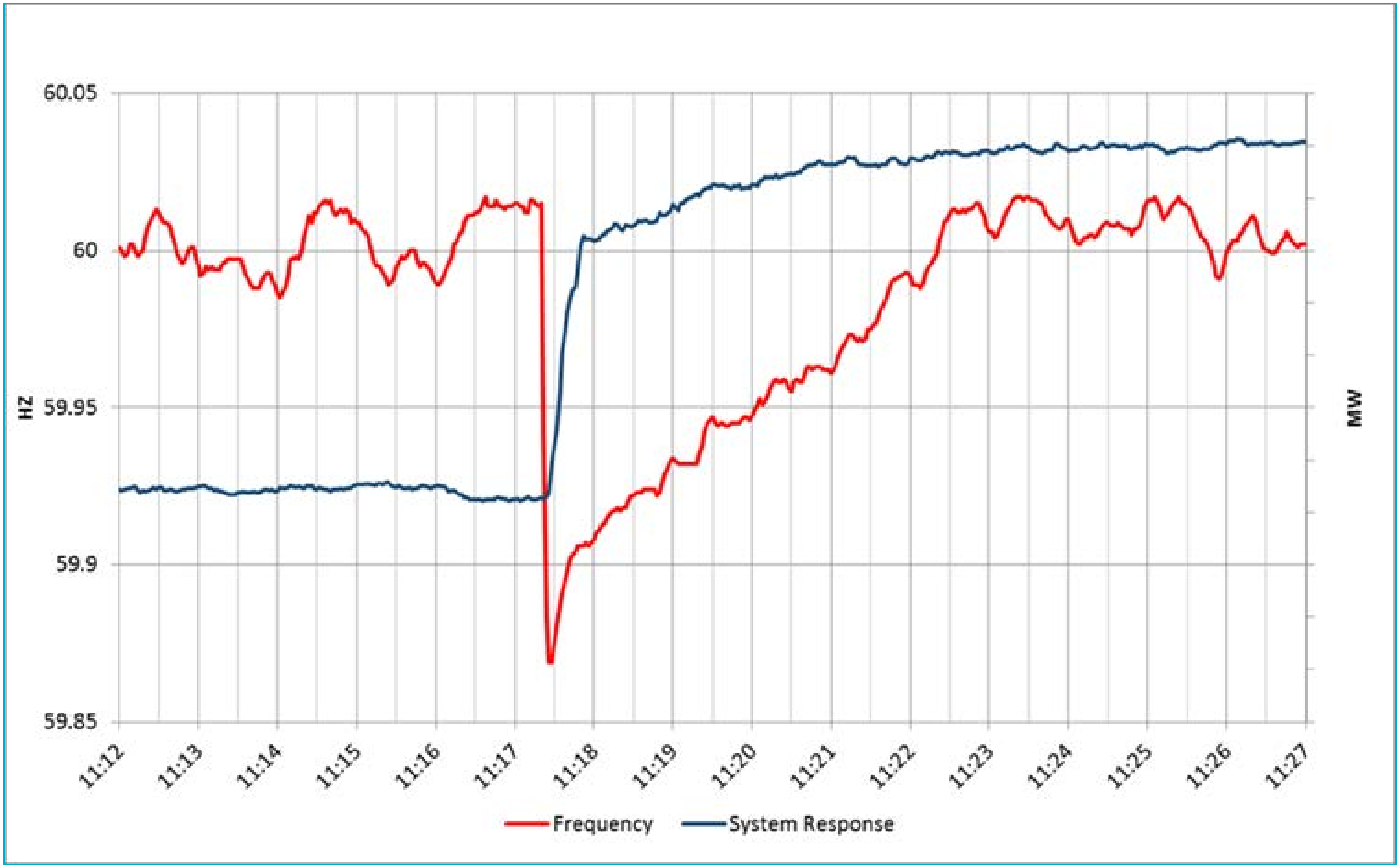
ERCOT ISO's initiative on the issue of Inertia

Sandip Sharma
Manager, Operations Planning
ERCOT

ESIG Fall Technical Workshop
October 1, 2018

System Response following a Unit Trip



Inertia Background

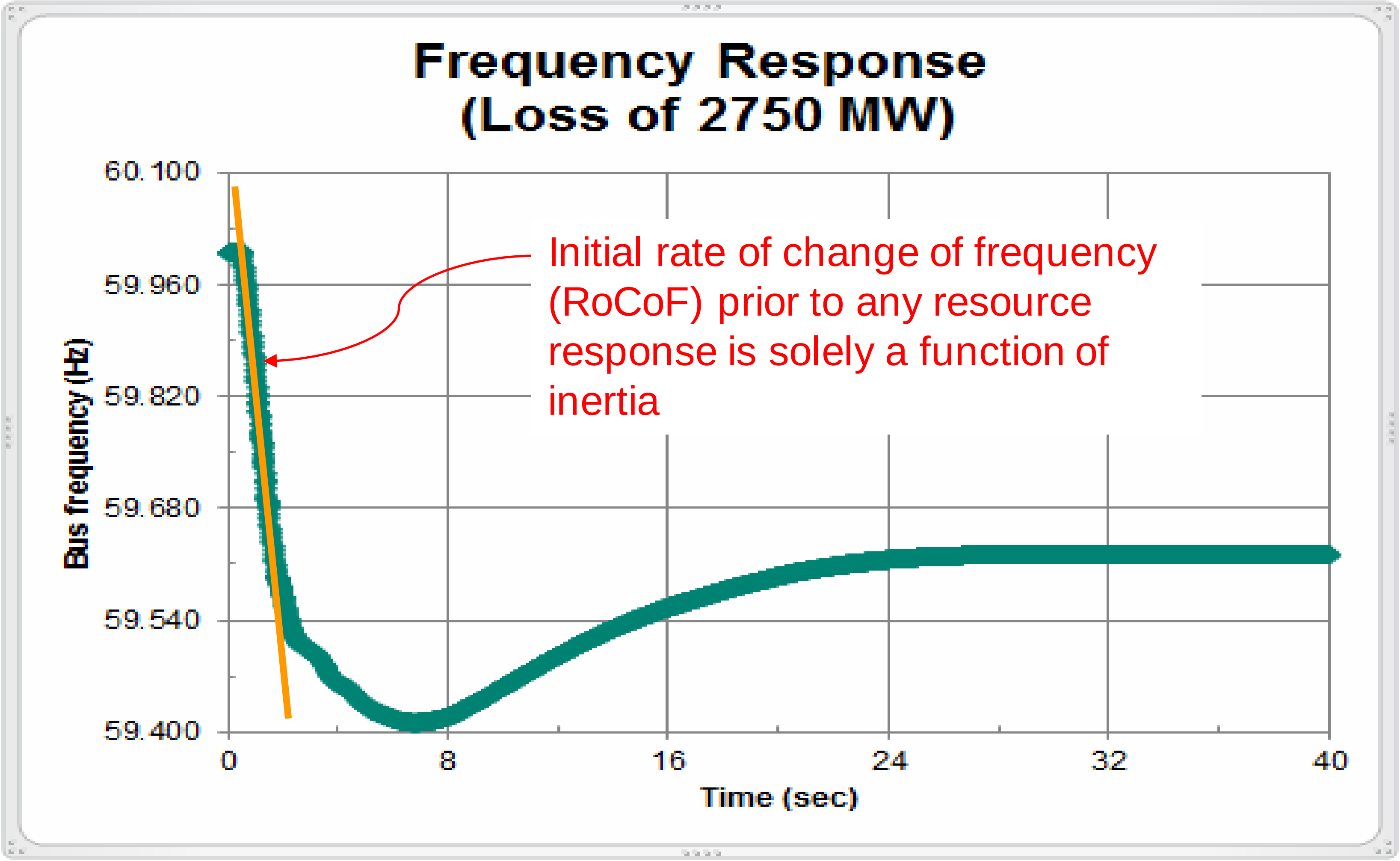
- Only synchronous machines provide inertia to the system

- Everything else provides a response, but does not provide system inertia

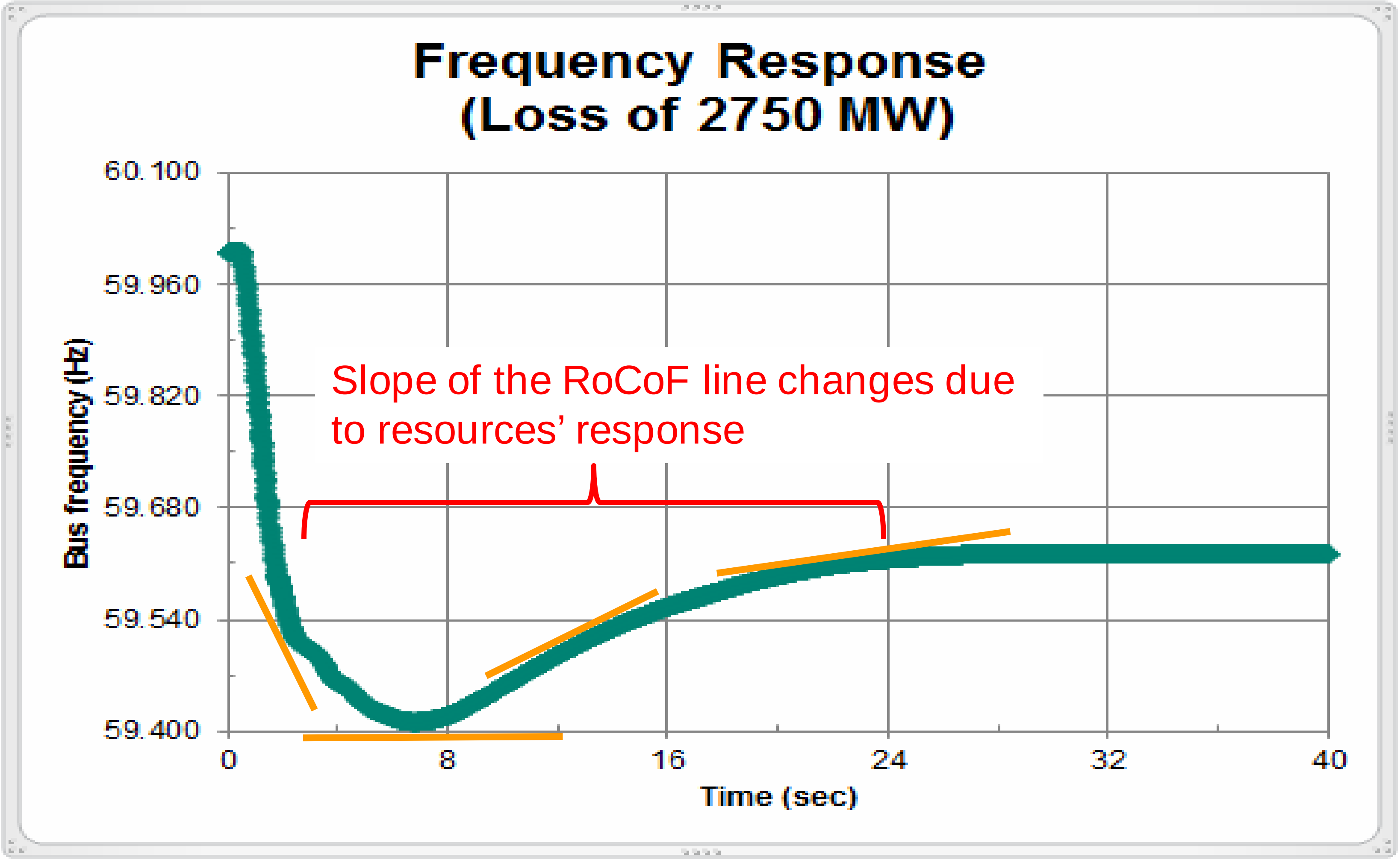
- The level of Inertia on the system is solely a function of the synchronously-connected machines online on the System and their characteristics

- However, because the synchronously-connected machines that are online at a particular point in time are related to the load and wind generation on the system at that point in time, the system inertia may be correlated with the load and wind generation

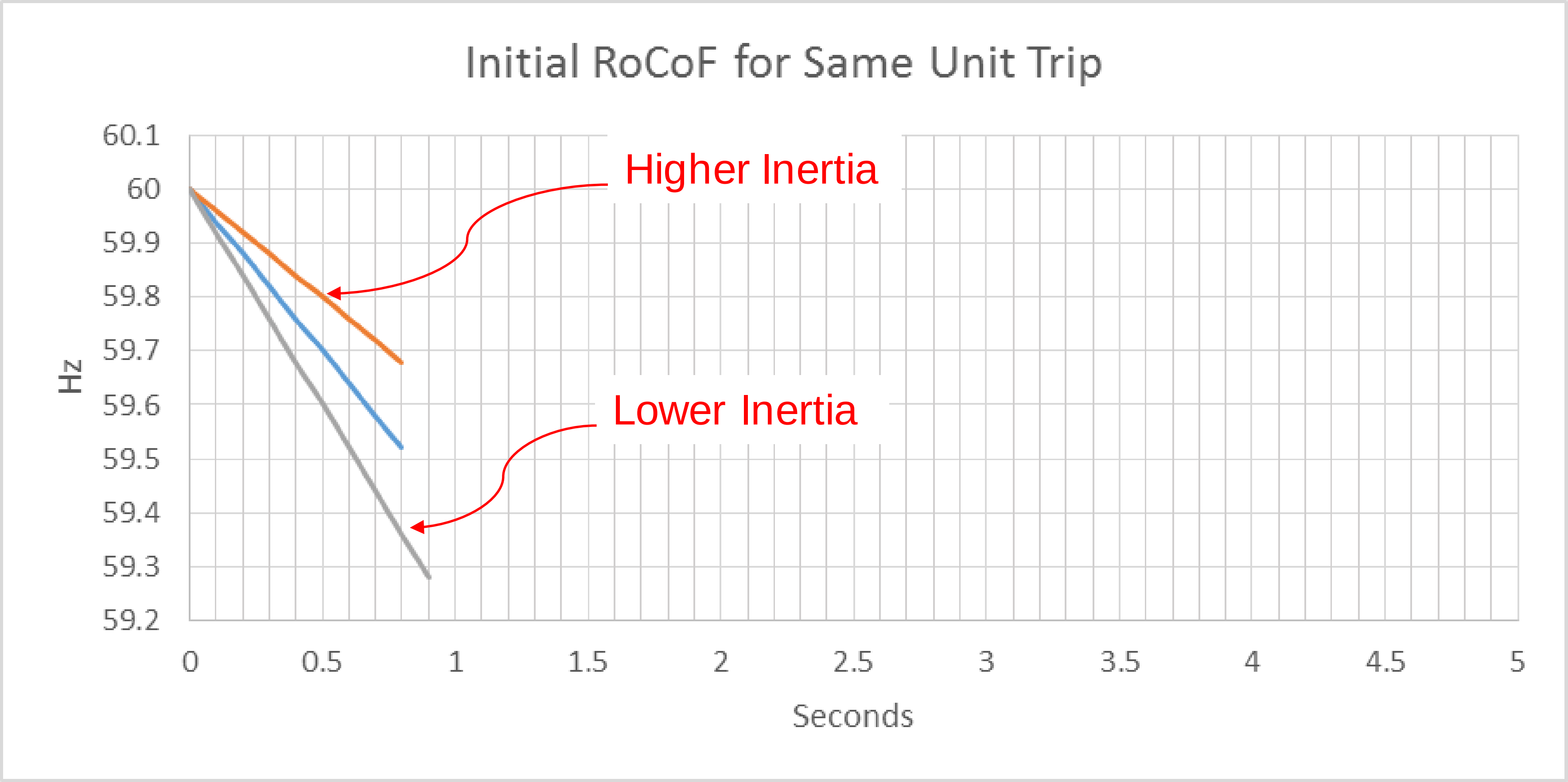
Inertial Effect



Inertial Effect



Inertial Effect



Frequency Response Times

- Load Resources (LR) providing RRS have underfrequency relays that respond in about 0.5s after the frequency drops below the trigger level (currently 59.7Hz)

- Governors of thermal generating units or Governor like response from curtailed renewable generating units begin to respond “immediately” but will take a few seconds to provide significant response (requires more steam or more combustion)

Response Time Definitions

- Early – response is triggered earlier after the unit trip (e.g. a Resource that triggers at 59.8Hz would respond earlier than a Resource that triggers at 59.7Hz, all else equal)

- Fast – response is delivered faster after the unit trip (e.g. a Resource that trips within 15 cycles is faster than one that trips within 30 cycles)

Design Criteria

- Underfrequency Load Shed (UFLS) relays will shed firm load if frequency drops to 59.3 Hz (5% of total ERCOT load).

- To consistently meet BAL-003 Interconnection Frequency Response Obligation, ERCOT must plan not to activate UFLS for the loss of 2750 MW of generation

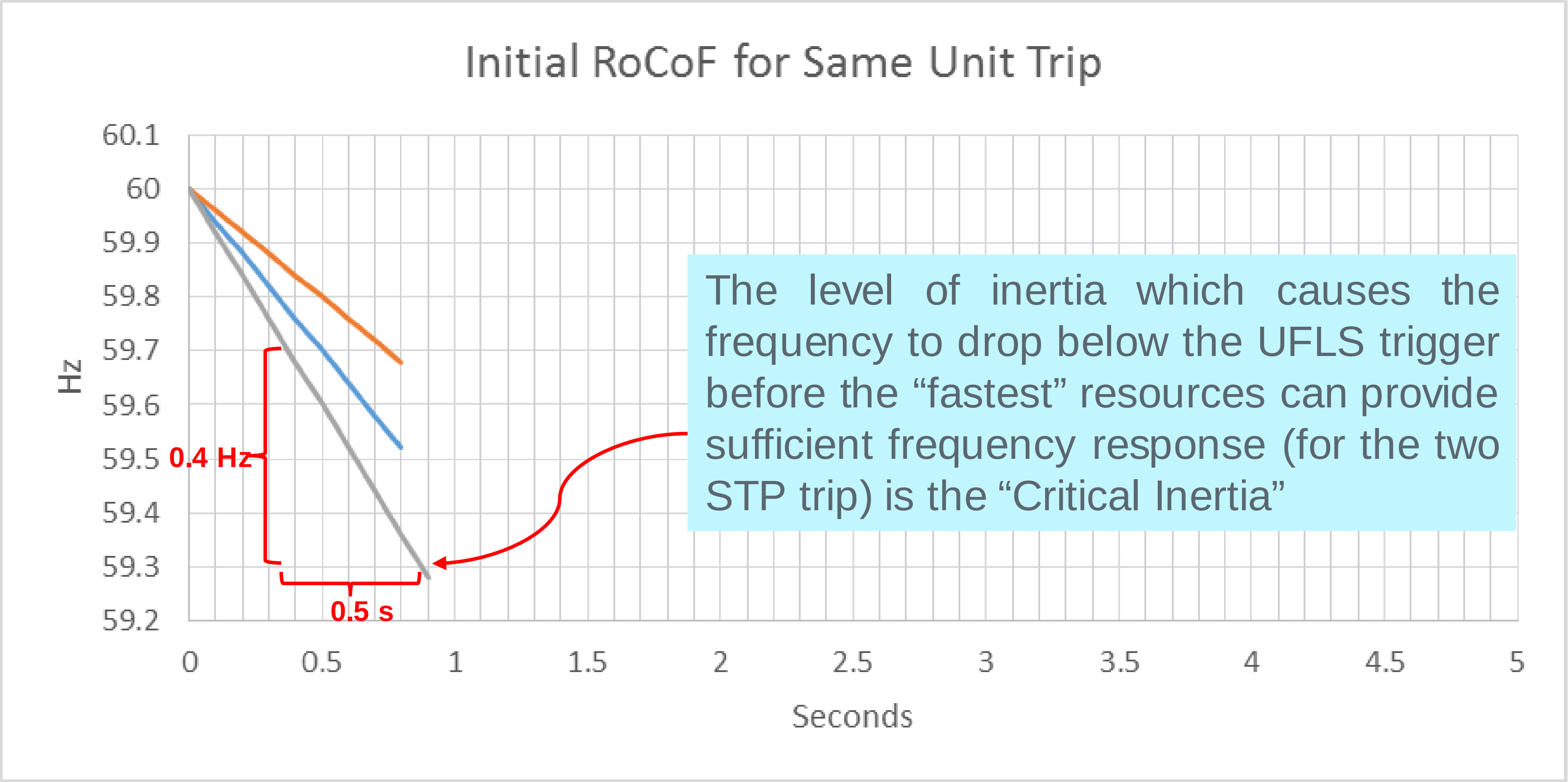
Two Inertia Issues to be Considered

1. Must maintain at least a Critical Inertia Level that is based on the current operation practices and characteristics of frequency responsive resources

2. As inertia approaches critical level, RRS requirements increase exponentially

Will discuss these on next few slides

Critical Inertia Concept



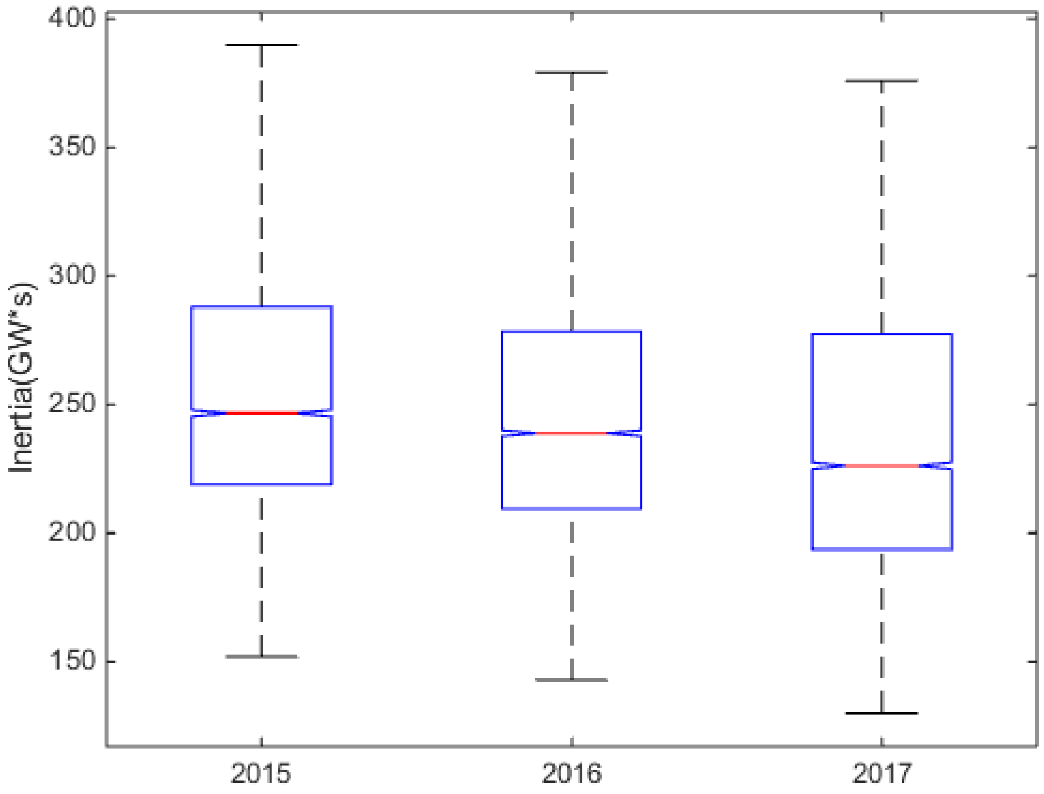
Critical Inertia

- Currently, the Critical Inertia Level for ERCOT appears to be around 100 GW-s (based on current operations and response characteristics of current resources)
  - Simulation results have shown that below this level RoCoF is high enough that frequency would drop below 59.3 Hz for the two STP trip
  - Simulation results have also shown wide-area voltage oscillations at inertia below this level; this is a separate but somewhat related issue as identified in the Panhandle region as weak grid

Technical Solutions to Maintain or Lower Critical Inertia

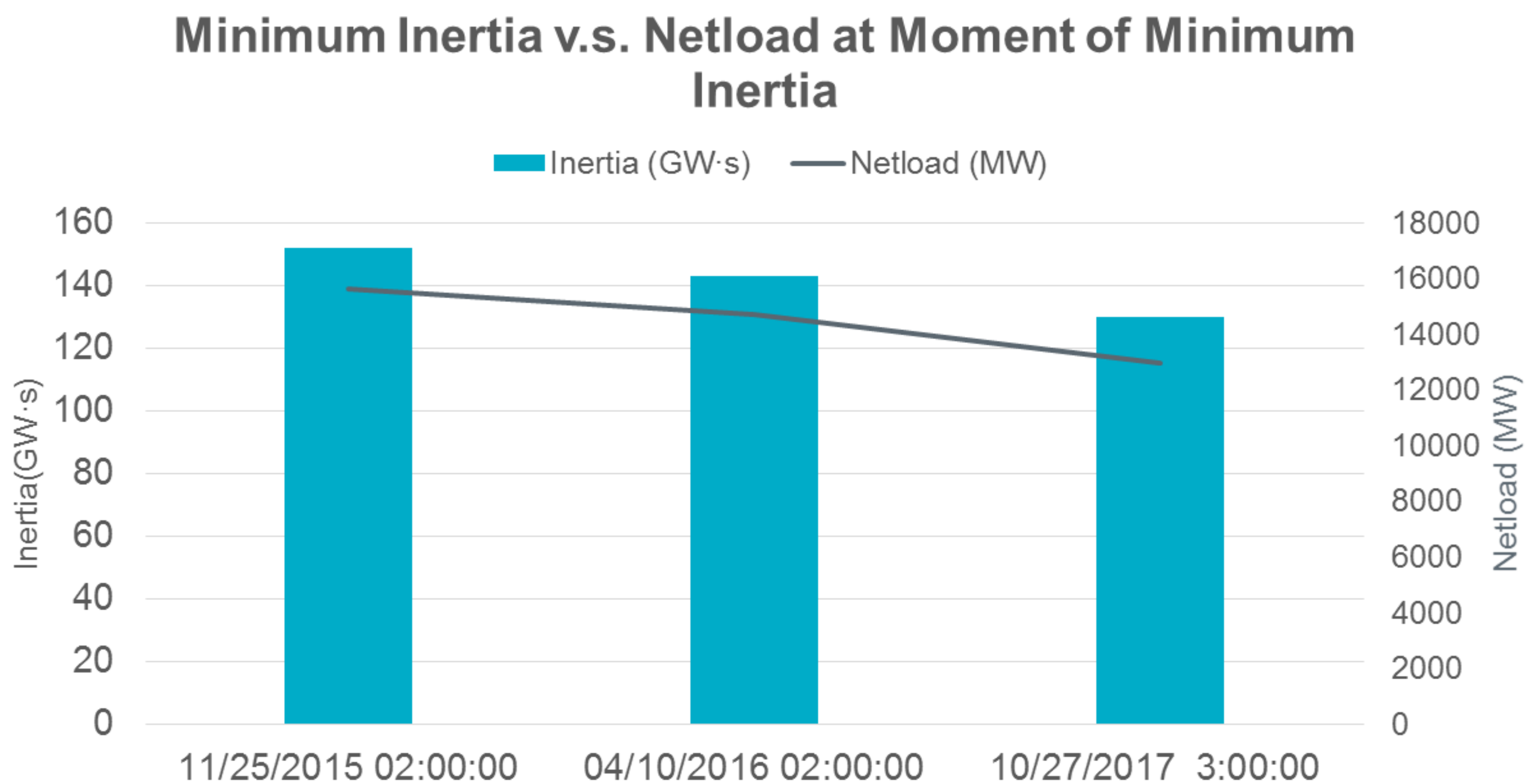
- Bring synchronous units with sufficient inertia online
- Lower the critical level of inertia by having "earlier" or "faster" frequency response resources
  - Although these resources may not help with voltage oscillation issue if they do not also provide system strength
- Change UFLS Setting
- Others….

System Inertia



	System Inertia (GW·s)
11/25/2015 02:00:00	152
04/10/2016 02:00:00	143
10/27/2017 3:00:00	130

Minimum Inertia



	System Inertia (GW·s)	Load (MW)	Wind Gen (MW)	Netload (MW)
11/25/2015 02:00:00	152	26607	10976	15631
04/10/2016 02:00:00	143	26801	12091	14710
10/27/2017 3:00:00	130	28228	15265	12963

Monitoring Inertia and Maintaining Critical Inertia – Near Term Solution

Inertia Monitoring

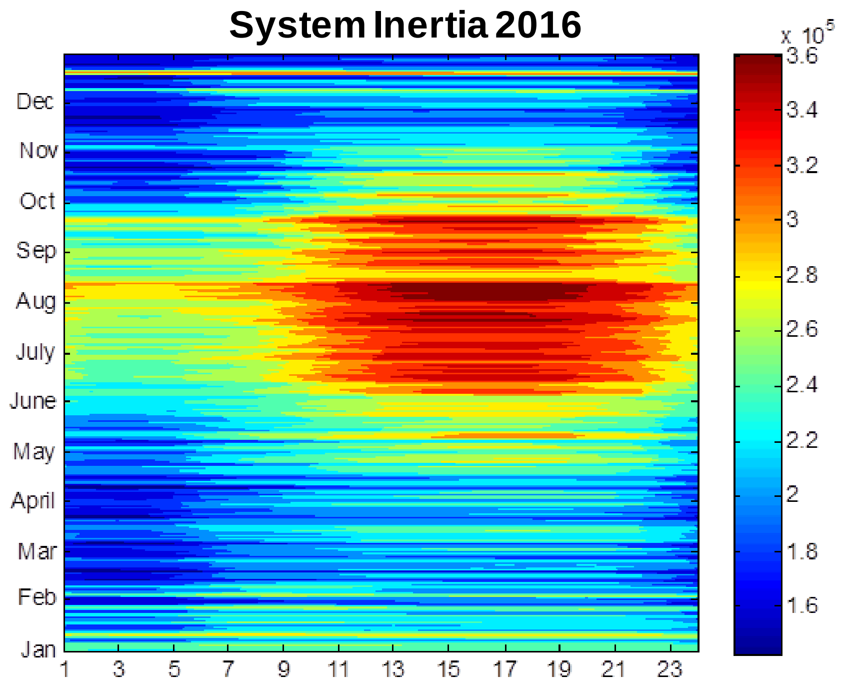
- Inertia is being monitored in Real Time.
  - The system inertia is calculated as

$$M_{sys} = \sum_{i \in I} H_i \cdot MVA_i$$

where I is the set of online synchronous generators or condensers,

MVA_i is MVA rating of on-line synchronous generator or synchronous condenser i, and

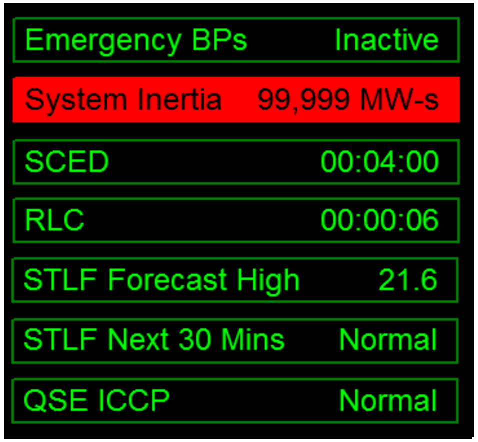
H_i is inertia constant for on-line generator or synchronous condenser i in a system (in seconds on machine MVA_i)



Maintaining Critical Inertia

- Critical Inertia for ERCOT appears to be around 100 GW-s

- Visual alarms are raised alarms when inertia gets close to critical
  - 120 GW*s >= Inertia Normal
  - 120 GW*s > Inertia >= 110 GW*s Yellow
  - 110 GW*s > Inertia >= 100 GW*s Orange
  - 100 GW*s < Inertia Red



Approach for Maintaining Critical Inertia

- Monitor grid conditions closely when system inertia < 120 GW*s
- Take Actions when system inertia < 105 GW*s
  - Target increasing system inertia >= 105 GW*s
  - Possible Actions
    - Deploy Non-Spin from Offline Generation Resources (including Quick Start Generation Resource (QSGRs) that carry Non Spin)
    - Deploy remaining Quick Starts (not carrying Non-Spin)
    - RUC Generation Resource that can be turned on within one hour

Approach for Maintaining Critical Inertia

- Monitor grid conditions closely when system inertia < 120 GW*s
- Take Actions when system inertia < 105 GW*s
  - Target increasing system inertia >= 105 GW*s
  - Possible Actions
    - Deploy Non-Spin from Offline Generation Resources (including Quick Start Generation Resources (QSGRs) that carry Non Spin)
      - Resources that have historically carried Offline Non-Spin can on an average provide ~4000 MW.s inertia increment.
    - Deploy Quick Starts (not carrying Non-Spin)
      - Quick Start resources that have historically not carried Non-Spin can on an average provide ~6000 MW.s inertia increment.
    - RUC Generation Resource that can be turned on within one hour

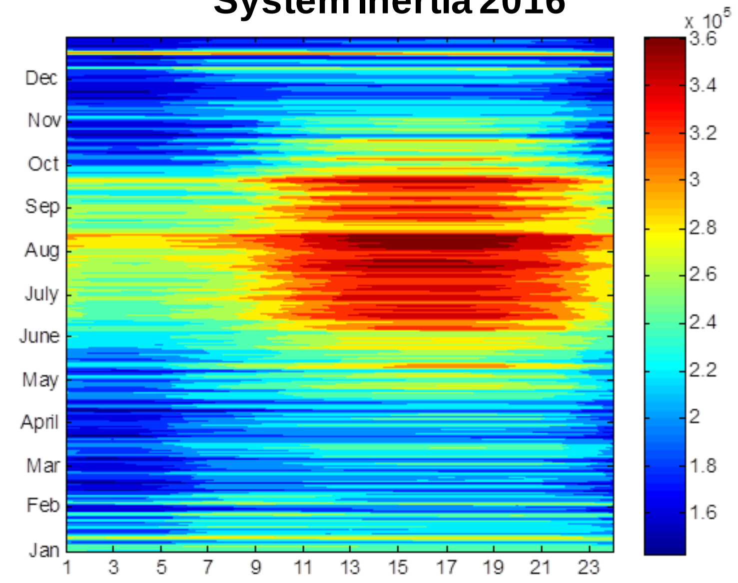
Impacts Of Parameter Changes On Critical Inertia

Responsive Reserve Service (RRS)

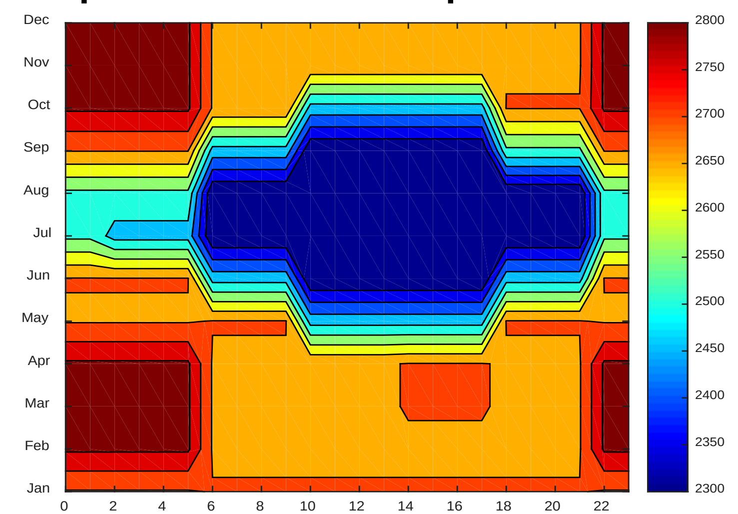
- RRS is procured to ensure sufficient capacity is available to respond to frequency excursions during unit trips.

- To consistently meet BAL-003 Interconnection Frequency Response Obligation, ERCOT must plan not to activate UFLS for loss of 2750 MW of generation.
  - UFLS relays will shed firm load if frequency drops to 59.3 Hz (5% of total ERCOT load).
  - ERCOT plans to maintain frequency nadir at or above 59.4 Hz for loss of 2750 MW (0.1 Hz margin).

System Inertia 2016



Responsive Reserve Requirements 2017



RRS Study Methodology

- Select recent cases with varying inertia levels to represent a wide range of expected inertia conditions for future years.

- The following assumptions are utilized in each study
  - Model 1150 MW of PFR from Generation Resources.
    - Generation mix when
      - Inertia < 250 GW·s: 30% Coal + 70% Gas
      - Inertia ≥ 250 GW·s: 15% Coal + 85% Gas
  - Load Resources providing RRS will trip at 59.7 Hz, with a delay of 0.416 s (relay delay = 0.333 s; breaker action = 0.083 s)
  - Load damping factor was assumed to be 2% at the system level

- The following study methodology is followed for each case that is studied
  - Trip 2750 MW of generation simultaneously. Identify the minimum amount of LRs required to ensure that frequency nadir remains at/or above 59.40 Hz.

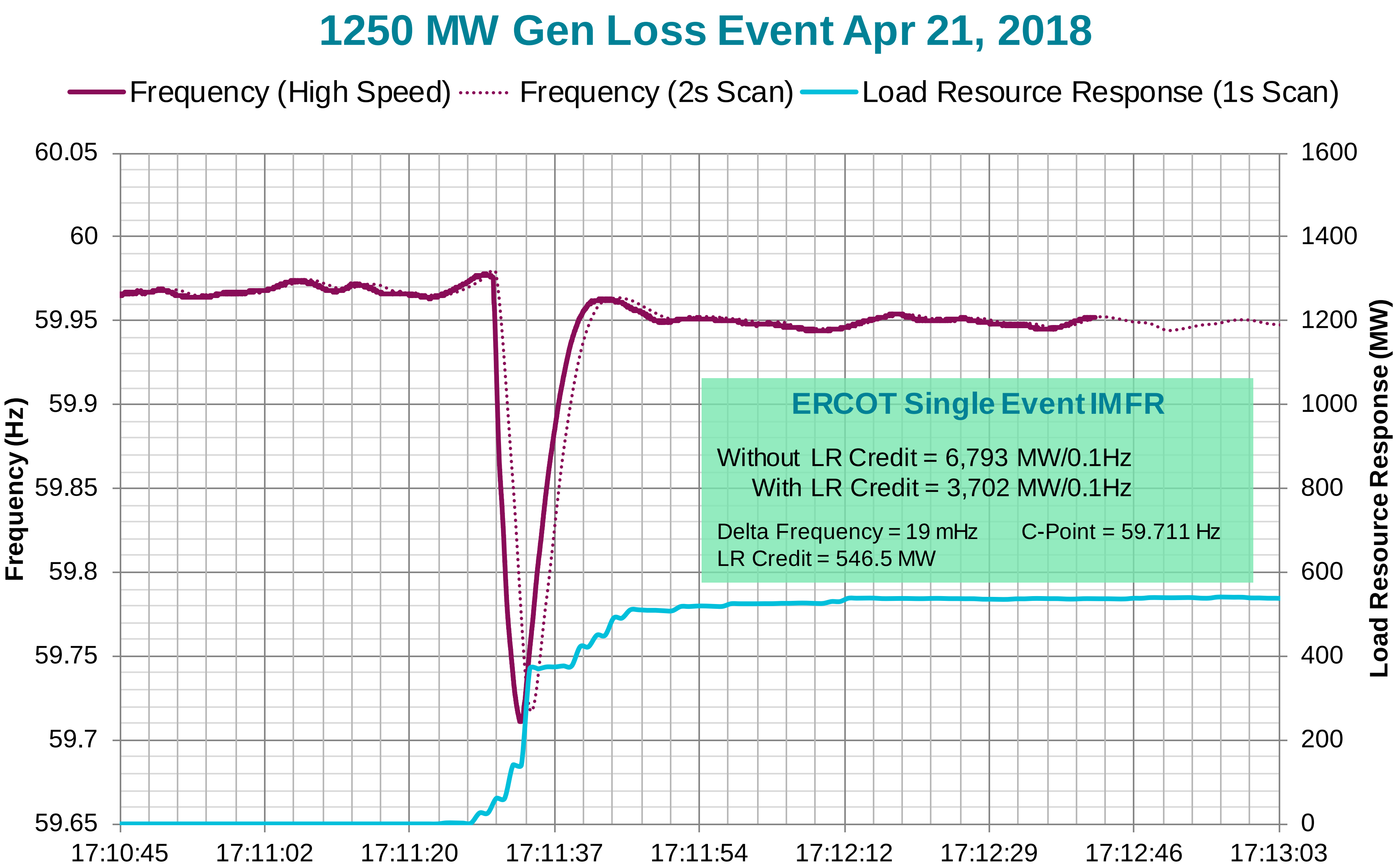
Current RRS Table

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12
LR/PFR	2.25:1	2.11:1	1.99:1	1.87:1	1.77:1	1.69:1	1.61:1	1.54:1	1.47:1	1.41:1	1.36:1	1.3:1
Inertia (GW·s)	130	140	150	160	170	180	190	200	210	220	230	240
PFR Req. (no LR) (MW)	5246	4916	4620	4361	4132	3927	3743	3576	3424	3285	3157	3040
RRS 50% Lim (MW)	3229	3162	3090	3039	2984	2920	2868	2815	2772	2726	2676	2643
RRS 60% Lim (MW)	2998	2951	2898	2867	2835	2793	2760	2725	2697	2664	2626	2604

	Scenario 13	Scenario 14	Scenario 15	Scenario 16	Scenario 17	Scenario 18	Scenario 19	Scenario 20	Scenario 21	Scenario 22	Scenario 23	Scenario 24	Scenario 25
LR/PFR	1.26:1	1.22:1	1.17:1	1.14:1	1.1:1	1.07:1	1.04:1	1.01:1	1.00:1	1.00:1	1.00:1	1.00:1	1.00:1
Inertia (GW·s)	250	260	270	280	290	300	310	320	330	340	350	360	370
PFR Req. (no LR) (MW)	2932	2831	2737	2650	2569	2492	2421	2353	2290	2230	2173	2119	2068
RRS 50% (MW)	2594	2550	2523	2477	2446	2408	2373	2342	2290	2230	2173	2119	2068
RRS 60% (MW)	2564	2528	2507	2466	2440	2405	2372	2341	2290	2230	2173	2119	2068

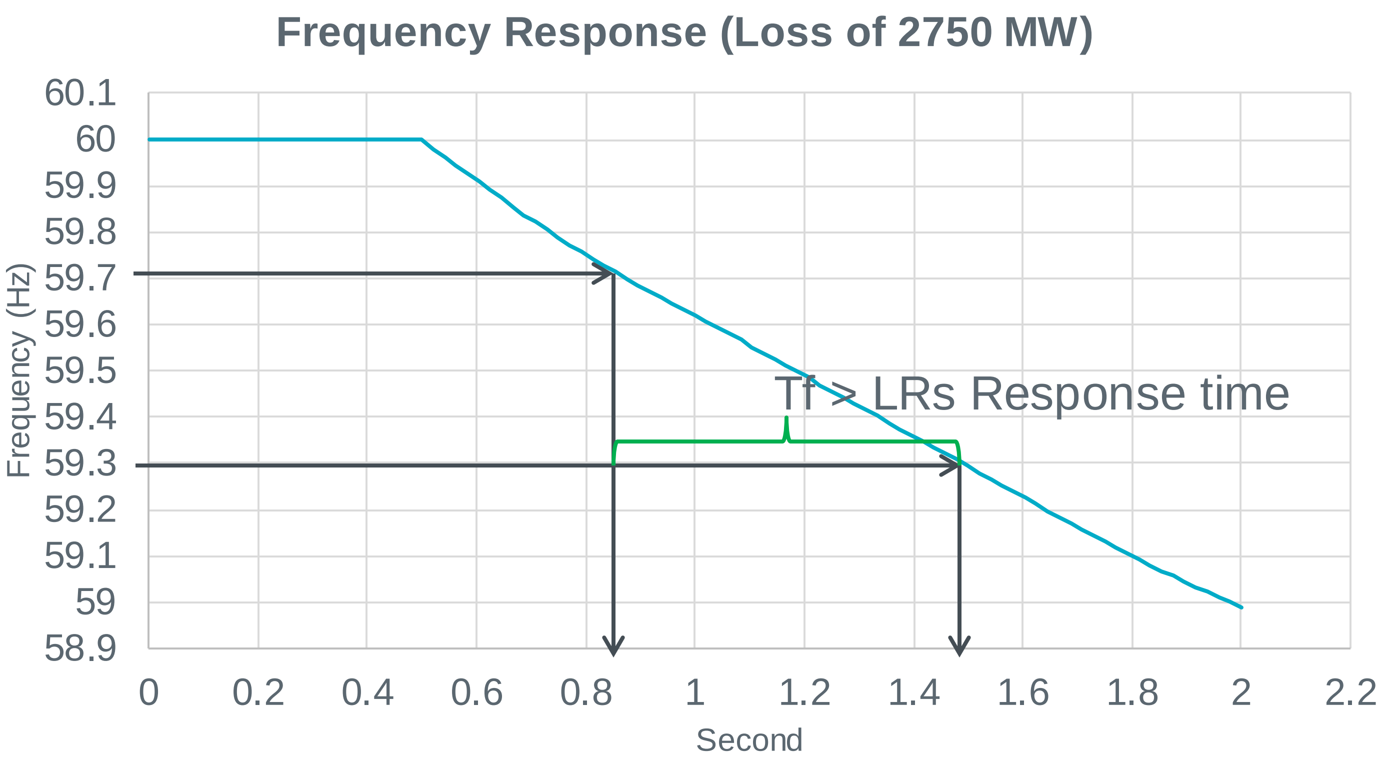
RRS 50% Lim (MW) - quantity is calculated with limit of 50% limit on LRs.
RRS 60% Lim (MW) - quantity is calculated using language approved in NPRR 815.
Red font in table above identifies study scenario where RRS needed < 2300 MW. 2300 MW floor will be used in RRS requirement determination.
Generation mix (CCs, Gas, SC, Coal, Steam) providing 1150 MW of PFR has been aligned with actual historic system operations.
Inertia < 250 GW·s: 30% Coal + 70% Rest. Inertia ≥ 250 GW·s: 15% Coal + 85% Rest

LR Response During Frequency Event

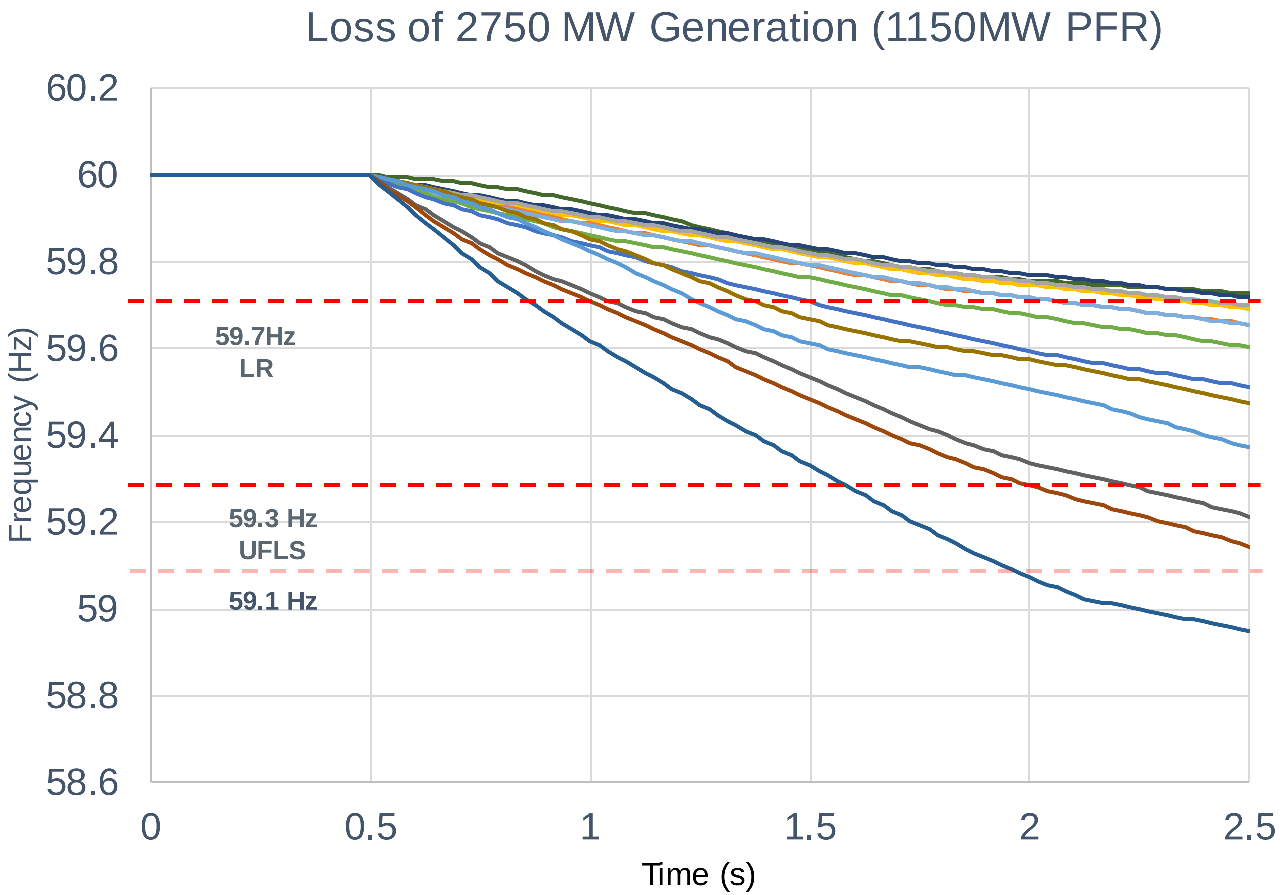


Critical Inertia Definition

- Minimum level of system inertia that will ensure LRs will have sufficient time to respond before Frequency hits 59.3 Hz (UFLS threshold)

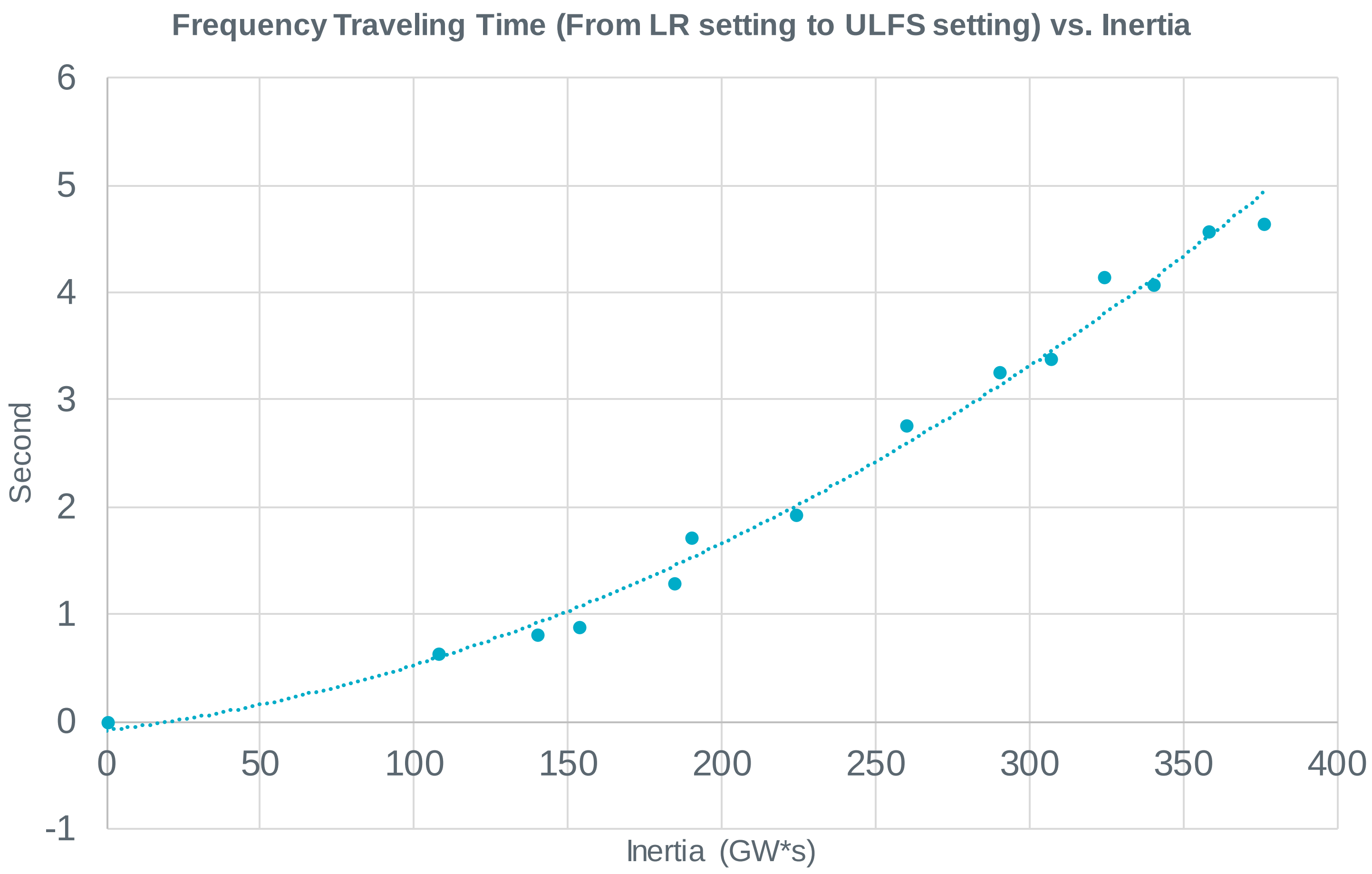


Frequency Response (Initial Stage)



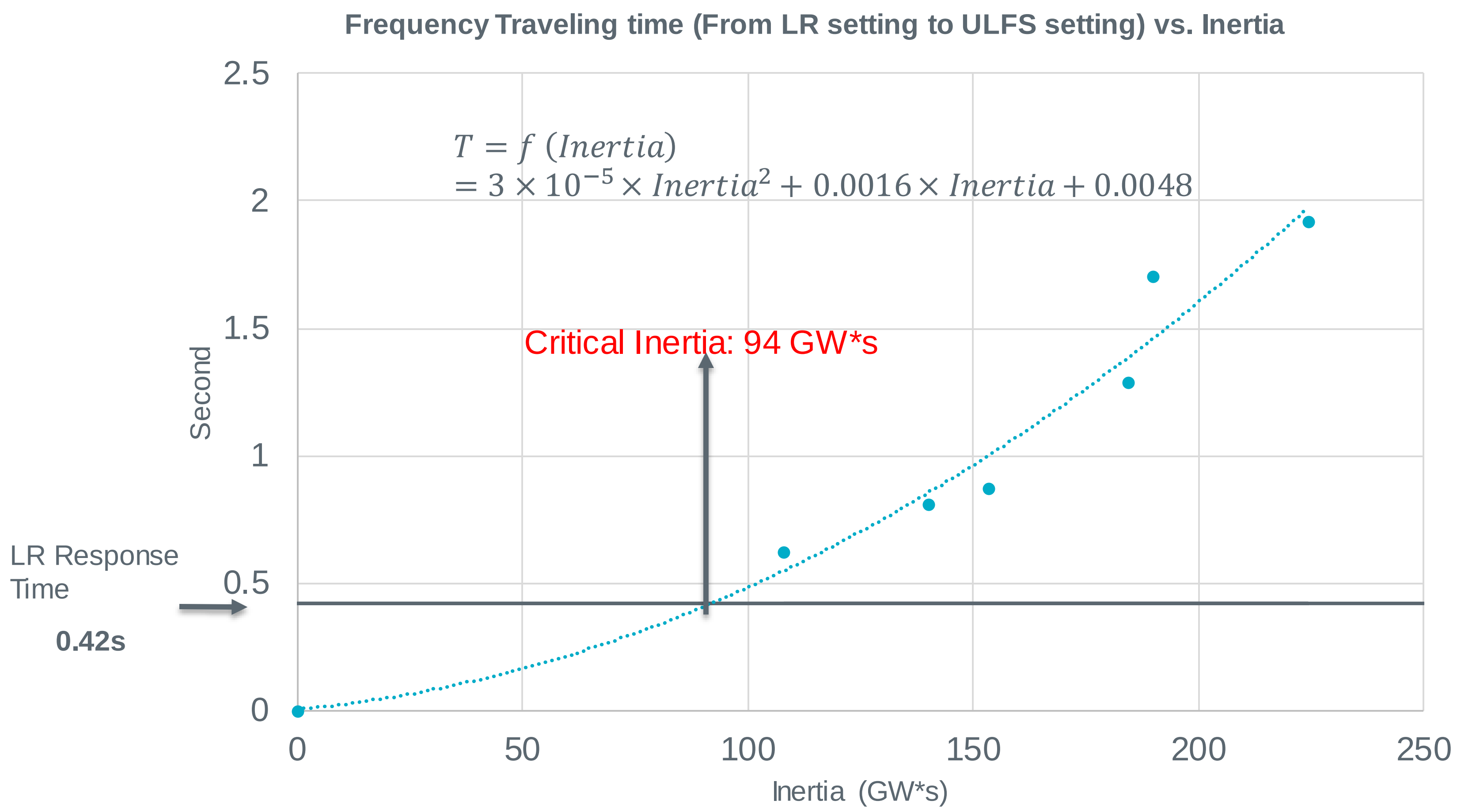
	Inertia (GW.s)
case13	376
case12	358.5
case11	340
case10	324
case9	307
case8	290
case7	260
case6	224.3
case5	190
case4	184.3
case3	153.6
case2	140
case1	108

Critical Inertia Quantification Methodology



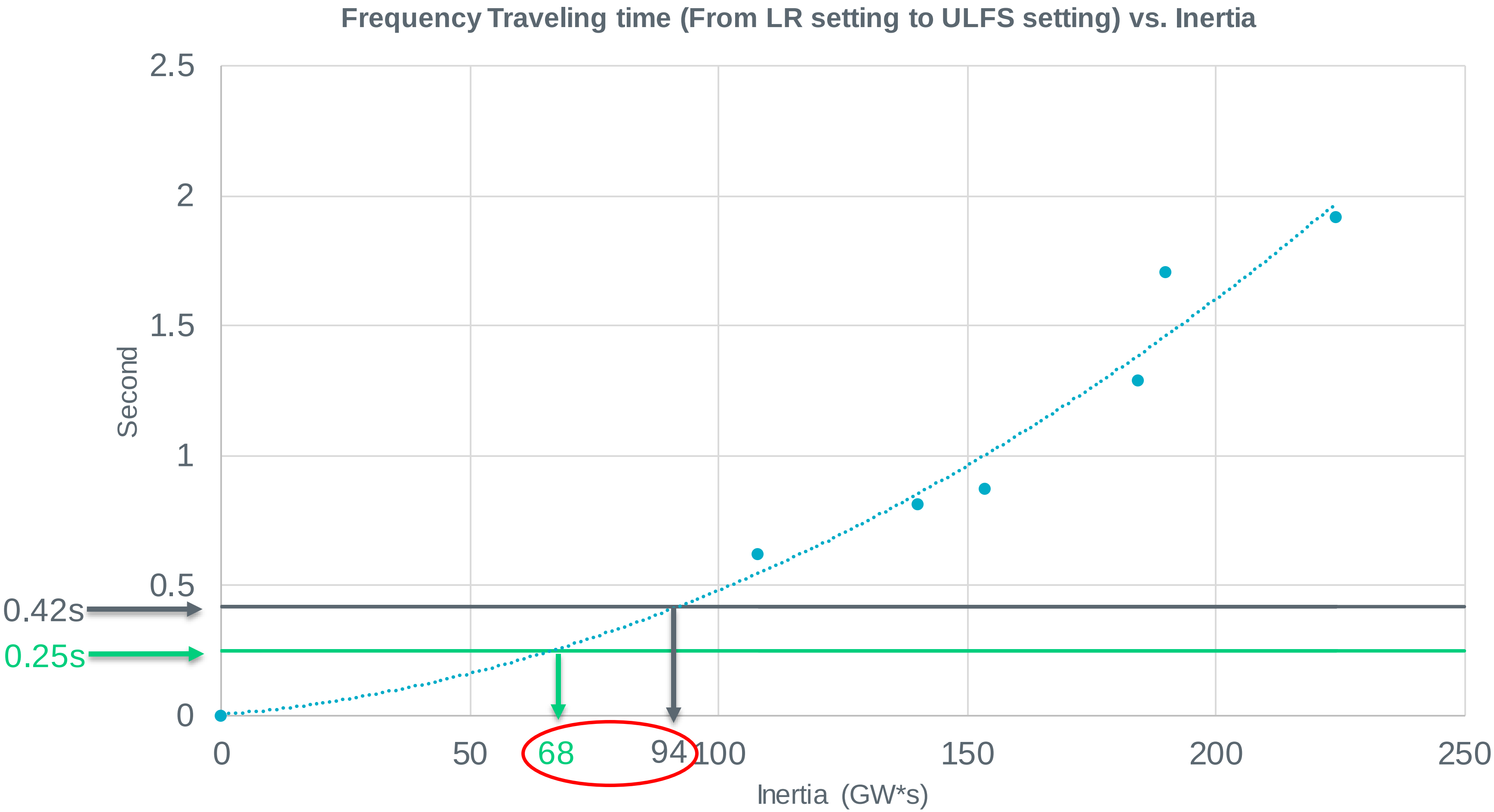
Impacts Of Parameter Changes

Current Critical Inertia for ERCOT



Potential Parameter Changes

1. Faster Response
   – 25 Cycle Delay (0.42s) ➡ 15 Cycle Delay (0.25s)



Faster Response Impact

Critical Inertia	UFLS @59.3Hz
0.42s LR Response Time	94 GW*s
0.25s LR Response Time	68 GW*s

Potential Parameter Changes

2. UFLS settings
   – UFLS @ 59.3 Hz to UFLS @ 59.1 Hz

Automatic Firm Load Shedding @ ERCOT

2.6.1 (1) At least 25% of the ERCOT System Load that is not equipped with high-set under-frequency relays shall be equipped at all times with provisions for automatic under-frequency load shedding. The under-frequency relays shall be set to provide Load relief as follows:

Threshold	Load Relief
59.3 Hz	5% of the ERCOT System Load (Total 5%)
58.9 Hz	An additional 10% of the ERCOT System Load (Total 15%)
58.5 Hz	An additional 10% of the ERCOT System Load (Total 25%)

Generators Under-frequency Protection @ ERCOT

2.6.2 (1) If under-frequency relays are installed, these relays shall be set such that the automatic removal of individual Generation Resources from the ERCOT System meets the following requirements:

Frequency Range	Delay to Trip
Above 59.4 Hz	No automatic tripping (Continuous operation)
Above 58.4 Hz up to And including 59.4 Hz	Not less than 9 minutes
Above 58.0 Hz up to And including 58.4 Hz	Not less than 30 seconds
Above 57.5 Hz up to And including 58.0 Hz	Not less than 2 seconds
57.5 Hz or below	No time delay required

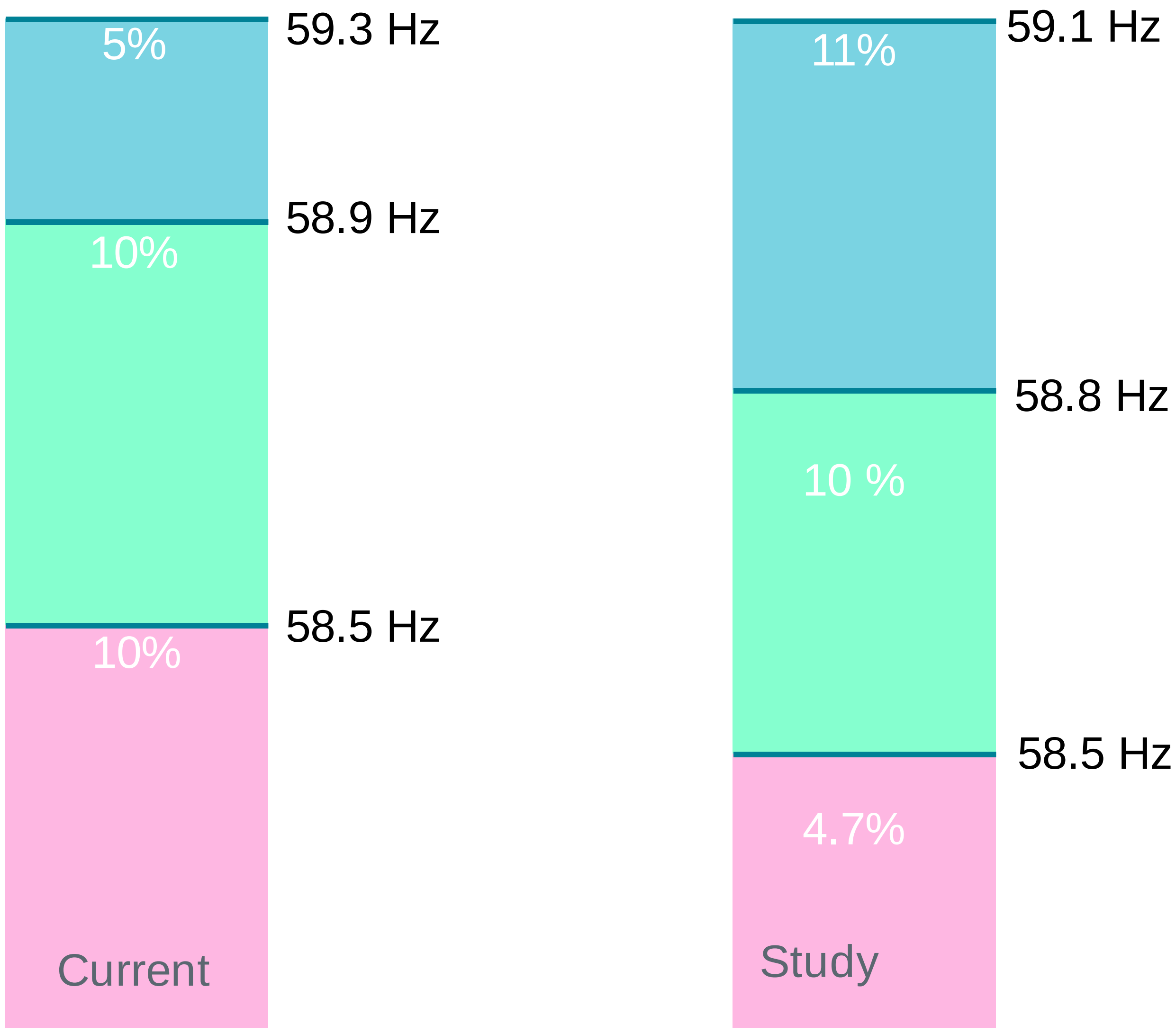
Worldwide Comparison of UFLS Settings

	Max (GW)	Min (GW)	Resource Contingency Criteria, under frequency MW	UFLS Frequency	UFLS Frequency on 60 Hz reference
Nordic TSOs	70.00	25.00	1450	48.8	58.56
ERCOT	69.86	24.17	2752	59.3	59.3
NG UK	53.00	17.00	1000	49.2	59.04
Hydro Quebec	39.00	15.00	1700 (but less @ low inertia)	58.5	58.5
ESKOM	35.00	19.00	930	49.2	59.04
Australia	30.40	14.30	760	49	58.8
Eirgrid	6.40	2.30	500	48.85	58.62
NZ Transpower North Island	4.50	1.70	572	47.8	57.36
NZ Transpower South Island	2.20	1.30	260	47.5	57
Rhodes	0.191	0.03	26	49.4	59.28
Faroe Islands	0.05	0.02		48.5	58.2

Source: ENTSO-E Report, Future System Inertia 2

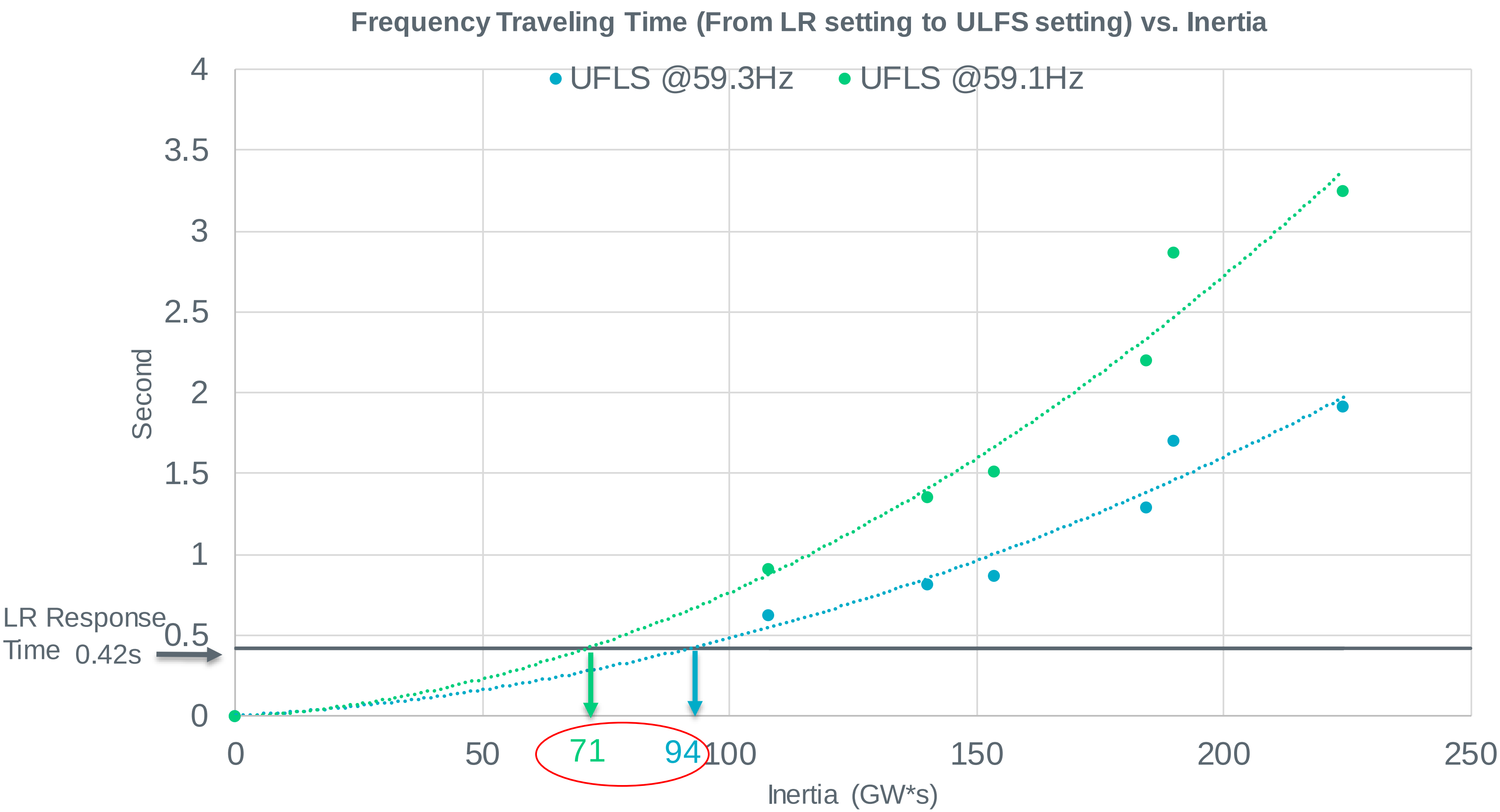
Note this table reflects UFLS settings as of 2016 for the regions annotated. This data has been sorted by maximum load to aid comparison of the settings used by similar sized regions.

UFLS Setting Current vs. Analysis



UFLS Setting Change

– UFLS @ 59.3 Hz ➡ UFLS @ 59.1 Hz



UFLS Change Impact

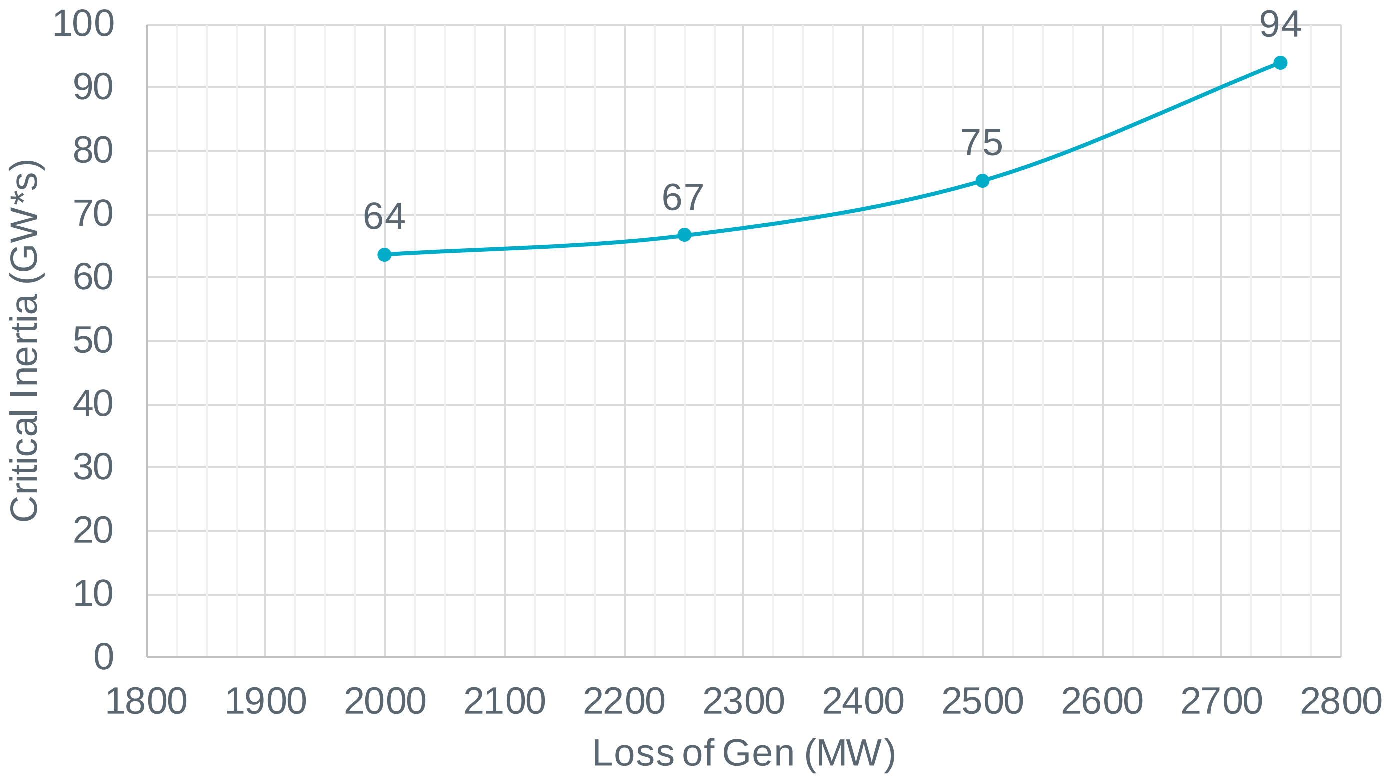
	UFLS @59.3Hz	UFLS @59.1Hz
0.42s LR Response Time	94 GW*s	71 GW*s

Faster Response & UFLS Change Impact

	UFLS @59.3Hz	UFLS @59.1Hz
0.42s LR Response Time	94 GW*s	71 GW*s
0.25s LR Response Time	68 GW*s	52 GW*s

Potential Parameter Changes

3. Critical Contingencies



Proposed NPRR 863 Ancillary Service Framework Changes

Last Edited on 7/30/2018

Current Framework

Regulation
*157 to 687 MW**

Responsive Reserve Service
1. Primary Frequency Response
2. Load Resources on Under Frequency Relay (UFR)

*2,300 to 3,200 MW**

Non-Spin
*967 to 2,361 MW**

Overall A/S: 3,807 to 5,958 MW*

NPRR 863 With STEC Comments (4/26, 8/2)

Regulation
*157 to 687 MW**

No Change

Frequency Response Service (FRS)
- Fast Frequency Response (FFR)
- Load Resources on UFR
- Primary Frequency Response (PFR)

*2,300 to 3,200 MW**

FFR
- Triggered at 59.85 Hz and full response in 15 cycles
- Once deployed, sustain for up to 15 mins. Once recalled, restore within 15 mins

PFR
- PFR capable capacity reserved on generators or Controllable Load Resources (CLR)
- Minimum 1,150 MW must be provided by resources capable of PFR

Load Resources on UFR
- Triggered at 59.70 Hz and full response in 30 cycles
- Sustain until recalled. Once recalled, restore within 3 hours
- Beyond the minimum PFR, up to 60% of total FRS can come from Load Resources on UFR or FFR.

ERCOT Contingency Reserve Service (ECRS)
- 10 minute ramp
- Load Resources may or may not be on UFR

*508 to 1,644 MW***

Generation
- Online or offline capacity that can be converted to energy within 10 minutes
- Dispatched by SCED

Load Resources (UFR not required)
- Up to 50% of ECRS capacity can come from Load Resources with or without UFR
- Once deployed, must respond within 10 minutes. Restoration within 3 hours

Non-Spin
*0 to 1,180 MW****

No protocol changes.
- Proposed methodology for Non-Spin Reserve Service quantities in this framework-quantities computed using 2018 A/S Methodology are reduced by ECRS quantities.

Overall A/S: 3,807 to 5,958 MW*

*Quantities computed/estimated using 2018 Ancillary Service Methodology. **Quantities estimated using this reference. ***Quantities estimated using this reference and method in box on far left.
For Discussion Purposes Only. The intent of this slide is to represent NPRR 863 (with ERCOT comments from 7/6/2018). Protocol language prevails to the extent of any inconsistency with this one page summary.

Summary

- Inertia determines the speed of Frequency Response delivery.
- ERCOT's Critical Inertia is sensitive to the parameters such as response characteristics of the LR's that provide RRS, UFLS setting and even the level at which critical contingencies are dispatched.
- Adopting one or more combinations of these can mitigate ERCOT's Critical Inertia and widen ERCOT's System Operating Limit.