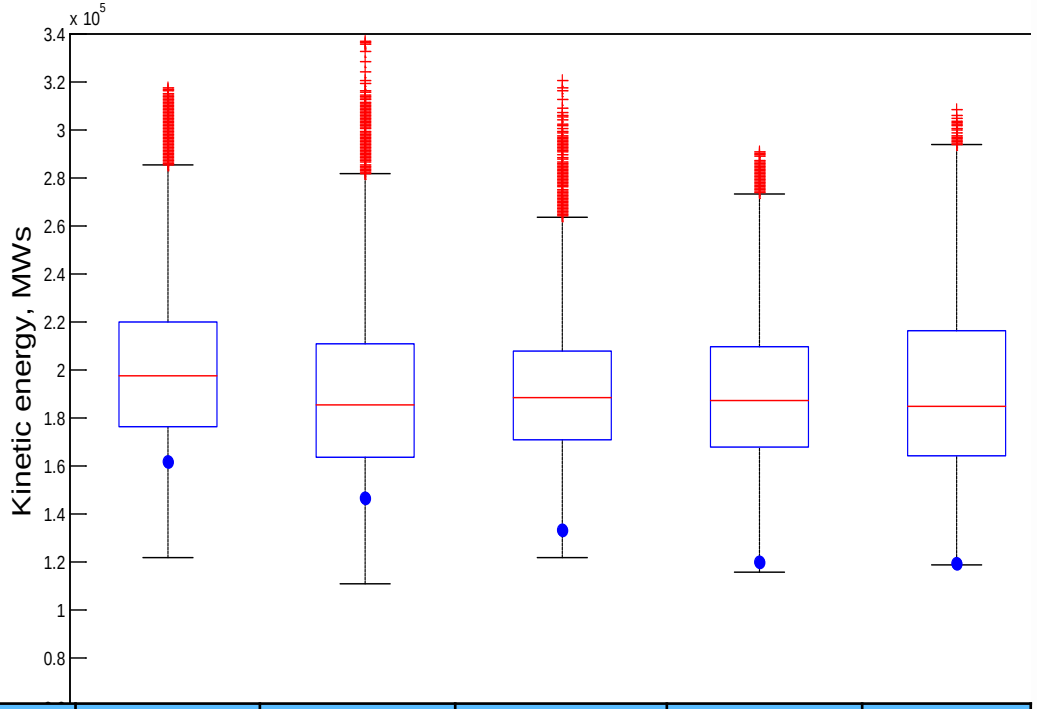
ERCOT Historic Synchronous Inertia (Kinetic Energy) and Future Projections

Julia Matevosyan, PhD
Sr. Planning Engineer
Resource Adequacy
ERCOT

Historic Analysis Assumptions

- Kinetic energy is calculated as a sum of H*MVA of all online synchronous generators on hourly basis;
- Jan-May, Nov-Dec data for 2010-2013 and January-May data for 2014 are included in the analysis;
- Peak wind penetration hour (i.e. max P_{wind}/P_{load}) in each year is analyzed in details (load, wind, wind capacity factor)

Historic Kinetic Energy



	2010	2011	2012	2013	2014
Installed Capacity, MW	9,116	9,452	10,034	10,570	11,066
Max P_{wind}/P_{load}	25.5%	27.4%	29.8%	35.8%	39.4%
P_{wind}, MW	6,483	6,772	7,247	8,773	9,699
Capacity Factor	71%	72%	72%	83%	88%
P_{load}, MW	25,427	24,745	24,328	24,488	24,617

Future Inertia Projection Methodology

Expected installed wind capacity in a future year (with SGIA or SGIA&FC)

Expected wind capacity in a future year X:

$P_{\text{wind capacity}}$

Project an hour with highest instantaneous penetration of wind based on historical trends

Projected peak wind penetration hour:

$P_{wind} = CapacityFactor_{hist} * P_{\text{wind capacity}}$

P_{load}= Avg. historical load at wind penetration peaks

Penetration = P_{load}/P_{wind}

Net Load=$P_{load} - P_{wind}$

Project system inertia for this hour, based on historical inertia trendline

Synchronous inertia at projected wind penetration peak:

SI = *a**Net Load +*b*

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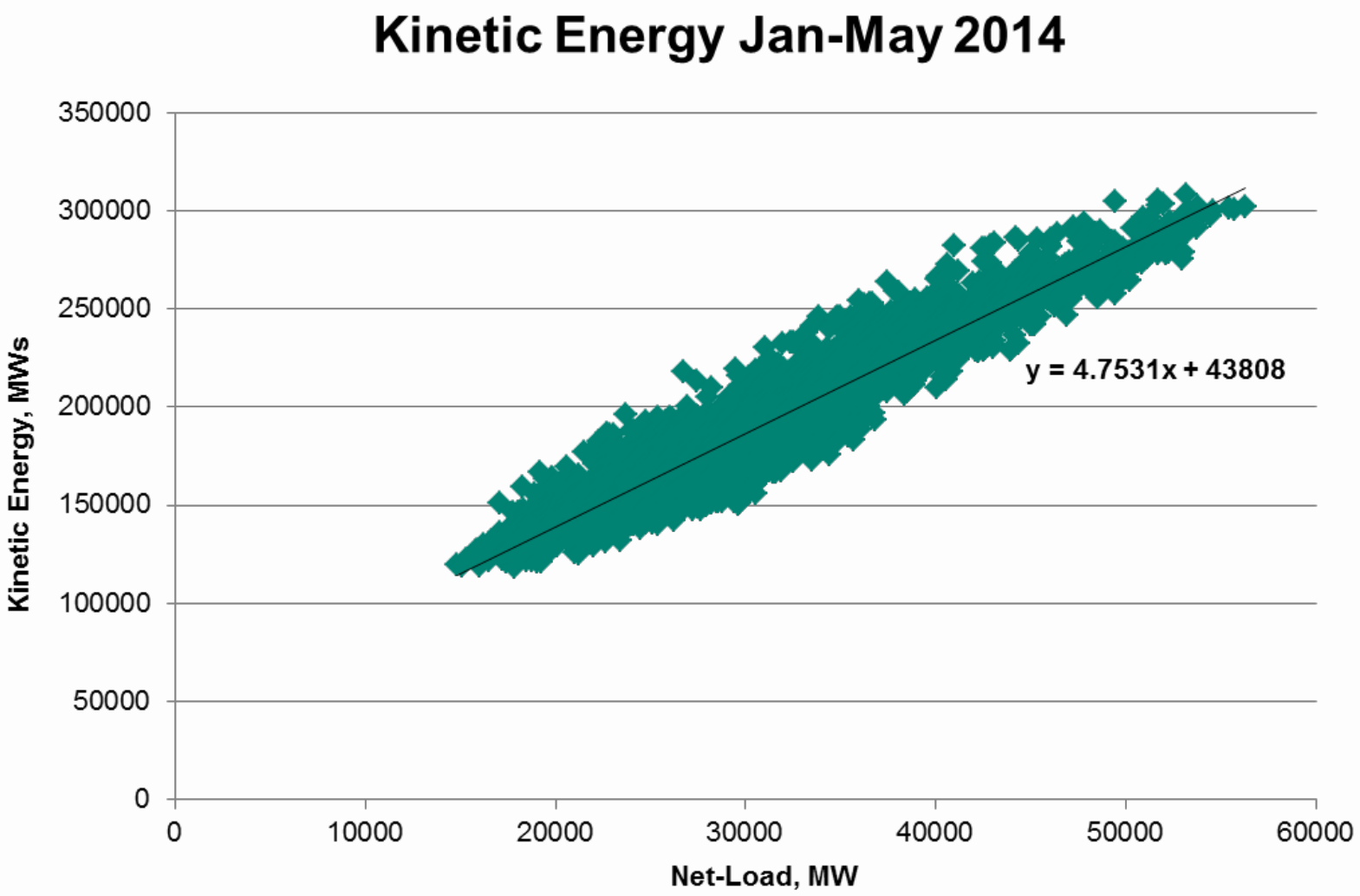
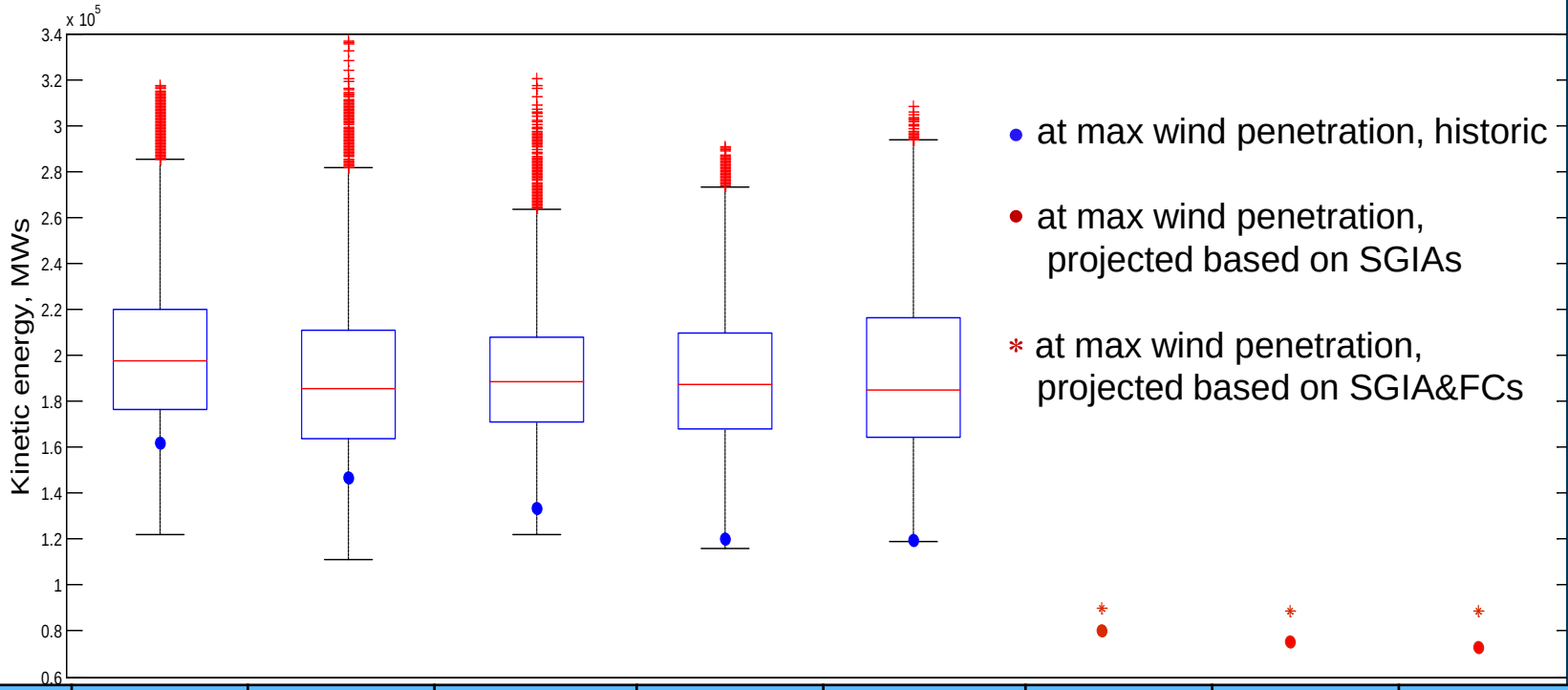
Kinetic Energy Trend used for Future Projections

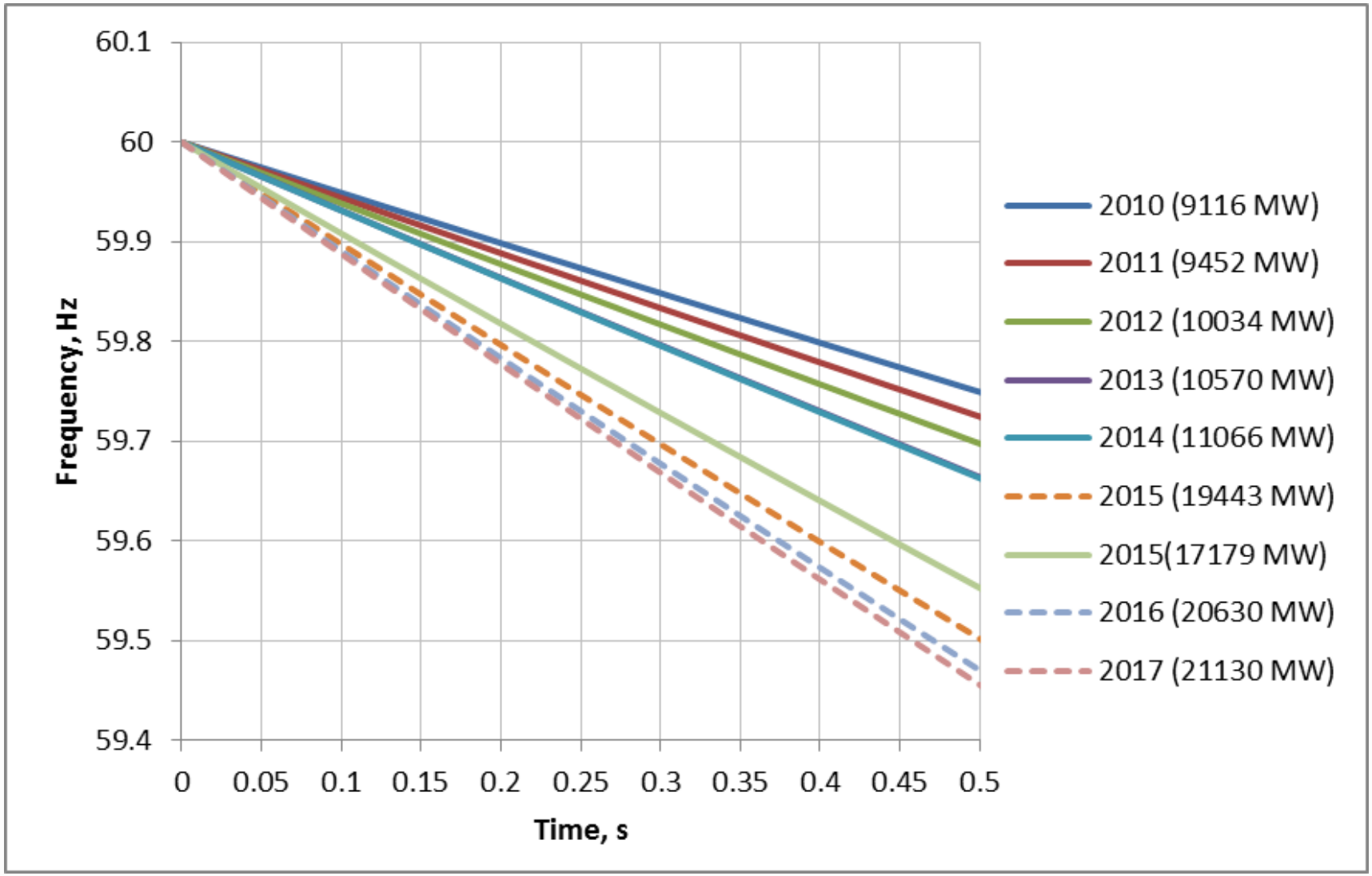


Historic Kinetic Energy and Future Projections



	2010	2011	2012	2013	2014	2015	2016	2017
Installed Capacity, MW	9,116	9,452	10,034	10,570	11,066	19,443	20,630	21,130
Max P_{wind}/P_{load}	25.5%	27.4%	29.8%	35.8%	39.4%	69%	73.2%	75%
P_{wind}, MW	6,483	6,772	7,247	8,773	9,699	17,041	18,082	18,520
Capacity Factor	71%	72%	72%	83%	88%	88%	88%	88%
P_{load}, MW	25,427	24,745	24,328	24,488	24,617	24,700	24,700	24,700

Frequency deviation after 2750 MW trip (in 0.5 s)



Additional metrics

- **Maximum permissible RoCoF, Hz/s:** based on frequency deviation to under-frequency load shed (UFLS) and time until first fast frequency response (FFR) in a system is fully deployed (e.g. 0.5 seconds for Responsive Reserve provided by Loads in ERCOT).

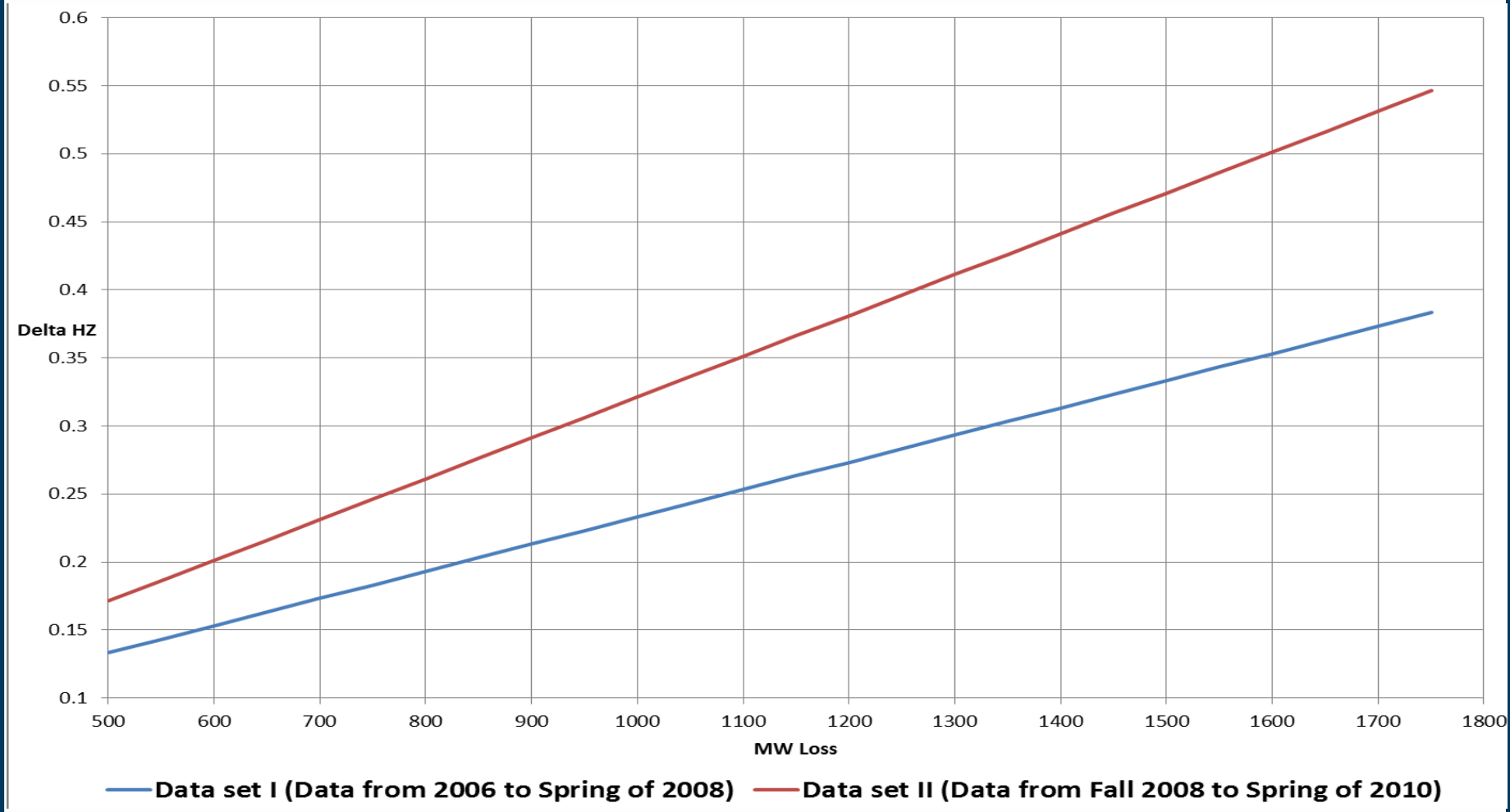
$$\mathbf{RoCoF_{max}=\Delta f_{UFLS}/t_{FFR}},$$

  From this metric based on largest contingency and load damping constant, **minimum inertia requirement** can be calculated for a system.

- **Hz/MW metric:** this is frequency nadir per MW generation trip, this metric does not only consider inertia but also includes governor response, load damping and fast frequency response.

  This metric can be tracked based on historic events and projected for the future (in use in ERCOT).

Frequency nadir for system load conditions ≤ 35000 MW (interpolated based on historical events)



Appendix: Supporting data for slide 6

	2010	2011	2012	2013	2014	2015 (w. FC)	2015	2016	2017
Installed Capacity, MW	9,116	9,452	10,034	10,570	11,066	17179	19,443	20,630	21,130
Max P_{wind}/P_{load}	25.5%	27.4%	29.8%	35.8%	39.4%	61%	69%	73.2%	75%
P_{wind}, MW	6,483	6,772	7,247	8,773	9,699	15057	17,041	18,082	18,520
Capacity Factor	71%	72%	72%	83%	88%	88%	88%	88%	88%
Net Load, MW	18944	17973	17082	15716	14918	9643	7659	6618	6180
Inertia, MWs	161741	147081	133675	120030	119604	89469	80020	75066	72979
Estimated RoCoF, Hz/s	**0.501**	**0.551**	**0.605**	**0.672**	**0.674**	**0.89**	**0.996**	**1.059**	**1.088**