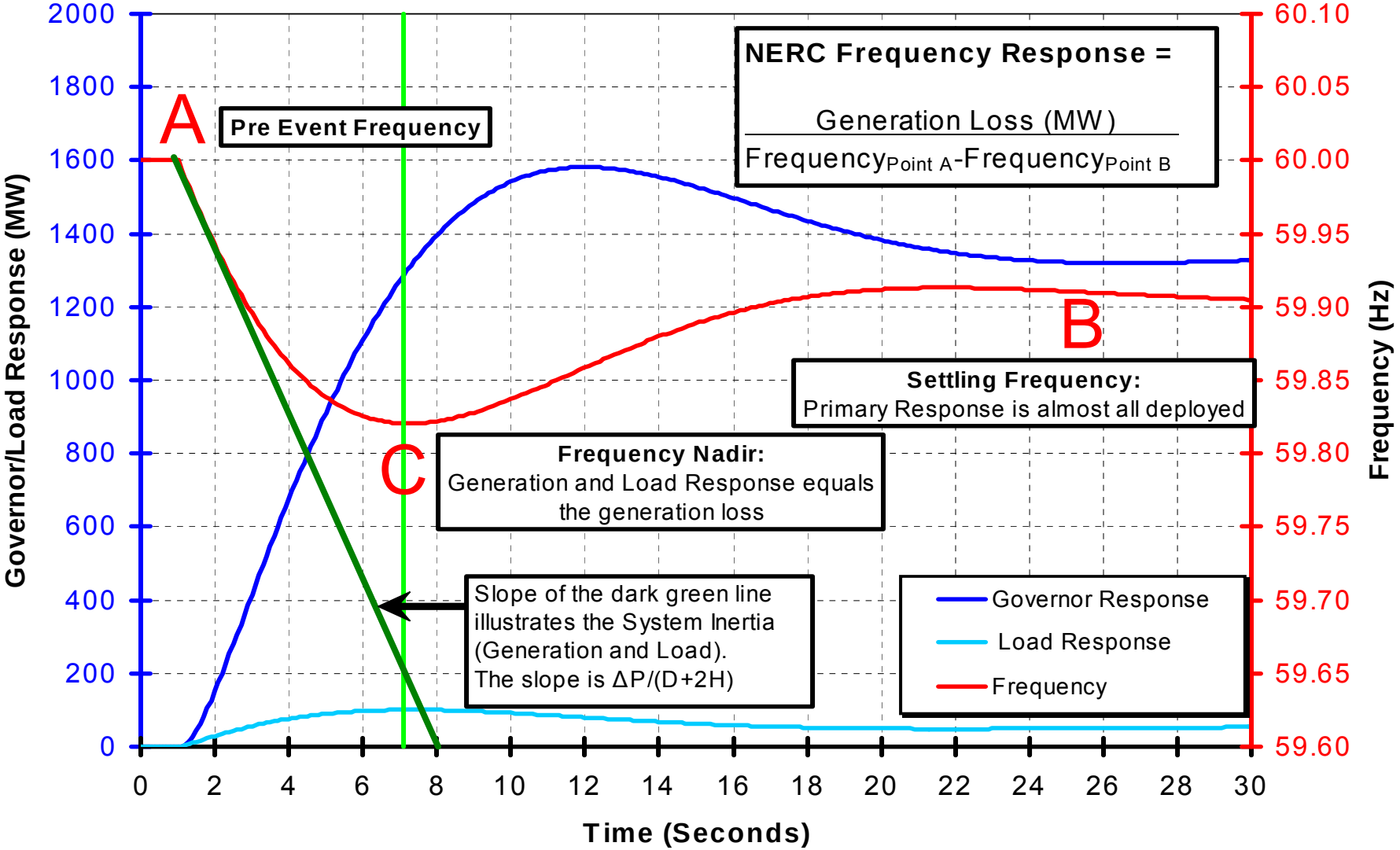
Slides for FR Technical Conference

Office of Electric Reliability

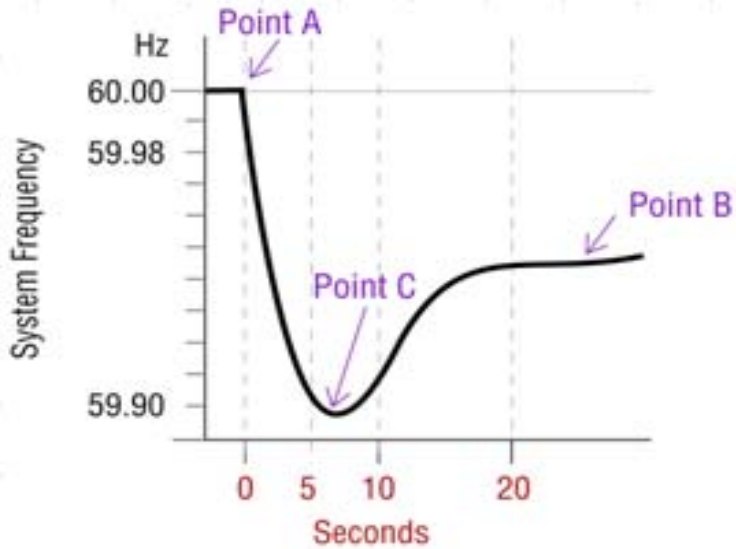
September 2010

Frequency Response Basics

(Using a 1400 MW generation loss event as an example)



Frequency Response Basics

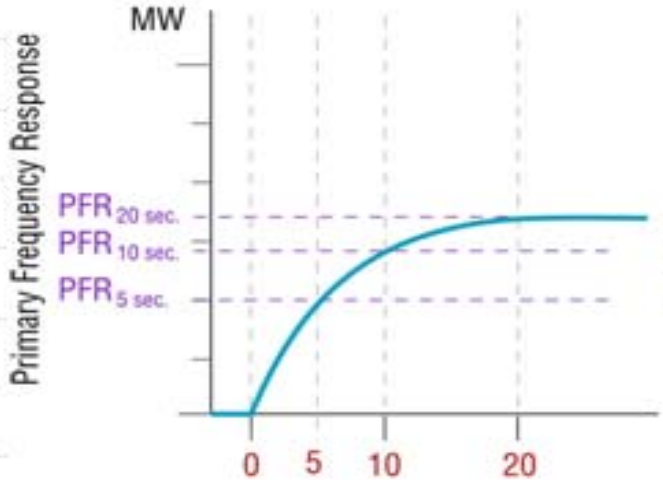


Pre-disturbance Frequency: $\text{Frequency}_{\text{point A}}$

Settling Frequency: $\text{Frequency}_{\text{point B}}$

Frequency Nadir: $\text{Frequency}_{\text{point C}}$

$$\text{Frequency Response (current practice)} = \frac{\text{Generation Lost (MW)}}{\text{Frequency}_{\text{point A}} - \text{Frequency}_{\text{point B}}}$$

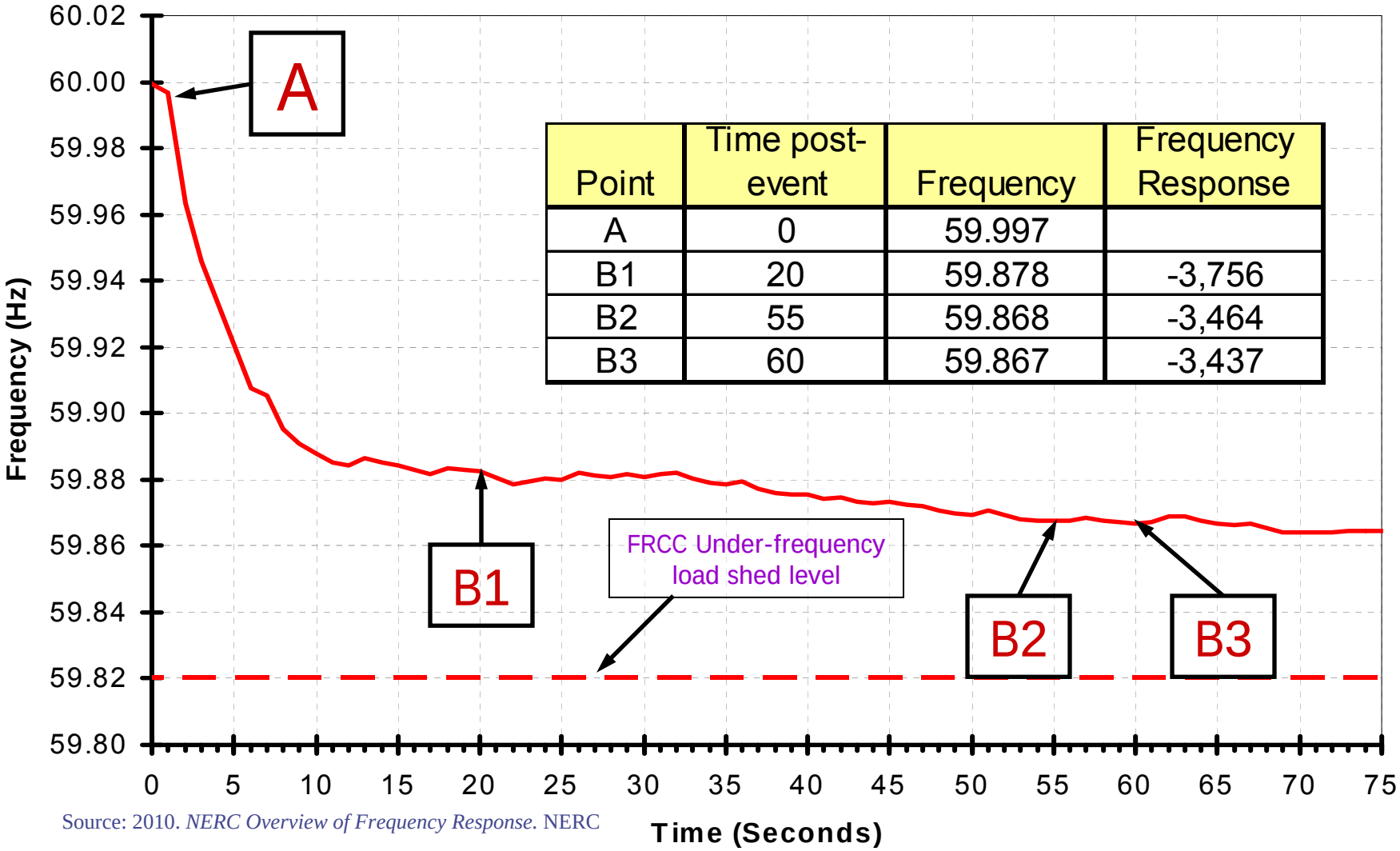


Primary frequency response (PFR) delivered at 20 seconds

Primary frequency response (PFR) delivered at 10 seconds

Primary frequency response (PFR) delivered at 5 seconds

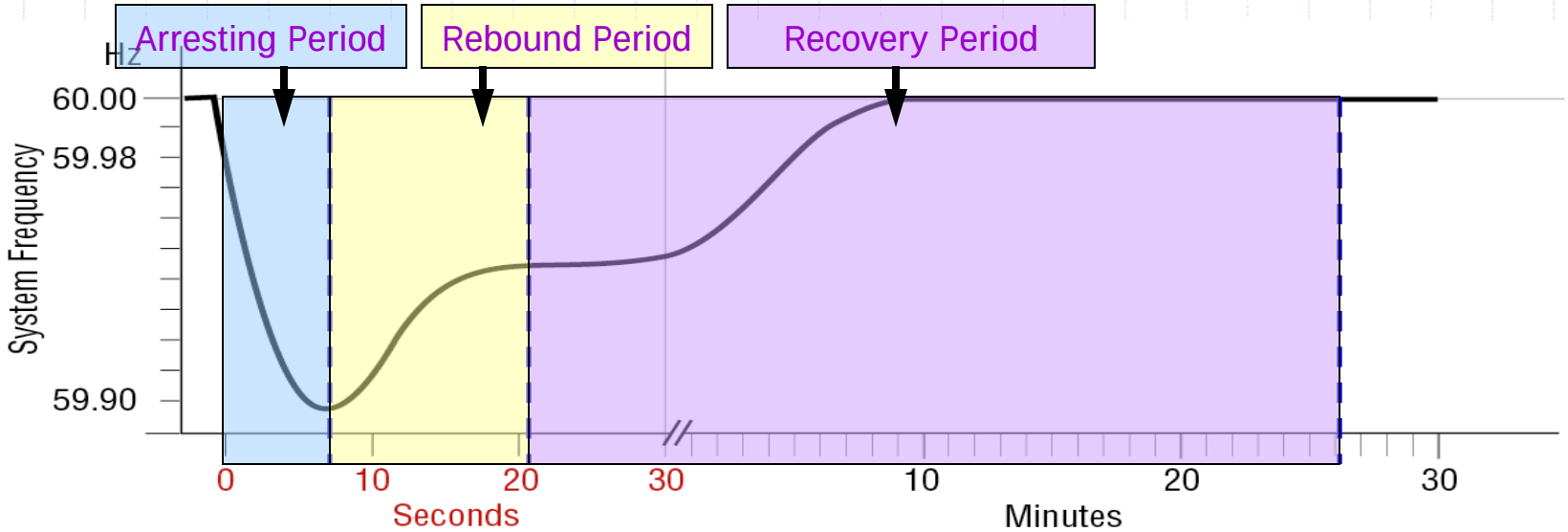
August 4, 2007 1744 Hours Event

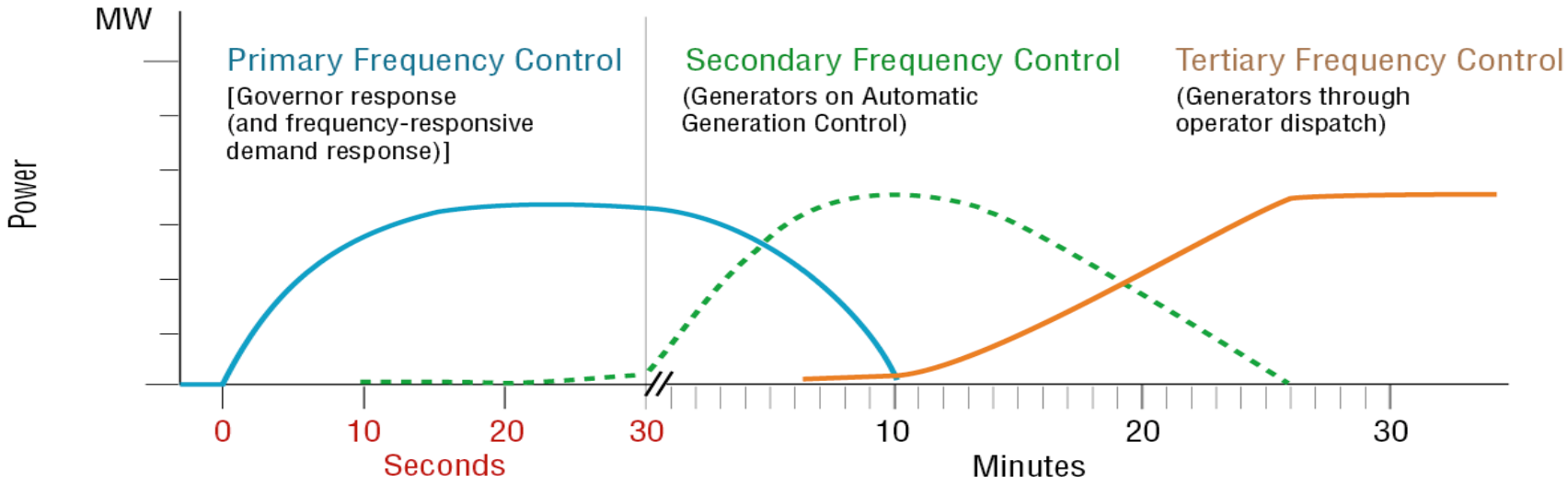


Point	Time post-event	Frequency	Frequency Response
A	0	59.997	
B1	20	59.878	-3,756
B2	55	59.868	-3,464
B3	60	59.867	-3,437

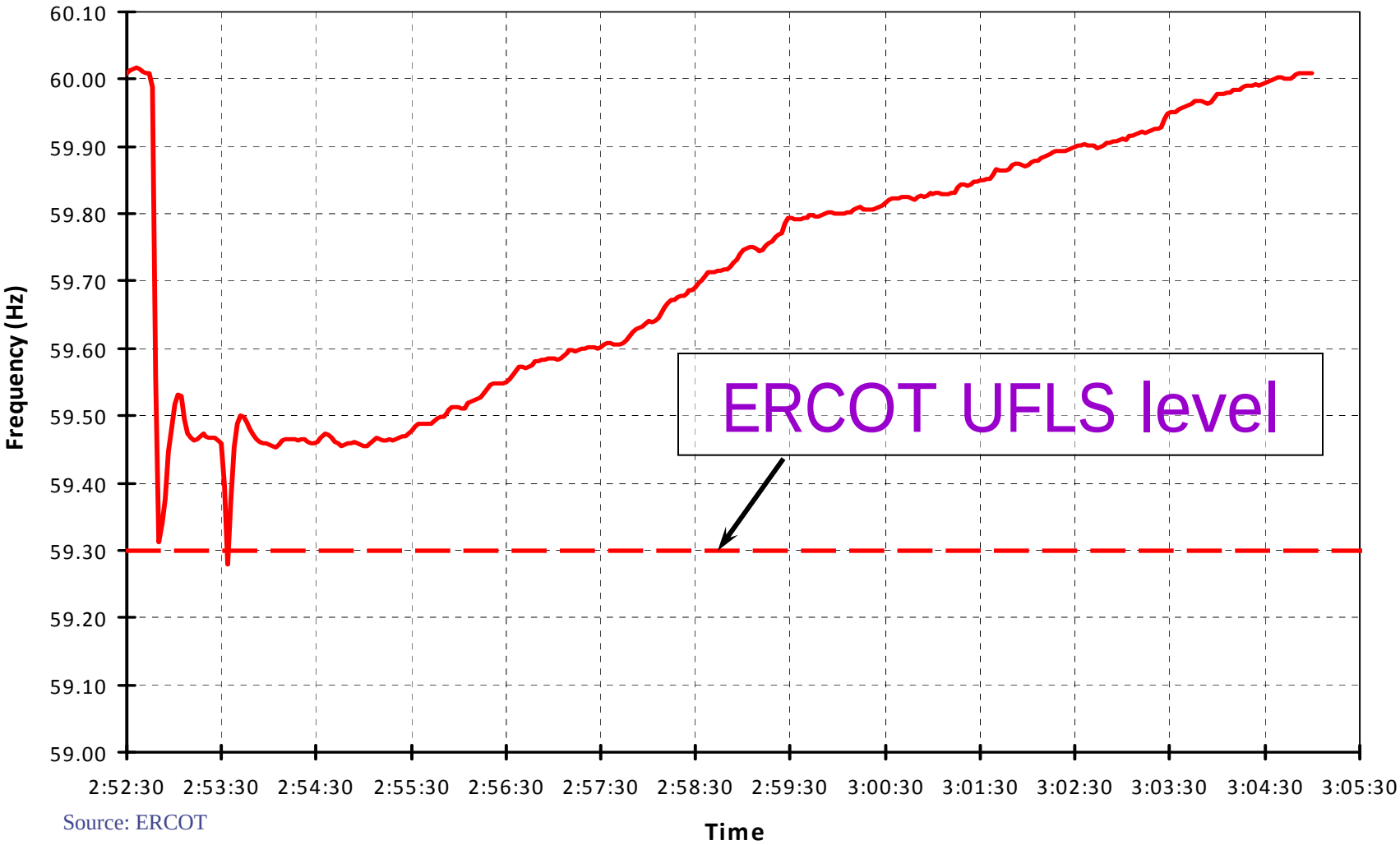
Source: 2010. *NERC Overview of Frequency Response.* NERC

Frequency Performance



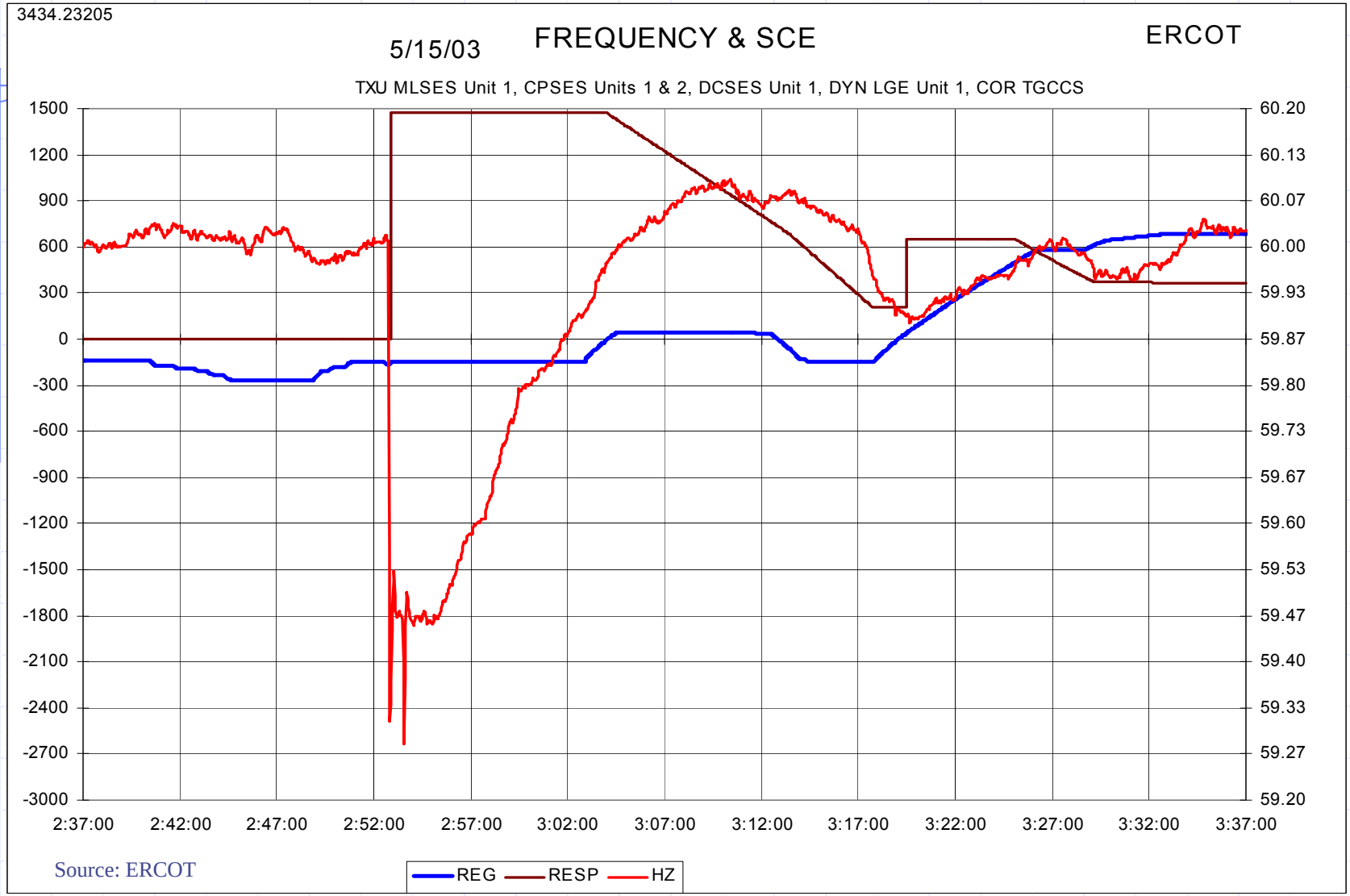


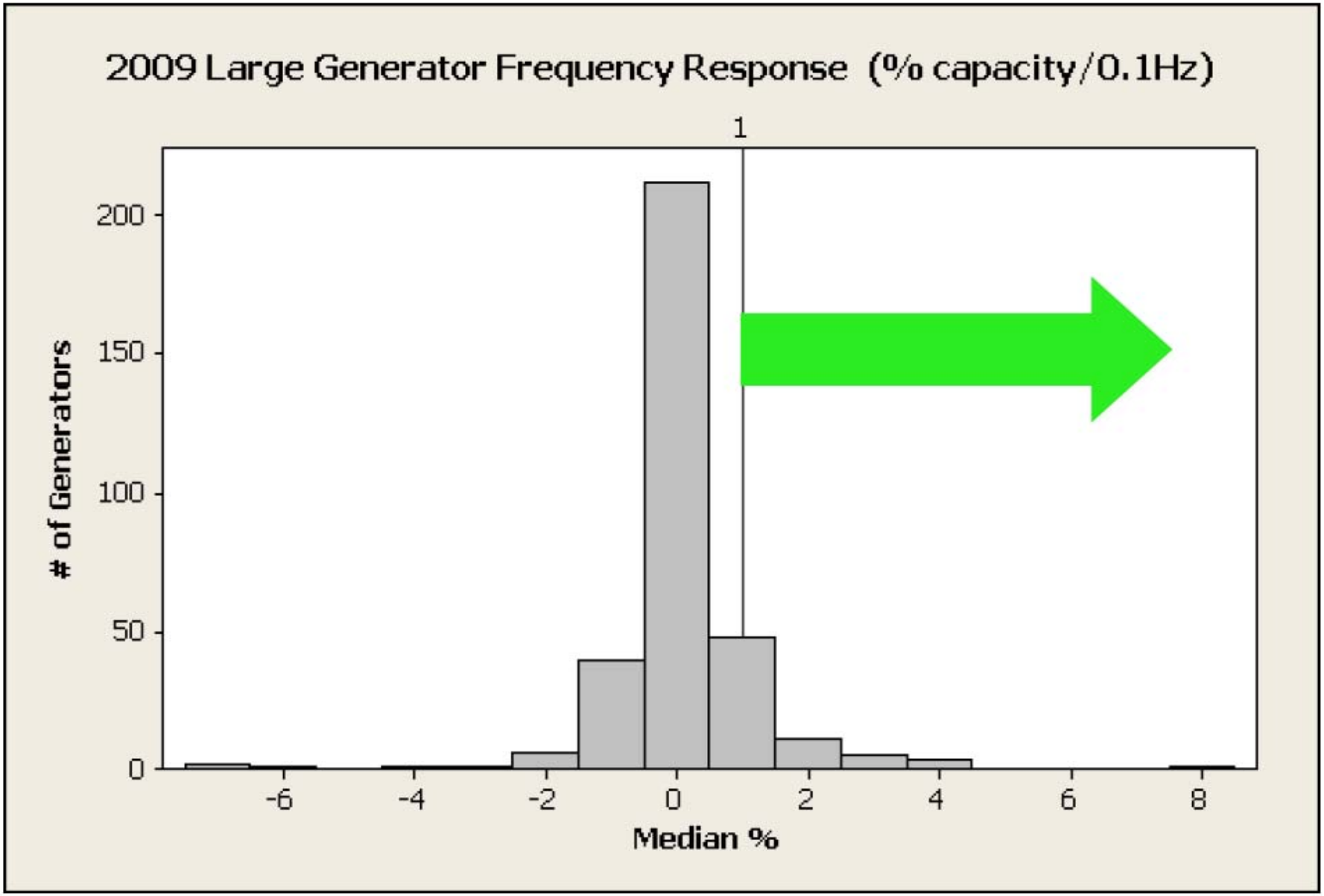
ERCOT May 15, 2003 Event



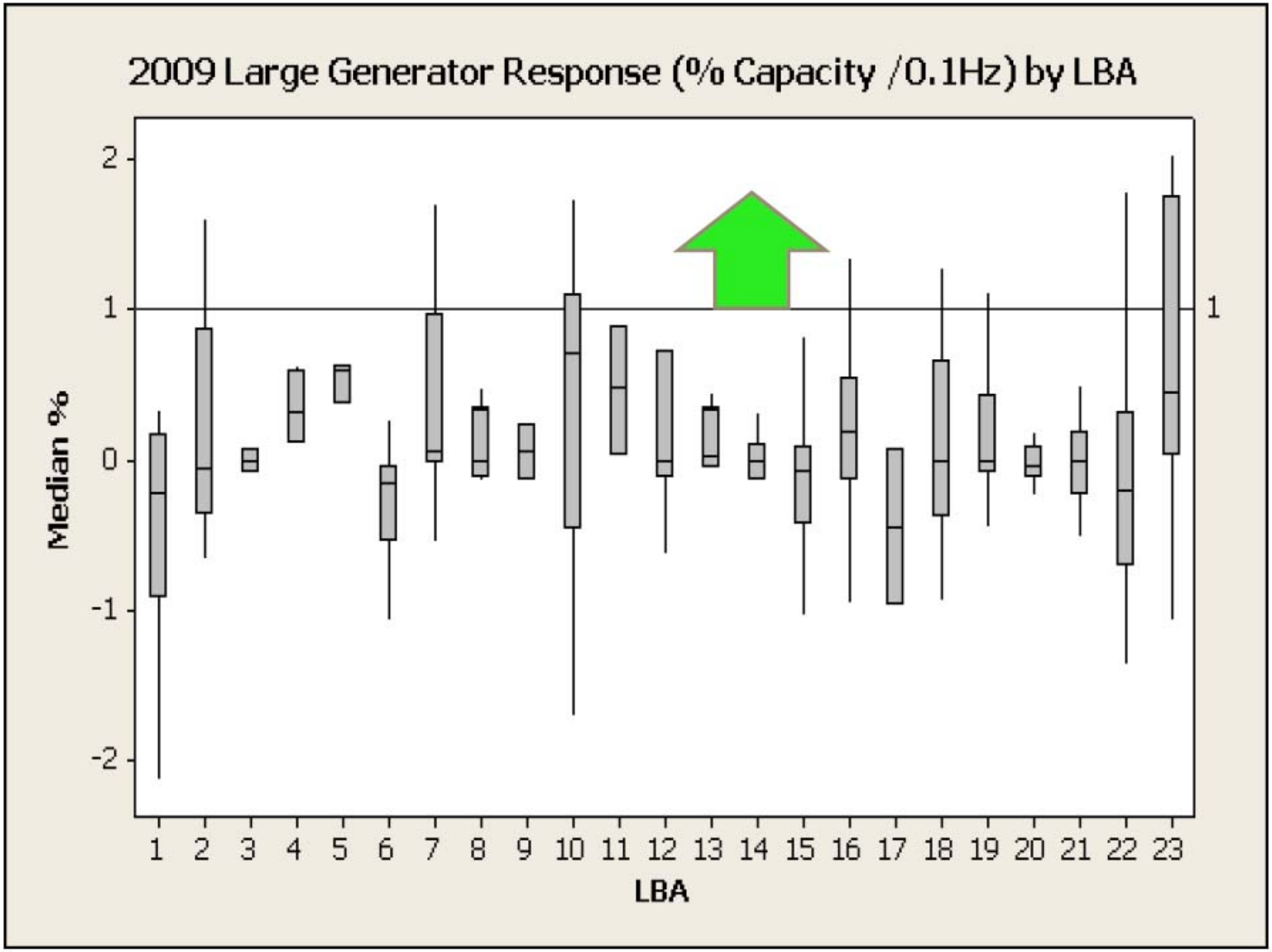
Source: ERCOT

ERCOT May 15, 2003 1453 Event

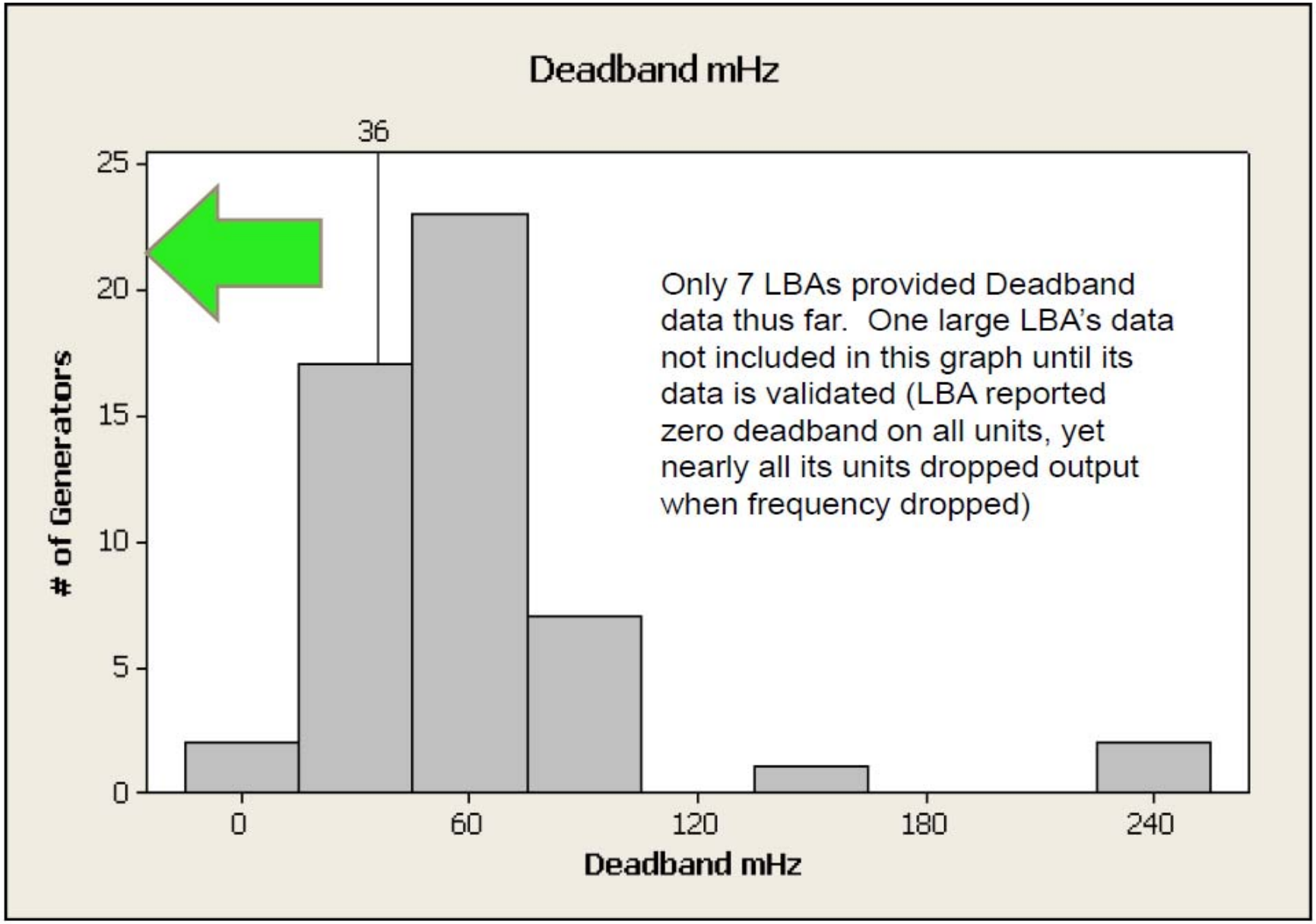




Source: MISO Reliability Subcommittee

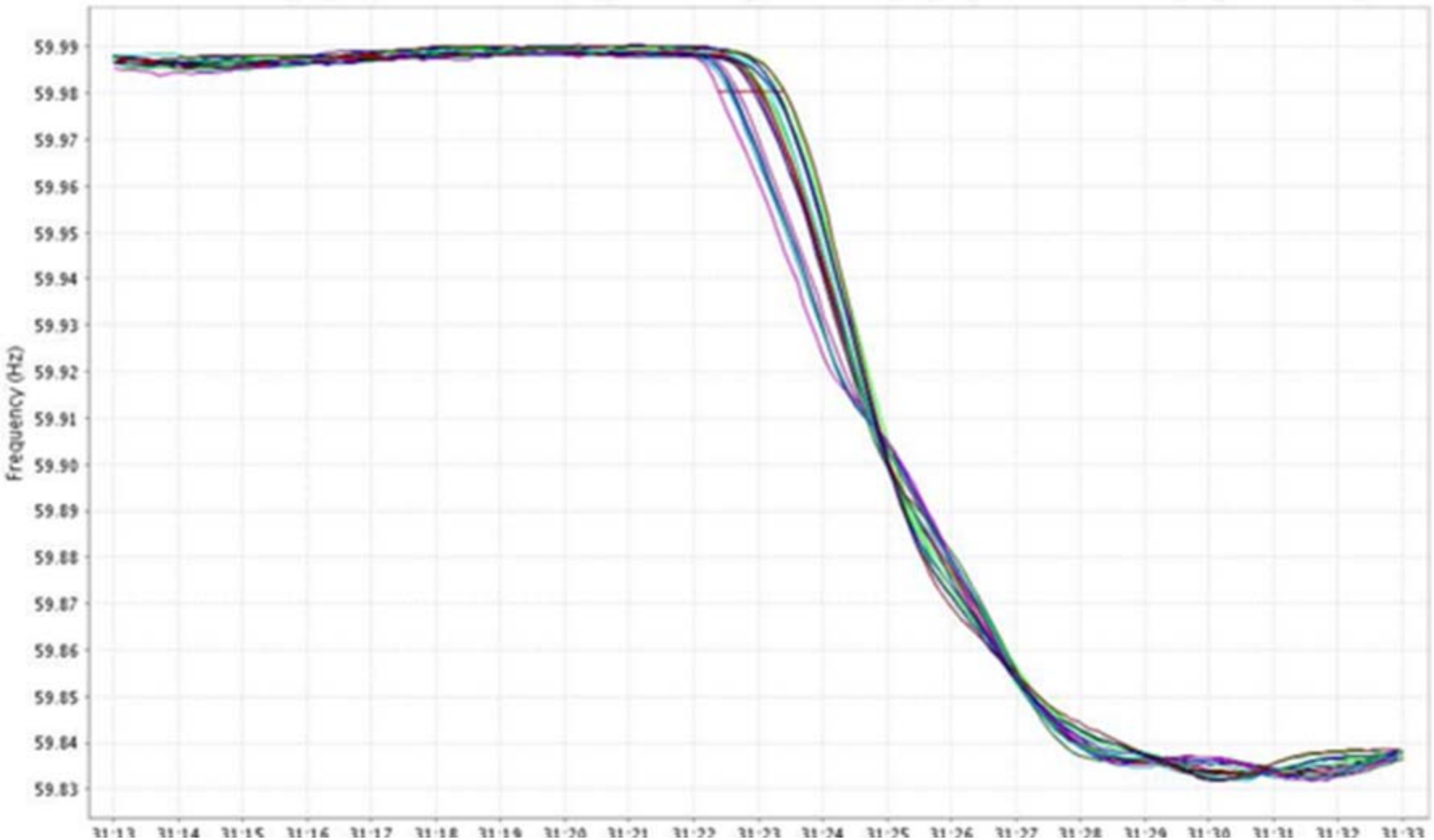


Source: MISO Reliability Subcommittee



Source: MISO Reliability Subcommittee

Frequency Recordings from Different Locations within the Western Interconnection Following the Sudden Loss of a Large Generator



Source: Courtesy of Genscape

Basic Representation of System Frequency Governing

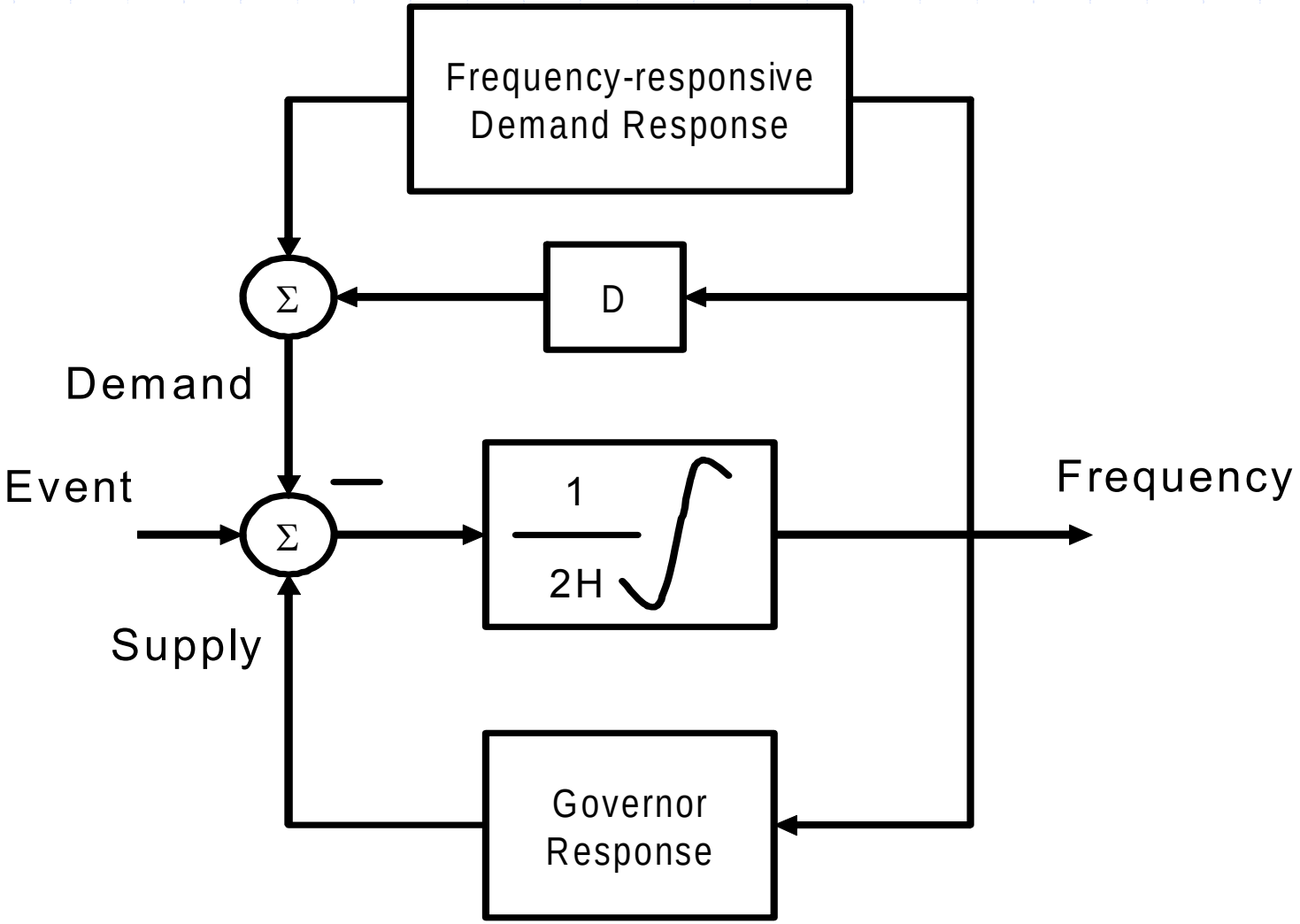
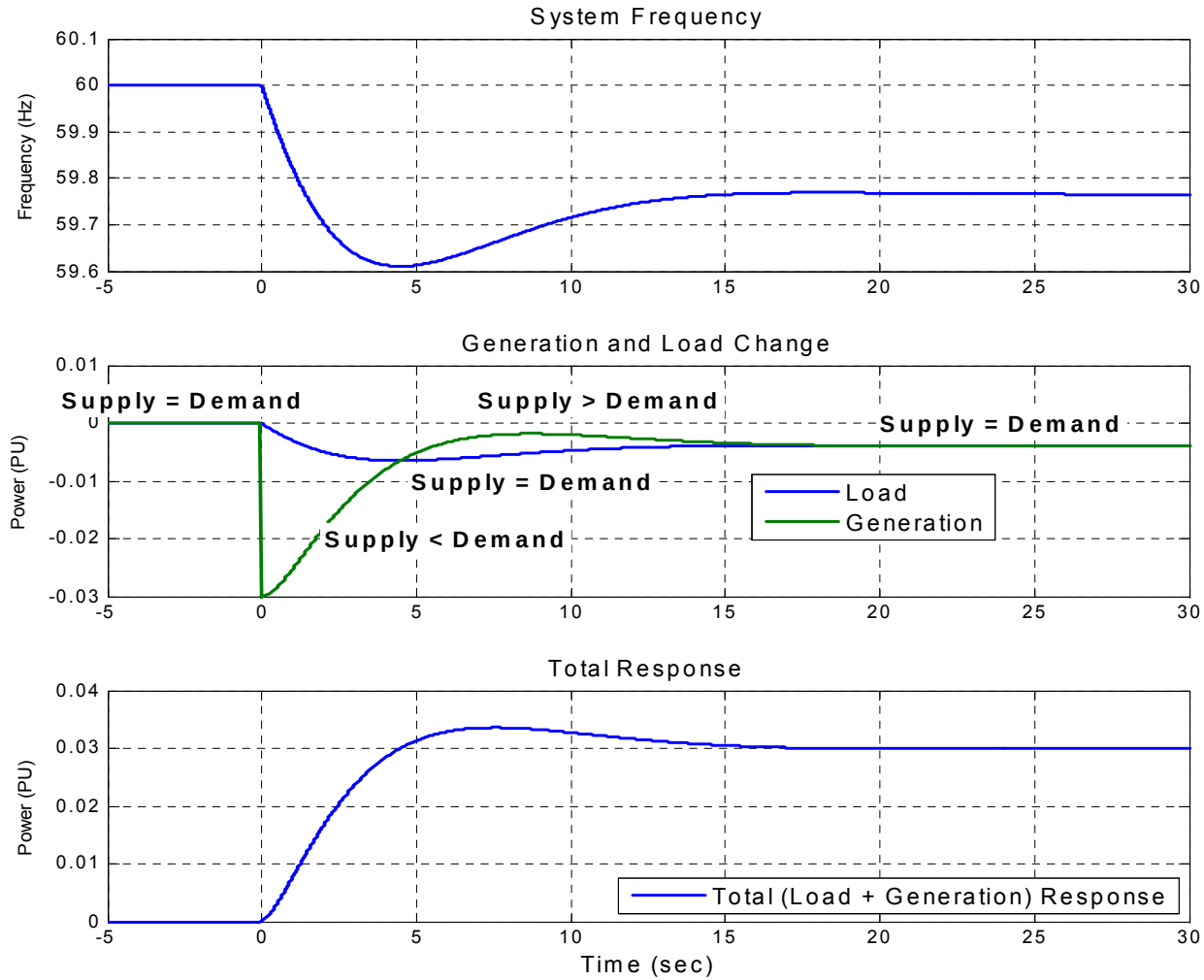
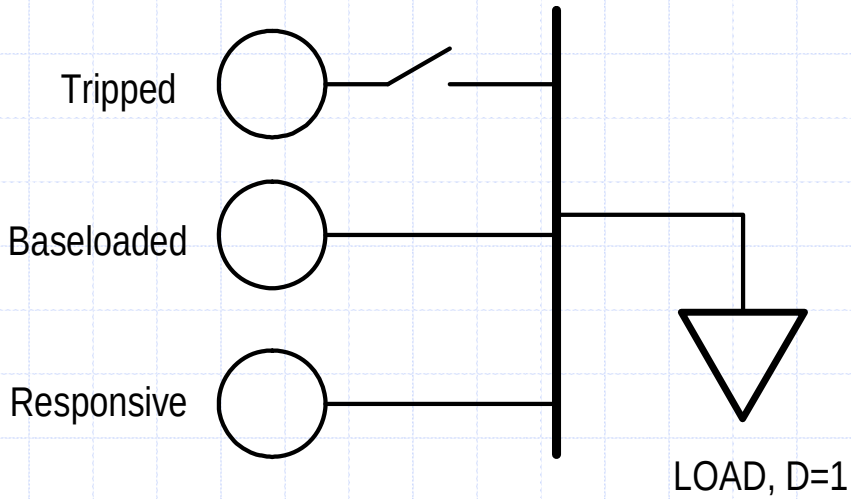


Illustration of Frequency Response for a 3% generation loss

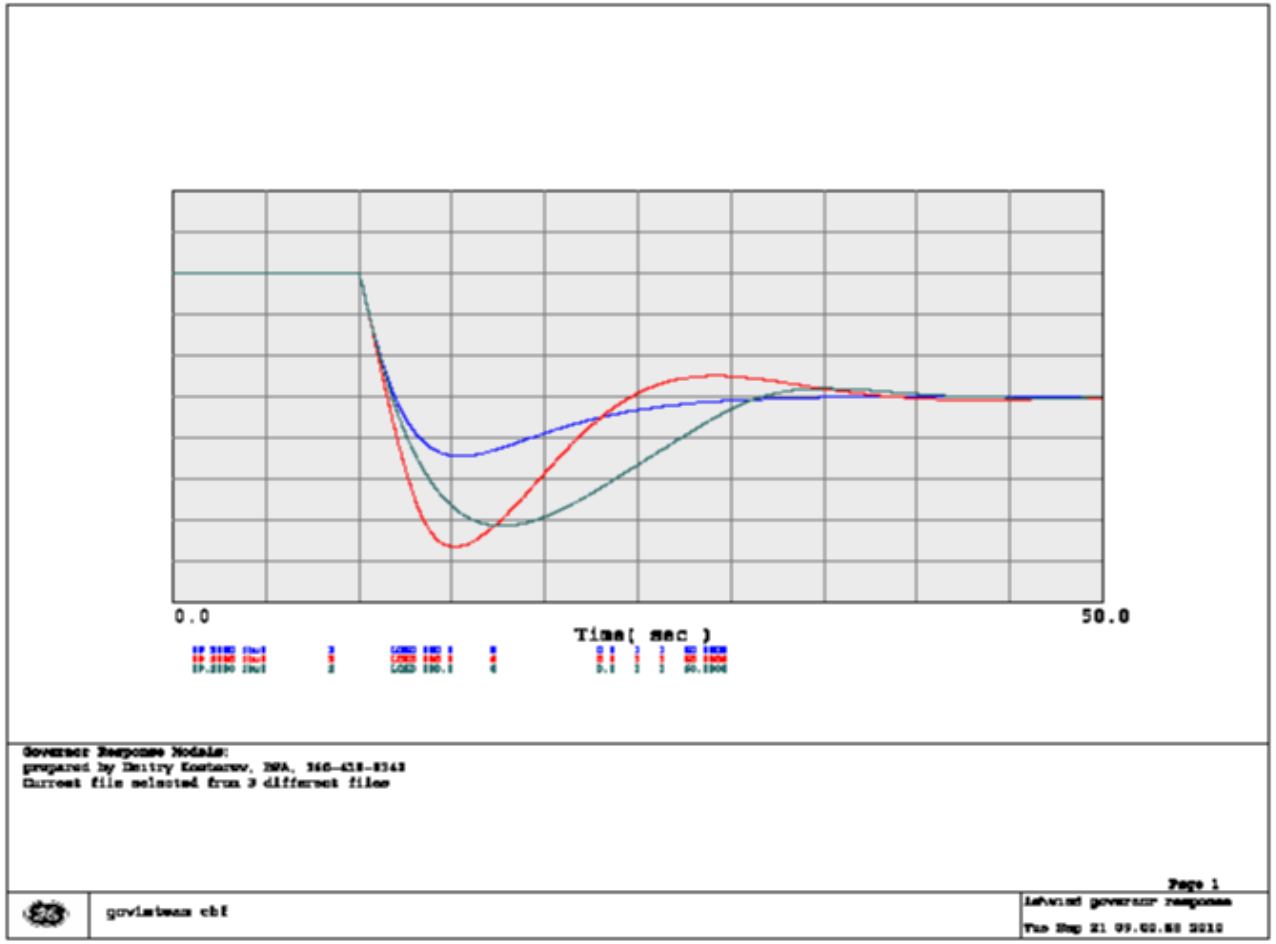


Simple Test System



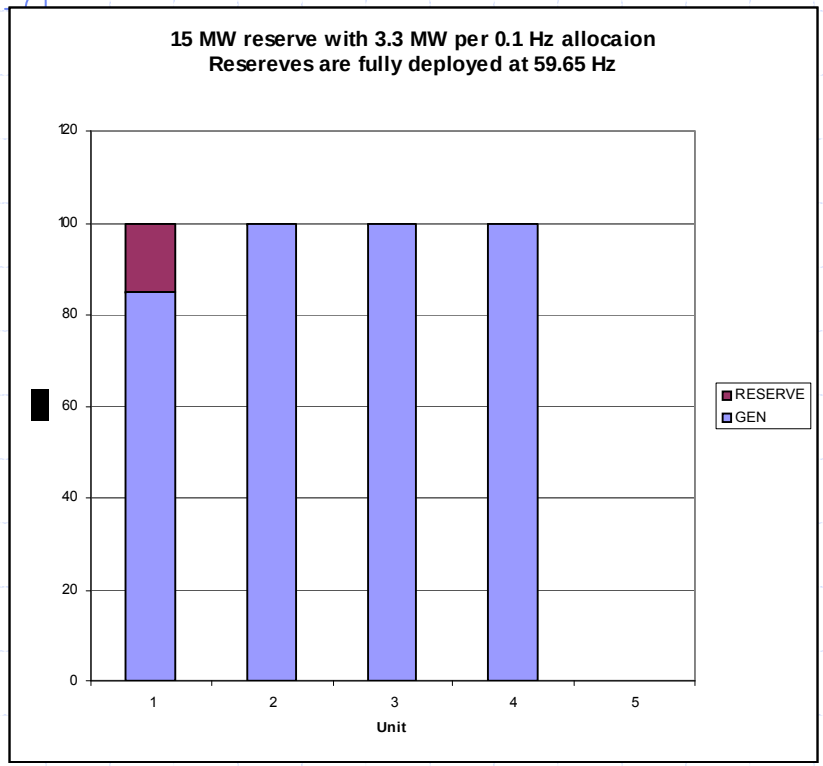
System size is 100 GW
3 GW of generation tripped
All generators have inertia of 4 seconds
Load damping D=1
Baseloaded generation does not response to frequency, produces the same MWs
Responsive generation has droop setting of 5% and head room of 3GW

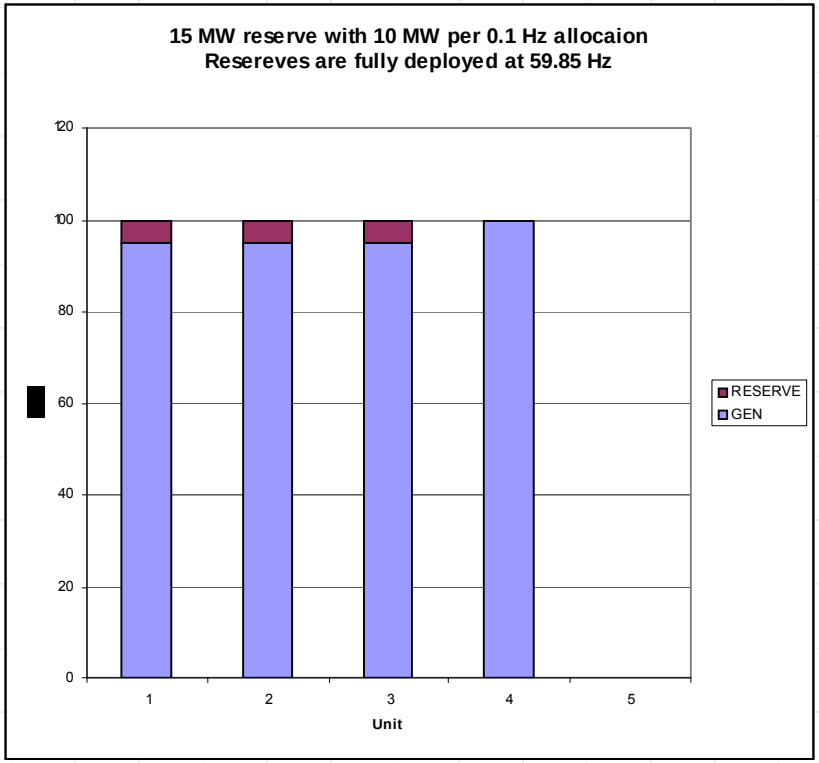
Different speed of reponse of “responsive” units



Blue = gas-turbine unit on governor control
Red = (fast) hydro-power unit on governor control
Green = (ideal) steam-turbine unit on governor control

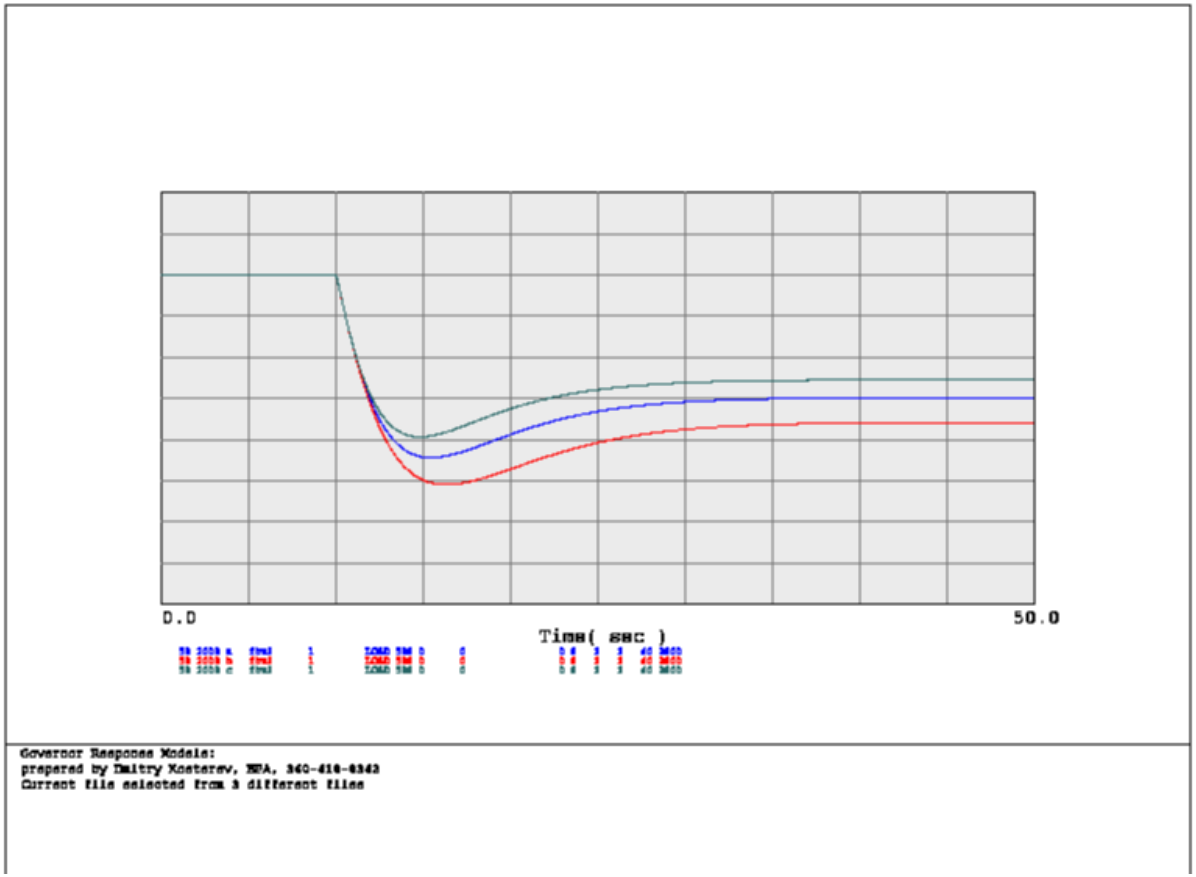
Nadir Frequency will greatly depend on how reserves are allocated





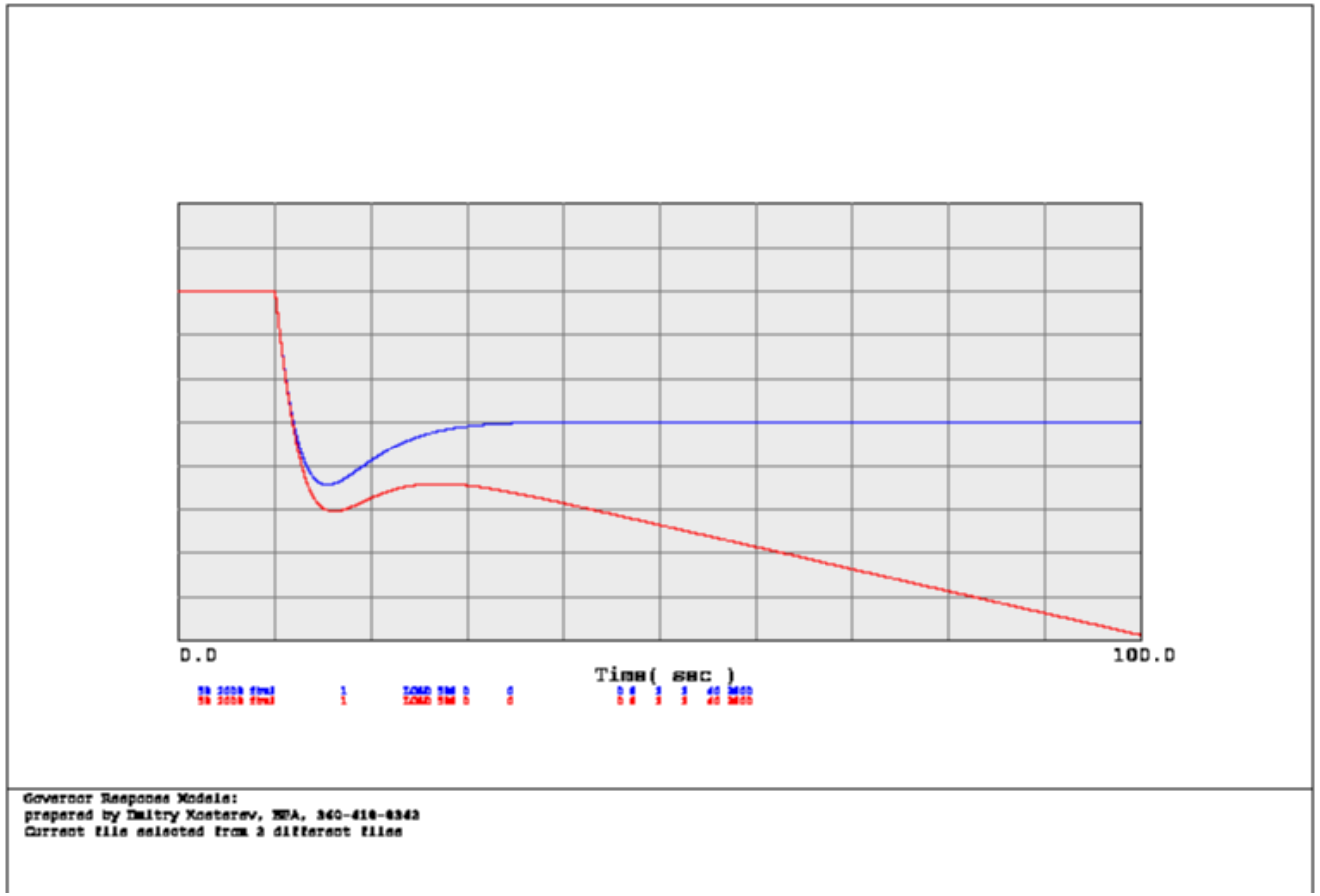
On the left side, all the reserves are put on a single unit. On the right, the reserves are spread among three units. With the same droop setting, the frequency drop for the case on the left case will be three times the frequency drop for the case on the right side.

Importance of Deployment Rate



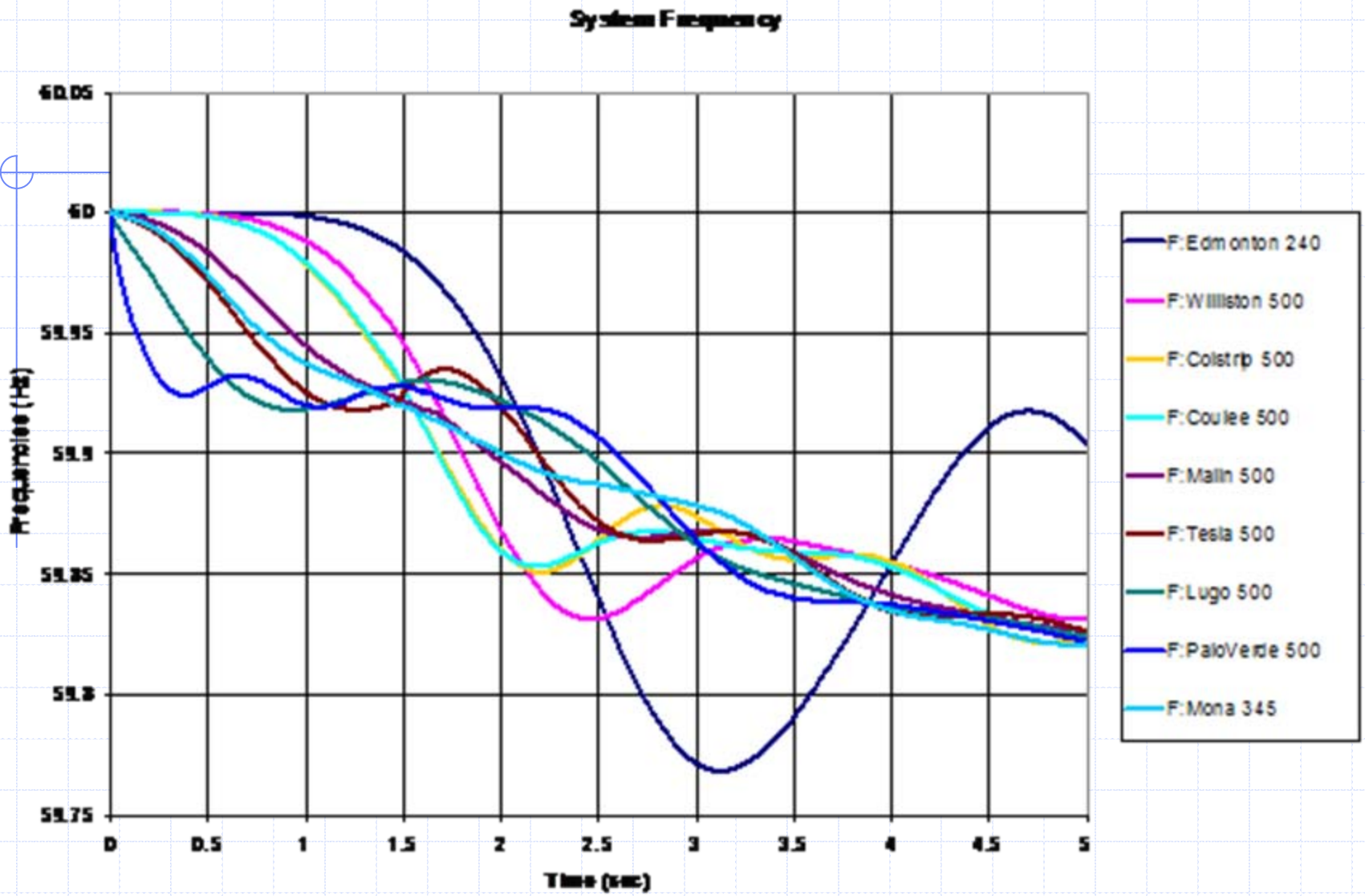
20 GW of generating capacity (red)
25 GW of generating capacity (blue)
30 GW if generating capacity (green)

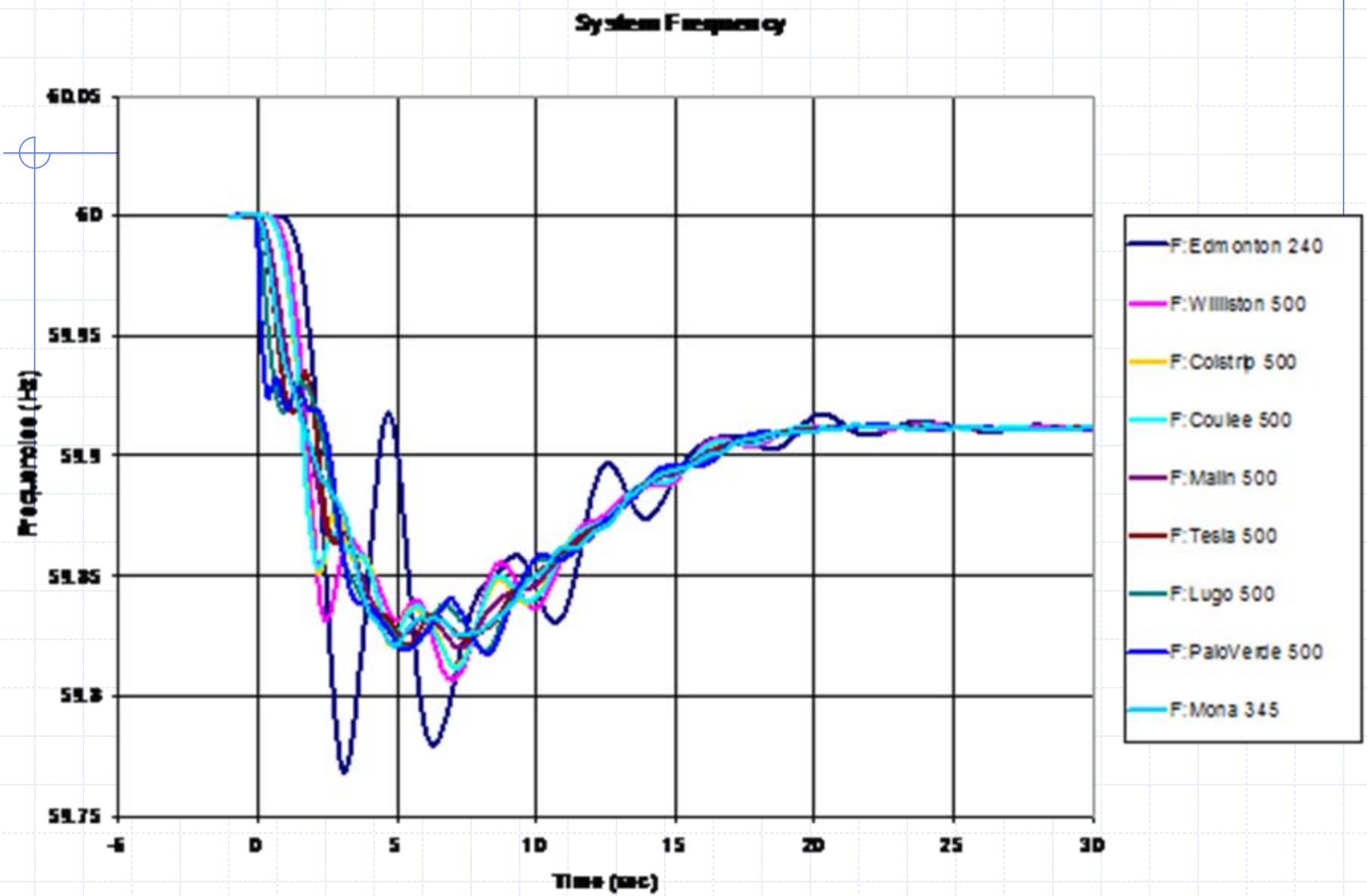
Frequency Response Sustainability



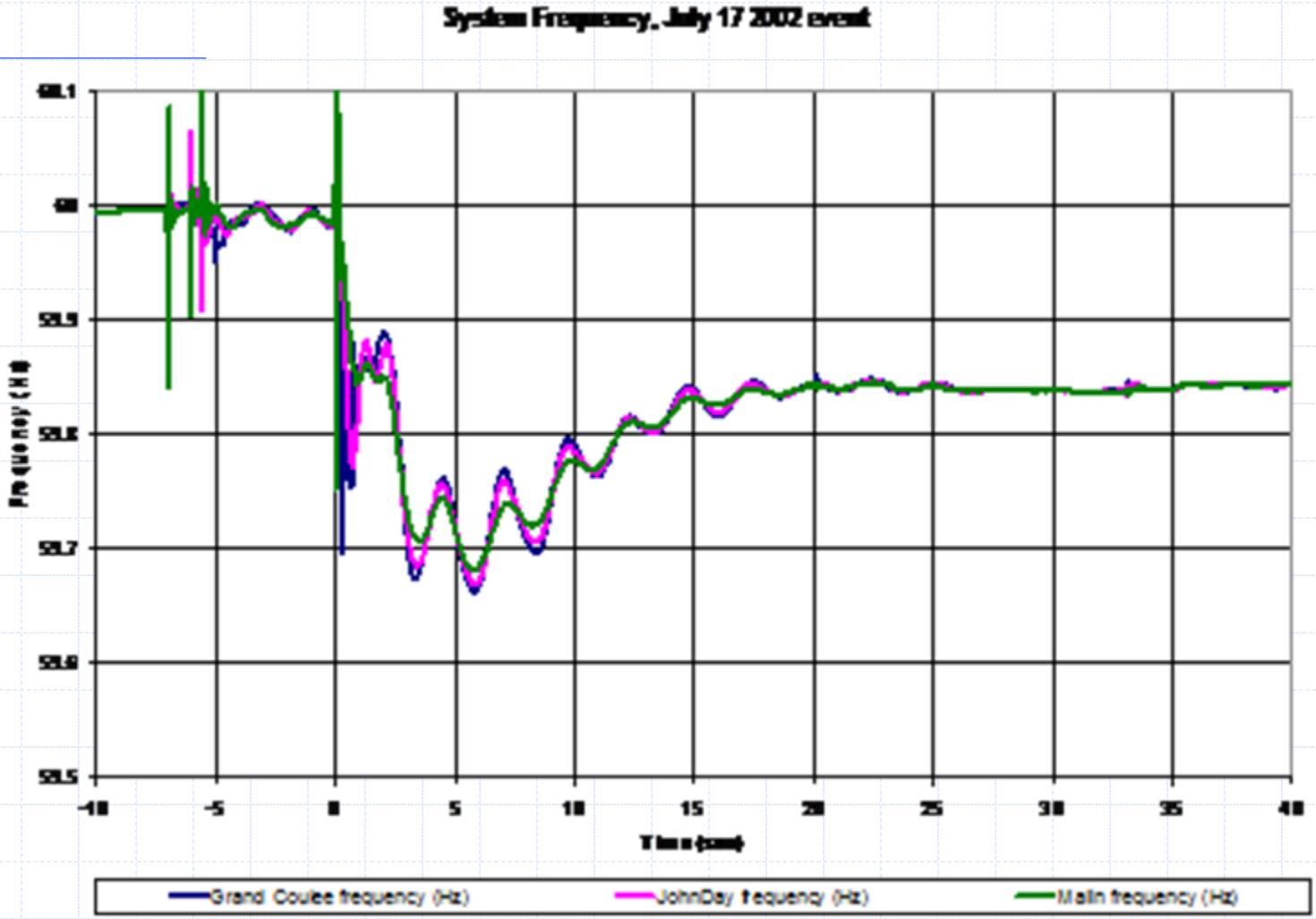
Blue = frequency response is sustained

Red = generator has a “slow” load controller returning to MW set-point

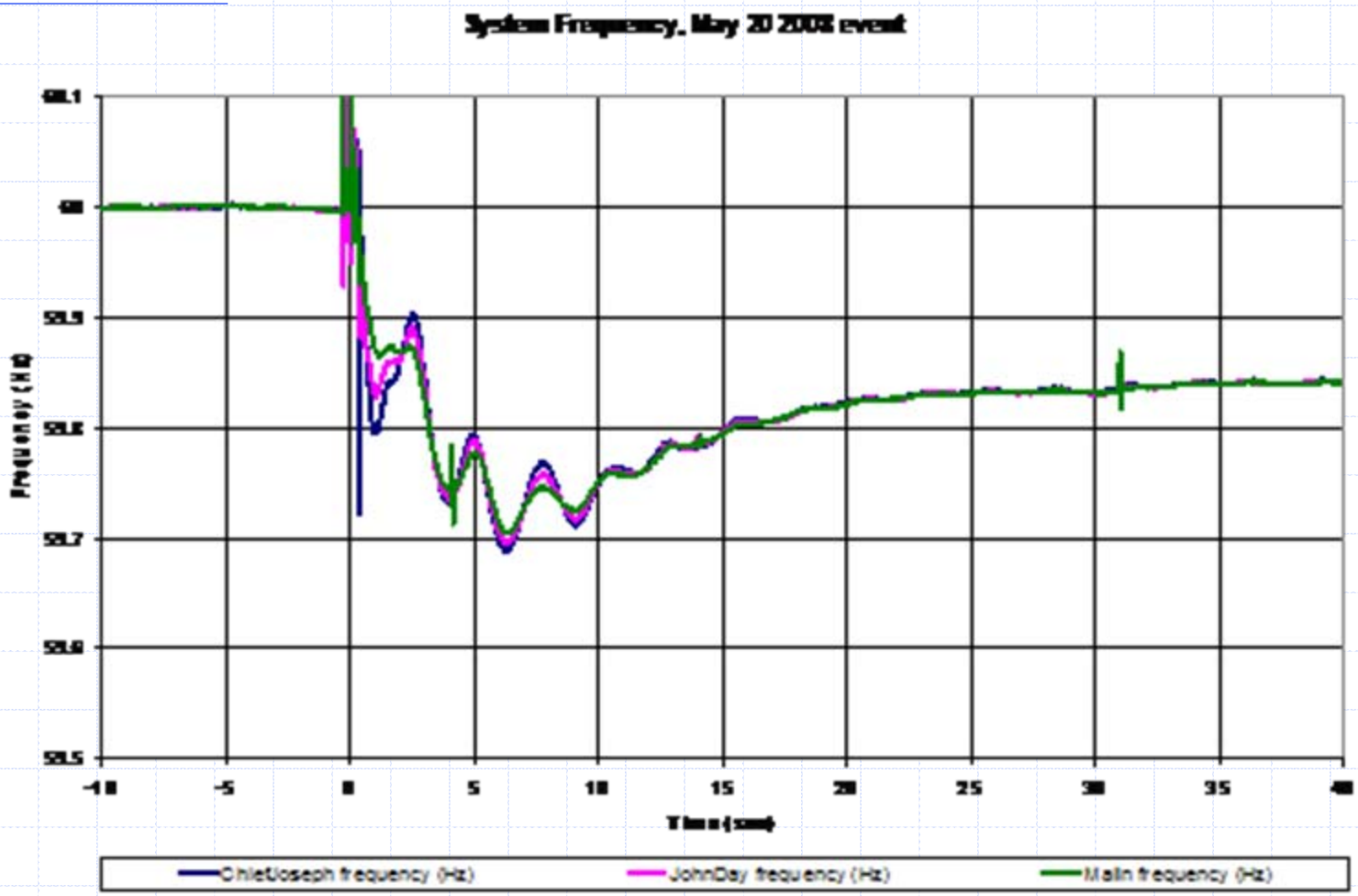

System Frequency
60.05
60
59.95
59.9
59.85
59.8
59.75
Frequency (Hz)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (sec)
F:Edmonton 240
F:Williston 500
F:Colstrip 500
F:Coulee 500
F:Malin 500
F:Tesla 500
F:Lugo 500
F:PaloVerde 500
F:Mona 345


System Frequency
60.05
60
59.95
59.9
59.85
59.8
59.75
Frequency (Hz)
-5
0
5
10
15
20
25
30
Time (sec)
F:Edmonton 240
F:Williston 500
F:Colstrip 500
F:Coulee 500
F:Malin 500
F:Tesla 500
F:Lugo 500
F:PaloVerde 500
F:Mona 345

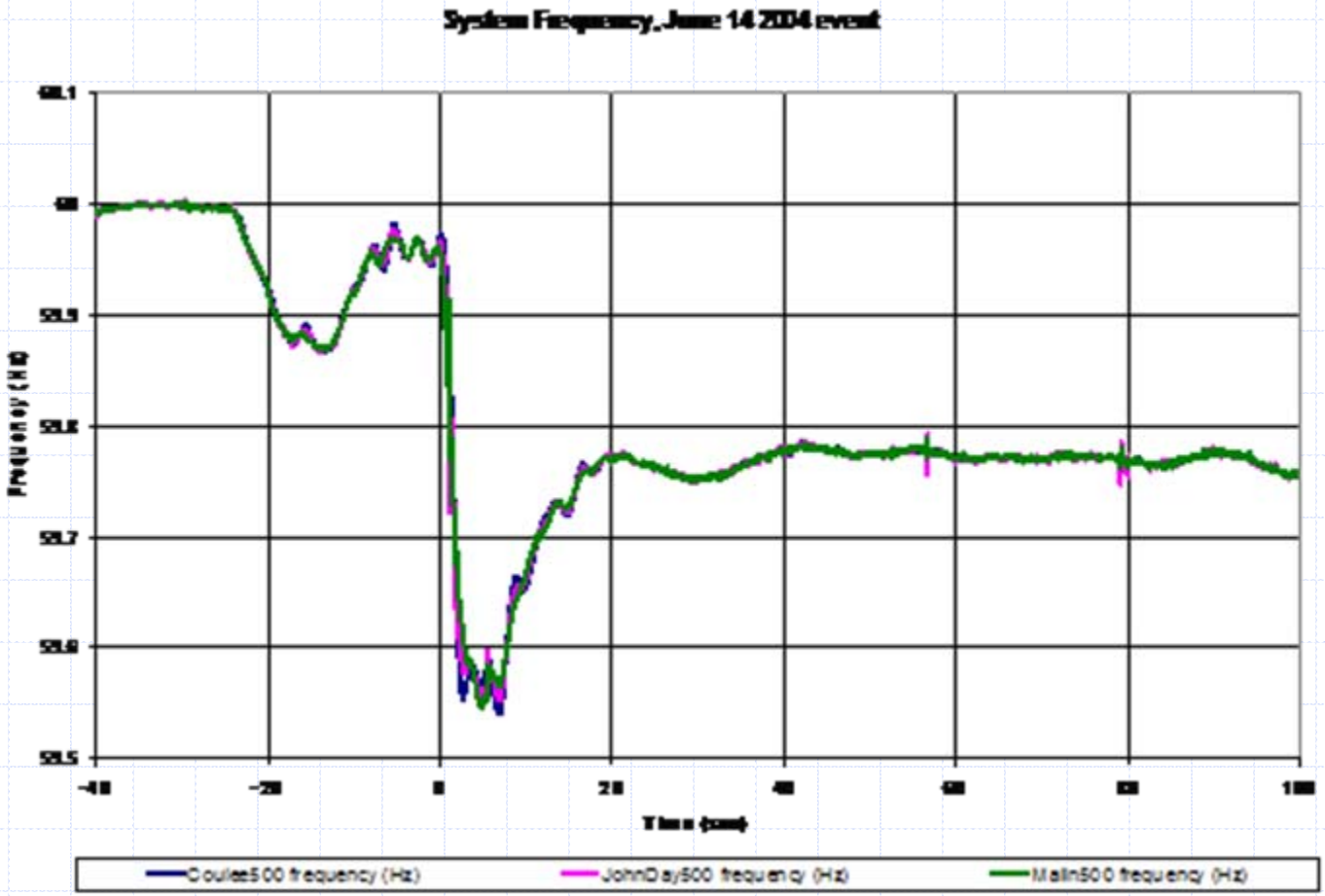
2,812 MW RAS event June 17, 2002



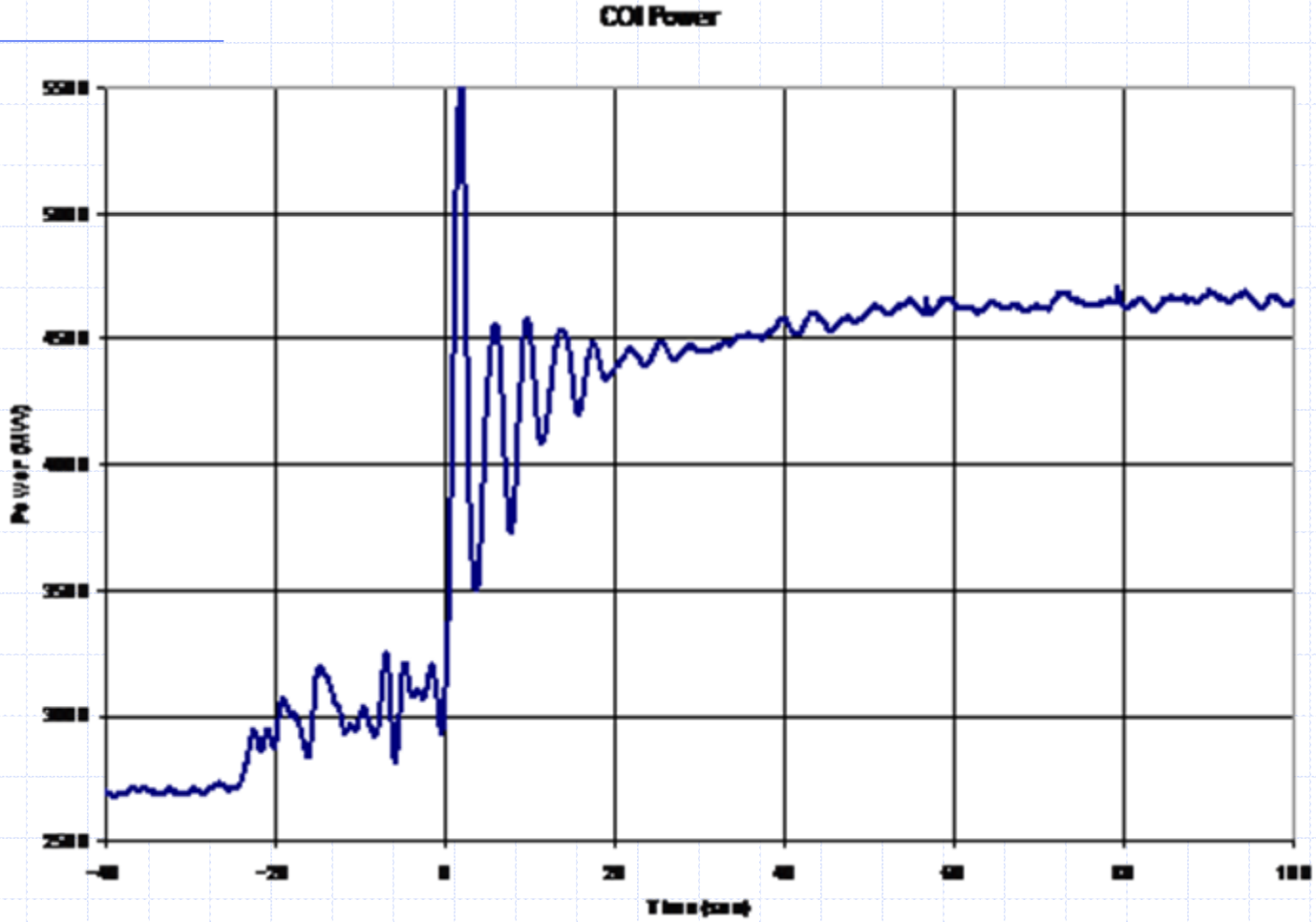
2,815 MW RAS event on May 20, 2008



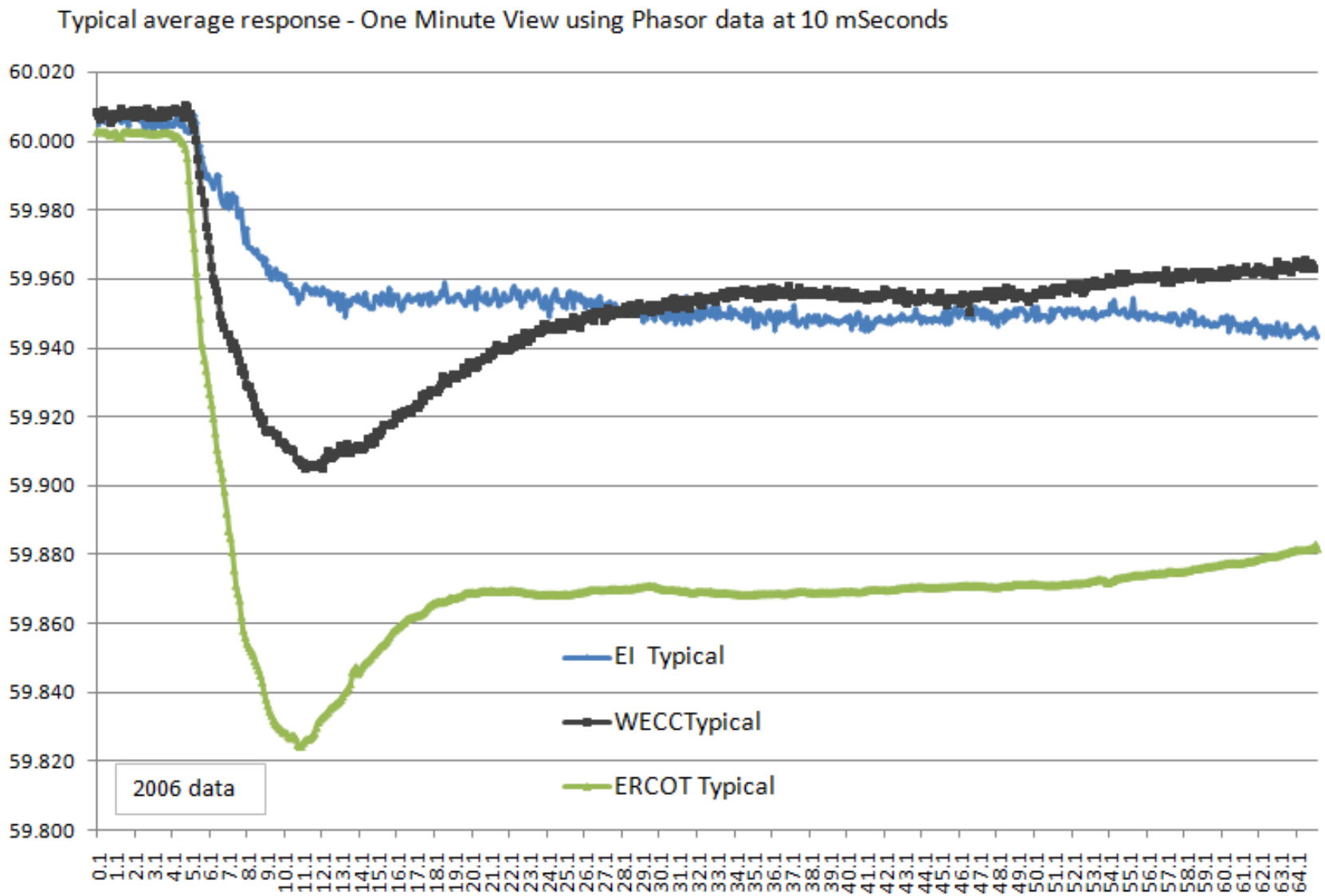
West Wing fault in Arizona on June 14, 2004: 3,900 MW lost at 0 seconds on plot scale



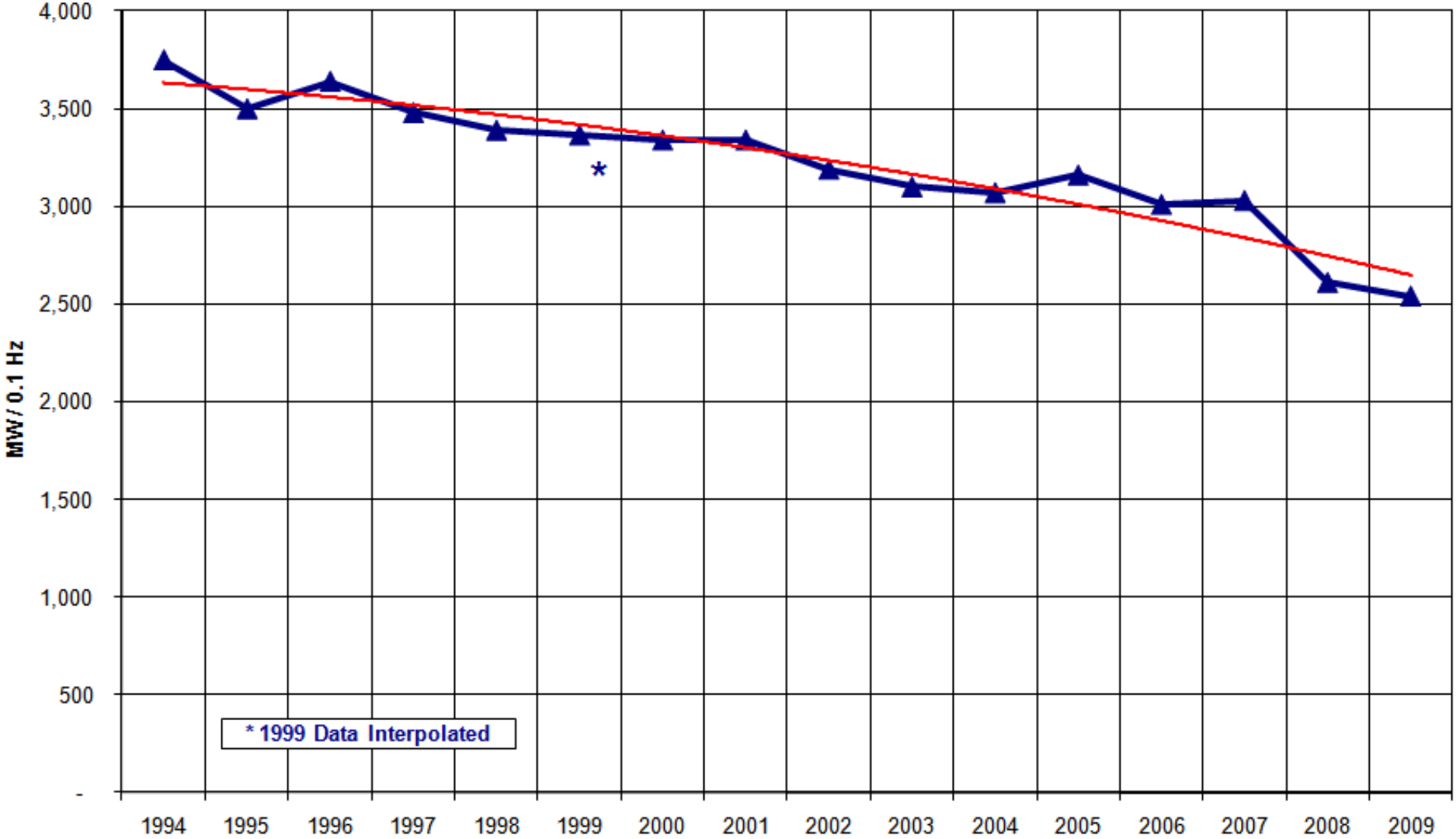
West Wing fault in Arizona on June 14, 2004: Captain – Jack – Olinda 500-kV line was out of service during the disturbance



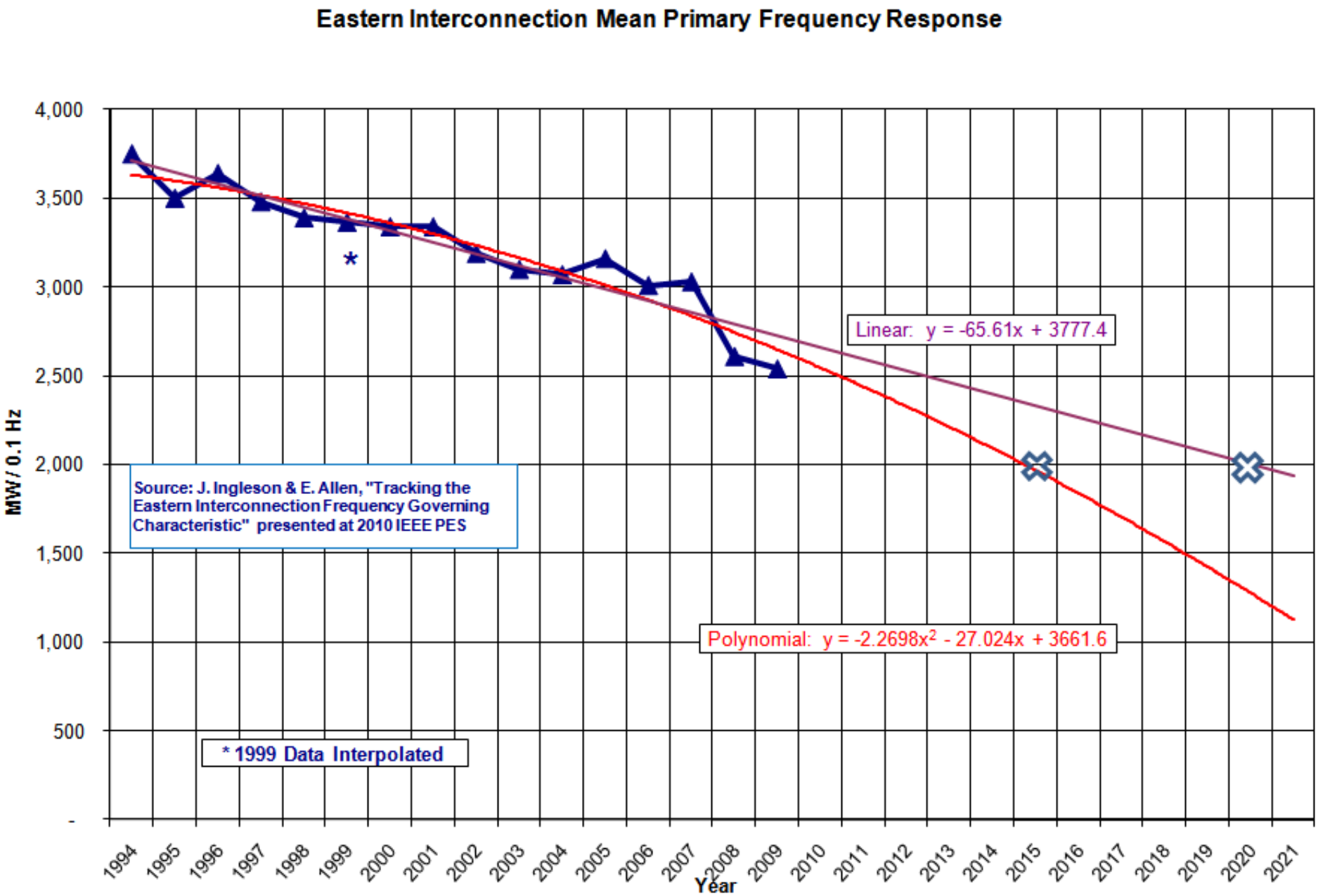
Typical Frequency Traces Following a Unit Trip



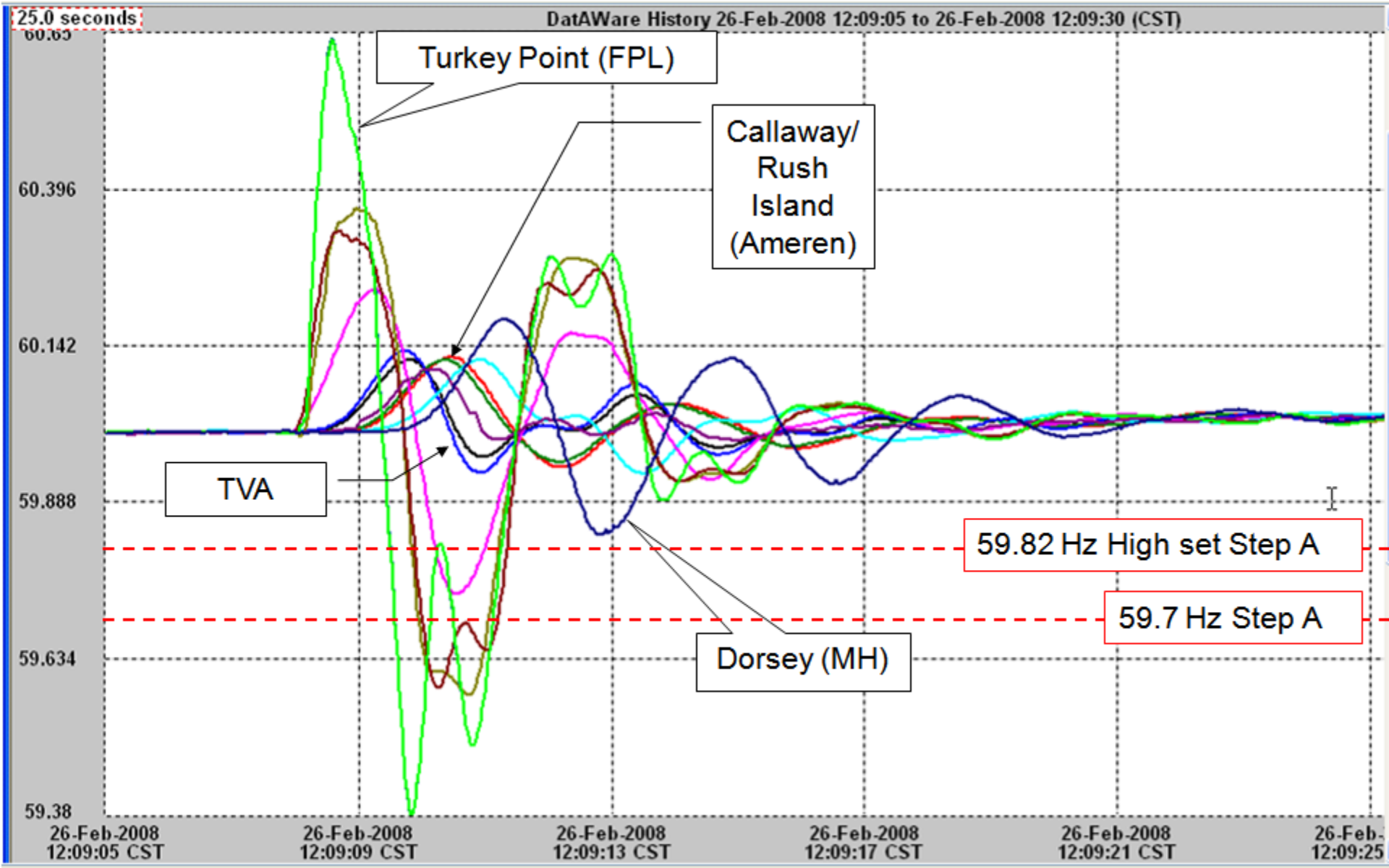
Eastern Interconnection Mean Primary Frequency Response



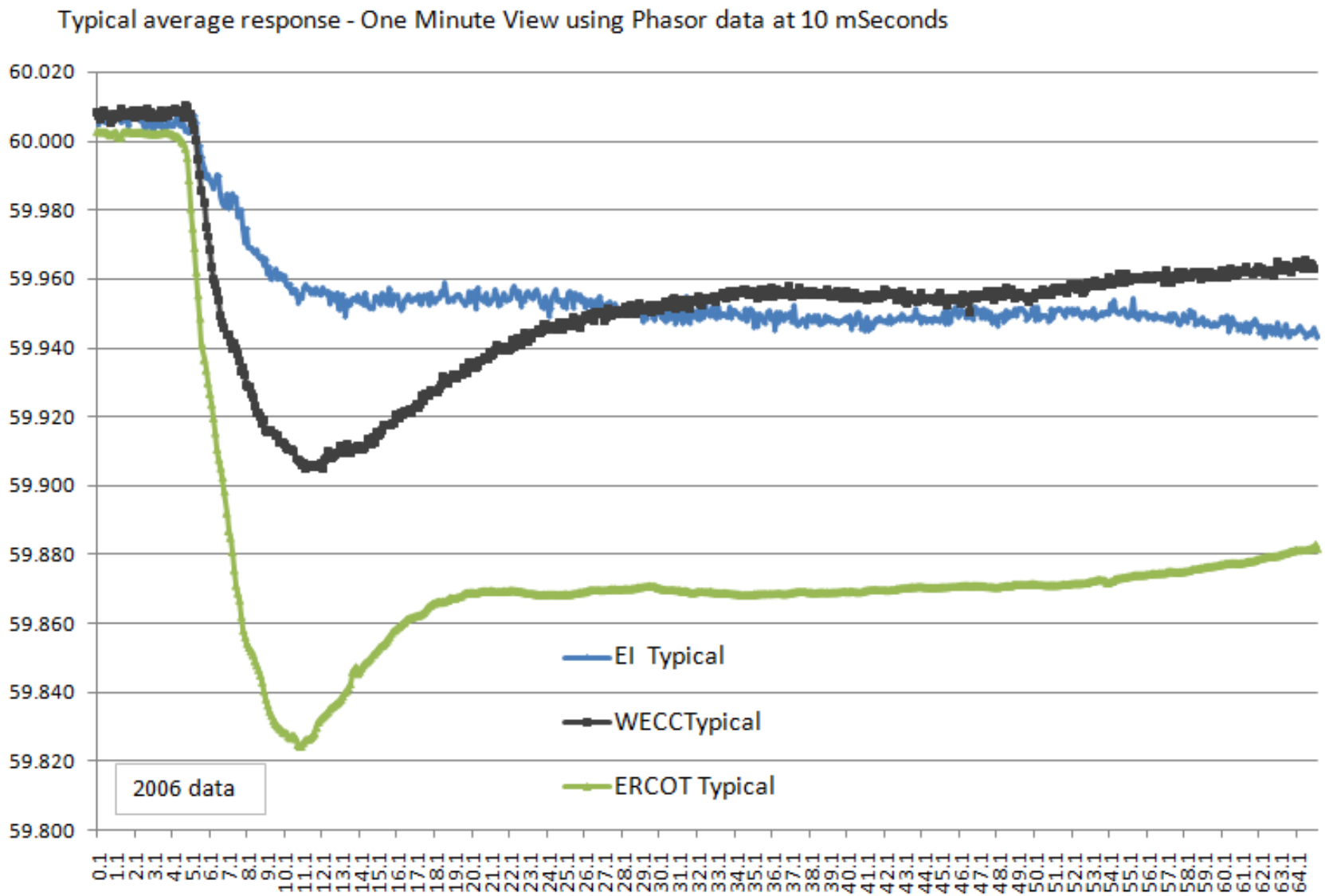
Source: J. Ingleson & E. Allen, "Tracking the Eastern Interconnection Frequency Governing Characteristic" presented at 2010 IEEE PES


Eastern Interconnection Mean Primary Frequency Response
MW / 0.1 Hz
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
-
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Year
*
Linear: y = -65.61x + 3777.4
Polynomial: y = -2.2698x2 - 27.024x + 3661.6
Source: J. Ingleson & E. Allen, "Tracking the Eastern Interconnection Frequency Governing Characteristic" presented at 2010 IEEE PES
* 1999 Data Interpolated

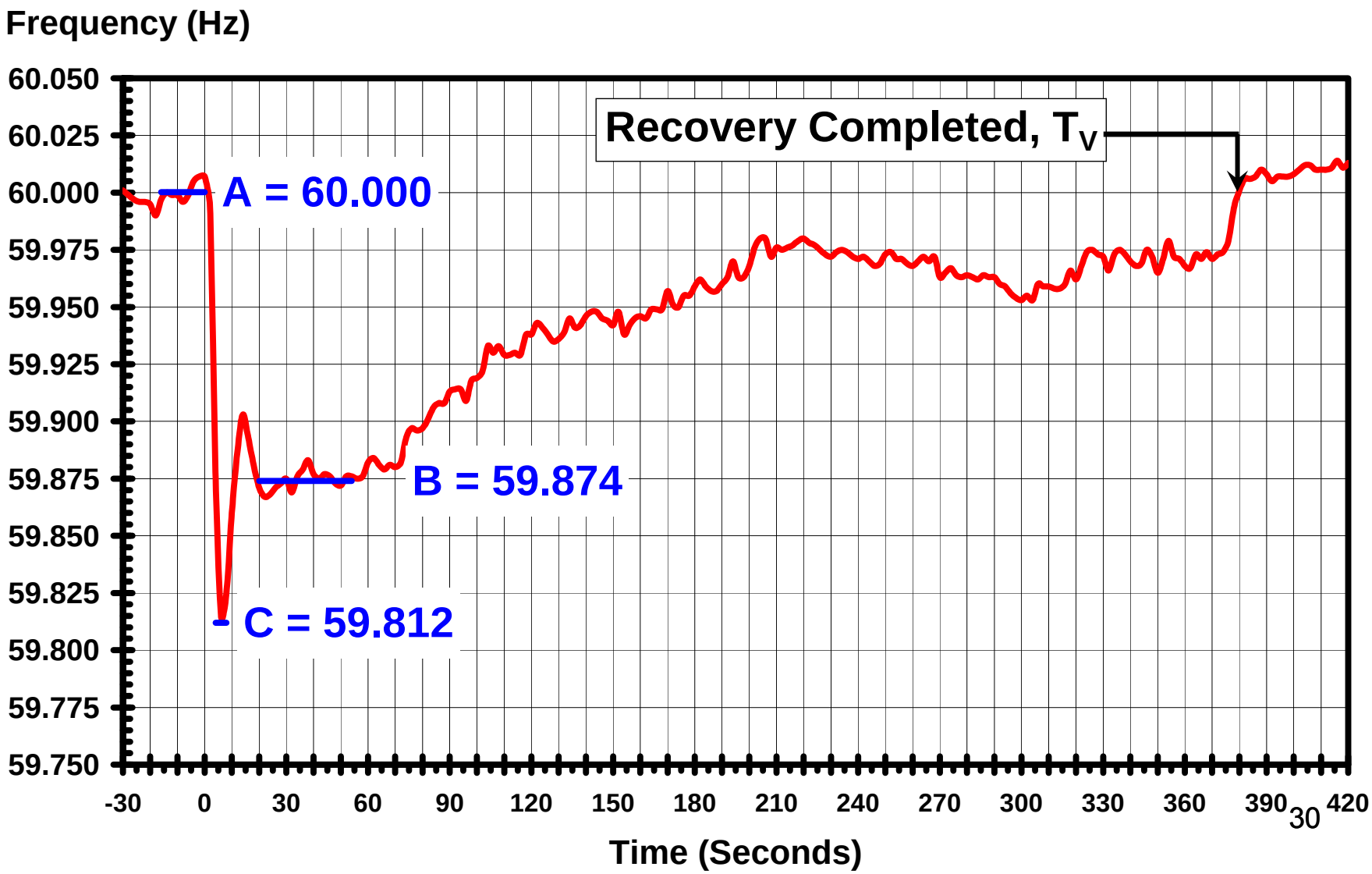
Florida Disturbance – Non-Local Impacts



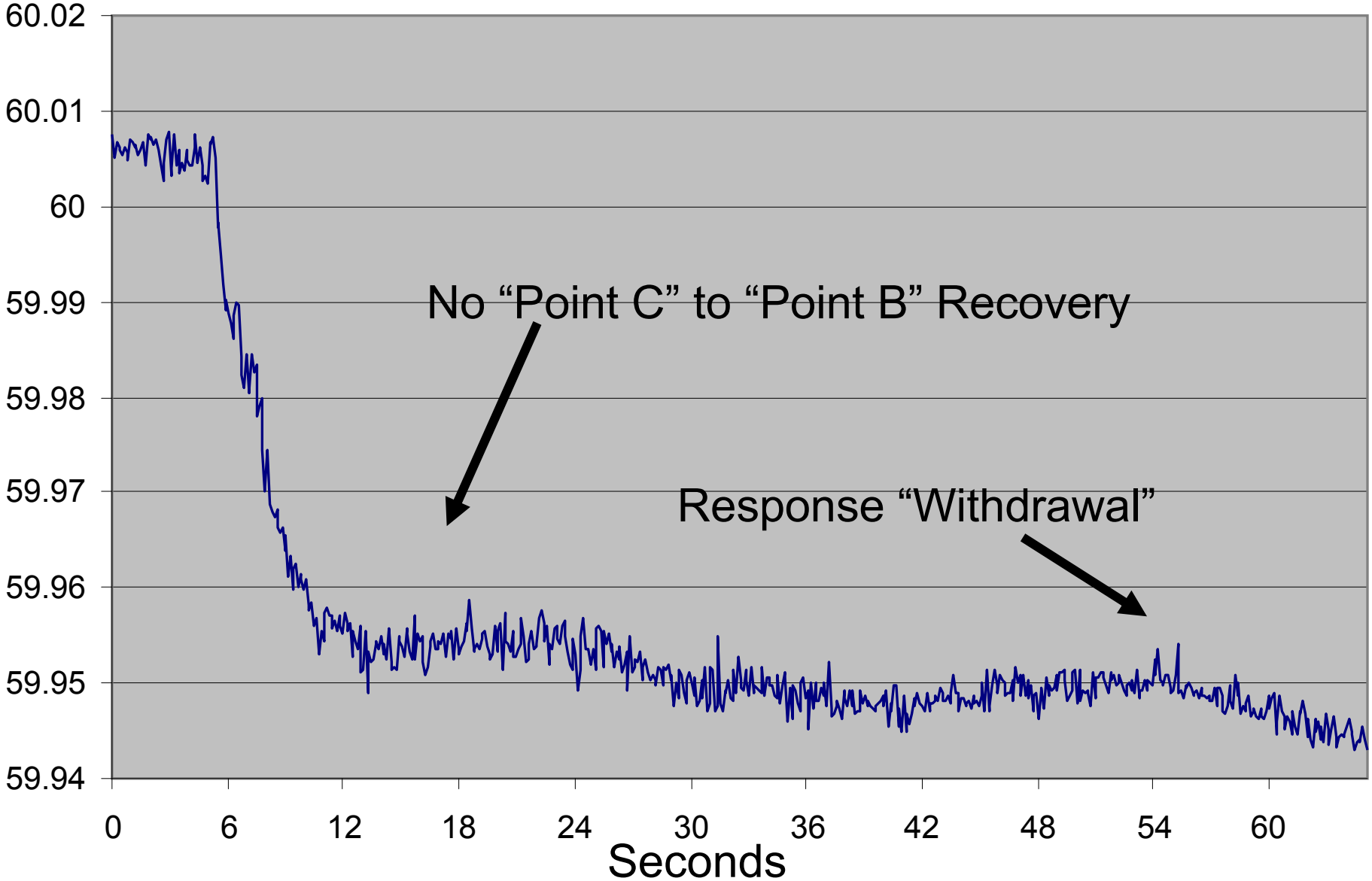
Typical Frequency Traces Following a Unit Trip



Classic Frequency Excursion Recovery



Typical Frequency Response Eastern Interconnection



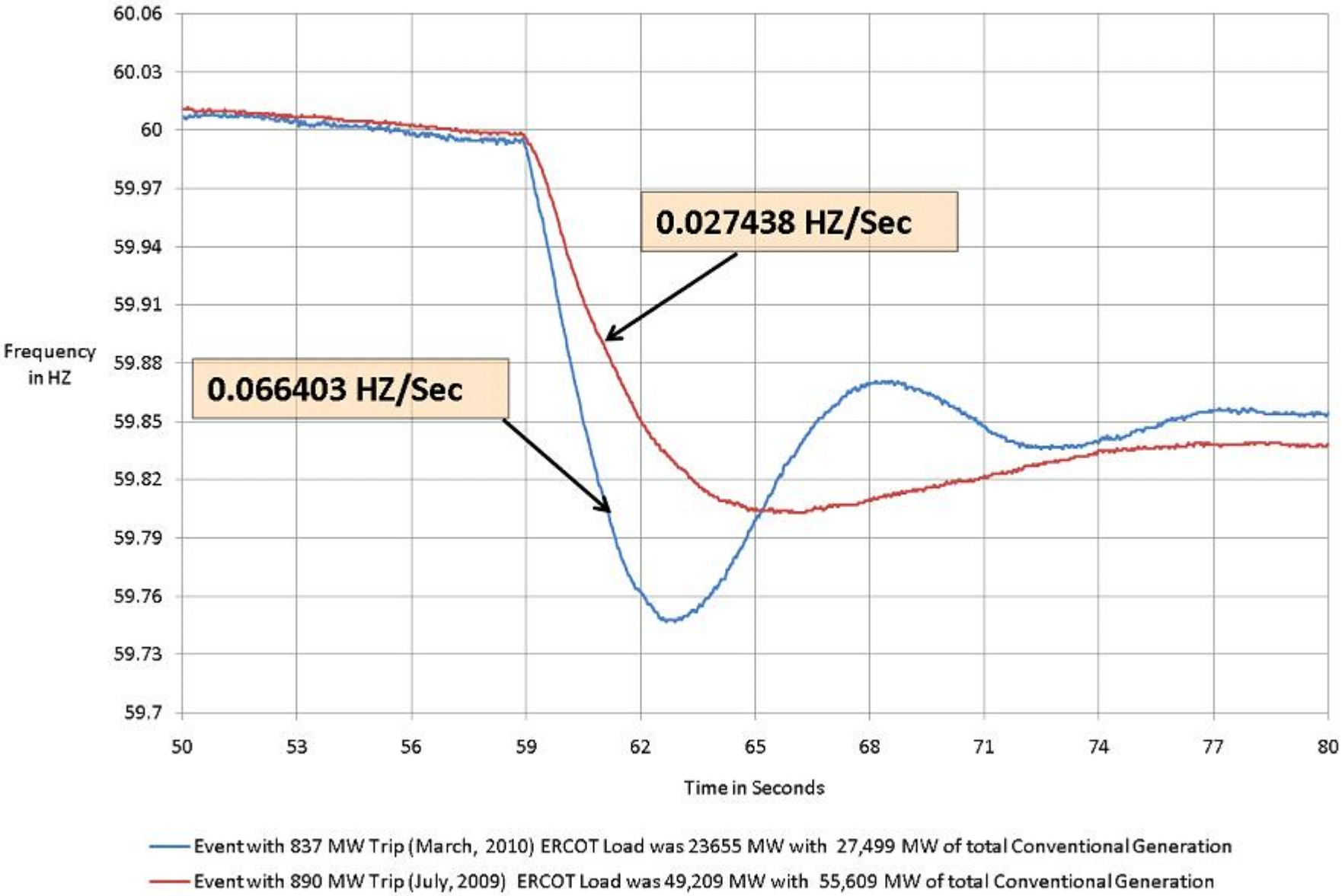
FERC Technical Conference Frequency Response September 23, 2010

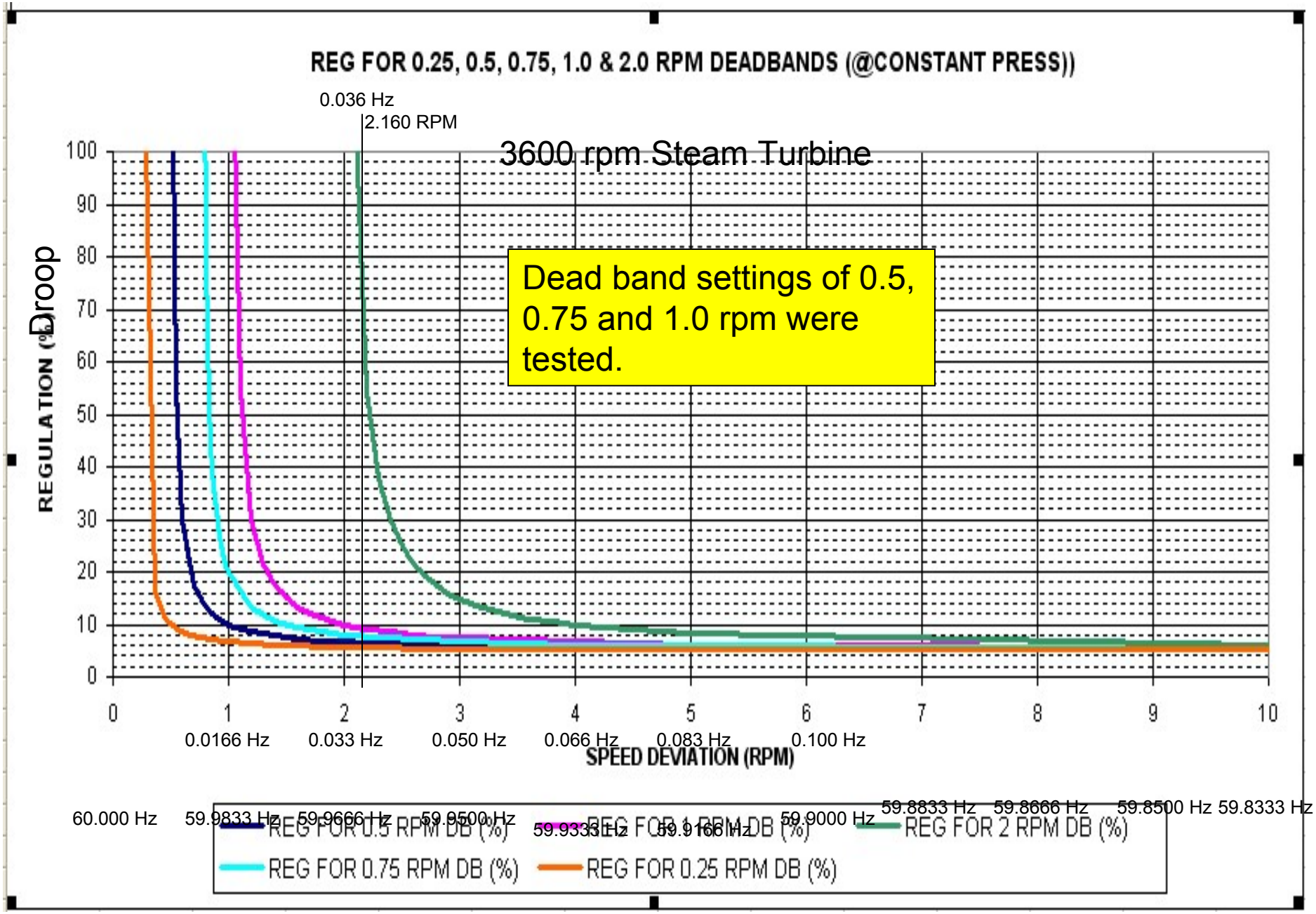
Submitted By:

Sydney L. Niemeyer – NRG Energy

Kenneth McIntyre - ERCOT

Depiction of Inertial Response




REG FOR 0.25, 0.5, 0.75, 1.0 & 2.0 RPM DEADBANDS (@CONSTANT PRESS))
0.036 Hz
2.160 RPM
3600 rpm Steam Turbine
Dead band settings of 0.5, 0.75 and 1.0 rpm were tested.
REGULATION (%) Droop
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
0.0166 Hz
0.033 Hz
0.050 Hz
0.066 Hz
0.083 Hz
0.100 Hz
SPEED DEVIATION (RPM)
60.000 Hz
59.9833 Hz
59.9666 Hz
59.9500 Hz
59.9333 Hz
59.9166 Hz
59.9000 Hz
59.8833 Hz
59.8666 Hz
59.8500 Hz
59.8333 Hz
REG FOR 0.5 RPM DB (%)
REG FOR 1 RPM DB (%)
REG FOR 2 RPM DB (%)
REG FOR 0.75 RPM DB (%)
REG FOR 0.25 RPM DB (%)

Governor response is proportional at the dead-band reaching 5% at 3 Hz deviation

Frequency Deviation Hz	Grid Frequency Hz	Frequency Response MW	Droop %
-0.04000	59.96000	4.69287	8.52357%
-0.03900	59.96100	4.49175	8.68258%
-0.03800	59.96200	4.29064	8.85650%
-0.03700	59.96300	4.08952	9.04752%
-0.03600	59.96400	3.88840	9.25830%
-0.03500	59.96500	3.68728	9.49208%
-0.03400	59.96600	3.48617	9.75283%
-0.03300	59.96700	3.28505	10.04551%
-0.03200	59.96800	3.08393	10.37636%
-0.03100	59.96900	2.88281	10.75338%
-0.03000	59.97000	2.68170	11.18694%
-0.02900	59.97100	2.48058	11.69081%
-0.02800	59.97200	2.27946	12.28359%
-0.02700	59.97300	2.07835	12.99110%
-0.02600	59.97400	1.87723	13.85020%
-0.02500	59.97500	1.67611	14.91548%
-0.02400	59.97600	1.47499	16.27125%
-0.02300	59.97700	1.27388	18.05512%
-0.02200	59.97800	1.07276	20.50786%
-0.02100	59.97900	0.87164	24.09245%
-0.02000	59.98000	0.67052	29.82737%
-0.01900	59.98100	0.46941	40.47654%
-0.01800	59.98200	0.26829	67.09147%
-0.01700	59.98300	0.06717	100.00000%
-0.01600	59.98400	0.00000	100.00000%

Dead-band

0.01666 Hz Dead-Band

BAL-001-TRE-1 Implementation

Governor response "Steps" to the 5% droop curve at the dead-band

Frequency Deviation Hz	Grid Frequency Hz	Frequency Response MW	Droop %
-0.04000	59.96000	8.00000	5.00000%
-0.03900	59.96100	7.80000	5.00000%
-0.03800	59.96200	7.60000	5.00000%
-0.03700	59.96300	7.40000	5.00000%
-0.03600	59.96400	7.20000	5.00000%
-0.03500	59.96500	0.00000	100.00000%
-0.03400	59.96600	0.00000	100.00000%
-0.03300	59.96700	0.00000	100.00000%
-0.03200	59.96800	0.00000	100.00000%
-0.03100	59.96900	0.00000	100.00000%
-0.03000	59.97000	0.00000	100.00000%
-0.02900	59.97100	0.00000	100.00000%
-0.02800	59.97200	0.00000	100.00000%
-0.02700	59.97300	0.00000	100.00000%
-0.02600	59.97400	0.00000	100.00000%
-0.02500	59.97500	0.00000	100.00000%
-0.02400	59.97600	0.00000	100.00000%
-0.02300	59.97700	0.00000	100.00000%
-0.02200	59.97800	0.00000	100.00000%
-0.02100	59.97900	0.00000	100.00000%
-0.02000	59.98000	0.00000	100.00000%
-0.01900	59.98100	0.00000	100.00000%
-0.01800	59.98200	0.00000	100.00000%
-0.01700	59.98300	0.00000	100.00000%
-0.01600	59.98400	0.00000	100.00000%

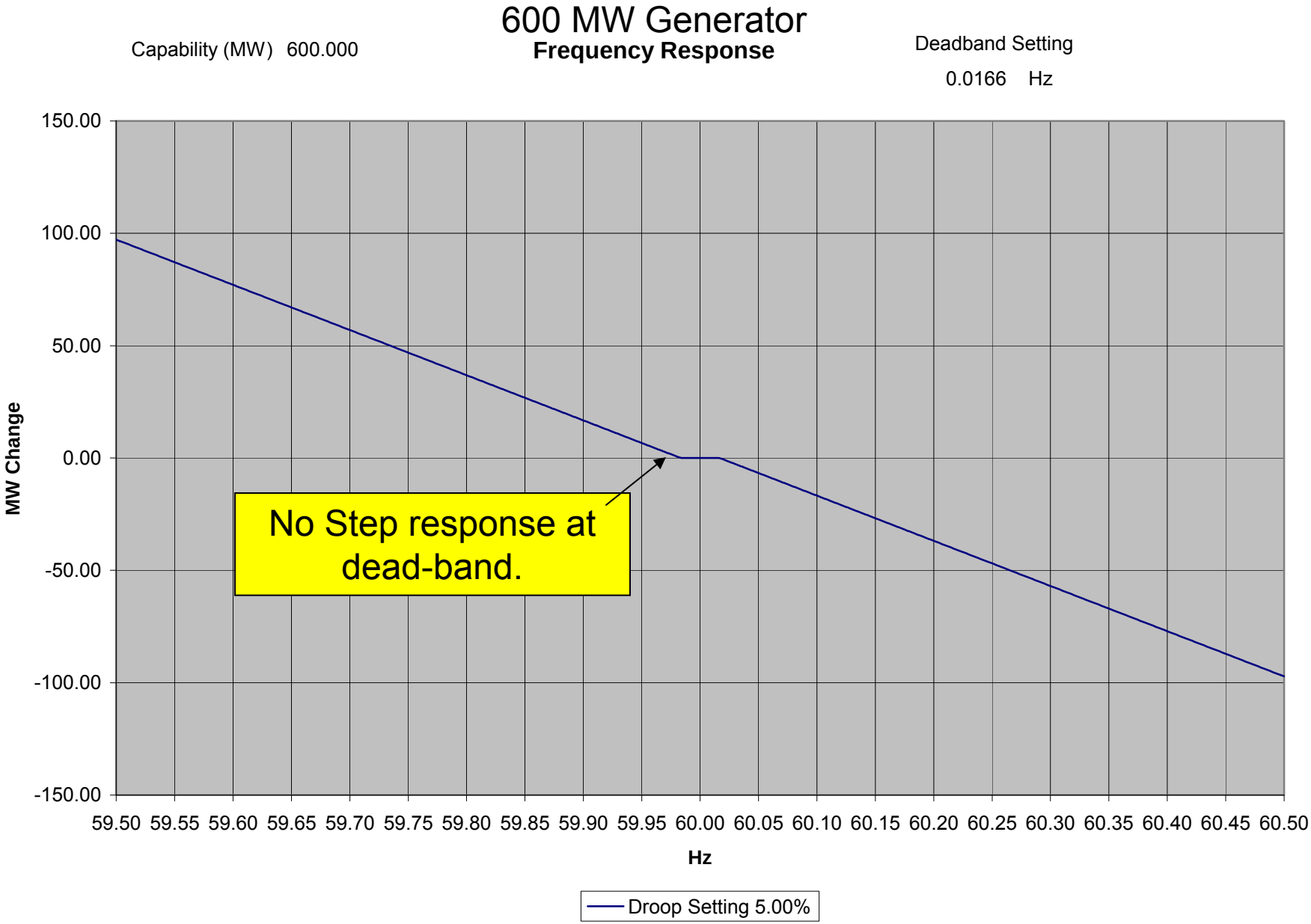
Dead-band

0.036 Hz Dead-Band

Common Industry Implementation

600 MW Steam Turbine 5% Droop Setting

Close up look at +/-0.0166 Hz Dead Band with No Step Implementation



Close up look at +/-0.036 Hz Dead Band with Step Implementation

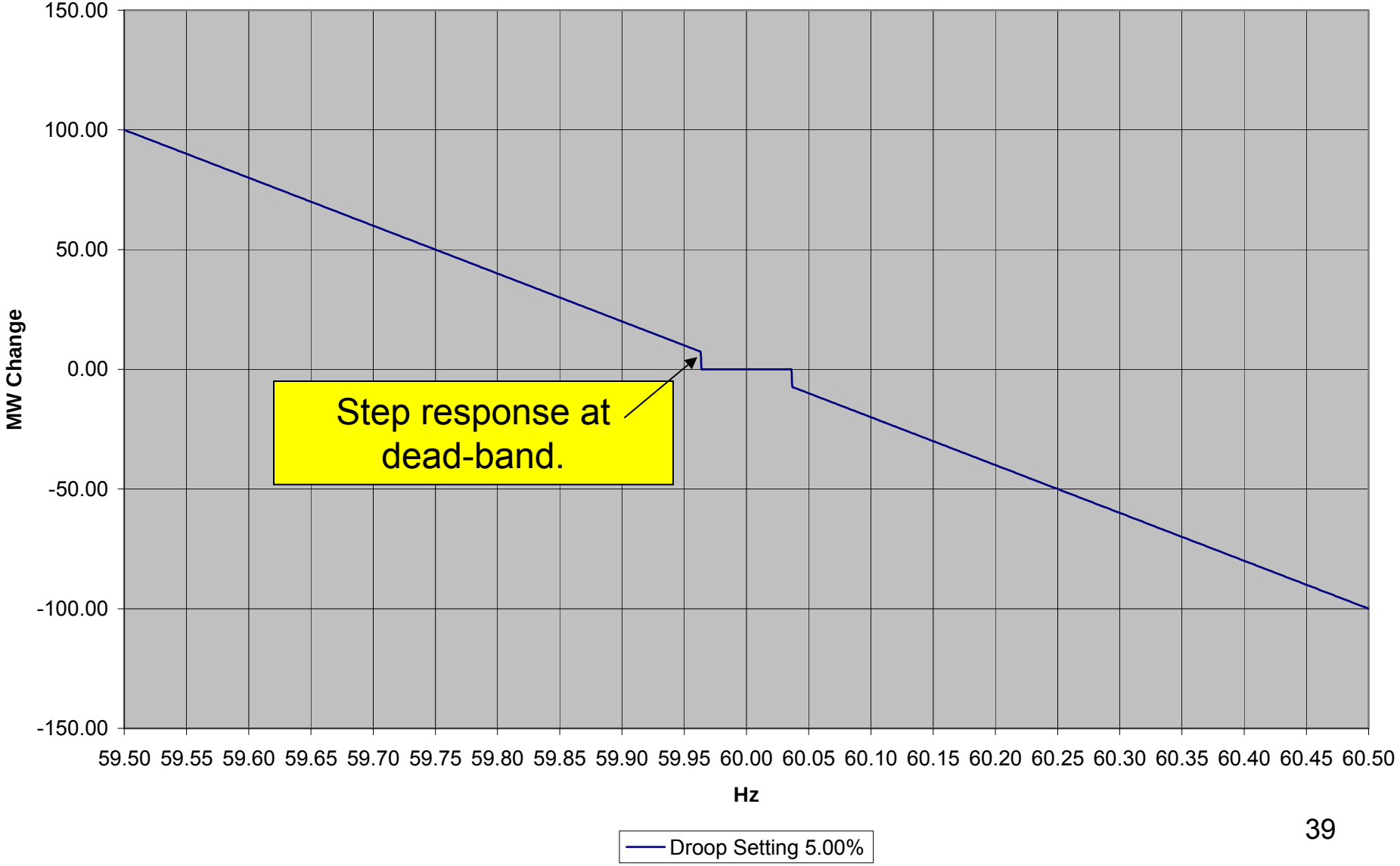
600 MW Generator

Capability (MW) 600.000

Frequency Response

Deadband Setting

0.036 Hz

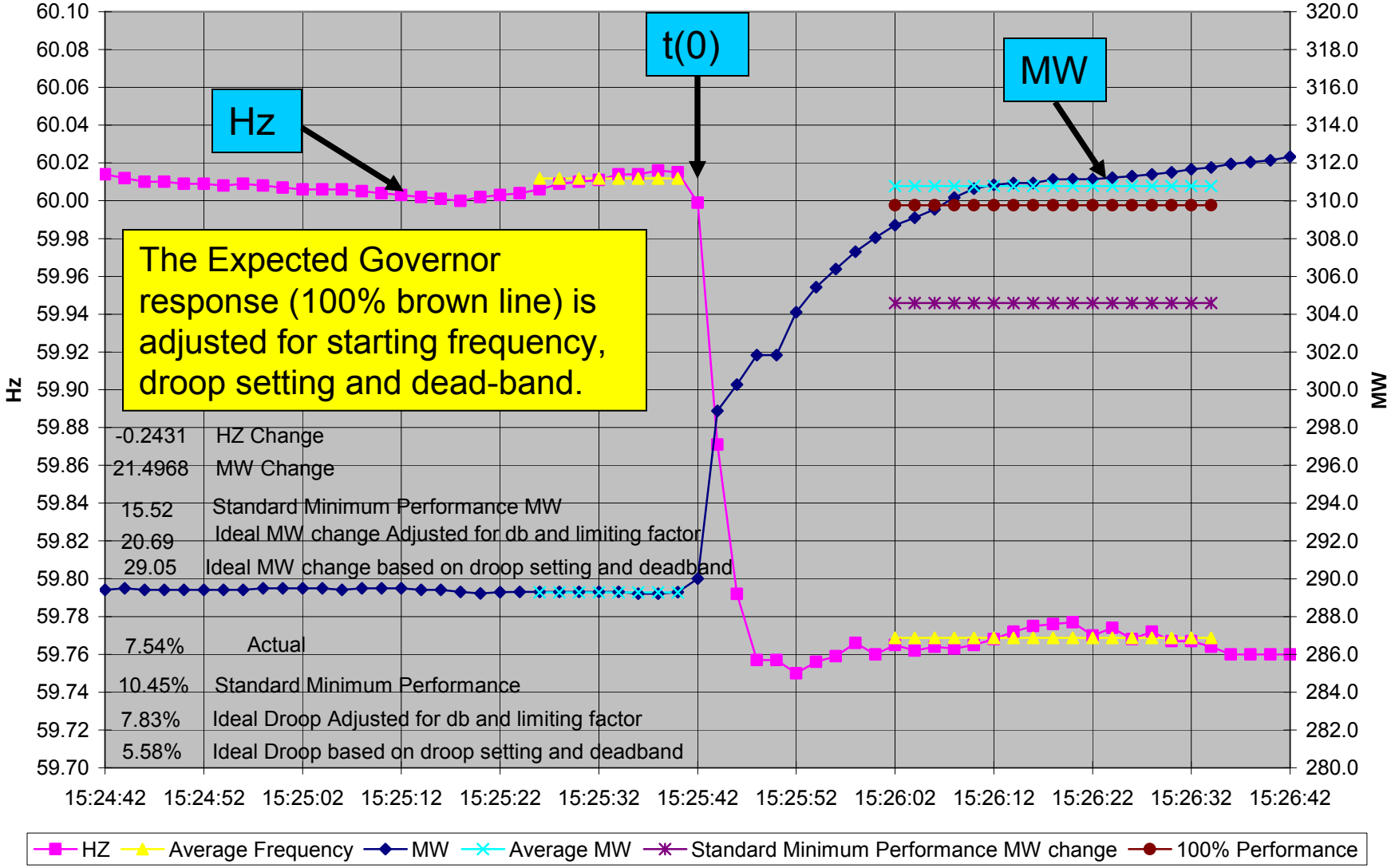


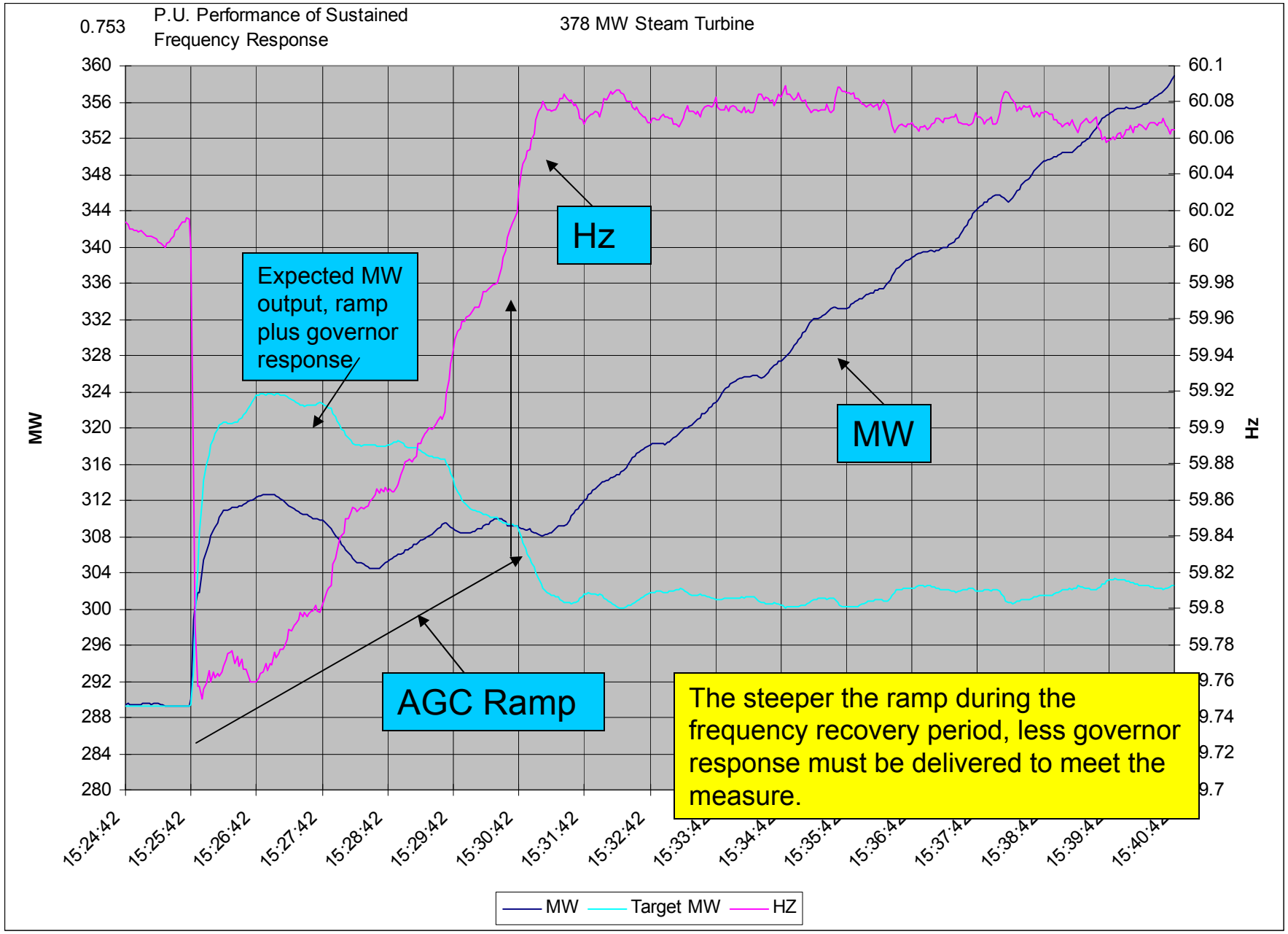
Initial P.U. Performance 1.04

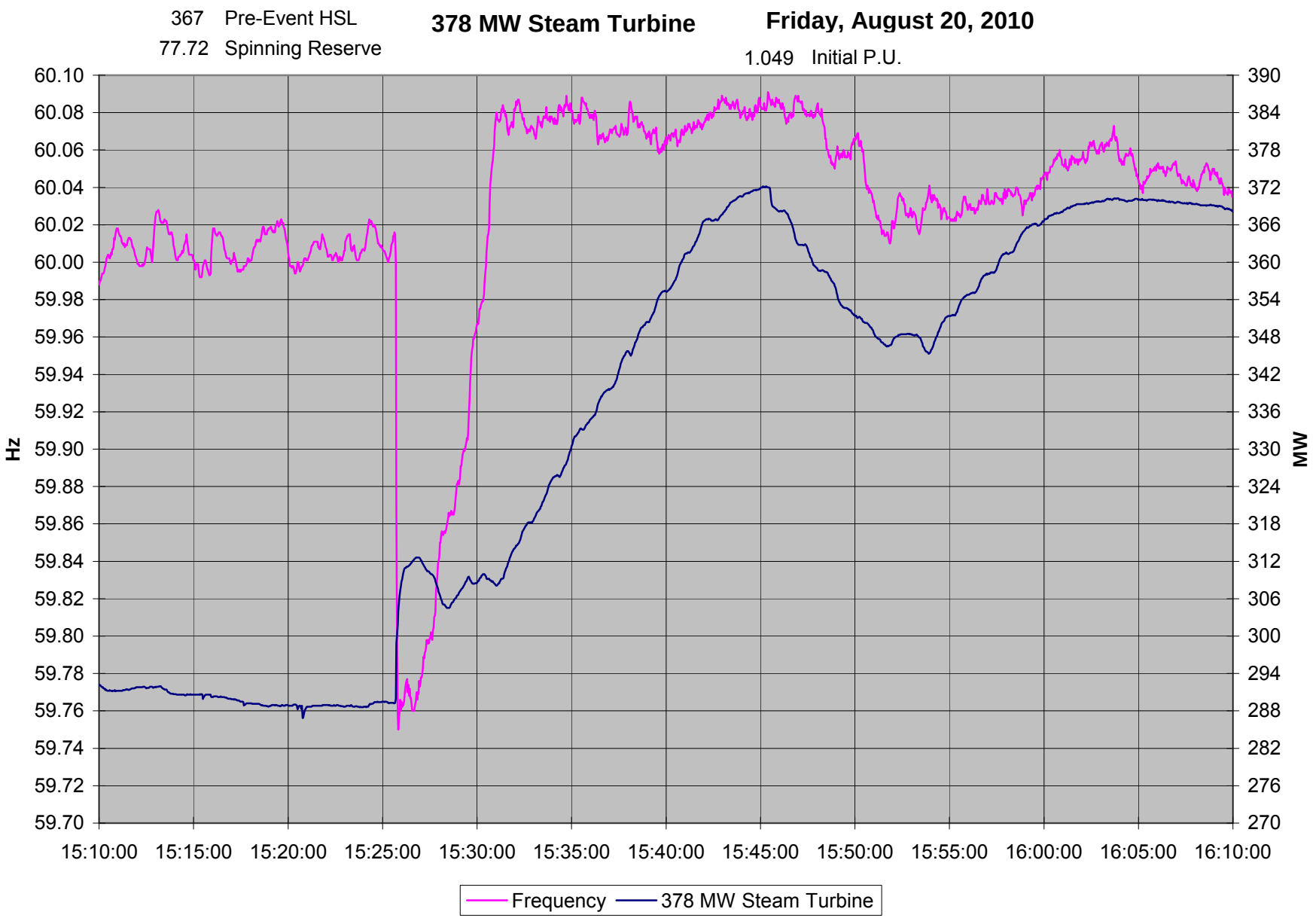
Spinning Reserve 77.72

378 MW Steam Turbine Performance

Friday, August 20, 2010

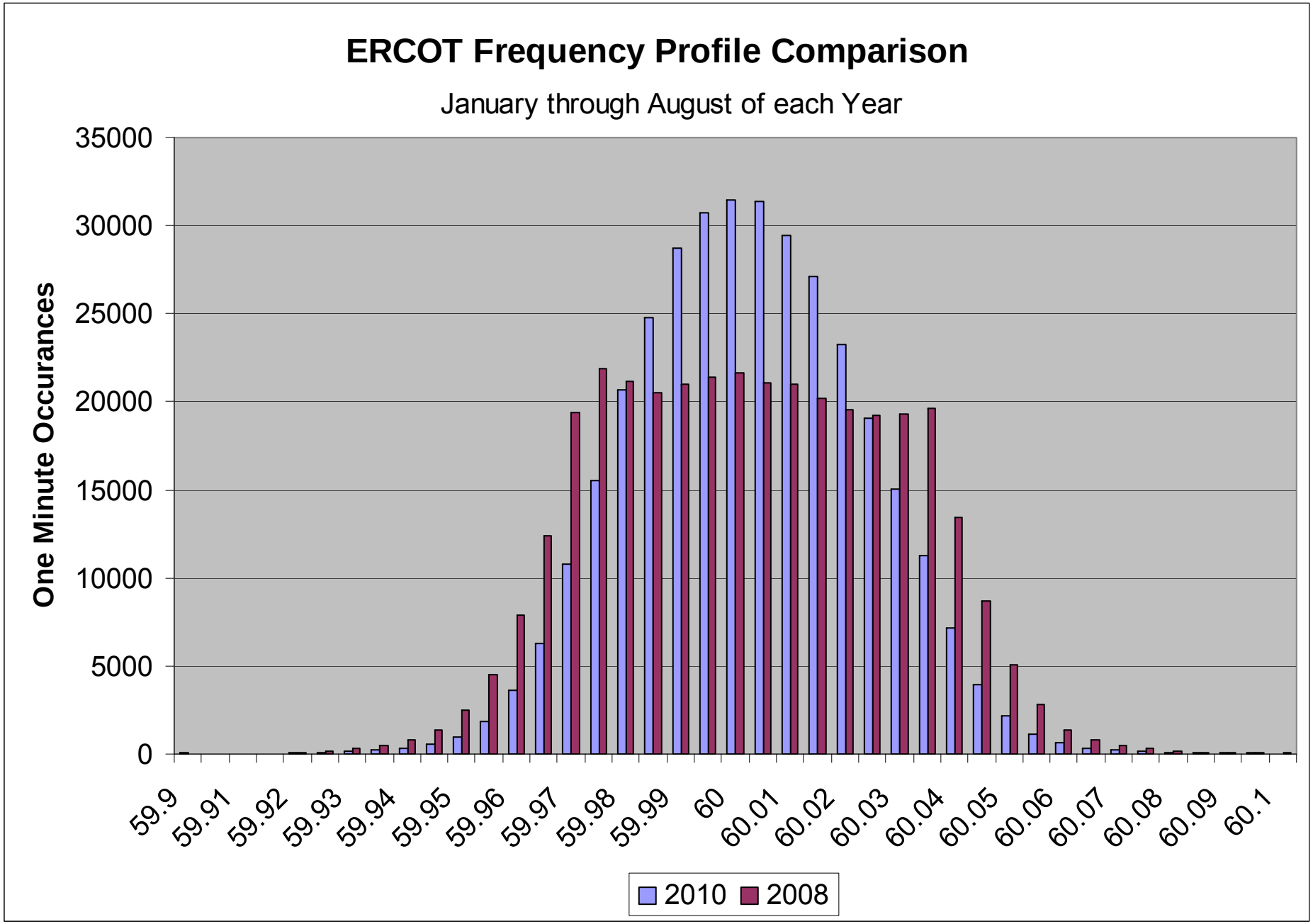


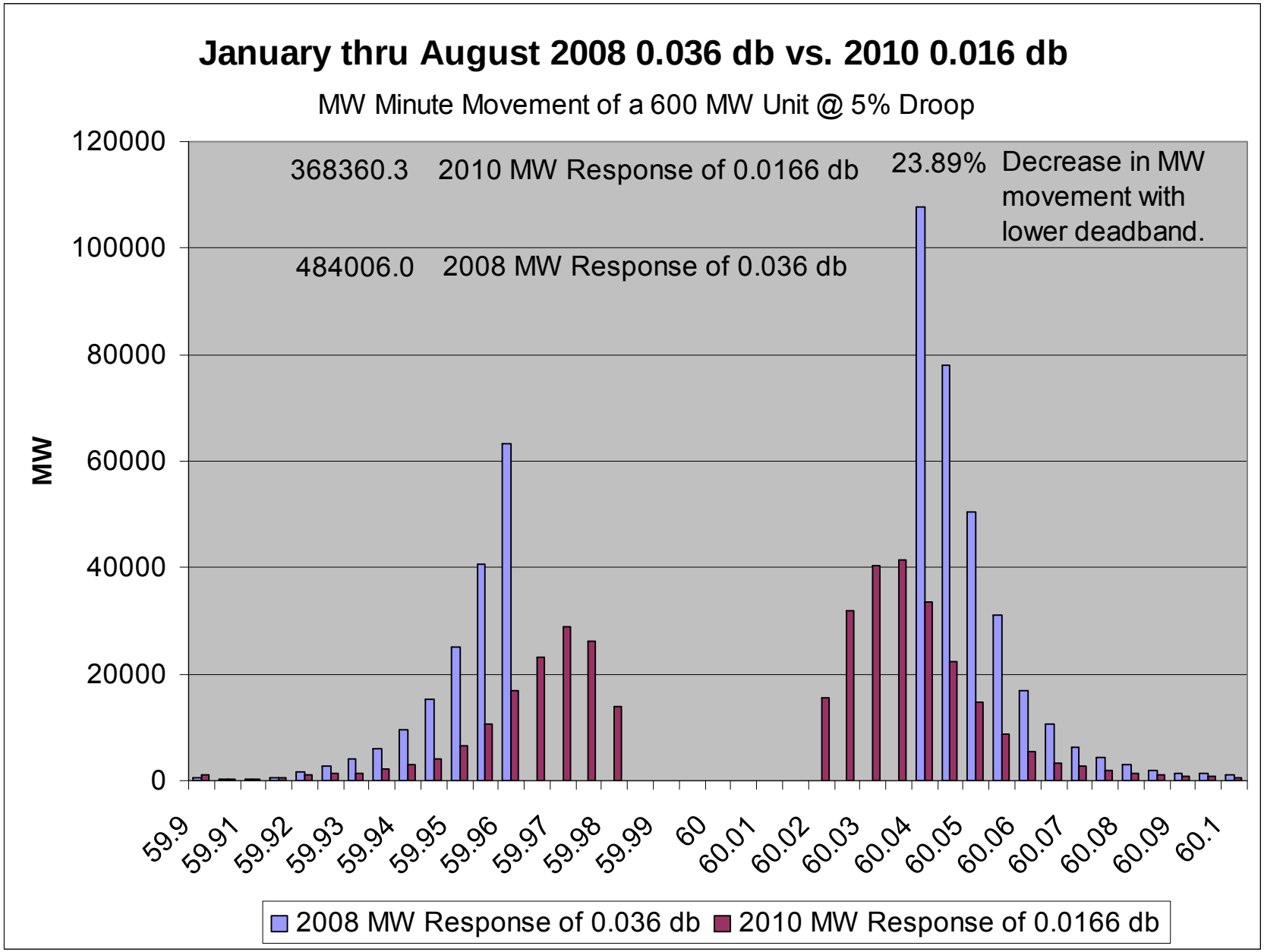

0.753
P.U. Performance of Sustained Frequency Response
378 MW Steam Turbine
MW
Hz
Hz
MW
Expected MW output, ramp plus governor response
AGC Ramp
The steeper the ramp during the frequency recovery period, less governor response must be delivered to meet the measure.
MW
Target MW
HZ


367 Pre-Event HSL
77.72 Spinning Reserve
378 MW Steam Turbine
Friday, August 20, 2010
1.049 Initial P.U.
Hz
MW
60.10
60.08
60.06
60.04
60.02
60.00
59.98
59.96
59.94
59.92
59.90
59.88
59.86
59.84
59.82
59.80
59.78
59.76
59.74
59.72
59.70
390
384
378
372
366
360
354
348
342
336
330
324
318
312
306
300
294
288
282
276
270
15:10:00
15:15:00
15:20:00
15:25:00
15:30:00
15:35:00
15:40:00
15:45:00
15:50:00
15:55:00
16:00:00
16:05:00
16:10:00
Frequency
378 MW Steam Turbine

Generation with Governor Settings per Draft Regional Standard

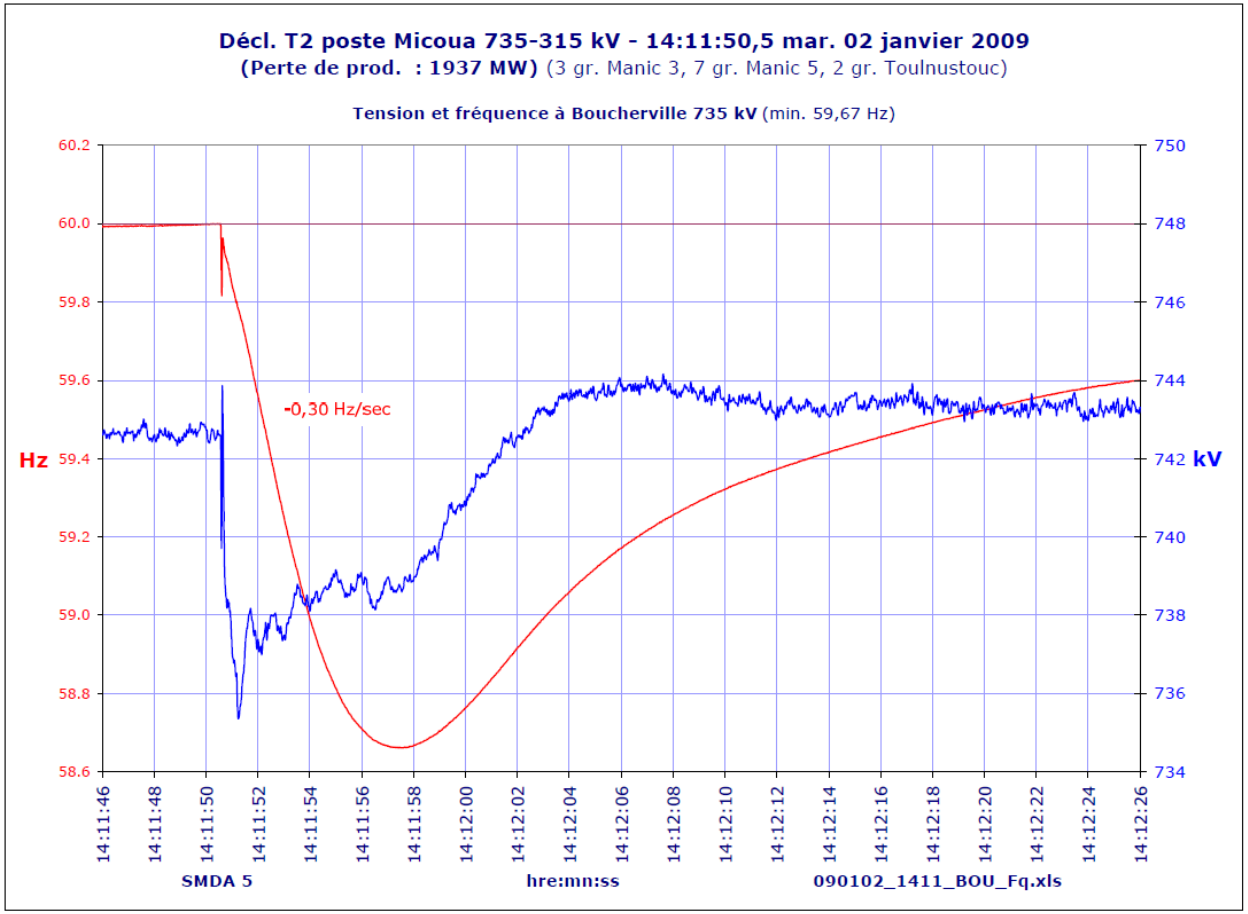
- Digital and Electronic Governors set with a Dead-band less than or equal to +/-0.01666 Hz and droop curve with no step function.
- Mechanical Governors with a maximum +/-0.034 Hz Dead-band
- 14,258 MW Total Capacity Identified.
  - 1690 MW Steam Turbine – Lignite fired
  - 5534 MW Steam Turbine – Coal fired
  - 3780 MW Combustion Turbine Combined Cycle
  - 1519 MW Combustion Turbine Simple Cycle
  - 1224 MW Steam Turbine – natural gas fired
  - 240 MW Hydro
  - 271 MW Wind Generators


ERCOT Frequency Profile Comparison
January through August of each Year
One Minute Occurances
35000
30000
25000
20000
15000
10000
5000
0
59.9
59.91
59.92
59.93
59.94
59.95
59.96
59.97
59.98
59.99
60
60.01
60.02
60.03
60.04
60.05
60.06
60.07
60.08
60.09
60.1
2010
2008

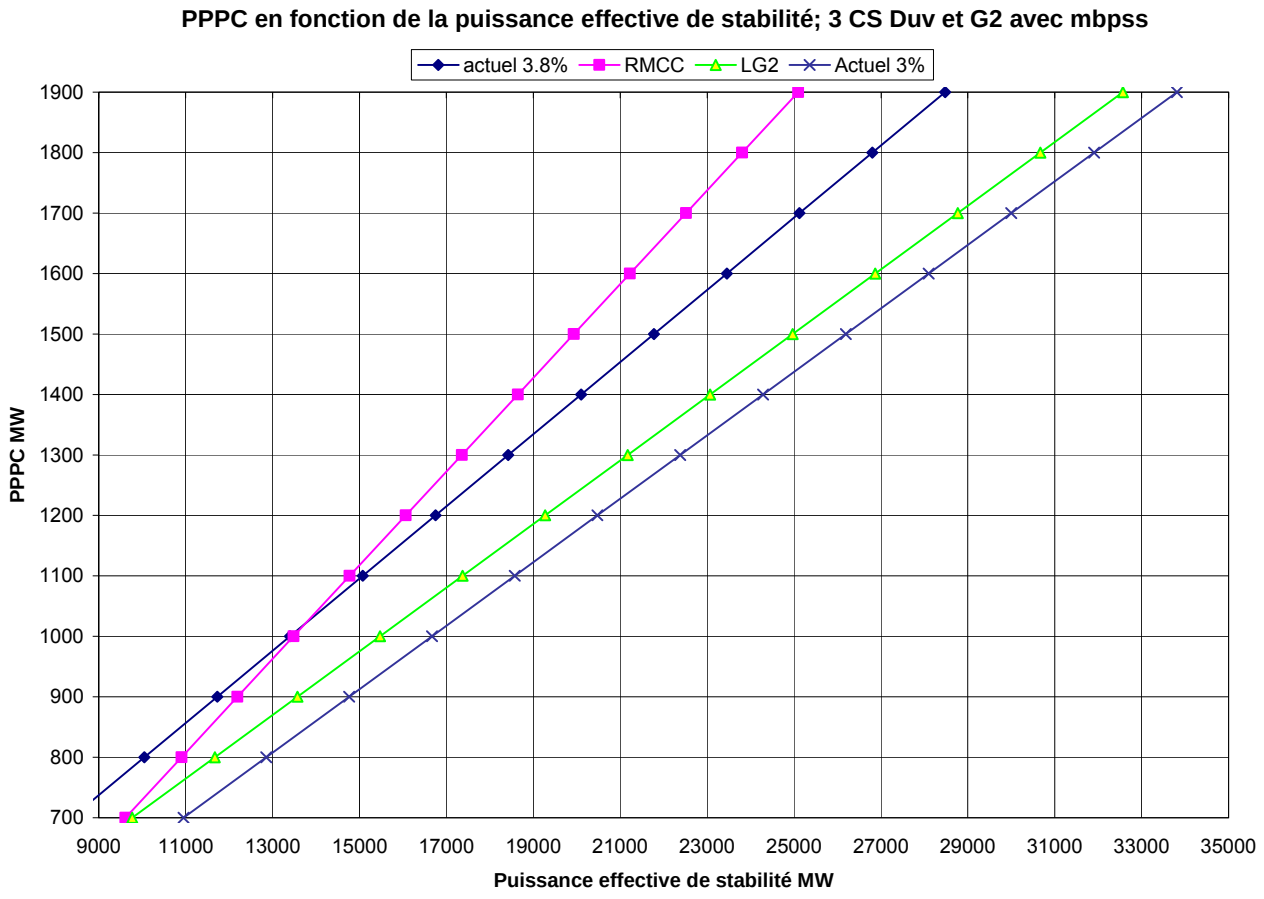


Same 600 MW unit - MW movement due to frequency each year.

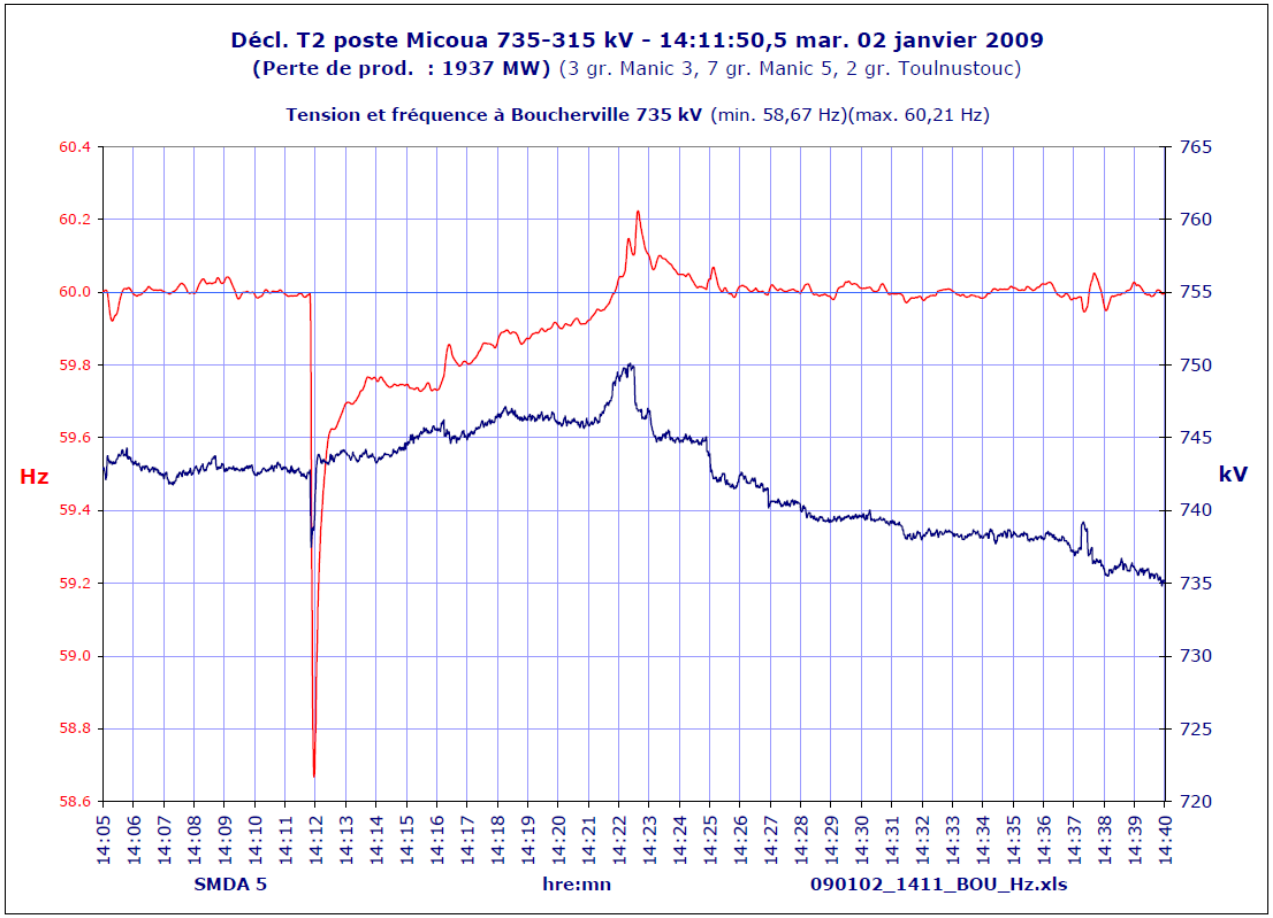
Typical A-C-B curve



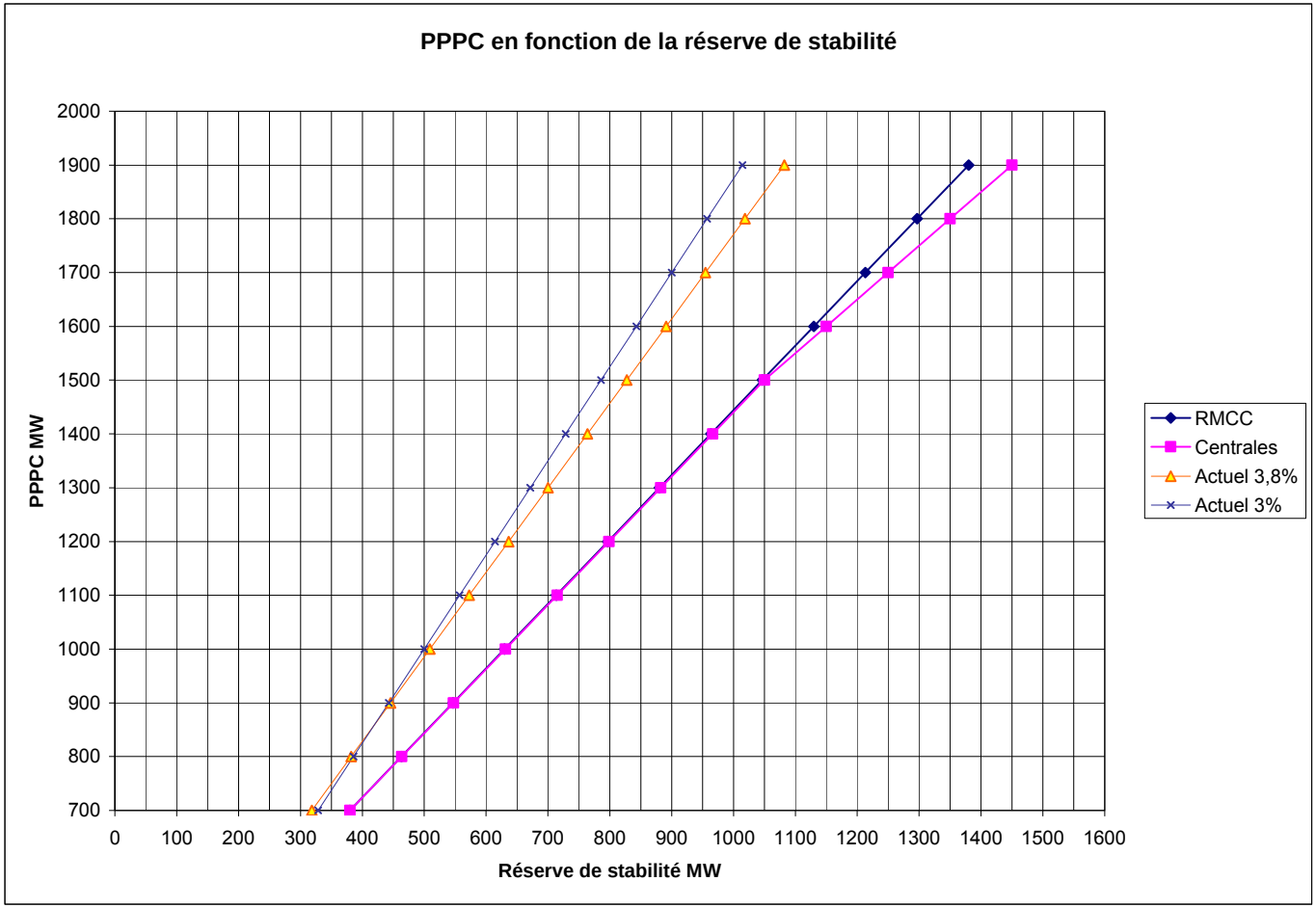
MSSC as a function of Sync Generation



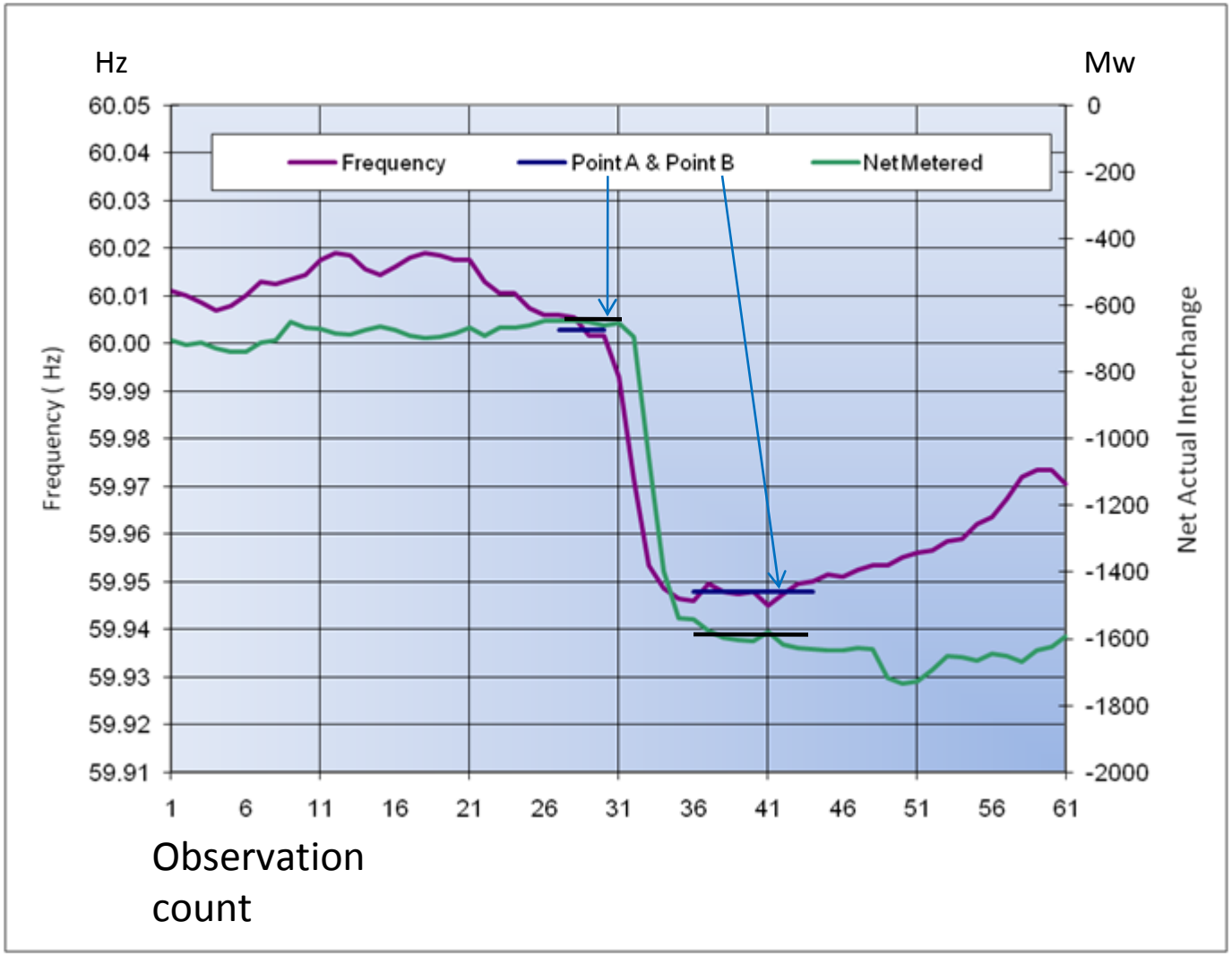
Stabilization of the frequency



Required Frequency Responsive Reserve as a function of MSSC



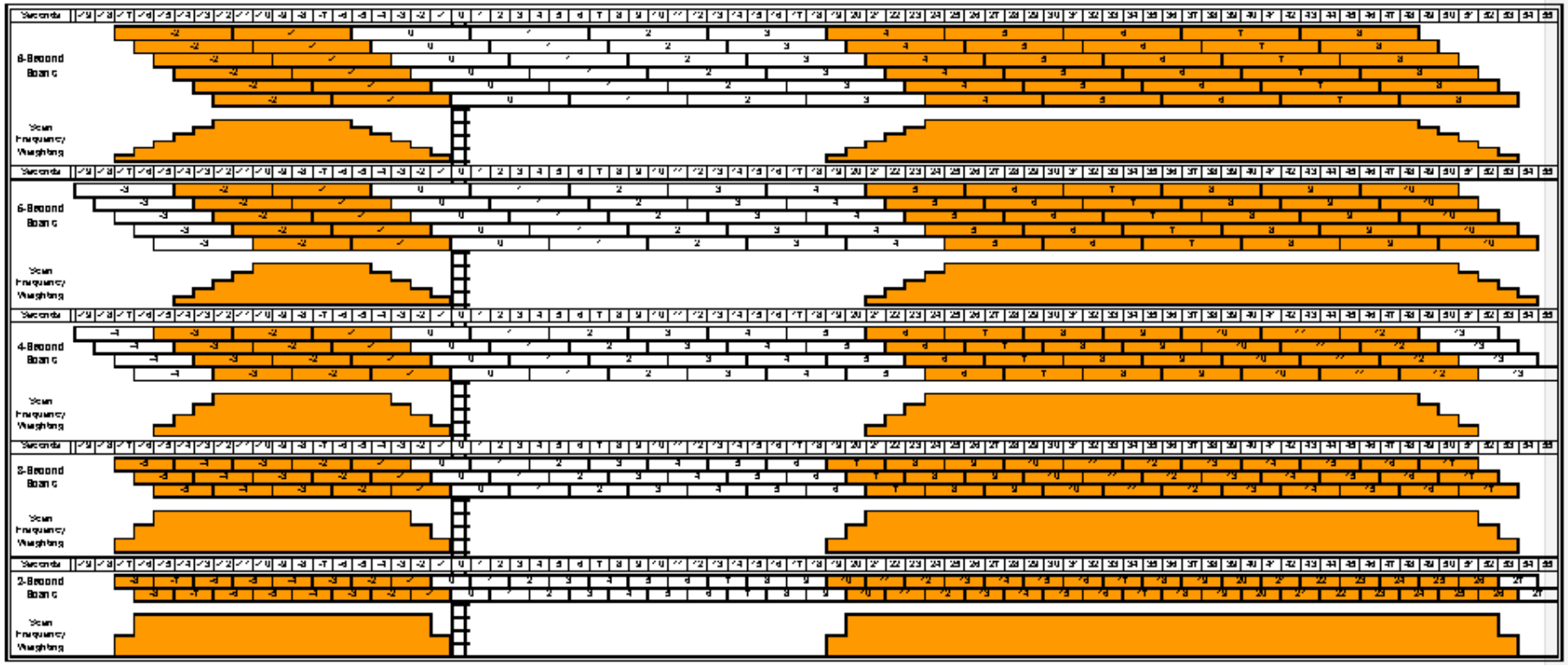
Balancing Authority – Energy Management System Scan rate data for determining frequency response



Scan Rate Factors in determining Frequency response – (not finalized)

Definitions of Frequency Values for Frequency Response Calculation

Scan Rate	T 0 Scan	A Value (average)	B Value (average)
6-Seconds	Identify first significant change in frequency as the T 0 scan	Average of T-1 through T-2 scans	Average of T+4 through T+8 scans
5-Seconds		Average of T-1 through T-2 scans	Average of T+5 through T+10 scans
4-Seconds		Average of T-1 through T-3 scans	Average of T+6 through T+12 scans
3-Seconds		Average of T-1 through T-5 scans	Average of T+7 through T+17 scans
2-Seconds		Average of T-1 through T-8 scans	Average of T+10 through T+26 scans



Scan Rate Data highlighting scan cycle samples – (example data)

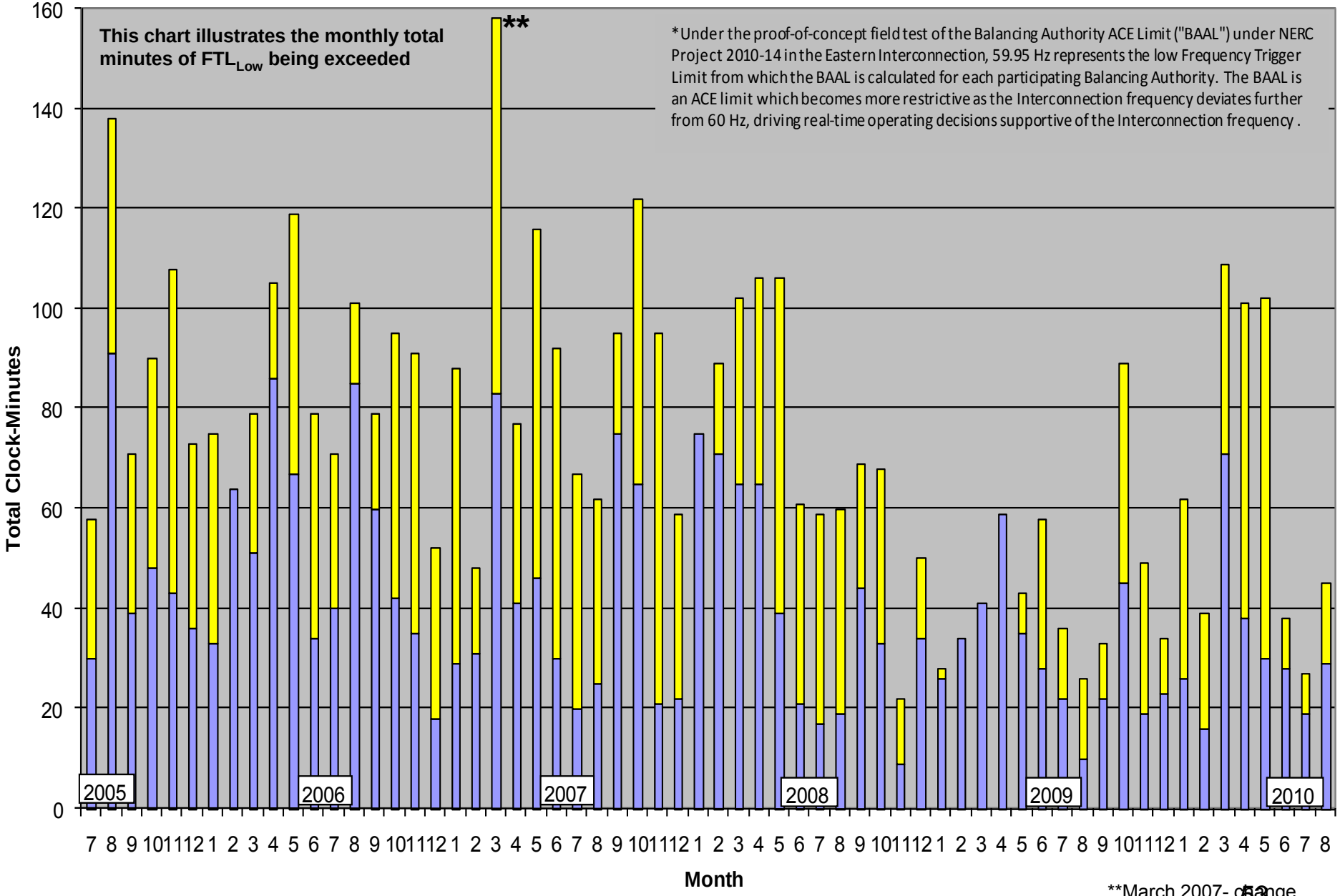
Net – Balancing Area values

NI_s NI_A

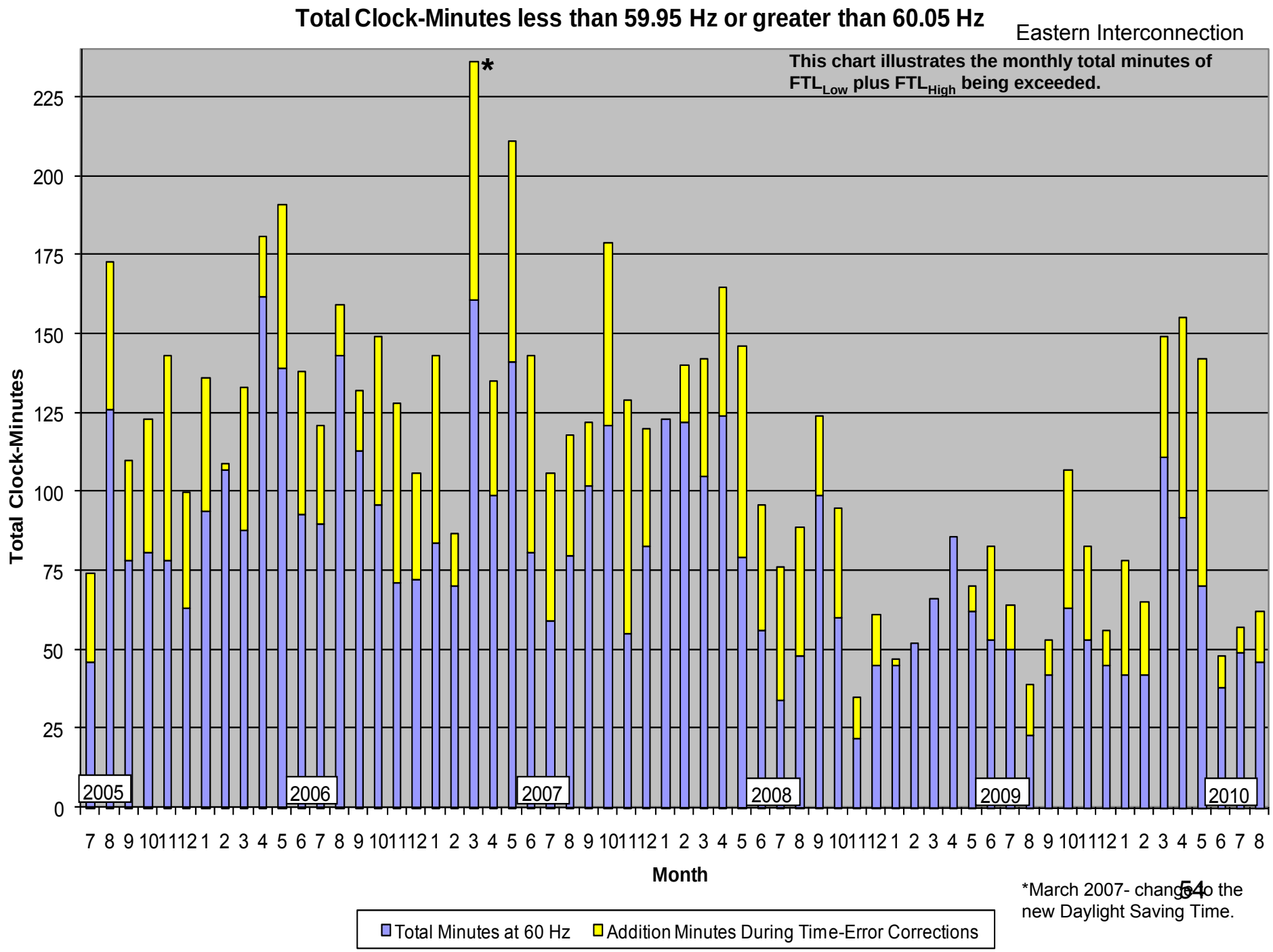
	Time	F	Sched	Actual	ACE	Index
T-24 sec	1:52:19	60.002	-58.3	-34.7	154.3	25
T-20 sec	1:52:23	60.001	-59.1	-34.7	146.4	26
T-16 sec	1:52:27	60.001	-60.3	-19.7	153.8	27
T-12 sec	1:52:31	59.999	-60.5	-28.3	137.5	28
T-08 sec	1:52:35	59.999	-61.4	-42.7	114.3	29
T-04 sec	1:52:39	59.999	-61.4	-62.4	84.0	30
T+0 sec	1:52:43	59.967	-61.7	22.4	144.0	31
T+04 sec	1:52:47	59.961	-60.2	54.0	157.0	32
T+08 sec	1:52:51	59.957	-60.3	240.5	305.3	33
T+12 sec	1:52:55	59.956	-61.4	270.4	301.9	34
T+16 sec	1:52:59	59.954	-61.5	283.9	285.7	35
T+20 sec	1:53:03	59.955	-60.1	255.9	215.9	36
T+24 sec	1:53:07	59.958	-59.7	237.0	160.7	37
T+28 sec	1:53:11	59.957	-60.2	228.5	121.1	38
T+32 sec	1:53:15	59.957	-60.6	200.3	70.4	39
T+36 sec	1:53:19	59.957	-59.8	219.2	45.1	40
T+40 sec	1:53:23	59.955	-61.1	203.1	16.3	41
T+44 sec	1:53:27	59.955	-59.3	213.1	-15.6	42
T+48 sec	1:53:31	59.957	-59.0	195.8	-52.3	43
T+52 sec	1:53:35	59.957	-59.2	223.7	-47.9	44
T+56 sec	1:53:39	59.956	-59.2	239.1	-52.4	45
T+60 sec	1:53:43	59.956	-61.2	212.9	-93.7	46

Total Clock-Minutes of Frequency below 59.95 Hz*

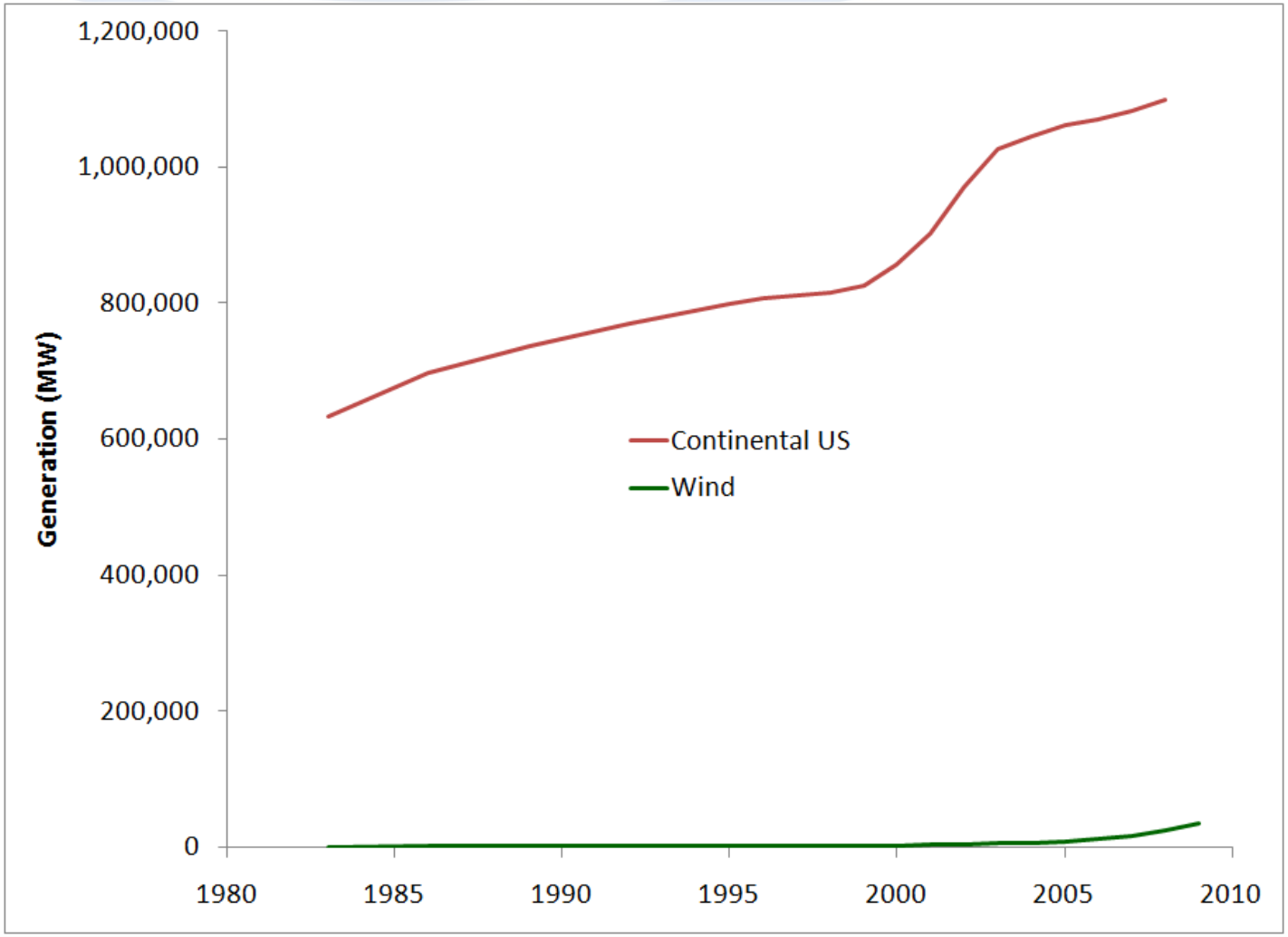
Eastern Interconnection



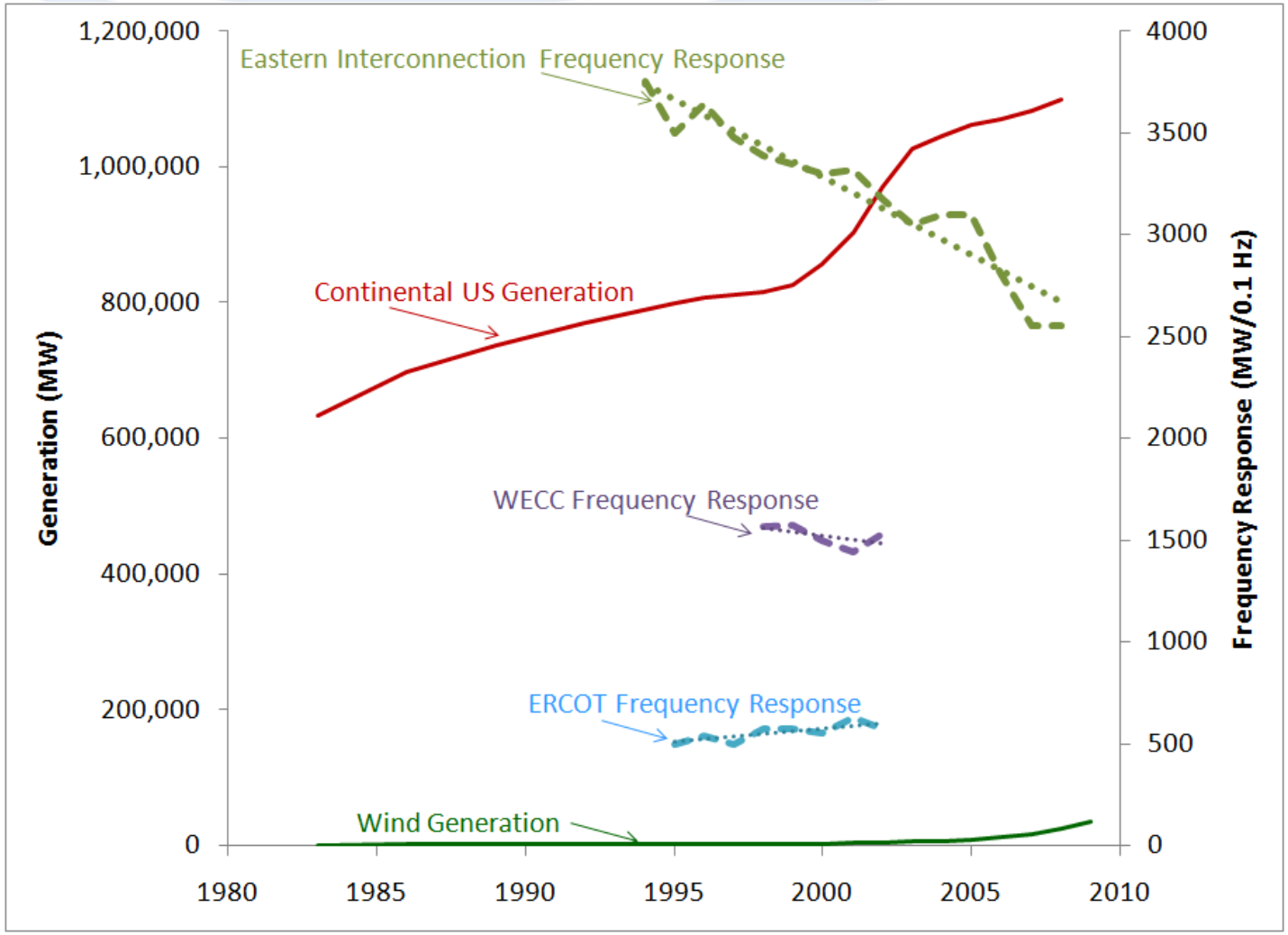
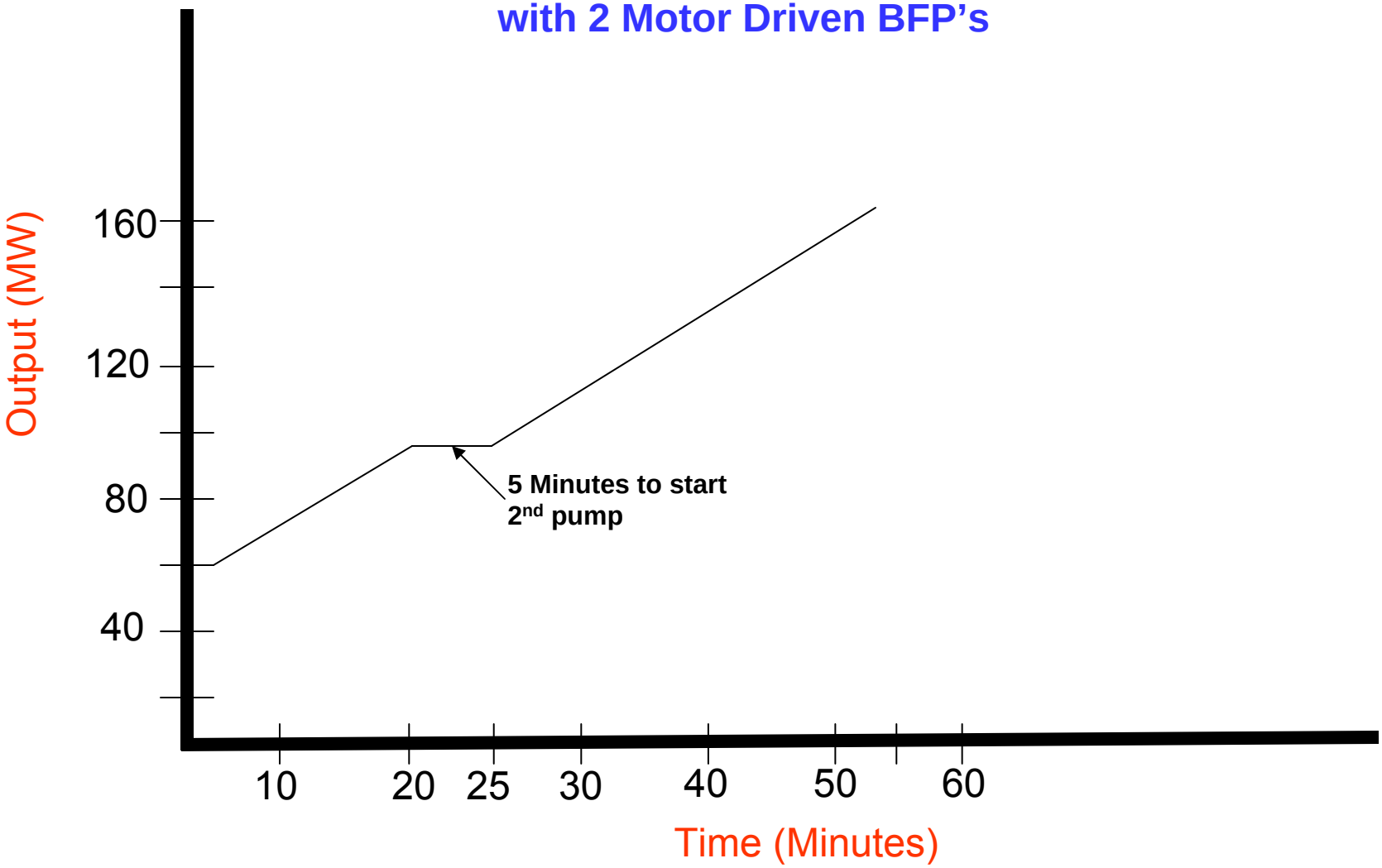
**March 2007- change to the new Daylight Saving Time.


Total Clock-Minutes less than 59.95 Hz or greater than 60.05 Hz
Eastern Interconnection
This chart illustrates the monthly total minutes of FTL$_{Low}$ plus FTL$_{High}$ being exceeded.
Total Clock-Minutes
0
25
50
75
100
125
150
175
200
225
*
2005
2006
2007
2008
2009
2010
7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8
Month
*March 2007- change to the new Daylight Saving Time.
Total Minutes at 60 Hz
Addition Minutes During Time-Error Corrections

Total Generation Fleet



Eastern Interconnection Frequency Response



Typical Loading Curve for a Coal Fired Unit with 2 Motor Driven BFP's