RESEARCH RESULTS AND RECOMMENDATIONS FOR AUTOMATIC PROCESSES FOR IDENTIFYING INTERCONNECTIONS FREQUENCY EVENTS AND ESTIMATE FREQUENCY RESPONSE

Final Report

By

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For

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EXECUTIVE SUMMARY

There are two objectives for Phase-3 of the DOE-CERTS supported research on Frequency Response performance and reliability standards adequacy. The first Phase-3 objective is to investigate automatic methods to identify interconnections frequency events by extending and validating the approach recommended by Florida Region Representatives and using phasor 1-second frequency data. The second Phase-3 objective is to research a methodology to automatically estimate and validate the Frequency Response for the events identified within the first objective. This is accomplished by: using the Frequency Response Standard Drafting Team (FRSDT) definitions of frequency events for locations of points A, B and C; and the Balancing Authority (BA) with the highest ACE during frequency events or ACE for the contingent BA.

First Objective – Investigate Automatic Methods and Processes to Identify Frequency Events

The team concluded that the method and parameters recommended by the Florida Region, to identify and define Eastern Interconnection frequency events, do not produce a representative and adequate set of frequency events. The team concluded that the method recommended by the Florida Region does produce a representative and adequate set of frequency events if the below 60.00 Hz initial frequency criteria is removed, and the size of the frequency change and/or time window is adjusted for each interconnection. The team further concluded that the proposed method selects events consistent with those manually selected by the Resources Subcommittee for 2008 if the Initial Frequency bounds are removed from the event selection process.

The team recommends an event selection criteria using a 15-second time window for frequency deviations greater than 36, 70, and 90 mHz for the Eastern, Western and Texas Interconnections respectively with 1 second frequency data. The team also recommends that data selection criteria select events that cause frequency to increase as well as decrease to maintain measurement symmetry. In addition, the team advises that the frequency change size and time window duration be reviewed periodically. These parameters should be modified to provide an average number of events per month between four (4) and seven (7) as the additional data is collected and data quality improves.

Second Objective – Investigate Methodology to Estimate and Validate Events Frequency Response

The team concluded there is still a great deal of uncertainty associated with the estimates for Frequency Response on all three interconnections as indicated by the Standard Deviations of the measured Frequency Responses. However, there is reasonable consistency in the mean values for Frequency Response for the years evaluated. This consistency in mean Frequency Response indicates that the measurement methodology is valid.

The team recommends ongoing evaluation and adjustments for the proposed event selection and Frequency Response methodologies as more data is collected and data quality improves. The team recognizes the value of selecting events with appropriate frequency characteristics. However, the team recommends that any event selection process be reviewed carefully to ensure the selection process produces an unbiased sample of frequency events. The potentially dire consequences of relying on biased samples, whether biasing is intentional or not, are well documented.

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1. Introduction

This research is part of Phase-3 of the DOE-CERTS supported research on interconnection Frequency Response performance and reliability standards started on 2007. There are two objectives for this phase-3 of the research work. The first Phase-3 objective is to investigate automatic methods to identify interconnections frequency events exploring, extending and validating the approach recommended by Florida Region Representatives during the January 2010 Resources Subcommittee meeting in Tucson and using 2007 to 2009 1-second interconnection phasor frequency data. The event-list produced automatically to meet objective one will be compared to the Resources Subcommittee yearly lists of events used for Balancing Authorities to calculate their yearly frequency bias. The second Phase-3 objective is to research a methodology to automatically estimate and validate Frequency Response for events identified within the first objective; using the Frequency Response Standard Drafting Team (FRSDT) definitions for frequency event points A, B and C, and estimating MW loss using the methodology recommended to the Resources Subcommittee during their meeting in September 2009 in Minneapolis based on Balancing Authorities' highest ACE during the event period. Frequency Response calculations use historical 2007 to 2009 1-second phasor frequency data and 1-minute ACE data currently available in NERC portfolio of wide-area reliability monitoring applications databases.

2. Background

Results and recommendations for Phases 1 and 2 of CERTS research work on interconnections' Frequency Response were presented in the document "Interconnections Frequency Response Research and Study" [1] prepared for CERTS by Energy Mark Inc., in August 2007, Phase 1 and 2 research results confirmed the interconnections' primary governing Frequency Response downtrend during the last 10 years, quantified criticality and risks for interconnection Frequency Response downtrend, and identified acceptable results may be achieved using 2-second or 1-minute data samplings. Results from the Phase-3 research will support automatic and systematic data collection, and archiving of interconnection frequency-event-related data and corresponding absolute value of Frequency Response estimates. CERTS research results and recommendations will be used by FRSDT and Resources subcommittee to define interconnection Frequency Response requirements and the method for distributing those requirements between Balancing Authorities, with a future objective to incorporate the findings in a Frequency Response standard. CERTS future research will support the investigations required for defining and validating the future Frequency Response standard and its corresponding performance metrics.

3. Research Results and Validation of Florida Reliability Region Recommendation for Identifying Eastern Interconnection Frequency Generation and Load Events

Florida recommended to the Resources Subcommittee during their January 2010 meeting, to produce and deliver a list of Eastern frequency events defined by using frequency changes greater than 0.040 Hz for consecutive 15-second periods, and below 60.00 Hz.

To validate the Florida recommendation, 1-second phasor frequency data was collected for the three interconnections from 07/01/2007 to 12/31/2009 and the Florida event identification criteria applied to produce the identified events in the "Number of Identified Events" column of Table-1 with the number of frequency events per month for the study period.

To address Phase-3 second objective for researching and validating interconnections Frequency Response calculations methods, CERTS estimated the Frequency Response for each of the identified events using the

[1] H. Illian, Energy Mark, Inc., "Interconnections Frequency Response Research and Study", Prepared for CERTS and NERC Frequency Response Standard Drafting Team, August 29, 2007

following method recommended to the Resources Subcommittee to produce the "Frequency Response Median" column in Table-1.

$$FreqResponse_{tnt} = \frac{MW\,Loss}{10 \times \Delta Freq} \quad \text{(FR5-1)}$$

$$\Delta Freq = Freq_B - Freq_A \quad \text{(FR5-2)}$$

$$Freq_A = \frac{\sum_{t-16}^{t-2} Freq}{n} \quad \text{(FR5-3)}$$

$$Freq_B = \frac{\sum_{t+19}^{t+52} Freq}{n} \quad \text{(FR5-4)}$$

MWLoss using RS equation

$$MW\,Loss_{tnt} = \max(\Delta ACE_{total})_{BA} - 0.6 \times 10 \times FreqBias_{BA} \times \Delta Freq \quad \text{(L-3)}$$

Table 1 – Eastern Interconnection Number of 15-Second Events Identified per Month and Corresponding Monthly Median of Absolute Value of Frequency Response Using 0.040 Hz Delta Frequency and Below 60.00 Hz

Month Year	15-Seconds Window	
	Frequency Response Median	Number of Identified Events
Jul07	2236	3
Aug07	3030	3
Sep07	1703	2
Oct07	1416	2
Nov07	NA	NA
Dec07	NA	NA
Jan08	3121	1
Feb08	3240	2
Mar08	2061	1
Apr08	2786	3
May08	2000	2
Jun08	2425	1
Jul08	NA	NA
Aug08	1338	1
Sep08	2608	3
Oct08	2193	1
Nov08	2251	3
Dec08	528	1
Jan09	NA	NA
Feb09	3993	1
Mar09	2930	1
Apr09	2460	4
May09	2334	4
Jun09	2175	1
Jul09	705	1
Aug09	NA	NA
Sep09	3305	2
Oct09	3185	1
Nov09	3091	1
Dec09	1883	2

To help analyze and visualize the results shown in Table-1, Figure-1 was created with the left Y-axis as monthly median of the absolute value of Frequency Response in MW/0.1 Hz for the line-plot, and the right Y-axis as the number of events per month for the vertical-bars.

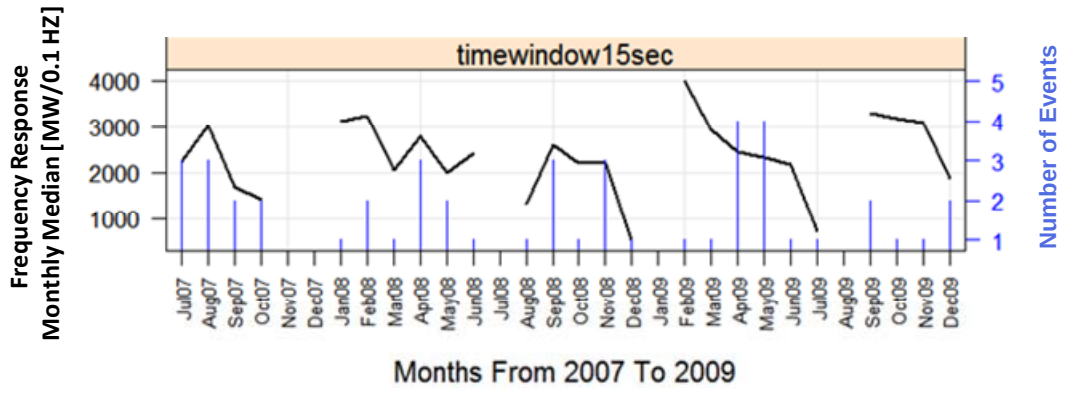

Figure 1 – Eastern Interconnection Number of 15-Second Events Identified per Month and Corresponding Monthly median of the absolute value of Frequency Response Using 0.040 Hz Delta Frequency and Below 60.00 Hz

Preliminary analysis of Table-1 and Figure-1 indicate the average number of events per month is about 2 with a yearly average of about 15 events, with 5 months without events. Only about 10-percent of the events identified match with the Resources Subcommittee 2009 disturbance list.

The above results indicate the Florida recommended parameters to identify and define Eastern Interconnection frequency events do not produce a representative, adequate set of frequency events. However, the method does appear capable of producing a representative and adequate set of frequency events if the below 60 Hz criteria is removed and the size of events frequency change and the time window is adjusted for each interconnection.

To identify a methodology and set parameters appropriately, the research team reviewed data while considering the following:

- There is value in finding a methodology that applies to all interconnections while allowing "parameters" to be set to recognize technical differences between those interconnections compared to a methodology that is unique to each interconnection.
- Frequency events should correlate, strongly, with reliability-concerns.
- The number of identified-frequency events should be large enough to provide reasonable calculation accuracy, but should be minimized to not burden entities beyond that need.
- Measuring frequency changes in one direction only may create perverse-incentives that reduce Frequency Response in the unmeasured direction, cause frequency to be biased away from schedule, etc.
- New technology associated with load and generation, operation of existing loads and generation based on market rather than operating issues, replacement of existing generation with variable generation, etc. will enhance reliability concerns for high frequency events compared to historic operation,
- Sufficient data, and data of reasonable quality, must be available before a frequency change should be included as a possible candidate for a frequency event. That is, there are frequency deviations that meet the proposed frequency deviation criterion that are not included in this analysis because related data is missing, data quality issues are not met, etc.

CERTS PHASE-3 FIRST OBJECTIVE FOR RESEARCH ON AUTOMATIC FREQUENCY RESPONSE EVENTS IDENTIFICATION

4. Eastern Interconnection Generation and Load Events Identification Results from 2007 to 2009 Using a Modified Florida Region Recommended Identification Process

Eastern Interconnection Generation Events Identified

To explore and identify a more representative and adequate frequency event list, Florida's frequency change criteria for event identification were changed from 0.040 Hz to 0.036 Hz and time-windows were expanded to include 20, 25, and 30 second periods. This frequency deviation is twice the published epsilon for this interconnection. NERC Resources Subcommittee (RS), and Frequency Response Standard Drafting Team (FRSDT) members observed the below 60 Hz criteria eliminated many critical events in the Eastern Interconnection. The Research Team investigated this observation and concluded that more than 50 percent of significant events were filtered out because of the below 60 Hz criteria. See section 7.

Table-2 below shows a summary with the number of generation events and corresponding absolute value of Frequency Response results for the four time-windows, with the below 60.00 Hz criteria removed.

Table 2 – Eastern Interconnection Number of 15, 20, 25, 30 Second Events Identified per Month and Corresponding Monthly Median of Absolute Value of Frequency Response Using 0.036 Hz Delta Frequency and Below 60 Hz Criteria Removed

Eastern 36mHz Generation Outages								
Month Year	15-Seconds Time Window		20-Seconds Time Window		25-Seconds Time Window		30-Seconds Time Window	
	Frequency Response Median	Number of Identified Events	Frequency Response Median	Number of Identified Events	Frequency Response Median	Number of Identified Events	Frequency Response Median	Number of Identified Events
Jul07	2236	5	2417	6	2526	8	2695	9
Aug07	2953	6	2886	7	2868	9	2886	9
Sep07	1703	2	2007	5	1837	8	1780	10
Oct07	1718	7	1718	11	1798	16	1715	23
Nov07	1934	8	1628	11	1641	16	1594	25
Dec07	1995	3	1995	3	1277	5	1277	7
Jan08	2085	5	2120	6	1833	10	1775	17
Feb08	1538	11	2006	14	1609	22	1538	33
Mar08	1872	5	1833	10	1793	13	1740	16
Apr08	2674	7	2109	11	1795	13	1767	21
May08	2568	8	2072	12	1737	16	1823	27
Jun08	2094	7	1720	8	1588	9	1714	13
Jul08	NA	NA	1101	2	959	3	1258	7
Aug08	1338	3	1339	3	1847	6	1598	9
Sep08	1911	9	2161	10	1774	14	2076	22
Oct08	2065	5	2030	6	2066	13	1924	20
Nov08	2209	6	2099	8	2068	10	1897	14
Dec08	1071	4	1572	5	1370	9	1513	14
Jan09	1373	3	1383	3	1217	6	1383	9
Feb09	2228	10	2228	10	1949	14	1939	19
Mar09	2216	8	2060	11	2010	14	1976	20
Apr09	1922	7	1914	8	1914	12	1883	25
May09	2152	8	2015	11	2149	14	2310	23
Jun09	2670	2	2496	4	2024	6	2088	8
Jul09	1701	8	1577	9	1708	11	1707	12
Aug09	1816	4	2650	5	1547	8	2074	11
Sep09	2879	6	3078	7	2724	10	2092	19
Oct09	1866	4	1998	8	2015	12	1976	27
Nov09	1890	8	2040	13	1929	18	1893	26
Dec09	2617	4	2667	5	2833	6	2293	13

To help analyze and visualize the results shown in Table-2, Figure-2 was created with the left Y-axis as monthly median of the absolute value of Frequency Response in MW/0.1 Hz for the line-plot, and the right Y-axis as the number of generation events per month for the vertical-bars.

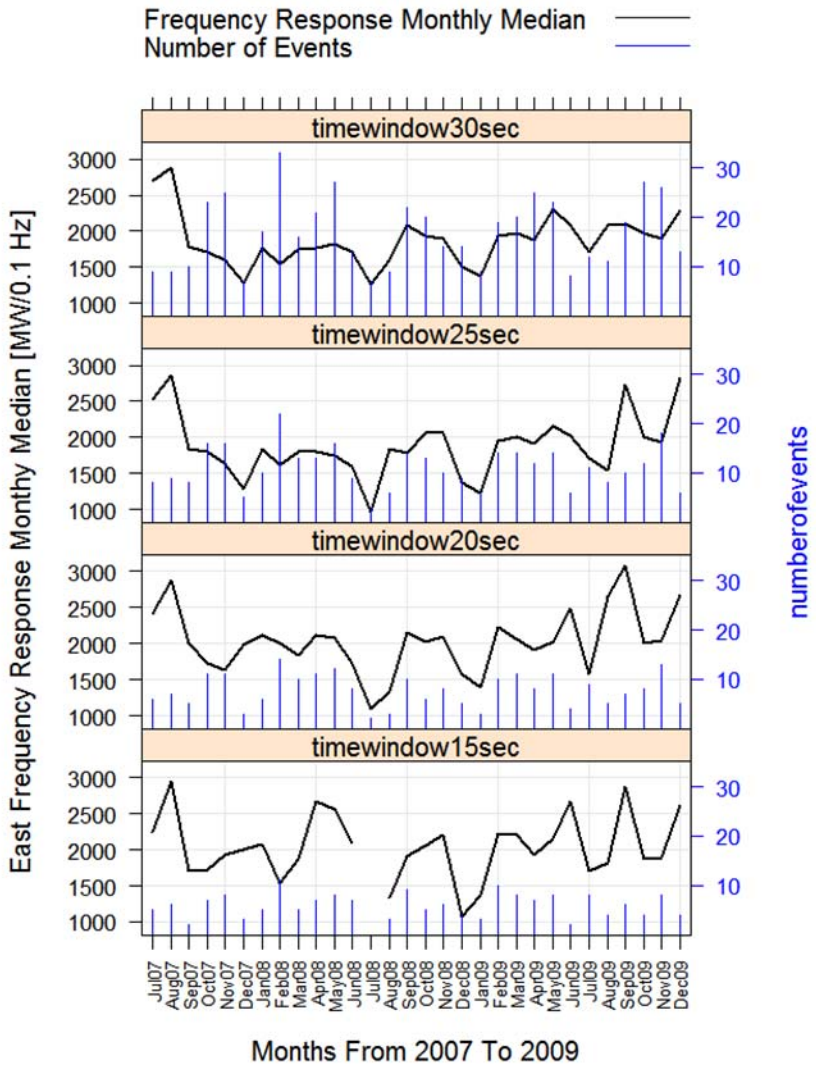

Figure 2 - Eastern Interconnection Number of 15, 20, 25, 30 Second Events Identified per Month And Corresponding Monthly Median of Absolute Value of Frequency Response Using 0.036 Hz Delta Frequency and Below 60 Hz Criteria Removed

Analysis of Table-2 and Figure-2 indicate that for a delta frequency of 0.036 Hz the 15-second event set is representative and produces an adequate list of frequency events. The 15-second event set contains about 6 events per month during the 2007 to 2009 period. By removing the below 60 Hz constraint, 90 percent of the events identified by the Resources Subcommittee for 2008 are in the events set identified automatically.

The above results indicate using the Florida recommended event identification approach with a delta frequency of 0.036 Hz with a time-window of 15-seconds produces a representative and adequate set of frequency events for the Eastern Interconnection.

Eastern Interconnection Load Events Identified

Table-3 below shows a summary with the number of load events and corresponding absolute value of Frequency Response results for the four time-windows using a delta frequency of 0.036 Hz and below 60 Hz criteria removed.

Table 3 - Eastern Interconnection Number of 15, 20, 25, 30 Second Events Identified per Month and Corresponding Monthly Median of Absolute Value of Frequency Response Using 0.036 Hz Delta Frequency and the Below 60 Hz Criteria Removed

Eastern 36mHz Load Outages								
Month Year	15-Seconds Time Window		20-Seconds Time Window		25-Seconds Time Window		30-Seconds Time Window	
	Frequency Response Median	Number of Identified Events	Frequency Response Median	Number of Identified Events	Frequency Response Median	Number of Identified Events	Frequency Response Median	Number of Identified Events
Jul07	1831	1	1856	1	1940	2	2141	3
Aug07	NA	NA	0	NA	2282	1	2387	1
Sep07	420	1	420	1	1128	3	1789	4
Oct07	1200	1	1506	2	1715	7	1604	17
Nov07	1506	1	1130	3	1417	14	1468	23
Dec07	NA	NA	NA	NA	2171	2	1600	8
Jan08	NA	NA	1111	1	1111	3	1374	10
Feb08	1389	5	733	9	905	14	815	20
Mar08	NA	NA	NA	NA	1355	5	1221	12
Apr08	NA	NA	1967	2	1358	13	1482	26
May08	1887	2	1849	6	1830	13	1796	27
Jun08	NA	NA	NA	NA	1934	3	1917	7
Jul08	NA	NA	NA	NA	1734	2	1426	6
Aug08	NA	NA	891	1	961	3	1033	5
Sep08	NA	NA	NA	NA	NA	NA	1608	4
Oct08	1201	1	1619	2	1448	10	1297	18
Nov08	NA	1	2417	2	1287	4	932	7
Dec08	NA	1	NA	1	1088	2	1133	6
Jan09	3340	1	1114	2	1114	2	1695	5
Feb09	1994	1	1994	4	1508	7	1668	12
Mar09	NA	NA	NA	NA	1511	1	1925	3
Apr09	2110	2	2154	6	1955	10	2015	26
May09	NA	NA	2240	3	1767	5	1740	13
Jun09	NA	NA	NA	2	NA	2	2516	6
Jul09	NA	NA	2057	4	1984	6	1960	12
Aug09	NA	NA	NA	NA	2270	2	2312	7
Sep09	NA	NA	1598	2	1607	3	1739	16
Oct09	NA	NA	1941	2	1608	12	1674	35
Nov09	NA	NA	2170	2	1650	6	1760	13
Dec09	1621	2	1761	2	1719	5	1793	10

To help analyze and visualize the results shown in Table-3, Figure-3 was created with the left Y-axis as monthly median of the absolute value of Frequency Response in MW/0.1 Hz for the line-plot, and the right Y-axis as the number of load events per month for the vertical-bars.

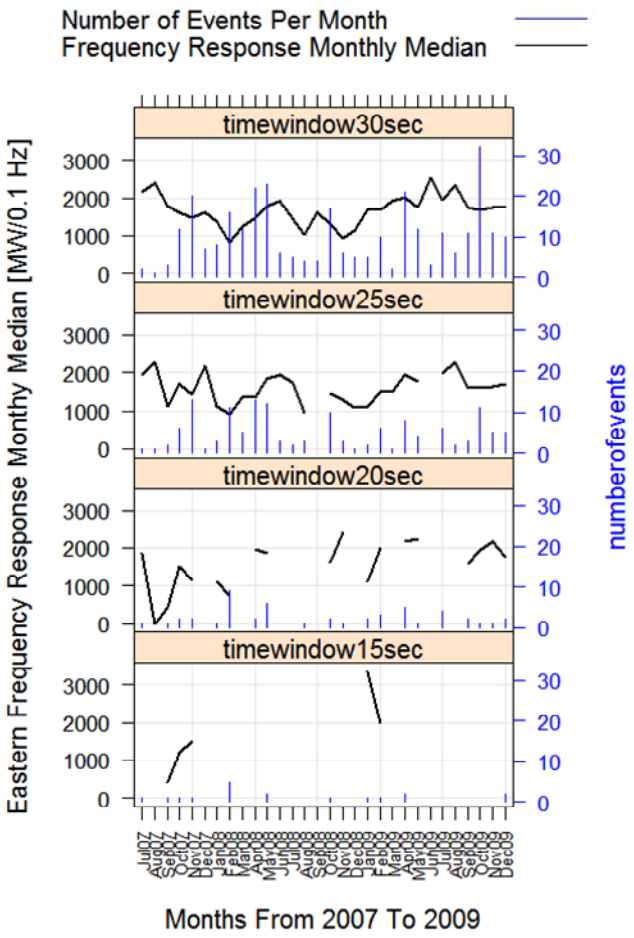

Figure 3 – Eastern Interconnection Number of 15, 20, 25, 30 Second Events Identified per Month and Corresponding Monthly Median of Absolute Value of Frequency Response Using 0.036 Hz Delta Frequency and the Below 60 Hz Criteria Removed

This analysis appears to show little value from including frequency changes in the positive direction. However, the analysis demonstrates that there is little burden from including this data in order to realize the benefits associated with symmetry in reporting and to monitor concerns related to Frequency Response for "high frequency" or load events.

In addition, these plots do not demonstrate the value of the timing of these load events. In several cases, load events occur during months when there are few generation events to measure. Therefore, including these events improves the accuracy of calculated Frequency Response beyond what the numbers may suggest.

Finally, there are data quality issues that cause so few events to be available. While this issue affects both generation and load events, it is apparent that it is a larger issue for load events. Therefore, it is valuable to include these events for the benefit of improving the industry's measurement and awareness of these events. This benefit will become greater as Balancing Authorities have less traditional generation available to control and embrace new sources of operating flexibility that will be available via market and/or interconnection rules.

5. Western Interconnection Generation and Load Events Identification Results from 2007 to 2009 Using a Modified Florida Recommended Identification Process

Western Interconnection Generation Events Identified

To explore and identify a representative and adequate frequency event list for WECC, Florida's frequency change criteria for event identification were applied for delta frequencies of 0.070, 0.060 and 0.050 Hz and time-windows were expanded to include 20, 25, and 30 second periods. It was determined only the 0.070 Hz delta frequency produces acceptable generation event lists. This frequency deviation is about three times the published epsilon for this interconnection. NERC Resources Subcommittee (RS), and Frequency Response Standard Drafting Team (FRSDT) members observed the below 60 Hz criteria eliminated many critical events in the Western Interconnection. The Research Team investigated this observation and concluded that more than 50 percent of significant events were filtered out because of the below 60 Hz criteria. See section 7.

Table-4 below shows a summary with the number of generation events and corresponding absolute value of Frequency Response results for the four time-windows using 0.070 Hz as delta frequency, with the below 60 Hz criteria removed.

Table 4 - Western Interconnection Number of 15, 20, 25, 30 Second Events Identified per Month and Corresponding Monthly Median of Absolute Value of Frequency Response Using 0.070 Hz Delta Frequency and Below 60 Hz Criteria Removed

Western 70mHz Generation Outages								
Month Year	15-Seconds Time Window		20-Seconds Time Window		25-Seconds Time Window		30-Seconds Time Window	
	Frequency Response Median	Number of Identified Events	Frequency Response Median	Number of Identified Events	Frequency Response Median	Number of Identified Events	Frequency Response Median	Number of Identified Events
Jan07	765	8	787	11	690	11	738	10
Feb07	639	7	582	8	582	8	582	8
Mar07	640	8	534	10	493	11	493	11
Apr07	501	5	487	5	487	5	487	5
May07	631	4	621	5	621	5	622	5
Jun07	899	4	815	6	755	7	815	7
Jul07	384	7	373	7	390	7	431	8
Aug07	706	6	706	6	747	7	747	9
Sep07	644	6	644	6	644	6	644	6
Oct07	471	3	471	3	476	4	477	4
Nov07	659	5	647	6	653	7	653	7
Dec07	871	3	871	3	871	3	871	5
Jan08	622	4	619	4	645	5	645	5
Feb08	821	9	786	9	786	9	776	12
Mar08	654	8	596	8	567	10	570	10
Apr08	625	4	625	4	563	5	528	6
May08	644	12	561	13	628	16	639	17
Jun08	806	12	827	13	827	13	827	13
Jul08	1051	8	939	8	959	8	959	8
Aug08	788	6	747	8	699	9	707	10
Sep08	826	7	826	7	826	9	826	9
Oct08	621	5	610	5	610	5	687	7
Nov08	1109	4	951	5	951	7	846	7
Dec08	294	1	341	2	349	2	422	3
Jan09	490	7	460	6	515	6	561	7
Feb09	881	5	870	7	870	7	683	8
Mar09	949	3	949	3	756	4	949	3
Apr09	638	6	638	6	537	9	555	10
May09	1110	2	809	4	776	5	776	7
Jun09	640	7	640	7	630	8	630	8
Jul09	679	4	601	4	393	5	469	5
Aug09	465	1	465	1	465	1	698	2
Sep09	683	8	683	8	683	8	683	8
Oct09	616	6	502	7	562	8	497	9
Nov09	544	7	547	8	547	8	555	9
Dec09	541	4	446	5	446	7	446	7

To help analyze and visualize the results shown in Table-4, Figure-4 was created with the left Y-axis as monthly median of the absolute value of Frequency Response in MW/0.1 Hz for the line-plot, and the right Y-axis as the number of generation events per month for the vertical-bars.

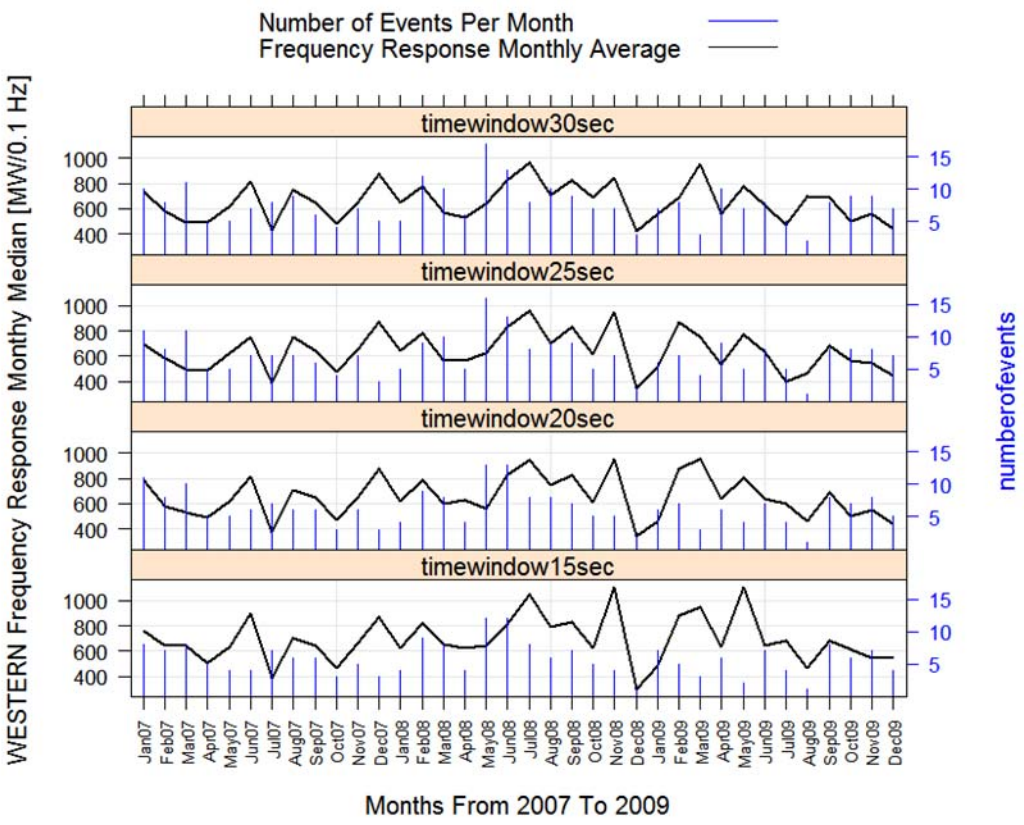

Figure 4 – Western Interconnection Number of 15, 20, 25, 30 Second Events Identified per Month and Corresponding Monthly Median of Absolute Value of Frequency Response Using 0.070 Hz Delta Frequency and Below 60 Hz Criteria Removed

Analysis of Table-4 and Figure-4 indicate that for a delta frequency of 0.070 Hz the 15-second event set is representative and produces an adequate list of frequency events. The 15-second event set contains about 6 events per month during the 2007 to 2009 period.

The above results indicate using the Florida recommended event identification approach with a delta frequency of 0.070 Hz with a time-window of 15-seconds produces a representative and adequate set of frequency events for the Western Interconnection.

Western Interconnection Load Events Identified

Table-5 below shows a summary with the number of load events and corresponding absolute value of Frequency Response results for the four time-windows using a delta frequency of 0.070 Hz.

Table 5 – Western Interconnection Number of 15, 20, 25, 30 Second Events Identified per Month and Corresponding Monthly Median of Absolute Value of Frequency Response Using 0.070 Hz Delta Frequency and Below 60 Hz Criteria Removed

Western 70mHz Load Outages								
Month Year	15-Seconds Time Window		20-Seconds Time Window		25-Seconds Time Window		30-Seconds Time Window	
	Frequency Response Median	Number of Identified Events	Frequency Response Median	Number of Identified Events	Frequency Response Median	Number of Identified Events	Frequency Response Median	Number of Identified Events
Jan07	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Feb07	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Mar07	NaN	NaN	NaN	NaN	485	1	708	1
Apr07	NaN	NaN	256	1	62	2	391	3
May07	218	1	218	1	218	1	218	1
Jun07	NaN	NaN	771	2	779	2	996	3
Jul07	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Aug07	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Sep07	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Oct07	NaN	NaN	NaN	NaN	794	1	794	1
Nov07	NaN	NaN	1377	2	1377	2	1166	3
Dec07	666	1	666	1	820	2	666	3
Jan08	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Feb08	502	1	502	1	502	1	754	2
Mar08	NaN	NaN	NaN	NaN	NaN	NaN	635	3
Apr08	491	1	491	1	491	1	397	1
May08	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Jun08	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Jul08	NaN	NaN	486	1	491	1	491	3
Aug08	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Sep08	512	4	512	4	431	6	431	6
Oct08	1030	2	1030	2	821	3	894	4
Nov08	NaN	NaN	NaN	NaN	1197	1	1246	1
Dec08	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Jan09	214	4	212	4	213	4	217	4
Feb09	NaN	NaN	NaN	NaN	NaN	NaN	843	1
Mar09	NaN	NaN	NaN	NaN	NaN	NaN	900	1
Apr09	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
May09	821	1	767	1	752	1	786	1
Jun09	110	1	110	1	110	1	110	1
Jul09	596	2	620	3	620	3	620	3
Aug09	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Sep09	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Oct09	339	3	370	4	369	4	369	4
Nov09	657	1	705	2	744	3	744	3
Dec09	NaN	NaN	NaN	NaN	1186	1	1186	1

To help analyze and visualize the results shown in Table-5, Figure-5 was created with the left Y-axis as monthly median of the absolute value of Frequency Response in MW/0.1 Hz for the line-plot, and the right Y-axis as the number of load events per month for the vertical-bars.

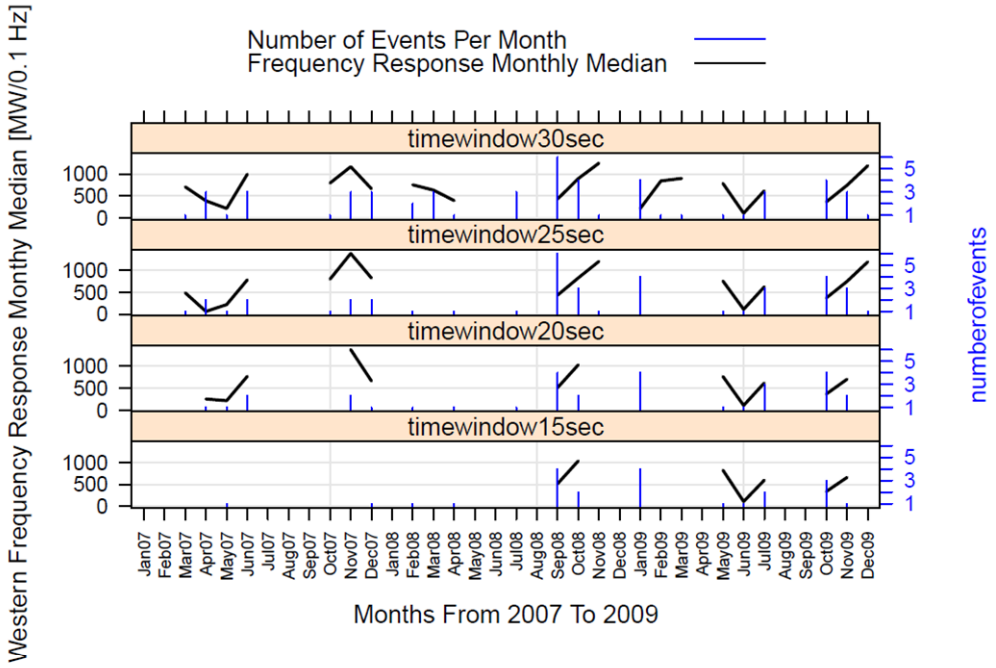

Figure 5 - Western Interconnection Number of 15, 20, 25, 30 Second Events Identified per Month and Corresponding Monthly Median of Absolute Value of Frequency Response Using 0.070 Hz Delta Frequency and Below 60 Hz Criteria Removed

As with the Eastern Interconnection, the analysis demonstrates that there is little burden from including this data in order to realize the benefits associated with symmetry in reporting and to monitor concerns related to Frequency Response for load events.

In addition, these plots do not demonstrate the value of the timing of these load events. In several cases, load events occur during months when there are few generation events to measure. Therefore, including these events improves the accuracy of calculated Frequency Response beyond what the numbers may suggest.

Finally, there are data quality issues that cause so few events to be available. While this issue affects both generation and load events, it is apparent that it is a larger issue for load events. Therefore, it is valuable to include these events for the benefit of improving the industry's measurement and awareness of these events. This benefit will become greater as Balancing Authorities have less traditional generation available to control and embrace new sources of operating flexibility that will be available via market and/or interconnection rules.

6. ERCOT Interconnection Generation and Load Events Identification Results from 2007 to 2009 Using a Modified Florida Recommended Identification Process

ERCOT Interconnection Generation Events Identified

To explore and identify a representative and adequate frequency event list for ERCOT, Florida's frequency change criteria for event identification were applied for delta frequencies of 0.090 and 0.070 Hz and time-windows were expanded to include 20, 25, and 30 second periods. It was determined only the 0.090 Hz delta frequency produces acceptable generation event lists. This frequency deviation is about three times the published epsilon for this interconnection. NERC Resources Subcommittee (RS), and Frequency Response Standard Drafting Team (FRSDT) members observed the below 60 Hz criteria eliminated many critical events in the ERCOT Interconnection. The Research Team investigated this observation and concluded that more than 50 percent of significant events were filtered out because of the below 60 Hz criteria. See section 7.

Table-6 below shows a summary with the number of generation events and corresponding absolute value of Frequency Response results for the four time-windows using 0.090 Hz as delta frequency, with the below 60 Hz criteria removed.

Table 6 - ERCOT Interconnection Number of 15, 20, 25, 30 Second Events Identified Per Month and Corresponding Monthly Median of Absolute Value of Frequency Response Using 0.090 Hz Delta Frequency And the Below 60 Hz Criteria Removed

ERCOT 90mHz Generation Outages								
Month Year	15-Seconds Time Window		20-Seconds Time Window		25-Seconds Time Window		30-Seconds Time Window	
	Frequency Response Median	Number of Identified Events	Frequency Response Median	Number of Identified Events	Frequency Response Median	Number of Identified Events	Frequency Response Median	Number of Identified Events
Jan07	572	9	572	9	572	9	572	9
Feb07	649	7	638	8	598	10	582	12
Mar07	541	7	464	9	472	9	472	11
Apr07	582	6	569	7	569	7	626	8
May07	580	7	577	7	524	8	555	8
Jun07	520	5	525	6	520	7	520	7
Jul07	603	3	603	3	603	3	603	3
Aug07	488	8	556	9	573	10	595	10
Sep07	512	6	512	6	512	6	547	9
Oct07	545	2	530	2	537	3	537	3
Nov07	518	6	518	6	632	6	621	6
Dec07	390	1	390	1	390	1	390	1
Jan08	538	2	486	2	445	3	445	3
Feb08	579	7	584	8	578	9	513	14
Mar08	500	8	500	8	472	12	511	16
Apr08	443	12	428	13	445	14	466	16
May08	571	6	561	6	592	6	614	9
Jun08	577	10	574	12	565	13	599	14
Jul08	394	5	394	5	448	6	457	8
Aug08	504	10	507	11	507	13	561	14
Sep08	566	6	614	9	577	10	652	10
Oct08	489	4	472	4	472	4	524	4
Nov08	603	4	507	6	507	6	569	8
Dec08	297	7	453	10	428	11	411	12
Jan09	317	4	319	4	338	4	338	4
Feb09	530	6	518	6	377	8	408	9
Mar09	625	8	605	9	627	12	621	14
Apr09	513	12	475	13	475	13	501	14
May09	413	10	413	10	413	10	413	10
Jun09	378	4	376	4	381	6	390	6
Jul09	475	8	454	8	466	9	548	9
Aug09	716	3	691	3	642	4	645	4
Sep09	514	9	515	10	492	12	498	12
Oct09	332	7	315	7	448	8	478	8
Nov09	311	5	311	5	312	5	316	6
Dec09	464	8	436	8	398	9	361	10

To help analyze and visualize the results shown in Table-6, Figure-6 was created with the left Y-axis as monthly median of absolute value of Frequency Response in MW/0.1 Hz for the line-plot, and the right Y-axis as the number of generation events per month for the vertical-bars.

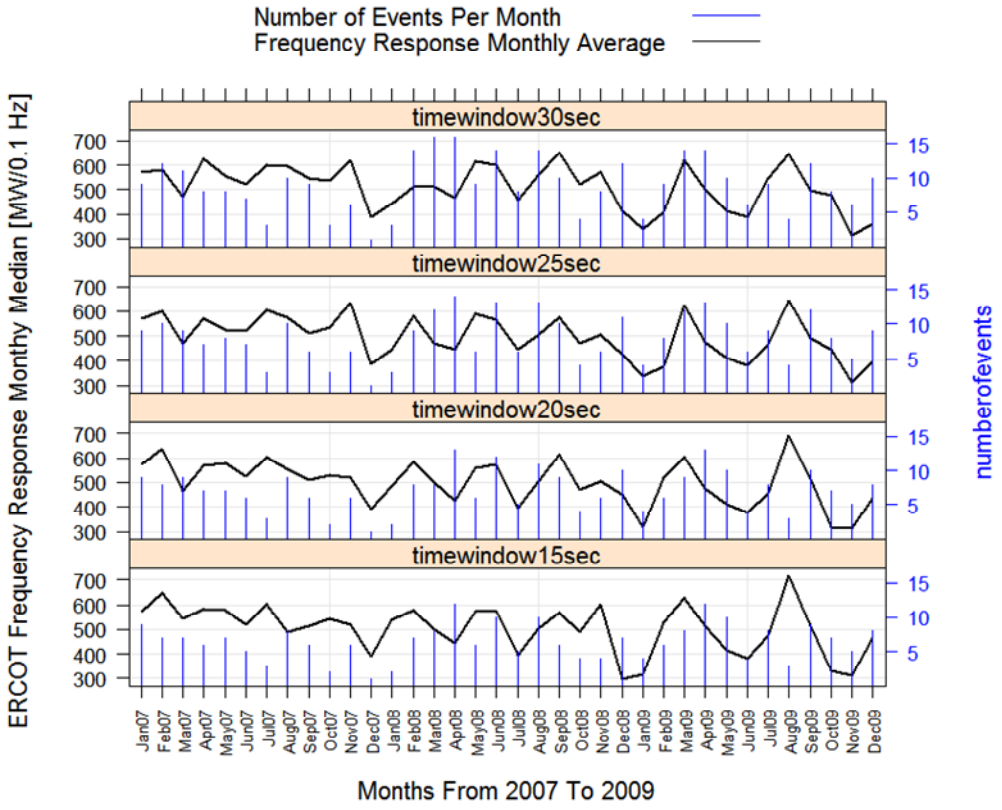

Figure 6 – ERCOT Interconnection Number of 15, 20, 25, 30 Second Events Identified per Month and Corresponding Monthly Median of Absolute Value of Frequency Response Using 0.090 Hz Delta Frequency And Below 60 Hz Criteria Removed

Analysis of Table-6 and Figure-6 indicate that for a delta frequency of 0.090 Hz the 15-second event set is representative and produces an adequate list of frequency events. The 15-second event set contains about 6 events per month during the 2007 to 2009.

The above results indicate using the Florida recommended event identification approach with a delta frequency of 0.090 Hz with a time-window of 15-seconds produces an adequate set of frequency events for the ERCOT Interconnection.

ERCOT Interconnection Load Events Identified

Table-7 below shows a summary with the number of load events and corresponding absolute value of Frequency Response results for the four time-windows using a delta frequency of 0.090 Hz.

Table 7 – ERCOT Interconnection Number of 15, 20, 25, 30 Second Events Identified per Month and Corresponding Monthly Median of Absolute Value of Frequency Response Using 0.090 Hz Delta Frequency and Below 60 Hz Criteria Removed

To help analyze and visualize the results shown in Table-7, Figure-7 was created with the left Y-axis as monthly median of the absolute value of Frequency Response in MW/0.1 Hz for the line-plot, and the right Y-axis as the number of load events per month for the vertical-bars.

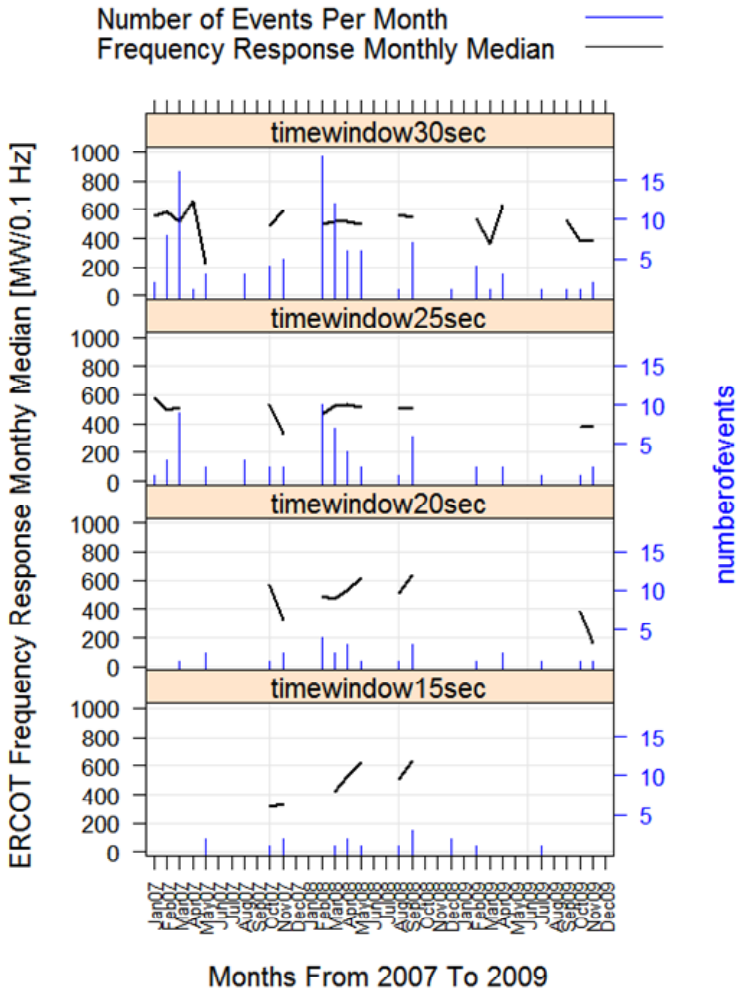

Figure 7 - ERCOT Interconnection Number of 15, 20, 25, 30 Second Events Identified per Month and Corresponding Monthly Median of Absolute Value of Frequency Response Using 0.090 Hz Delta Frequency and Below 60 Hz Criteria Removed

As with the Eastern and Western Interconnections, the analysis demonstrates that there is little burden from including this data in order to realize the benefits associated with symmetry in reporting and to monitor concerns related to Frequency Response for load events.

In addition, these plots do not demonstrate the value of the timing of these load events. In several cases, load events occur during months when there are few generation events to measure. Therefore, including these events improves the accuracy of calculated Frequency Response beyond what the numbers may suggest.

Finally, there are data quality issues that cause so few events to be available. While this issue affects both generation and load events, it is apparent that it is a larger issue for load events. Therefore, it is valuable to include these events for the benefit of improving the industry's measurement and awareness of these events.

7. Impact of the Below 60 Hz Criteria on Interconnections Events Selection Sets

The box plots statistical graphs used in this section and section 9 are used to visualize the events point A frequency (section 7) and the events Frequency Response (section 9) median, variability, and outliers. The median value is shown as the red horizontal line. The "box" containing the median defines the upper and lower limits of the inter-quartile range, which bound 50 percent of observed values. The "whiskers" that surround the box bounds values that are within one and one-half times the inter-quartile range above and below the box. Individual outliers that exceed this range are shown above and below the whiskers. This form of statistics visualization and the definitions of the graphic symbols used to describe the distributions of observations are consistent throughout sections 7 and 9.

After presenting the original research results and recommendations from sections 1 through 7 to the Resources Subcommittee (RS) and the Frequency Response Standard Drafting Team (FRSDT) during May 2010, some Resources Subcommittee members observed critical Eastern frequency events were filtered by using the 60 Hz criteria recommended. The Research Team extended the research to investigate and quantify the impact of the below 60 Hz criteria on the selection of adequate sets of frequency events for the three interconnections. Following is a summary of the results of this investigation, and the base for recommending removal of the initial 60 Hz constraint proposed by the Florida Region.

7.1 Eastern Events Filtered Using the Below 60 Hz Criteria

Figure 8 shows the indentified events point-A or initial frequency monthly frequency variability in the box plot and the monthly number of events in the bar plot. The box plots indicate more than 50 percent of the identified events had a point-A frequency above 60 Hz. Consequently the below 60 Hz criteria eliminates more than 50 percent of the identified events, some of them required by the Resources Subcommittee for defining adequate sets of events to present to interconnections and BAs and for them to estimate their yearly Frequency Response and Frequency Bias estimates.

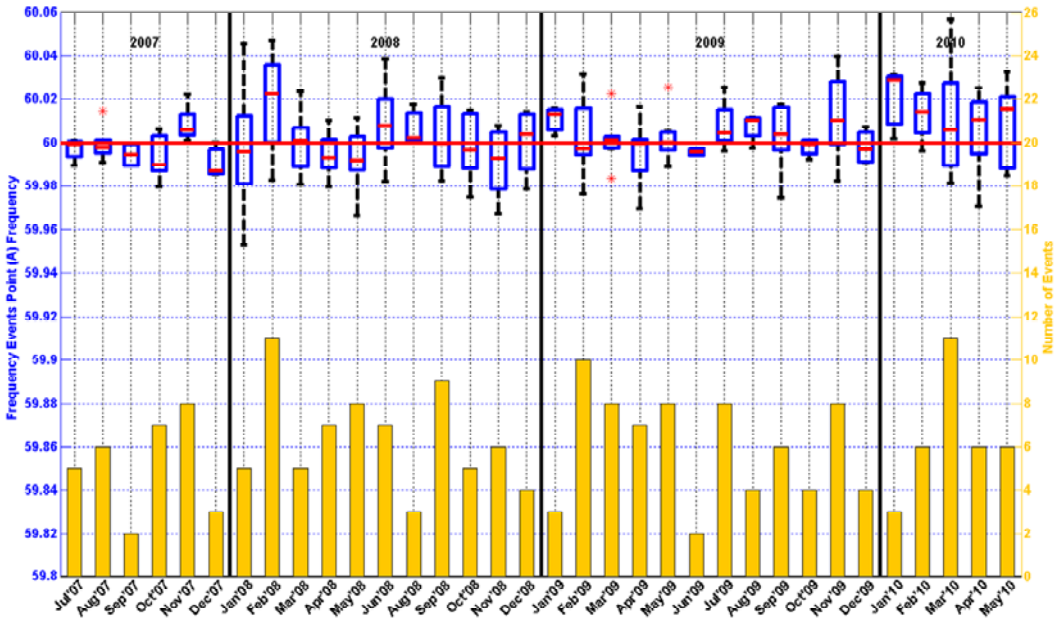

Figure 8 – Eastern Frequency Response Characteristics for Events with 36 mHz Delta in a 15-Seconds Window and Below 60 Hz Constraint Removed

7.2 Western Events Filtered Using the Below 60 Hz Criteria

Figure 9 shows the indentified events point-A or initial frequency monthly frequency variability in the box plot and the monthly number of events in the bar plot. The box plots indicate more than 50 percent of the identified events had a point-A frequency above 60 Hz. Consequently the below 60 Hz criteria eliminates more than 50 percent of the identified events, some of them required by the Resources Subcommittee for defining adequate sets of events to present to interconnections and BAs for them to estimated their yearly Frequency Response and Frequency Bias estimates.

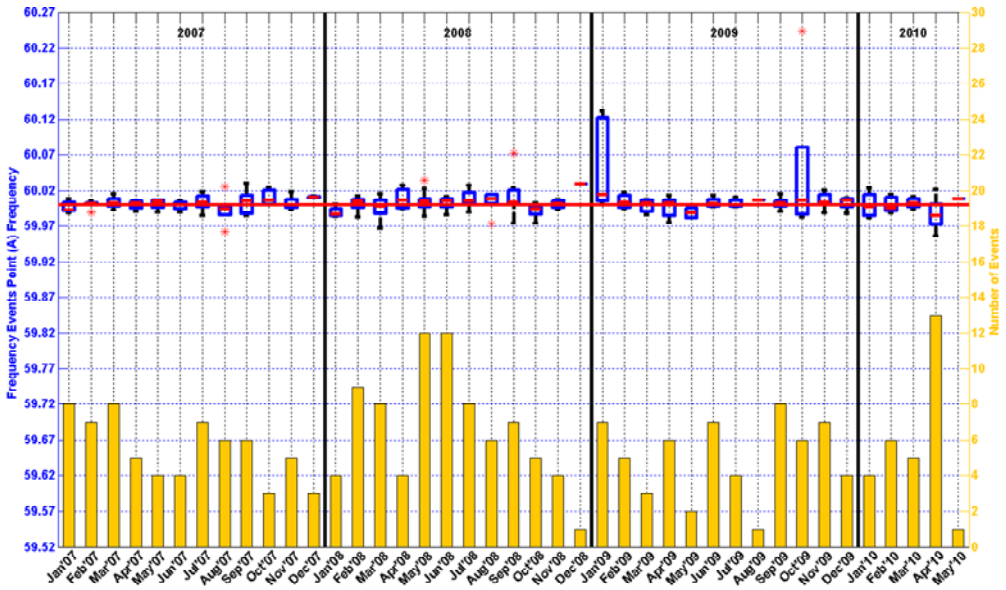

Figure 9 - Western Frequency Response Characteristics for Events with 70 mHz Delta in a 15-Seconds Window and Below 60 Hz Constraint Removed

7.3 ERCOT Events Filtered Using the Below 60 Hz Criteria

Figure 8 shows the indentified events point-A or initial frequency monthly frequency variability in the box plot and the monthly number of events in the bar plot. The box plots indicate more than 50 percent of the identified events had a point-A frequency above 60 Hz. Consequently the below 60 Hz criteria eliminates more than 50 percent of the identified events, some of them required by the Resources Subcommittee for defining adequate sets of events to present to interconnections and BAs for them to estimated their yearly Frequency Response and Frequency Bias estimates.

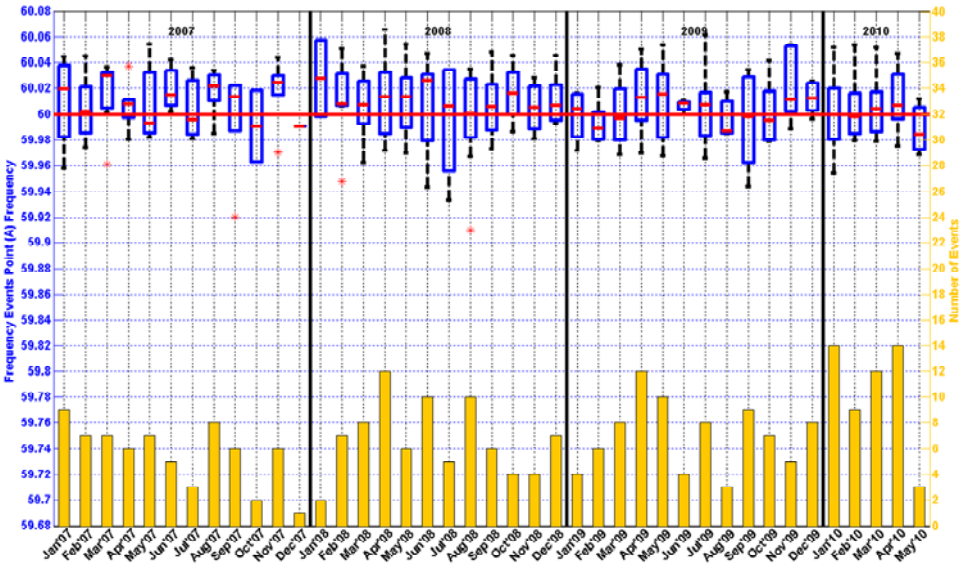

Figure 10 - ERCOT Frequency Response Characteristics for Events with 90 mHz Delta in a 15-Seconds Window and Below 60 Hz Constraint Removed

8. Automatic Interconnections Frequency Events Identification – Summary of Research Results and Recommendations

The following table summarizes the final recommended parameters to automatically identify frequency events for the three interconnections. Research results indicate the set of events produced using the recommended parameters gives reasonable and representative sets of frequency events:

Interconnection	Frequency Delta	Time Windows (Sec)	Initial Frequency for frequency Events <=60 Hz	Initial Frequency for frequency Events >= 60 Hz
Eastern	36 mHz	15	Criteria Removed	Criteria Removed
Western	70 mHz	15	Criteria Removed	Criteria Removed
ERCOT	90 mHz	15	Criteria Removed	Criteria Removed

These parameters address comments from the Resources Subcommittee. Frequency deviation values, time windows, and initial frequency filters were modified and selected to produce a representative sample of frequency events. This set of events exhibits the following characteristics that include, but are not limited to:

- Comparing to historically-selected frequency events with acceptable accuracy.
- Capturing events with frequency characteristics important to the Resources Subcommittee regardless of initial frequency.
- Achieving a reasonable number of identified events to balance concerns for calculation accuracy and possible workload ramifications.

Proposed frequency deviations of 36, 70, and 90 mHz are roughly 2, 3, and 3 times the published epsilon values of 18, 22.8, and 30 mHz for the Eastern, Western, and ERCOT Interconnections, respectively.

The team expects the number of events selected by these parameters, per year and per month, to increase as data quality improves. In addition, availability of data and further analysis of it will guide changes to these parameters over time. Therefore, these parameters should be viewed as adequate initial values that will require future review and possible modification.

CERTS PHASE-3 SECOND OBJECTIVE FOR RESEARCH ON AUTOMATIC FREQUENCY RESPONSE EVALUATION AND VALIDATION

9. Automatic Frequency Response Evaluation and Validation for Three Interconnections

Phase-3 second objective for this research is to estimate, analyze, and evaluate a methodology to automatically calculate the Frequency Response for each of the identified events using the methodology described in section 3. This methodology and information could be very valuable to help NERC stakeholders select and define a final set of frequency events they will publish for use by Balancing Authorities and interconnections to estimate their yearly Frequency Response and Frequency Bias commitments.

To achieve the second objective, the research team used the set of frequency events identified in sections 4 - 7 together with the corresponding 1-second interconnection frequency and 1-minute NetACE data to calculate the Frequency Response for each event using the methodology described in section 3.

To facilitate the analysis and assessment of the calculated Frequency Response for each interconnection, the research results are presented in the following visuals and format:

- Calculate and visualize, using box plots (described in section 7), the interconnections estimated monthly Frequency Response median and variability for monthly events.
- Visualize, using contour plots, the temporal distribution of the estimated Frequency Response per month and per hour for the 2007 to 2009 period

9.1 Eastern Events Frequency Response Median, Variability and Temporal Distribution

Figure-11 shows the estimated monthly median of the absolute value of Frequency Response and sensitivity for each of the monthly data sets of events identified in the first part of this research.

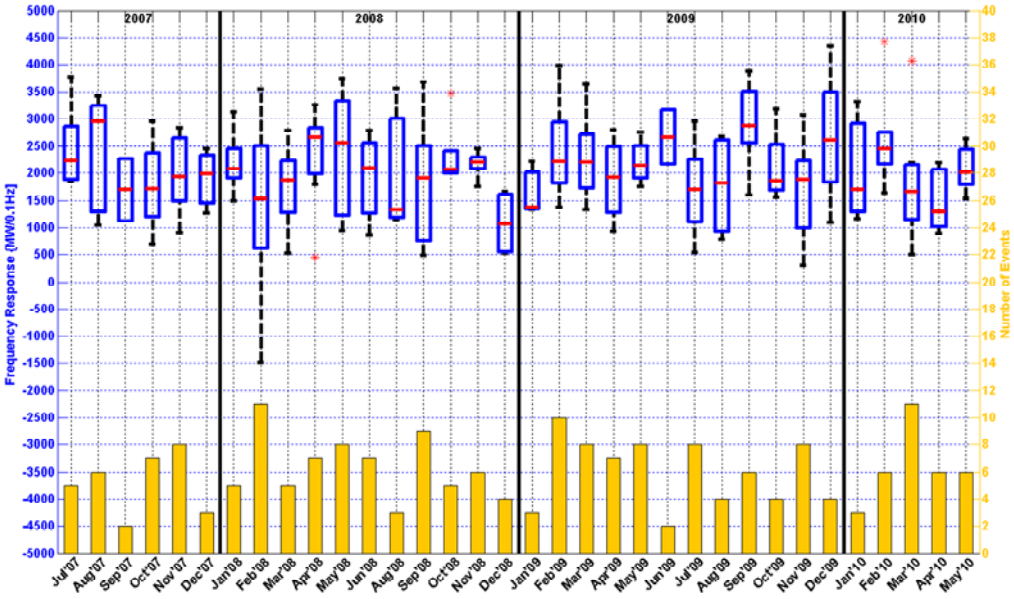

Figure 11 –Frequency Response Variability and Number of Events for Eastern 2007 to 2010 Events for 36 mHz Delta, 15-Seconds Time Window and 60 Hz Constraint Removed

Figure-12 shows the estimated Frequency Response temporal distribution for each month and each hour type for the 2007 to 2009 period. It should be noticed that the lowest Frequency Response occurs during hours 21 to 23 and lower during hour 8AM to 5PM when compare to hours 1AM to 6AM.

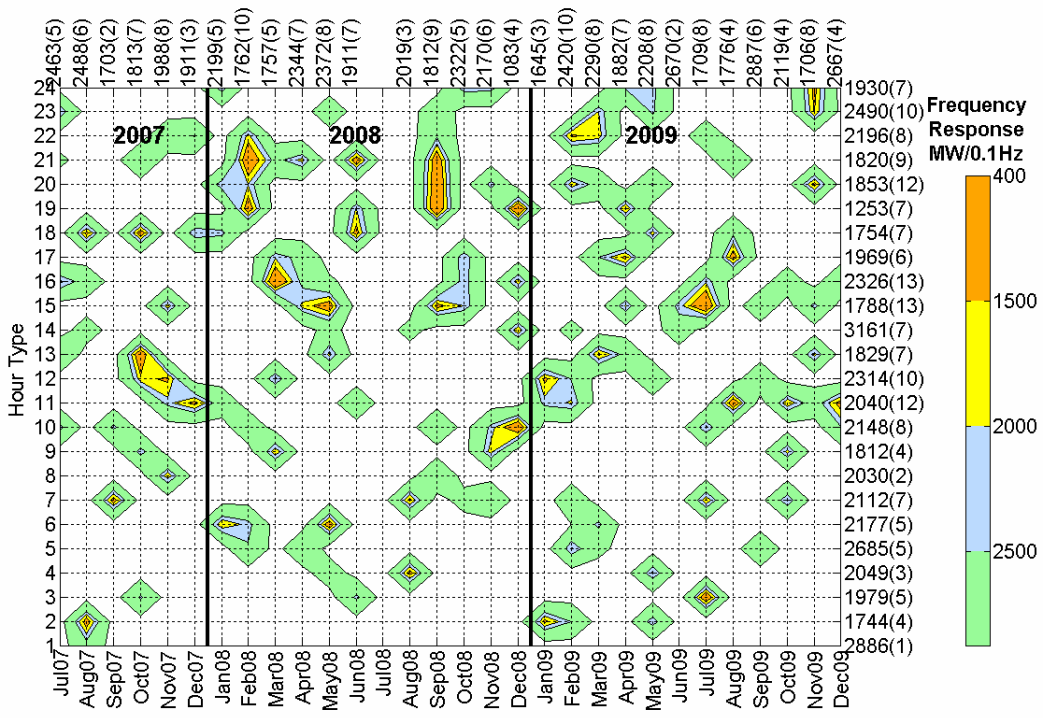

Figure 12 – Eastern 15-Second Events Frequency Response Temporal Distribution per Month and per Hour for 0.036 Hz Delta Frequency and 60 Hz Constraint Remove

As these Figures 11 and 12 illustrate, calculated Frequency Response varies widely for identified events. While some variation is expected due to changing system conditions and other factors, variation between monthly means and the size of Standard Deviations associated with identified events raises questions. Clearly, there is significant uncertainty associated with estimates of Frequency Response on the Eastern Interconnection as indicated by the Standard Deviations of the measured Frequency Responses. However, there is reasonable consistency in the mean and median values for Frequency Response for the years evaluated. This consistency in mean Frequency Response indicates that the measurement methodology is valid.

9.2 Western Events Frequency Response Statistics and Temporal Distribution

Figure-13 shows the estimated monthly median of the absolute value of Frequency Response and sensitivity for each of the monthly data sets of events identify in the first part of this research.

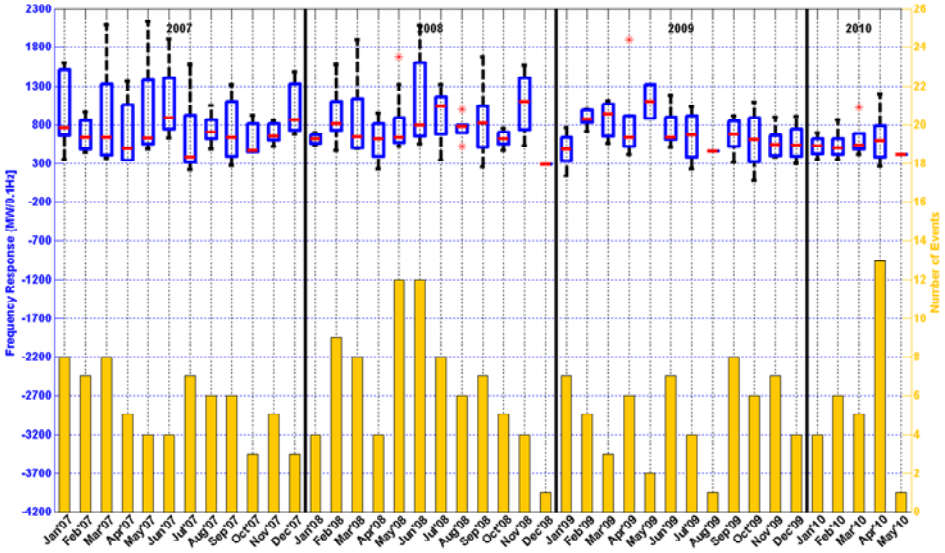

Figure 13 - Frequency Response Variability and Number of Events for Western 2007 to 2010 Events for 70 mHz Delta, 15 Seconds Time Window and 60 Hz Constraint Removed

Figure-14 shows the estimated Frequency Response temporal distribution for each month and each hour type for the 2007 to 2009 period. It should be noticed that the lowest Frequency Response occur during the morning peak hours.

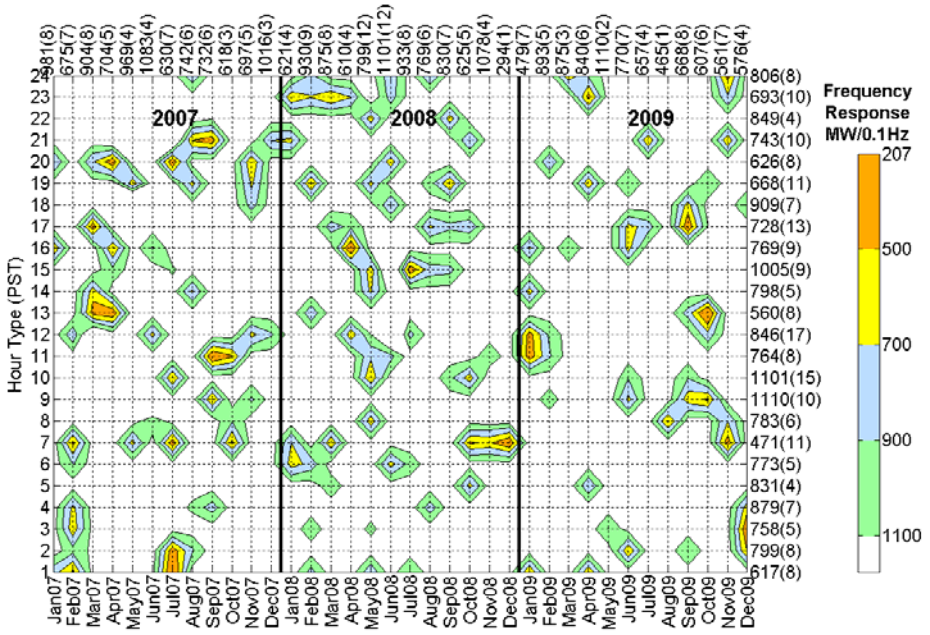

Figure 14 - Western 15-Second Events Frequency Response Temporal Distribution per Month and per Hour for 0.070 Hz Delta Frequency and 60 Hz Constraint Removed

As with the Eastern Interconnection and as these Figures illustrate, calculated Frequency Response varies widely for identified events. While some variation is expected due to changing system conditions and other factors, variation between monthly means and the size of Standard Deviations associated with identified events raises questions. Clearly, there is significant uncertainty associated with estimates of Frequency Response on the Western Interconnection as indicated by the Standard Deviations of the measured Frequency Responses. However, there is reasonable consistency in the mean and median values for Frequency Response for the years evaluated. This consistency in mean Frequency Response indicates that the measurement methodology is valid.

9.3 ERCOT Events Frequency Response Statistics and Temporal Distribution

Figure-15 shows the estimated monthly median of the absolute value of Frequency Response and sensitivity for each of the monthly data sets of events identify in the first part of this research.

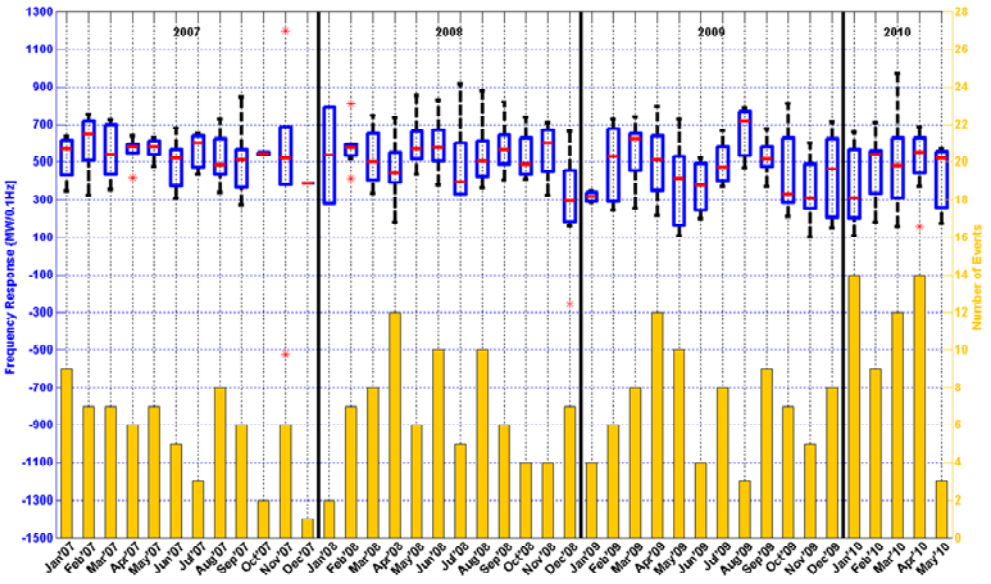

Figure 15 – Frequency Response Variability and Number of Events for ERCOT 2007 to 2010 Events for 90 mHz Delta, 15 Seconds Time Window and 60 Hz Constraint Removed

Figure-16 shows the estimated Frequency Response temporal distribution for each month and each hour type for the 2007 to 2009 period. It should be noticed that during 2009 there were lower Frequency Responses when compared with 2007 and 2008.

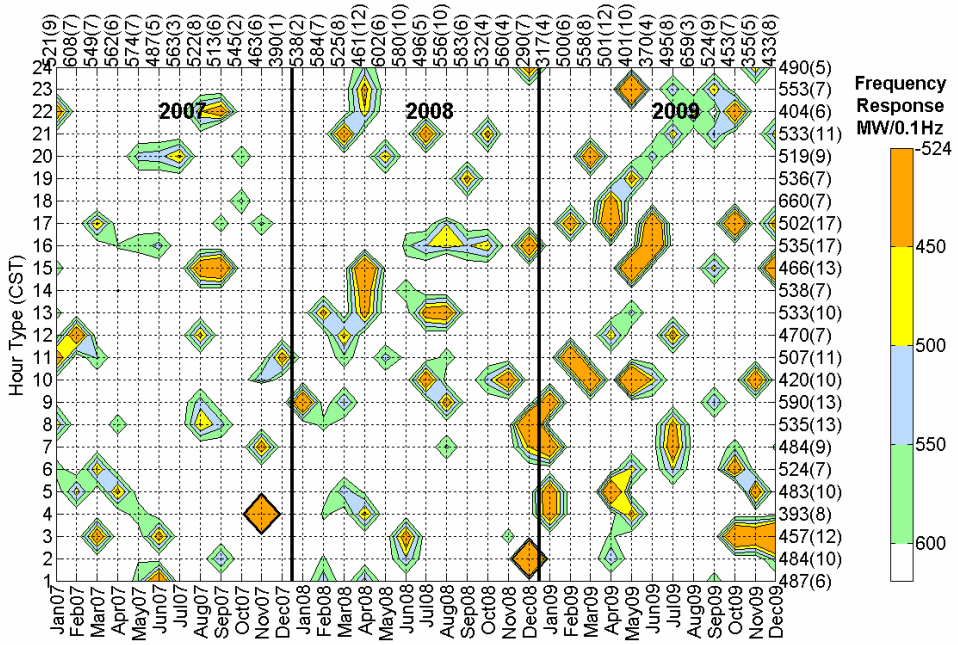

Figure 16 – ERCOT 15-Second Events Frequency Response Temporal Distribution per Month and per Hour for 0.090 Hz Delta Frequency and 60 Hz Constraint Removed

As with the previous interconnections and as these Figures illustrate, calculated Frequency Response varies widely for identified events. While some variation is expected due to changing system conditions and other factors, variation between monthly means and the size of Standard Deviations associated with identified events raises questions. Clearly, there is significant uncertainty associated with estimates of Frequency Response on the Texas (ERCOT) Interconnection as indicated by the Standard Deviations of the measured Frequency Responses. However, there is reasonable consistency in the mean and median values for Frequency Response for the years evaluated. This consistency in mean Frequency Response indicates that the measurement methodology is valid.

10. Conclusions/Recommendations

The team reviewed available data to determine automatic methods and processes to identify frequency events within each interconnection by exploring, extending and validating the approach recommended by Florida Region representatives during the January 2010 Resources Subcommittee meeting in Tucson using 2007 to 2009 1-second phasor frequency data for each interconnection. The team concluded that the Florida recommended parameters to identify and define Eastern Interconnection frequency events do not produce a representative and adequate set of frequency events. However, the method does appear capable of producing a representative and adequate set of frequency events if the size of the frequency change and/or time window is adjusted.

To meet the objectives of 1) investigating automatic methods and processes to identify frequency events on each interconnection by exploring, extending and validating the approach recommended by Florida Region representatives, and 2) validating Frequency Response estimates for the events identified by the first objective using the methodology recommended to the Resources Subcommittee; the team used historical 2007 to 2009 1-second phasor frequency data and 1-minute ACE data currently available in NERC wide-area reliability monitoring applications databases. The team reviewed this data while considering the following issues:

- There is value in finding a methodology that applies to all interconnections while allowing "parameters" to be set to recognize technical differences between those interconnections compared to a methodology that is unique to each interconnection.
- Frequency events should correlate well with reliability-concerns.
- The number of identified-frequency events should be large enough to provide reasonable calculation accuracy, but should be minimized to not burden entities beyond that need.
- Measuring frequency changes in one direction only may create perverse-incentives that reduce Frequency Response in the unmeasured direction, cause frequency to be biased away from schedule, etc.
- New technology associated with load and generation, operation of existing loads and generation based on market rather than operating issues, replacement of existing generation with variable generation, etc. will enhance reliability concerns for high frequency events compared to historic operation,
- Sufficient data, and data of reasonable quality, must be available before a frequency change should be included as a possible candidate for a frequency event. That is, there are frequency deviations that meet the proposed frequency deviation criterion that are not included in this analysis because related data is missing, data quality issues are not met, etc.

The team concluded the following:

- A selection methodology that is symmetrical around scheduled frequency should be used to minimize concerns of perverse incentives that may bias frequency above or below schedule.
- There is value in minimizing differences in methodology between interconnections. This suggests using a common time window for events in all interconnections, and using comparable-sized frequency changes. Regarding frequency changes, the team did not have sufficient time to research all possibilities. However, this goal cannot ignore the need for an appropriate number of events (see next bullet). Therefore, proposed frequency changes are roughly 2, 3, and 3 times the published epsilons for each interconnection as frequency changes of this size provided a manageable number of events per month and per year.
- Calculating Frequency Response as described in section 3 requires roughly four (4) to seven (7) events per month to provide reasonable accuracy. Likely, this number could be reduced if data quality improves.

The following table summarizes the recommended parameters to use for automatically identify frequency events for the three interconnections. Research results indicate the produce set of events using the recommended parameters gives reasonable and representative sets of frequency events:

Interconnection	Frequency Delta	Time Windows (Sec)	Initial Frequency for frequency Events <=60 Hz	Initial Frequency for frequency Events >= 60 Hz
Eastern	36 mHz	15	Criteria Removed	Criteria Removed
Western	70 mHz	15	Criteria Removed	Criteria Removed
ERCOT	90 mHz	15	Criteria Removed	Criteria Removed

The team recommends that frequency change size and time window duration should be reviewed periodically and modified to provide an average number of events per month between four (4) and seven (7).

The team concluded there is significant uncertainty associated with estimates for Frequency Response on all three interconnections as indicated by the Standard Deviations of the measured Frequency Responses. However, there is reasonable consistency in the mean values for Frequency Response for the years evaluated. This consistency in mean Frequency Response indicates that the measurement methodology is valid.

The team recommends ongoing evaluation of the measurement methodology as more data is collected and adjustments are made in event selection, evaluation and measurement processes. The team recognizes the value of selecting events with appropriate frequency characteristics. However, the team recommends that any event selection process be reviewed carefully to ensure the selection process produces an unbiased sample of frequency events. The potentially dire consequences of relying on biased samples, whether biasing is intentional or not, are well documented.

The team recommends improvement of data quality as this will allow increasing the frequency deviation size, and/or possibly reducing the number of events needed per month. Data quality improvements will also add credibility and confidence regarding frequency events and calculation of Frequency Response. Said differently, it will minimize concerns regarding “garbage in – garbage out.”