Consortium for Electric Reliability Technology Solutions

Research on Frequency Event Identification and Frequency Response

CERTS RESEARCH SUPPORTING DEFINITION AND VALIDATION OF A FREQUENCY RESPONSE STANDARD

Including Results and Recommendations for Automatic Processes for Identifying Interconnection Frequency Events and Estimating Frequency Response

By

CERTS Frequency Response Project Team
C. Martinez, L. Patterson, H. Illian

For

NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION (NERC)
Frequency Response Standard Drafting Team, Resources Subcommittee, and Frequency Response Initiative Group

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EXECUTIVE SUMMARY

The electric power industry is developing frequency response requirements to maintain and/or enhance reliable power system operation. This North American Electric Reliability Corporation (NERC) effort must determine the minimum interconnection frequency response needed for reliability and how to ensure that appropriate entities provide that response. Critical components to support this NERC effort are identifying frequency events of interest, calculating frequency response for those events, and providing a viable and reliable methodology to measure interconnection and Balancing Authority (BA) Area frequency response. This report provides information related to this NERC effort.

This research is part of Phase 3 of U.S. Department of Energy (DOE)- and Consortium for Electric Reliability Solutions (CERTS)-supported research on interconnection frequency response performance and reliability standards, which began in 2007. Phase 3 has three objectives. The first is to investigate automatic methods to identify interconnection frequency events by extending and validating an approach recommended by Florida Region representatives and using phasor one-second frequency data. The second objective is to research a methodology for automatically estimating and validating interconnection frequency response for the events identified by the investigations described under the first objective. This would be accomplished by using NERC Frequency Response Standard Drafting Team (FRSDT) definitions of frequency events for locations of points A, B and C; and BA with the highest area control error (ACE) during frequency events or ACE for the contingent BA. The final Phase-3 objective is to investigate interconnection frequency events and frequency response statistical performance and patterns during different temporal periods as well as during on-off peak, ramps, and time error correction (TEC) periods, assessing their impact on the definition of adequate sets of frequency events.

All three objectives researched in this report apply directly to NERC efforts to identify frequency events automatically and calculate frequency response automatically, and inform methodologies to measure frequency response automatically. The research team is working closely with the industry to ensure that our research addresses appropriate issues within the stated research objectives.

Key components of the proposed standard for frequency response are: first, identify an appropriate yearly list of frequency events for each interconnection that will be used by all BAs as a basis for consistently calculating their yearly frequency response performance; and, second, estimate interconnection frequency response using NERC archived data compared with frequency response performance data that BAs will submit to NERC. These data is also useful for tuning an interconnection's yearly frequency response requirement.

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

The team concluded that the method recommended by the Florida Region for identifying frequency events produces a representative and adequate set of frequency events if the below-60-Hertz (Hz) initial frequency criterion 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 NERC Resources Subcommittee (RS) for 2008 if the initial frequency bounds are removed from the event selection process.

The team recommends event selection criteria using a 15-second time window for frequency deviations greater than 36, 70, and 90 megaHz (MHz) for the Eastern, Western and Electric Reliability Council of Texas (ERCOT) Interconnections, respectively, with one-second frequency data. The team also recommends that data selection criteria include 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 additional data are collected and data quality improves.

Second Objective – Investigate Automatic Methodology to Estimate and Validate Interconnection Event Frequency Response

There is still a great deal of uncertainty associated with the frequency response estimates for all three interconnections, as indicated by the standard deviations of measured frequency responses. However, there is reasonable consistency in the mean values for frequency response for the years evaluated, which indicates that the measurement methodology is valid.

The team recommends that, in the long term, the determination of interconnection frequency response requirements and performance use one-second synchronized frequency data and apply appropriate statistical analysis to large samples of calculated frequency response rather than using a single or a small number of events. Although the team recognizes the value of selecting events with appropriate frequency characteristics, the team recommends that any event selection process be reviewed and validated carefully to ensure that 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 recommendations include using selection criteria that do not exclude otherwise acceptable events if they occur during off-peak periods, periods of time error correction (TEC), and/or transition hours.

The team recommends ongoing evaluation and adjustments for the proposed event selection and frequency response methodologies as additional, accurate, and synchronized data become available and data quality improves.

Third Objective – Investigate Interconnection Frequency Events and Frequency Response Statistical Performance and Patterns During Different Temporal Periods, and During On-Off Peak, Ramp, and TEC Periods to Assess Impact on the Definition of Adequate Sets of Frequency Events

The team concludes that it is viable to automatically identify frequency events and calculate frequency response using currently available data. In addition, the team concludes that the variability of calculated frequency responses for individual events can be mitigated by using larger sample sizes (more events) and prudently selecting statistical values, such as the median, mean, etc., to determine frequency response.

Preliminary comparisons of interconnection frequency data between one-second resolution and one-minute resolution indicate that there could be significant differences in frequency response estimates using these two data rates. The team recommends using scan-rate data in the short term and one-second synchronized data in the long term for frequency response calculations.

Reliability Coordinators have expressed to the CERTS team that for the same event there could be significant differences in the delta frequency at points A and B between two distant Reliability Regions, which could affect frequency response comparisons. CERTS will research and quantify this issue using interconnection synchronized frequency phasor data and will report findings.

The estimated probability of Eastern Interconnection frequency events larger than 5,000 megawatts (MW) relied on DOE event data from 2000 to 2010, but it is recommended that more accurate data from the NERC databases be utilized to improve the significant event probability calculations for each interconnection.

Based on the analysis of Eastern Interconnection 2010 frequency event patterns using one-second data, the team recommends consideration of changing the definition of event frequencies for points C and B from a classical “V” frequency event pattern to an “L” frequency event pattern in the Eastern Interconnection. The team recommends this new definition for evaluation until there is a change from the current “L” frequency event pattern on the Eastern Interconnection.

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Acronyms and Abbreviations

ACE	area control error
ARR	automatic reliability reports
BA	balancing authority
BAAL	balancing authority area limit
CERTS	Consortium for Electric Reliability Solutions
DOE	U.S. Department of Energy
ERCOT	Electric Reliability Council of Texas
FMA	frequency monitoring and analysis
FRSDT	Frequency Response Standard Drafting Team
Hz	Hertz
MHz	megahertz
MW	megawatt
NERC	North American Electric Reliability Corporation
RS	Resources Subcommittee
TEC	time error correction
SCADA	supervisory control and data acquisition
WECC	Western Electricity Coordinating Council

1. Introduction

This research is part of Phase 3 of U.S. Department of Energy (DOE)- and Consortium for Electric Reliability Solutions (CERTS)- supported research on interconnection frequency response performance and reliability standards, which started in 2007. Phase 3 has three objectives. These objectives are to: 1) investigate automatic methods to identify interconnection frequency events; 2) research a methodology to automatically estimate and validate frequency response for events identified under the first objective; and 3) research statistical performance and patterns during different operational periods such as on-off peak and time error correction (TEC) periods.

The first Phase-3 objective is to investigate automatic methods to identify interconnection frequency events by exploring, extending, and validating the approach recommended by Florida Region representatives during the January 2010 Resources Subcommittee (RS) meeting in Tucson, as well as using 2007 to 2009 one-second interconnection phasor frequency data. The event list produced automatically to meet this objective will be compared to the RS yearly lists of events used to calculate Balancing Authorities' (BAs') yearly frequency bias.

The second Phase-3 objective is to research a methodology to automatically estimate and validate frequency response for events identified under the first objective. This research is to use the Frequency Response Standard Drafting Team (FRSDT) definitions for frequency event points A, B and C, and estimates megawatt (MW) loss based on BAs' highest area control error (ACE) during the event period. This methodology was recommended to the RS during their September 2009 Minneapolis meeting. The frequency response calculations for this second objective use historical 2007 to 2009 one-second phasor frequency data and one-minute ACE data currently available in NERC portfolio of wide-area reliability monitoring applications databases.

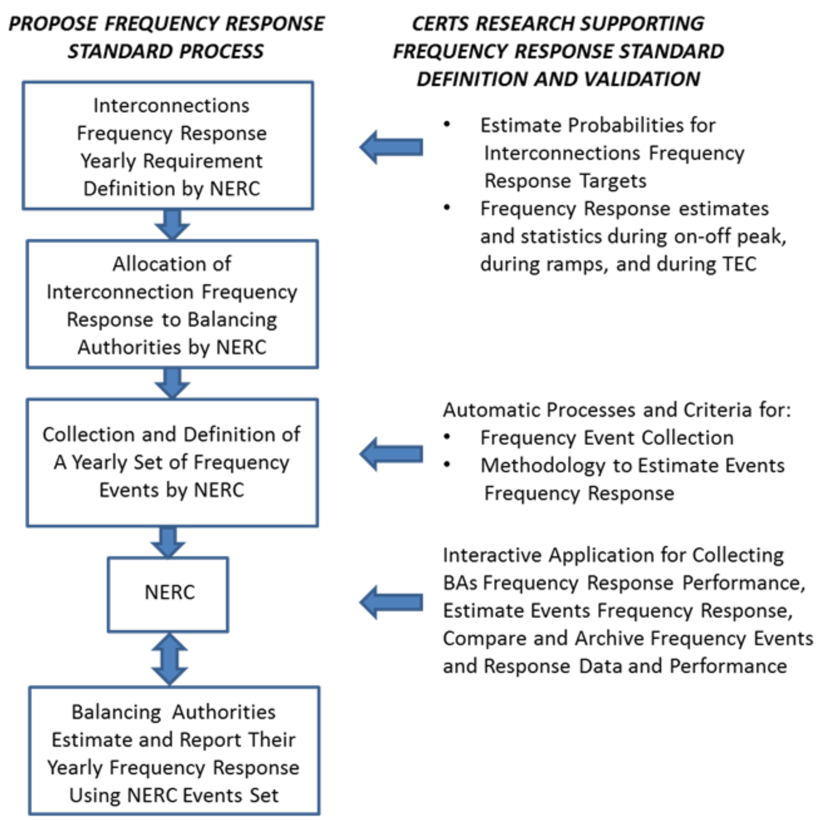
The third Phase-3 objective is to investigate interconnection frequency events and frequency response statistical performance and patterns during different temporal periods as well as during on-off peak, ramp, and TEC periods, assessing their impacts on the definition of adequate sets of frequency event. This objective requires analyzing critical frequency response statistics for each interconnection and includes: 1) provision of frequency events and frequency response statistics and trends – mean, median, standard deviation, shape of probability density function, and Q-Q plots; 2) determination of key statistics correlating the occurrence of frequency events and their calculated frequency response with important variables such as time error correction (TEC), on- versus off-peak, month of year, day of week, hour of day, and minute of hour; and 3) identification of Eastern interconnection 2010 event frequency A, B, and C patterns using one-second data.

Under the first research objective, one-second phasor frequency data and BA ACE supervisory control and data acquisition (SCADA) data were identified, collected, and filtered for the three interconnections. The second research objective results showed that it is feasible to automatically identify frequency events using the input data sources identified under the first research objective. The research demonstrated that, with proper adjustment of the time window and frequency delta magnitude used to define significant events, a representative and adequate monthly and yearly set of frequency events can automatically be identified for each interconnection. The research validation also demonstrated that the frequency events identified based on the modified automatic frequency event selection methodology were very close to those events currently produced by the North American Electric Reliability Corporation (NERC) RS using the manual process. The third research objective results showed that the interconnection frequency response for the events identified under the second objective can be automatically estimated for the three interconnections using frequency phasor data and ACE SCADA data.

2. Background

Results and recommendations for Phases 1 and 2 of CERTS research on interconnection frequency response were presented in the "Interconnections Frequency Response Research and Study" [1] prepared for CERTS by Energy Mark Inc., in August 2007. Phase 1 and 2 research results confirmed a downward trend during the past 10 years in the interconnections' primary governing frequency response, quantified the critical nature and risks of this frequency response downtrend, and showed that acceptable frequency response results may be achieved using two-second or one-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 frequency response values. FRSDT and RS will then use these CERTS research results and recommendations to define interconnection FRSDT and RS requirements and the method for distributing those requirements among BAs, with a future objective of incorporating the findings in a frequency response standard. Future CERTS research will support definition and validation of that frequency response standard and its corresponding performance metrics.

The left column of the chart below presents the four major steps proposed by the industry for a frequency response standard. The right column describes the specific areas that CERTS is researching to support the definition and validation of the proposed standard. This report describes the research results and recommendations for the specific process steps in the chart that CERTS is researching.



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

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

At the NERC RS January 2010 meeting, Florida representatives recommended that the RS produce and deliver a list of Eastern Interconnection frequency events defined by frequency changes greater than 0.040 Hertz (Hz) and below 60 Hz for consecutive 15-second periods. To validate the Florida recommendation, one-second phasor frequency data were collected for the three interconnections from 07/01/2007 to 12/31/2009, and the Florida event identification criteria were applied to produce the events in the "Number of Identified Events" column of Table 1, which shows the number of frequency events per month for the study period.

To address the second Phase-3 objective, to research and validate interconnection frequency response calculation methods, CERTS estimated the frequency response for each of the identified events using the following method recommended to the RS, 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-Hz Criterion

Month Year	15-Second Time Window	
	Frequency Response Median	Number of Identified Events
Jul07	2236	3
Aug10	3030	3
Sep07	1703	2
Oct10	1416	2
Nov07	NA	NA
Dec07	NA	NA
Jan10	3121	1
Feb10	3240	2
Mar08	2061	1
Apr08	2786	3
May10	2000	2
Jun10	2425	1
Jul10	NA	NA
Aug10	1338	1
Sep10	2608	3
Oct10	2193	1
Nov10	2251	3
Dec10	528	1
Jan10	NA	NA
Feb10	3993	1
Mar09	2930	1
Apr10	2460	4
May09	2334	4
Jun09	2175	1
Jul10	705	1
Aug09	NA	NA
Sep09	3305	2
Oct10	3185	1
Nov10	3091	1
Dec09	1883	2

To help analyze 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.

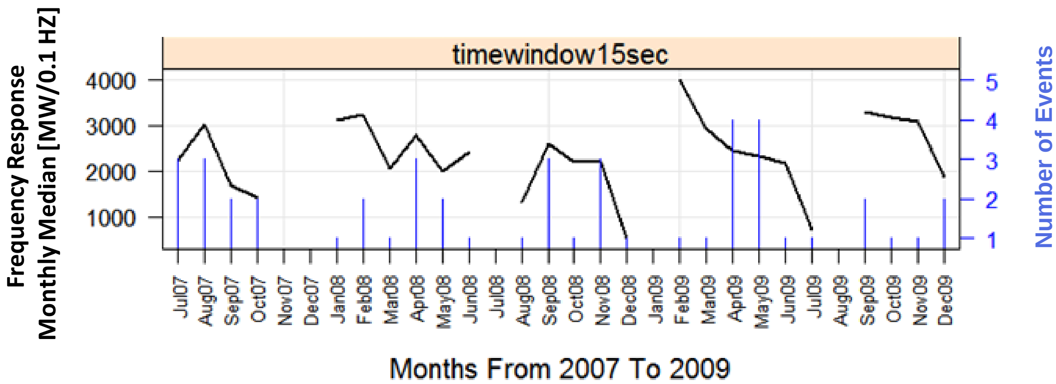


Figure 1 – Eastern Interconnection Number of 15-Second Events Identified per Month and Corresponding Monthly Median of the Absolute Value of Frequency Response Using 0.040-Hz Delta Frequency and Below-60-Hz Criterion

Preliminary analysis of Table 1 and Figure 1 indicates that the average number of events per month is about two, with a yearly average of about 15 events; five months do not have events. Only about 10 percent of the events identified match with the RS 2009 disturbance list.

The above results indicate that the parameters recommended by the Florida Region 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 criterion is removed and the sizes of event frequency change and time window are 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 that recognize technical differences among 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 the number needed for accuracy.
- 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, and other similar changes will increase reliability concerns for high frequency events compared to what has been the case for historic operation.
- Sufficient data of reasonable quality must be available before a frequency change should be considered a possible candidate to be defined as 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 are missing, data quality is not sufficient, etc.

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

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

Eastern Interconnection Generation Events Identified

To develop a 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 the Eastern Interconnection. NERC RS and FRSDT members observed that the below-60-Hz criterion 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 criterion. See Section 7 for more detail.

Table 2 summarizes the number of generation events and corresponding absolute value of frequency response for the four time windows, with the below -60-Hz criterion 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 Criterion Removed

Eastern 36mHz Generation Outages								
	15-Second Time Window		20-Second Time Window		25-Second Time Window		30-Second Time Window	
Month Year	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 analyze 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.

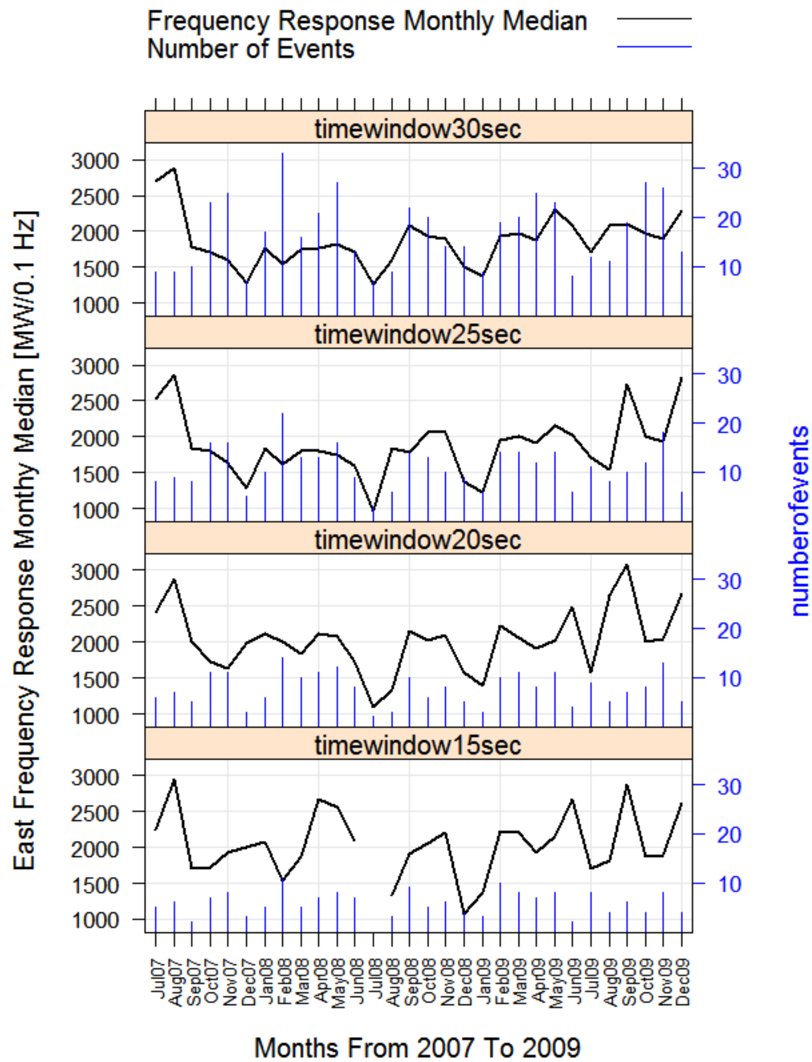


Figure 2 - Eastern Interconnection Number of 15-, 20-, 25-, and 30-Second Events Identified per Month and Corresponding Monthly Median of Absolute Value of Frequency Response Using 0.036-Hz Delta Frequency and Below-60-Hz Criterion Removed

Analysis of Table 2 and Figure 2 shows 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 six events per month during the 2007 to 2009 period. With the below-60-Hz constraint removed, 90 percent of the events identified by the RS for 2008 are in the set of events generated automatically.

The above results indicate that using the Florida-recommended event identification approach with a delta frequency of 0.036 Hz and 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 summarizes the number of load events and corresponding absolute value of frequency response for the four time windows, using a delta frequency of 0.036 Hz and the below-60-Hz criterion 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 Criterion Removed

Eastern 36mHz Load Outages								
Month Year	15-Second Time Window		20-Second Time Window		25-Second Time Window		30-Second 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 analyze 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.

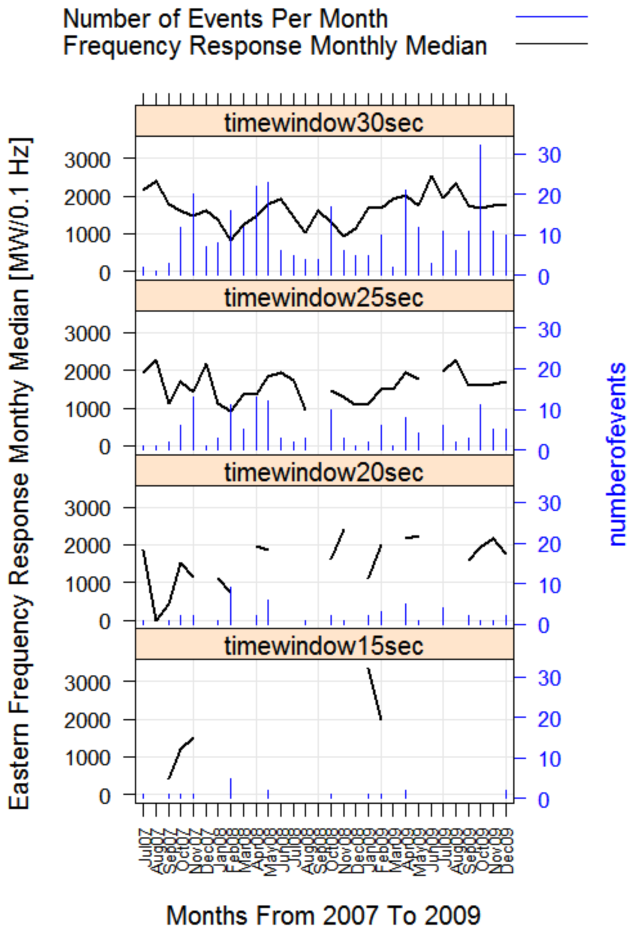


Figure 3 – Eastern Interconnection Number of 15-, 20-, 25-, 30-Second Events Identified per Month and Corresponding Monthly Median of Absolute Value of Frequency Response Using 0.036-Hz Delta Frequency and the Below-60-Hz Criterion Removed

This analysis appears to show little value from including frequency changes in the positive direction. However, the analysis also demonstrates that there is little burden from including these 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.

Finally, data quality issues are the reason that so few events are available. Although data quality issues affect both generation and load events, they are more significant for load events. Therefore, it is valuable to include these events to improve the industry's measurement and awareness of them. This benefit will become greater as BAs have less traditional generation available to control, and embrace new sources of operating flexibility that will become available as a result of market and/or interconnection rules.

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

Western Interconnection Generation Events Identified

To explore and identify a representative and adequate frequency event list for the Western Electricity Coordinating Council (WECC), Florida's frequency change criteria for identifying frequency events 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. 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 RS and FRSDT members observed that the below-60-Hz criterion 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 criterion. See Section 7 for more detail.

Table 4 below summarizes the number of generation events and corresponding absolute value of frequency response for the four time windows, using 0.070 Hz as delta frequency, with the 60-Hz criterion 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 Criterion Removed

Western 70mHz Generation Outages								
Month Year	15-Second Time Window		20-Second Time Window		25-Second Time Window		30-Second 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 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.

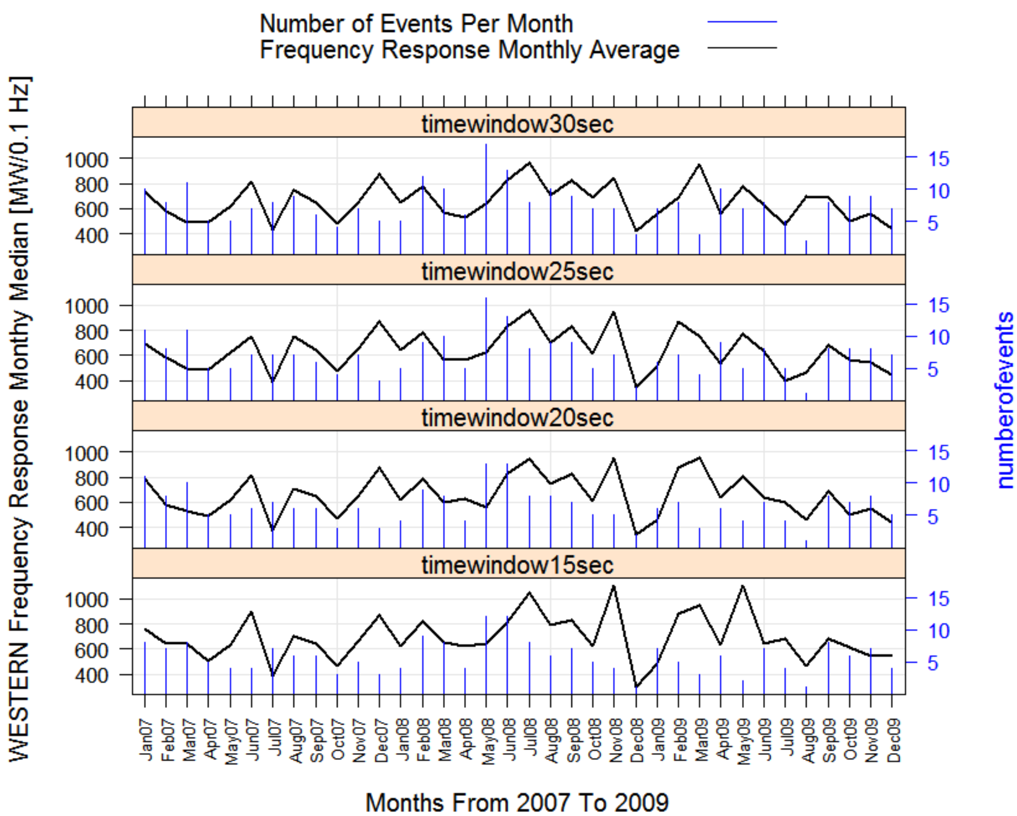


Figure 4 – Western Interconnection Number of 15-, 20-, 25-, 30-Second Events Identified per Month and Corresponding Monthly Median of Absolute Value of Frequency Response Using 0.070-Hz Delta Frequency and Below-60-Hz Criterion Removed

Analysis of Table 4 and Figure 4 indicates 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 six events per month during the period 2007 to 2009.

The above results indicate that using the identification approach recommended by Florida representatives, with a delta frequency of 0.070 Hz and 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 summarizes the number of load events and corresponding absolute frequency response values 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 Criterion Removed

Western 70mHz Load Outages								
Month Year	15-Second Time Window		20-Second Time Window		25-Second Time Window		30-Second 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 analyze 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.

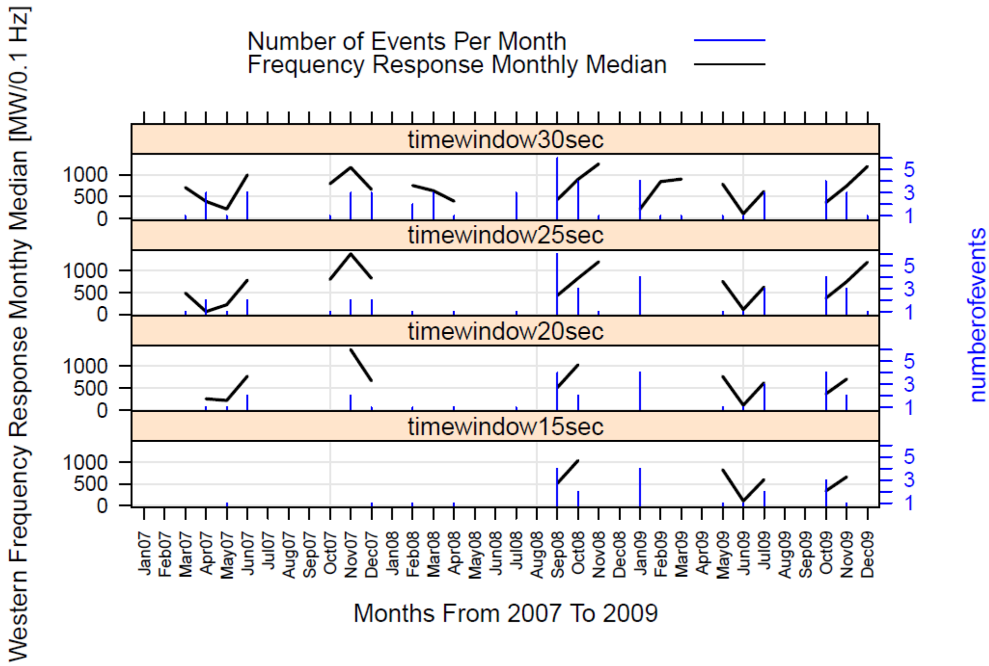


Figure 5 - Western Interconnection Number of 15-, 20-, 25-, 30-Second Events Identified per Month and Corresponding Monthly Median of Absolute Value of Frequency Response Using 0.070-Hz Delta Frequency and Below-60-Hz Criterion Removed

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

Finally, data quality issues are the reason that so few events are available. Although data quality issues affect both generation and load events, it is apparent that they are more significant 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 BAs 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 Event Identification Results from 2007 to 2009 Using a Modified Florida Region 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 identifying frequency events 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. 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 RS and FRSDT members observed that the below-60-Hz criterion 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 criterion. See Section 7 for more information.

Table 6 summarizes the number of generation events and corresponding absolute frequency response values for the four time windows, using 0.090 Hz as delta frequency, with the below-60-Hz criterion 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 Below-60-Hz Criterion Removed

ERCOT 90mHz Generation Outages								
Month Year	15-Second Time Window		20-Second Time Window		25-Second Time Window		30-Second 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 analyze 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.

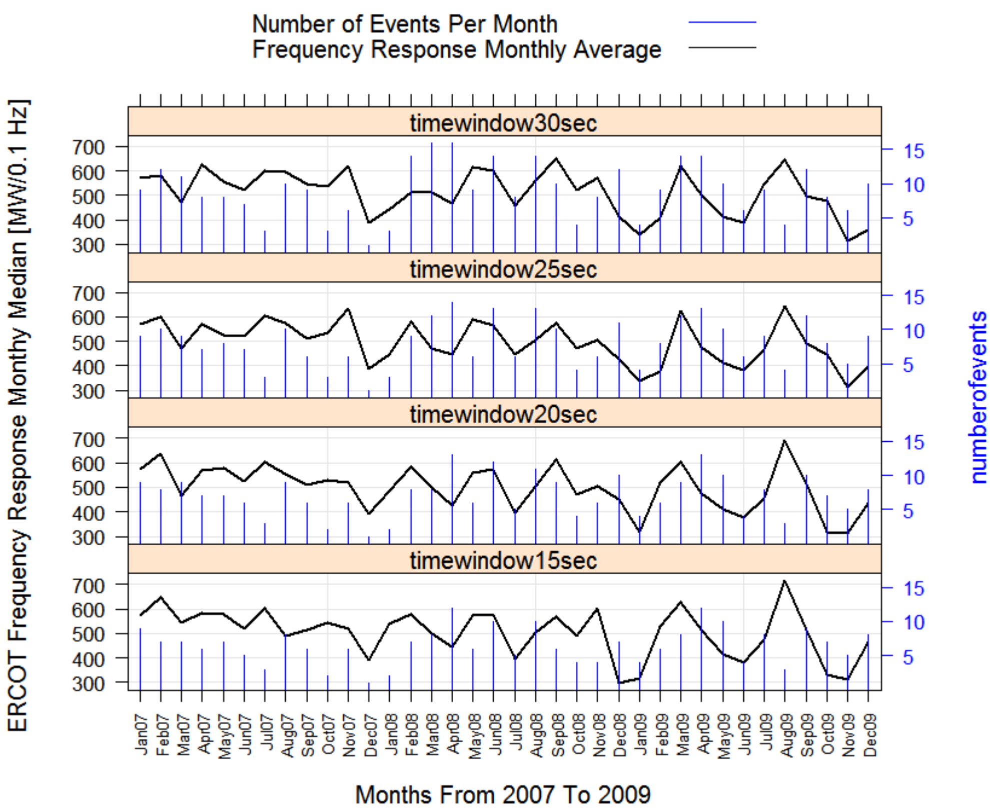


Figure 6 – ERCOT Interconnection Number of 15-, 20-, 25-, 30-Second Events Identified per Month and Corresponding Monthly Median of Absolute Value of Frequency Response Using 0.090-Hz Delta Frequency and Below-60-Hz Criterion Removed

Analysis of Table 6 and Figure 6 indicates 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 six events per month during the period 2007 to 2009.

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

ERCOT Interconnection Load Events Identified

Table 7 summarizes the number of load events and corresponding absolute frequency response values 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-Criterion Removed

ERCOT 90mHz Load Outages									
Month Year	15-Second Time Window		20-Second Time Window		25-Second Time Window		30-Second 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	576	1	554	2
Feb07	NaN	NaN	NaN	NaN	496	3	586	8
Mar07	NaN	NaN	516	1	516	9	518	16
Apr07	NaN	NaN	NaN	NaN	NaN	NaN	656	1
May07	39	2	39	2	39	2	229	3
Jun07	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Jul07	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Aug07	NaN	NaN	NaN	NaN	679	3	679	3
Sep07	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Oct07	310	1	563	1	528	2	488	4
Nov07	330	2	330	2	330	2	594	5
Dec07	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Jan08	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Feb08	NaN	NaN	489	4	463	10	492	18
Mar08	423	1	472	2	522	7	518	12
Apr08	522	2	527	3	533	4	514	6
May08	619	1	619	1	513	2	501	6
Jun08	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Jul08	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Aug08	506	1	505	1	505	1	567	1
Sep08	632	3	632	3	509	6	542	7
Oct08	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Nov08	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Dec08	383	2	NaN	NaN	NaN	NaN	167	1
Jan09	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Feb09	538	1	538	1	517	2	533	4
Mar09	NaN	NaN	NaN	NaN	NaN	NaN	358	1
Apr09	NaN	NaN	968	2	887	2	631	3
May09	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Jun09	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Jul09	83	1	84	1	87	1	91	1
Aug09	NA	NA	NaN	NaN	NaN	NaN	NaN	NaN
Sep09	NA	NA	NaN	NaN	NaN	NaN	524	1
Oct09	NA	NA	380	1	380	1	380	1
Nov09	NA	NA	160	1	374	2	380	2
Dec09	NA	NA	NA	NA	NA	NA	NA	NA

To analyze 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.

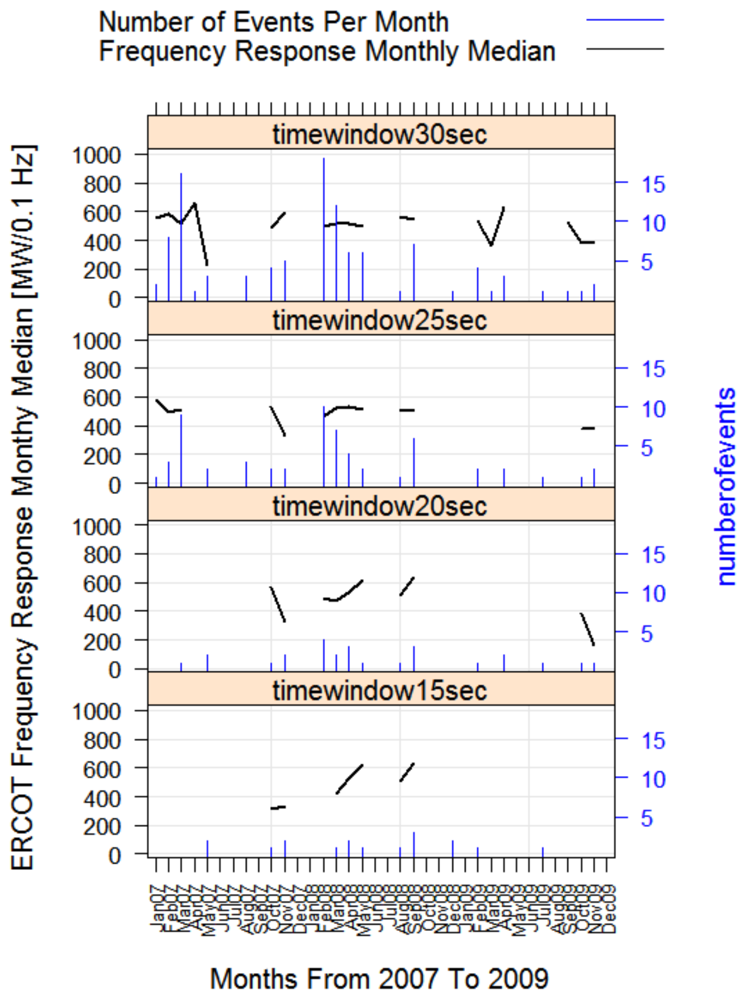


Figure 7 - ERCOT Interconnection Number of 15-, 20-, 25-, 30-Second Events Identified per Month and Corresponding Monthly Median of Absolute Value of Frequency Response Using 0.090-Hz Delta Frequency and Below-60-Hz Criterion Removed

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

Finally, data quality issues are the reason that so few events are available. Although data quality issues affect both generation and load events, they are more significant 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 Criterion on Interconnection Event Selection Sets

After the original research results and recommendations described in Sections 1 through 7 of this report were presented to the NERC RS and FRSDT in May 2010, some RS members observed that critical Eastern Interconnection frequency events were filtered by using the 60-Hz criterion that had originally been recommended. The research team investigated and quantified the impact of the below-60-Hz criterion on the selection of adequate sets of frequency events for the three interconnections. The follow subsections summarize the results of this investigation and the basis for recommending elimination of the 60-Hz constraint initially proposed by the Florida Region.

7.1 Eastern Interconnection Events Filtered Using the Below-60-Hz Criterion

Figure 8 shows the Eastern Interconnection point-A or initial frequency monthly variability for identified events (in the box plot) and the monthly number of events (in the bar plot). [2] The box plots show that more than 50 percent of the identified events had a point-A frequency above 60 Hz. This means that the below-60-Hz criterion eliminates more than 50 percent of the identified events, some of which are required by the RS for defining adequate sets of events to present to interconnections and BAs for estimating their yearly frequency response and frequency bias.

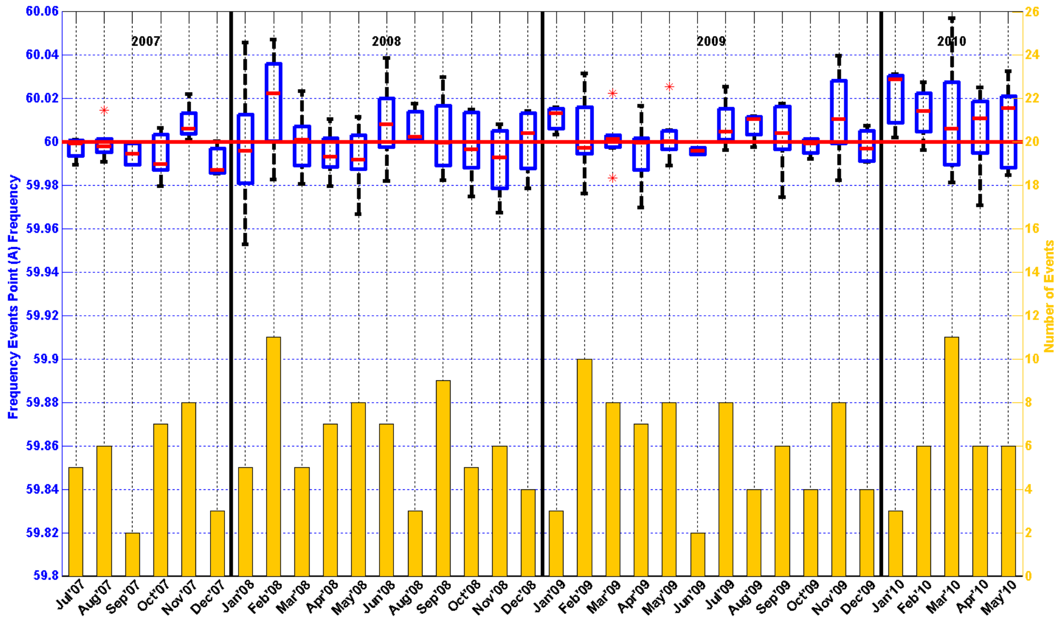


Figure 8 – Eastern Interconnection Frequency Response Characteristics for Events with 36-MHz Delta in a 15-Second Window with Below-60-Hz Constraint Removed

7.2 Western Interconnection Events Filtered Using the Below-60-Hz Criterion

Figure 9 shows the Western Interconnection point-A or initial frequency monthly variability for identified events (in the box plot) and the monthly number of events (in the bar plot). The box plots show that more than 50 percent of the identified events had a point-A frequency above 60 Hz. Consequently, the below-60-Hz criterion eliminates more than 50 percent of the identified events, some of which are required by the RS for defining adequate sets of events to present to interconnections and BAs for estimating their yearly frequency response and frequency bias.

[2] The box plot statistical graphs in this section and in Section 9 were created to visualize the event point-A frequency (Section 7) and the event 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 bound values that are within 1.5 times the inter-quartile range above and below the box. Individual outliers that exceed this range are shown above and below the whiskers. This visualization approach to statistics and the definitions of the graphic symbols used to describe the distributions of observations are consistent throughout Sections 7 and 9.

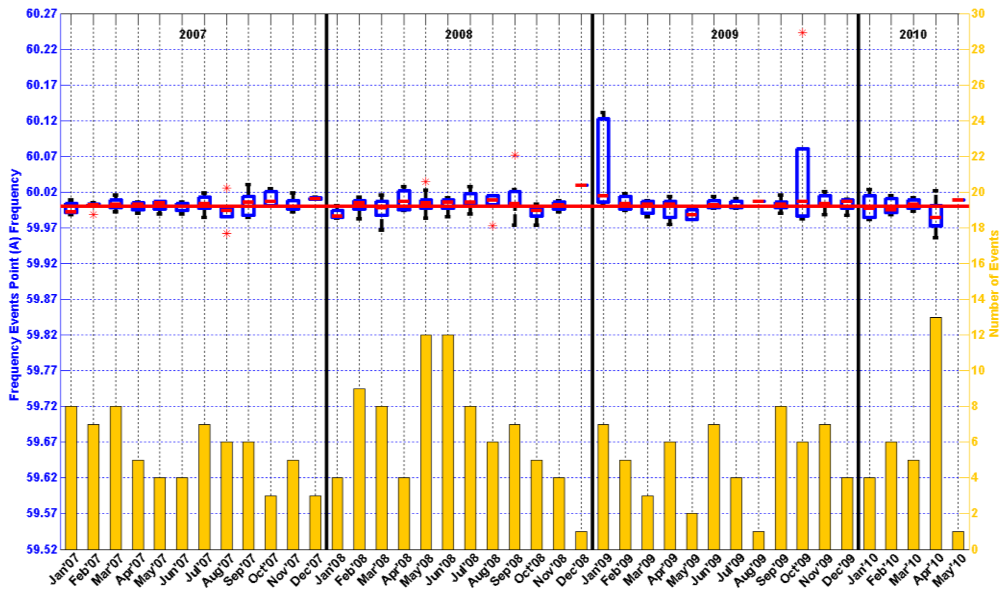


Figure 9 - Western Interconnection Frequency Response Characteristics for Events with 70-MHz Delta in a 15-Second Window with Below-60-Hz Constraint Removed

7.3 ERCOT Interconnection Events Filtered Using the Below-60-Hz Criterion

Figure 10 shows the ERCOT point-A or initial frequency monthly variability (in the box plot) for identified events and the monthly number of events (in the bar plot). The box plots show that more than 50 percent of the identified events had a point-A frequency above 60 Hz. Consequently, the below-60-Hz criterion eliminates more than 50 percent of the identified events, some of which are required by the RS for defining adequate sets of events to present to interconnections and BAs for estimating their yearly frequency response and frequency bias.

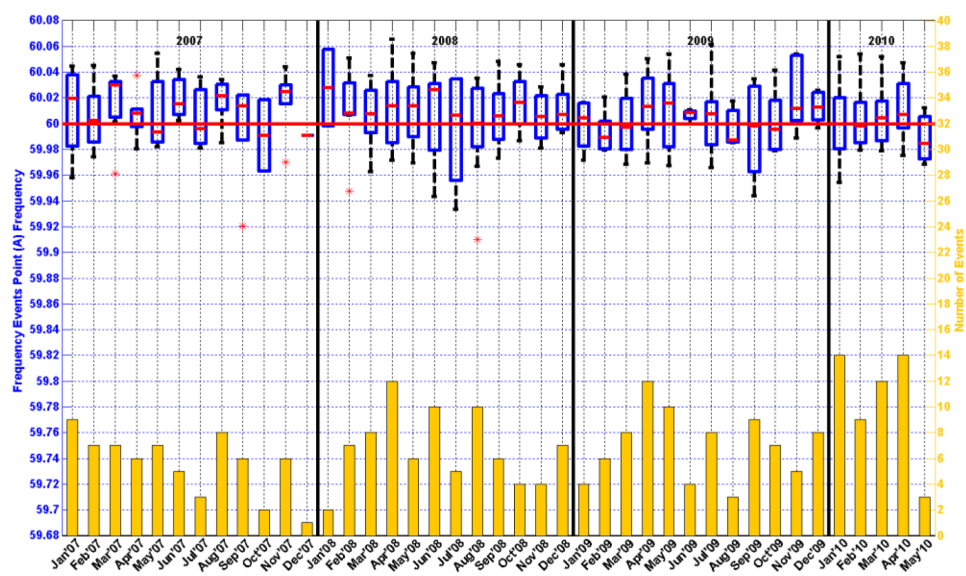


Figure 10 - ERCOT Frequency Response Characteristics for Events with 90-MHz Delta in a 15-Second Window with Below-60-Hz Constraint Removed

8. Automatic Interconnection Frequency Event Identification – Summary of Research Results and Recommendations

The following table summarizes the final recommended parameters for automatically identifying frequency events for the three interconnections. Research results indicate that using the recommended parameters produces reasonable and representative sets of frequency events:

Table 8 – Recommended Parameters for Automatically Identifying Frequency Events

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

These parameters address comments from the RS. 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, among others:

- Compares to historically selected frequency events with acceptable accuracy
- Captures events with frequency characteristics important to the RS regardless of initial frequency
- Achieves a reasonable number of identified events to balance concerns about calculation accuracy and possible workload ramifications

The 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 identified by these parameters, per year and per month, to increase as data quality improves. In addition, availability and further analysis of data will guide changes to these parameters over time. Therefore, these parameters should be considered 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 the Three Interconnections

The second Phase-3 objective is to research a methodology to automatically estimate and validate frequency response for frequency events. This methodology could help NERC stakeholders select and define a final set of frequency events to publish for use by BAs 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 of this report, together with the corresponding one-second interconnection frequency and one-minute NetACE data, to calculate the frequency response for each event. The methodology used is described in Section 3.

To facilitate analysis and assessment of the calculated frequency response for each interconnection, the research results are presented using the following visuals and format:

- Box plots are used to calculate and show the interconnections' estimated monthly frequency response median and variability for monthly events.[3]
- Contour plots are used to show the temporal distribution of the estimated frequency response per month and per hour for the period 2007 to 2009.

9.1 Eastern Interconnection Event Frequency Response Median, Variability, and Temporal Distribution

Figure 11 shows the estimated monthly median of the absolute frequency response value and sensitivity for each of the monthly data sets of events identified for the Eastern Interconnection in the first part of this research.

[3] The box plot statistical graphs in this section and in Section 7 were created to visualize the event point-A frequency (Section 7) and the event 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 bound values that are within 1.5 times the inter-quartile range above and below the box. Individual outliers that exceed this range are shown above and below the whiskers. This visualization approach to statistics and the definitions of the graphic symbols used to describe the distributions of observations are consistent throughout Sections 7 and 9.

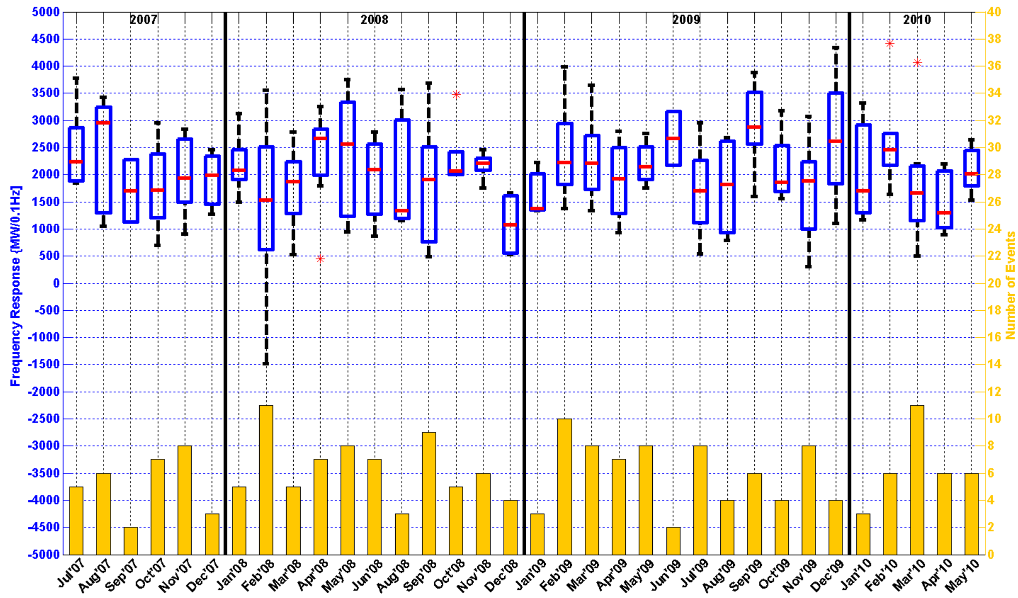


Figure 11 - Frequency Response Variability and Number of Events for Eastern Interconnection 2007 to 2010 for 36-MHz Delta, 15-Second Time Window, and below-60-Hz Constraint Removed

Figure 12 shows the estimated frequency response temporal distribution for each month and each hour type for the period 2007 to 2009. Note that the lowest frequency response occurs during hours 21 to 23; frequency response is also lower during the hours of 8AM to 5PM when compared to the hours of 1AM to 6AM.

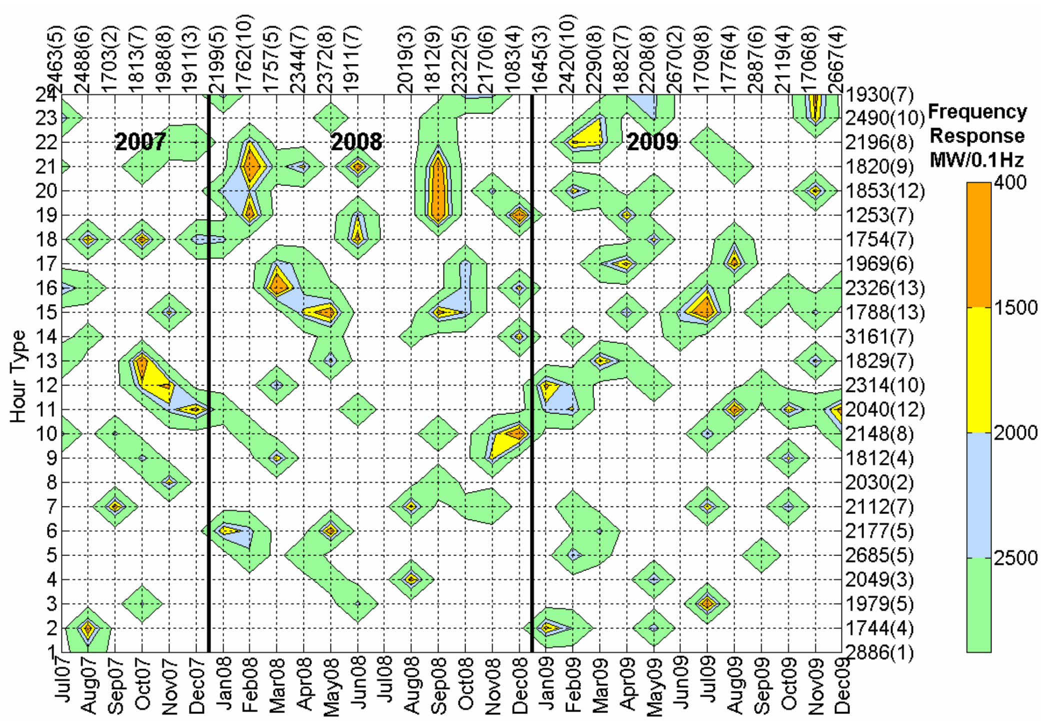


Figure 12 – Eastern Interconnection 15-Second Event Frequency Response Temporal Distribution per Month and per Hour for 0.036-Hz Delta Frequency and below-60-Hz Constraint Removed

As Figures 11 and 12 illustrate, calculated frequency response varies widely for identified events. Although some variation is expected because of changing system conditions and other factors, variation among monthly means and in 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 in measured frequency response. 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 Interconnection Event 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 for the Western Interconnection identified in the first part of this research.

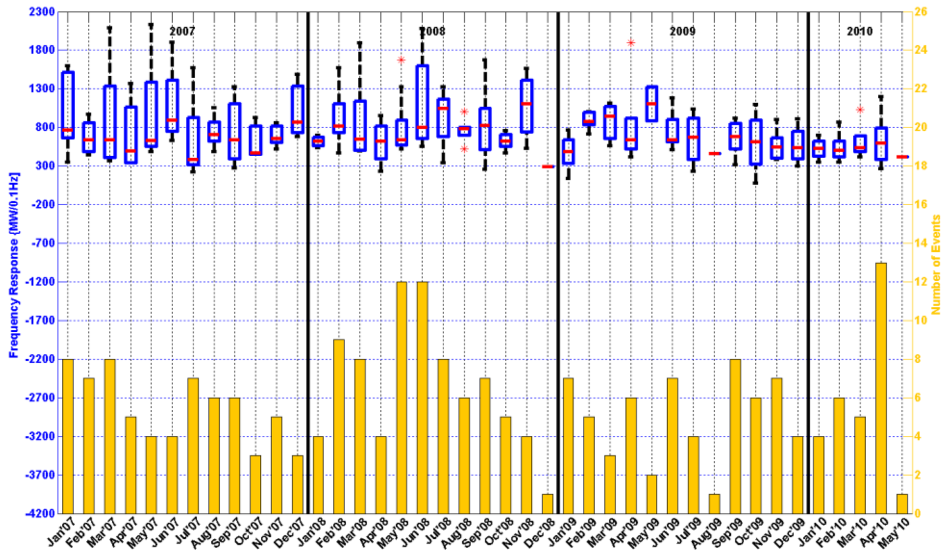


Figure 13 - Frequency Response Variability and Number of Events for Western Interconnection 2007 to 2010 for 70-MHz Delta, 15-Second Time Window, and below-60-Hz Constraint Removed

Figure 14 shows the estimated frequency response temporal distribution for each month and each hour type for the period 2007 to 2009. Note that the lowest frequency response occurs during the morning peak hours.

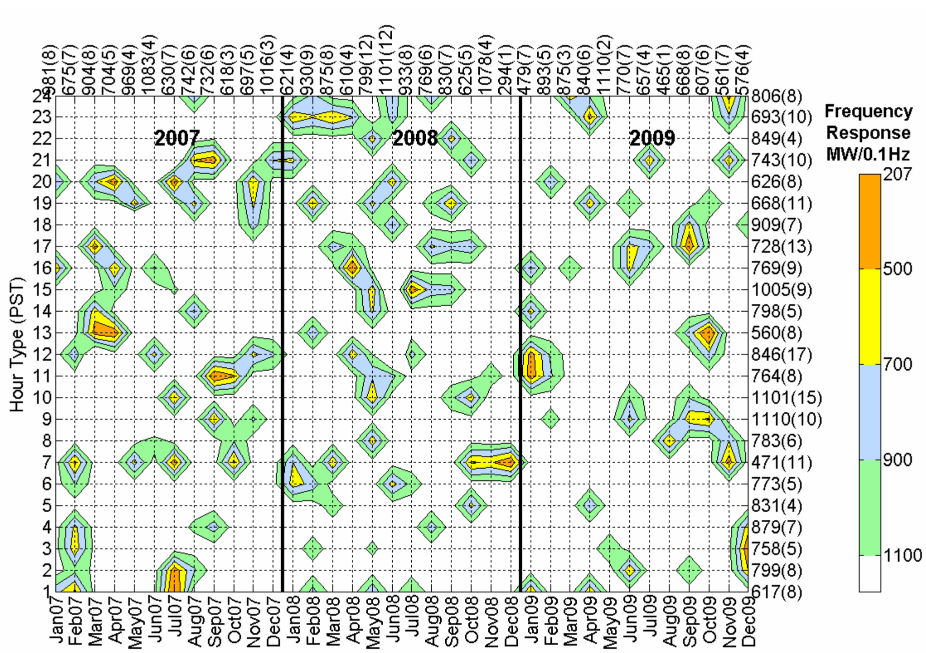


Figure 14 - Western Interconnection 15-Second Event Frequency Response Temporal Distribution per Month and per Hour for 0.070-Hz Delta Frequency and below-60-Hz Constraint Removed

As with the Eastern Interconnection, calculated frequency response varies widely for identified events. Although some variation is expected because of changing system conditions and other factors, variation among monthly means and in 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 in 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 Interconnection Event Frequency Response Statistics and Temporal Distribution

Figure 15 shows the estimated monthly median of the absolute frequency response value and sensitivity for each of the monthly data sets of events identified for the ERCOT Interconnection in the first part of this research.

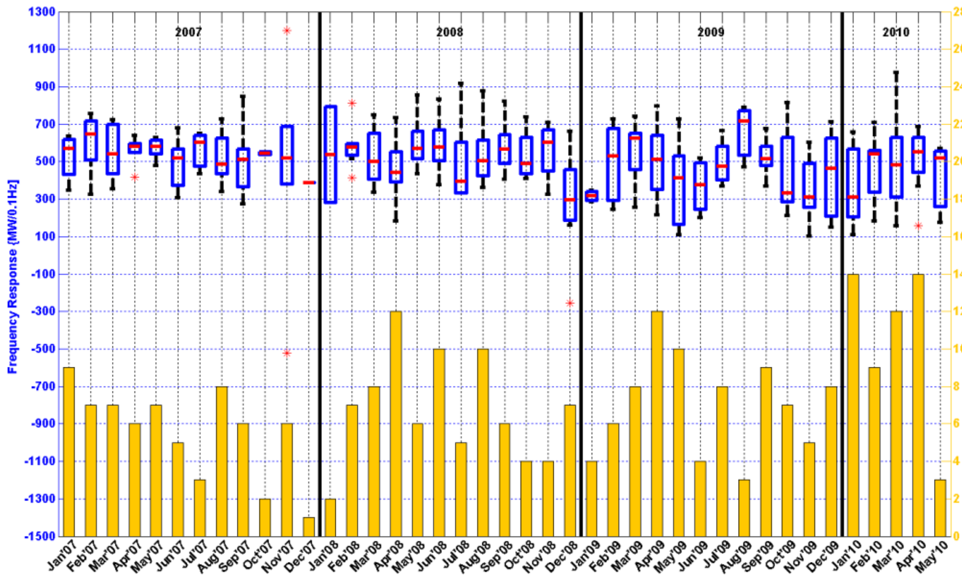


Figure 15 – Frequency Response Variability and Number of Events for ERCOT 2007 to 2010 for 90-MHz Delta, 15-Second Time Window, and below-60-Hz Constraint Removed

Figure 16 shows the estimated value of temporal distribution for each month and each hour type for the period 2007 to 2009. Note that frequency response values in 2009 were lower than in 2007 and 2008.

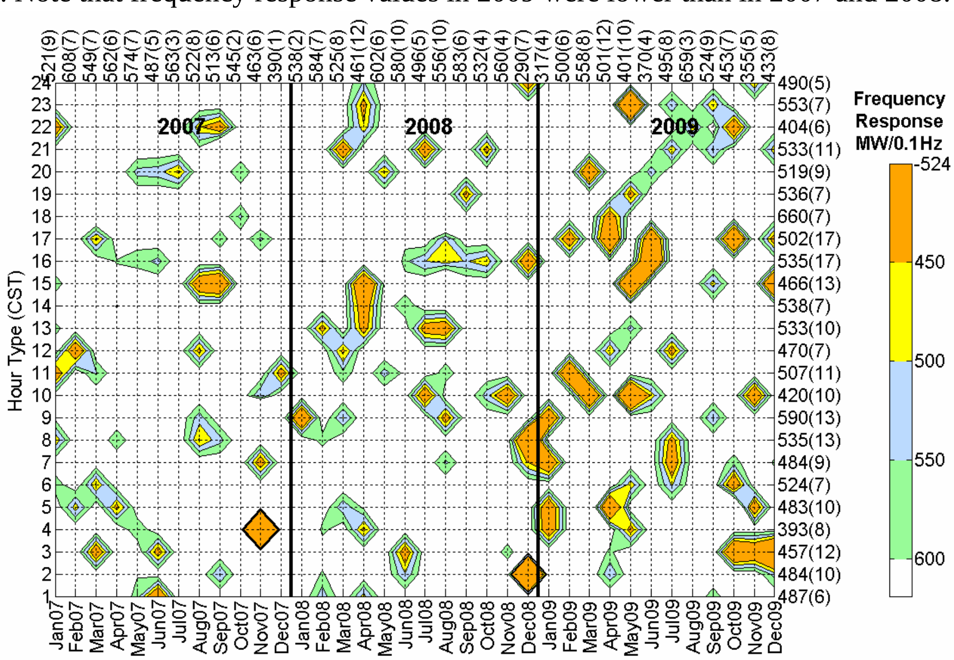


Figure 16 – ERCOT 15-Second Event Frequency Response Temporal Distribution per Month and per Hour for 0.090-Hz Delta Frequency and below-60-Hz Constraint Removed

As with the previous interconnections, calculated frequency response varies widely for identified events. Although some variation is expected because of changing system conditions and other factors, variation among monthly means and in the size of standard deviations associated with identified events raises questions. Clearly, there is significant uncertainty associated with estimates of frequency response on the ERCOT Interconnection, as indicated by the standard deviations in the measured frequency response. 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.

CERTS PHASE-3 THIRD OBJECTIVE - RESEARCH INTERCONNECTION FREQUENCY EVENTS AND FREQUENCY RESPONSE STATISTICAL PERFORMANCE AND PATTERNS DURING DIFFERENT TEMPORAL PERIODS, AND DURING ON-OFF PEAK, RAMP, AND TEC PERIODS, AND ASSESS IMPACT ON THE DEFINITION OF ADEQUATE SETS OF FREQUENCY EVENTS

10. Frequency Events and Frequency Response Statistical Performance and Patterns of Significant Frequency Events for the Three Interconnections

The third Phase-3 objective requires analyzing critical frequency events and frequency response statistical performance and patterns for each interconnection. This objective includes: 1) provision of frequency response statistics and trends: mean, median, standard deviation, shape of probability density function, and Q-Q plots; 2) key statistics correlating frequency event occurrences and their calculated frequency response with important variables such as TEC, on- versus off-peak, month of year, day of week, hour of day, and minute of hour; and 3) estimation of probability of occurrence of events larger than 5,000 MW in the Eastern Interconnection, using historical event data for the past 10 years.

To achieve the third objective, the research team selected frequency deviations of 40 MHz for the Eastern and Western Interconnections and 70 MHz in for the ERCOT Interconnection. This analysis uses raw 10-second "scan cycle" data that have been averaged over one-minute intervals. Therefore, the selected frequency deviations are somewhat different from those identified in Objective 2 because averaging data over one-minute periods reduces maximum values. This is discussed more fully in Section 10.2 as the team compared frequency for a specific day and hour to visualize one-minute average data versus one-second average data.

Analysis undertaken for Objective 3 estimates frequency response from calculations of MW loss, as determined using methodologies identified under Objectives 1 and 2. That is, the research team calculates frequency response from NERC data using the same formulas used by NERC Frequency Monitoring and Analysis (FMA) and Automatic Reliability Reports (ARR) applications.

For the preliminary estimates of the probability of occurrence of events larger than 5,000 MW on the Eastern Interconnection, the team used event data reported by Eastern BAs to DOE from 2000 to 2010.

The analysis in this section addresses the third Phase-3 objective and is also relevant to event selection and measurement of ARRs, which are being addressed by the industry as NERC develops a response to Federal Energy Regulatory Commission Order 693 relating to frequency response. In addition, this analysis demonstrates the viability of automatically identifying frequency events and calculating frequency response using data that are currently available. Although the statistics suggest that data accuracy needs to improve, the variability of calculated frequency response can be mitigated by using larger sample sizes (more events) and prudently selecting statistical values such as a median and/or mean to determine frequency response from those samples.

Table 9 summarizes key findings related to frequency deviations on all three interconnections for January through August 2010 data, to provide a quick overview of results. Individual charts for each interconnection provide insight into the statistics and correlations discussed above. The team is providing similar individual charts for 2008 (2009 in the case of ERCOT), for comparison purposes to determine whether 2010 data are typical or anomalous. The team selected 2008 for comparison because it is a recent year and should reflect recent operational changes while avoiding anomalies that may occur because of recent economic trends. Results from the balancing authority area limit (BAAL) field trial suggest there may be unexplained anomalies that began late in 2008 and continue today. However, the BAAL field trial data show a return to more typical numbers of frequency excursions on the Eastern Interconnection for a few months in 2010 before reverting to reduced numbers of frequency deviations in recent months. The team has not attempted to analyze whether 2010 and/or 2008 data represent “typical” frequency events beyond these anecdotal data.

Table 9 – Summary of Calculated Frequency Response Key Statistics and Correlations with Important Variables

INTERCONNECTION FREQUENCY RESPONSE (FR) STATISTICS, TRENDS AND DISTRIBUTIONS – JANUARY TO AUGUST 2010							
	Statistics # of Events Mean Median Std.Dev. (40 MHz for East and West and 70 MHz for ERCOT)	**On-Off Peak** Events On-Peak % Events Off-Peak % Poorest FR Variability	**Time Error**[4] Events Not TEC % Events During TEC	**Distribution Per Month** Month with Most Events Month with 2nd Most Events Month with Poorest FR Month with 2nd Poorest FR	**Distribution Per Hour** Hours with Most Events Hours with Poorest FR	**Distribution Per Minute** Minutes with Most Events Minutes with Poorest FR	**Observations**
East	136 -1891 -1840 417	54% 46% Poorer FR During Off-Peak More Variability On-Peak	85% 15%	April (39) May (35) June March	Hours 7 (22), 24 (18), 1 (12), and 23 (11) Hours 2, 11	3 (16), 4(10) 1 (12), 60, 35 and 34	About 40% of events occur during morning peak and late evening hours About 70% of events occur during March, April, and May
West	68 -817 -758 335	57% 43% Poorer FR During On-Peak More Variability On-Peak	93% 7%	April (17) July (13) March April	Hours 5 (7), 2 (6) 8 (6), and 18 (5) Hours 7, 8	23 (4), 2(3) 5, and 13	About 55% of events occur during April and July About 27% of events occur during hours 5, 2, and 8
ERCOT	120 -725 -729 100	63% 37% Poorer FR During Off-Peak More Variability On-Peak	100% 0%	January (30) April (26) January February	Hours 15 (16), 6 (9), 1 (7), Hours 9, 10	3 (16), 4(10) 1 (12), 60, 35 and 34	About 77% of events occur from January to April About 33% of events occur during hours 1 to 7

Figure 17 to 20 for the Eastern Interconnection, Figure 24 to 27 for the Western Interconnection and Figure 29 to 32 for the ERCOT Interconnection, provide more detailed information to help the reader analyze and visualize the results summarized in Table 9. To facilitate the analysis and assessment of the numbers of significant events and calculated frequency response for each interconnection, the research results are presented in the following formats:

- Histograms of the number of events with calculated frequency response

[4] TEC correlations are based on events that meet the selection criteria. These percentages have not been normalized using data on time spent in TEC for each interconnection. These correlations address issues of sampling bias and frequency response calculation accuracy. The reader is cautioned against drawing conclusions that extend beyond these issues.

- Box plots showing the interconnections' estimated frequency response mean, median, standard deviation, and variability for events over the entire period
- Cumulative probability distributions of frequency response over the period
- Normal Q-Q plots of frequency response calculated over the period
- Box plots showing the interconnections' estimated frequency response for events that occur during:
    - On-peak and Off-peak periods
    - TEC and non-TEC periods
    - Each month of the year
    - Each day of the week
    - Each hour of the day
    - Each minute of the hour

10.1 Statistical Performance, Patterns, and Charts for Significant Events and Frequency Response for Eastern Interconnection, 2010 and 2008

To achieve the third Phase-3 objective, the research team selected frequency deviations of 40 MHz in the Eastern Interconnection. This analysis uses available NERC data and averages 10-second "scan cycle" data over one-minute intervals, estimating frequency response from calculation of MW loss as determined using methodologies identified in previous sections of this report.

In addition to the previously described charts, the team used high-speed frequency data (10 samples per second) to calculate one-second frequency averages for 2010 frequency events. The team used these data to calculate Frequency Points A, B, and C for all 2010 events using NERC methodologies. This analysis provides insight into the shape of frequency events for the Eastern Interconnection. The 2010 data show little or no recovery between Frequency Points C and B for most 2010 events, as illustrated in Figure 21. Definition of Eastern Interconnection event frequencies for points C and B should consider changing from a classical "V" frequency event pattern to an "L" frequency event pattern. This new definition should be used until there is a significant change in the current "L" frequency event pattern in the Eastern Interconnection.

The industry has questioned whether it is possible to accurately calculate frequency response. There is special concern about the accuracy of calculations during times of known transition, such as periods when schedules are being ramped to new values, cyclical load changes e.g., from on-peak to off-peak and vice versa, etc. Many in the industry have suggested ignoring frequency events that occur during these times because of the inherent difficulty calculating frequency response with sufficient accuracy.

To address this industry issue, the team produced an additional set of charts for the Eastern Interconnection that removed all frequency events occurring from minute 55 to minute 5 (i.e., during schedule ramps) to analyze effects of schedule ramping on calculation of frequency response. The additional charts show previously described statistics and correlations using a subset of the 2010 data from which the "Top of Hour" events have been removed. Please see Figure 22 and Figure 23.

Observations

There are 136 events through August of 2010 that result in a mean, median, and standard deviation of calculated frequency response of -1,891, -1,840, and 417 MW/0.1Hz, respectively, compared to 150 events in 2008 that result in a mean, median, and standard deviation of -1,746, -1,744, and 637 MW/0.1Hz, respectively. Filtering the 2010 data to remove "Top of Hour" events provides 80 events in 2010 that result in a mean, median, and standard deviation of -1,976, -1,911, and 447 MW/0.1 Hz, respectively. These results demonstrate the variability associated with calculation of frequency response for individual events.

Variability in key statistics when correlating events by month of year, day of week, hour of day, and minute of hour suggest that determining frequency response using mean, median, etc. of calculated values from larger sample sizes is preferable to a calculation from a single event or small number of events. However, these statistics appear to be stable for on-peak versus off-peak and for TEC compared to non-TEC events. The mean and median between on- and off-peak do not appear large enough to warrant disregarding measurement of frequency response for off-peak events.

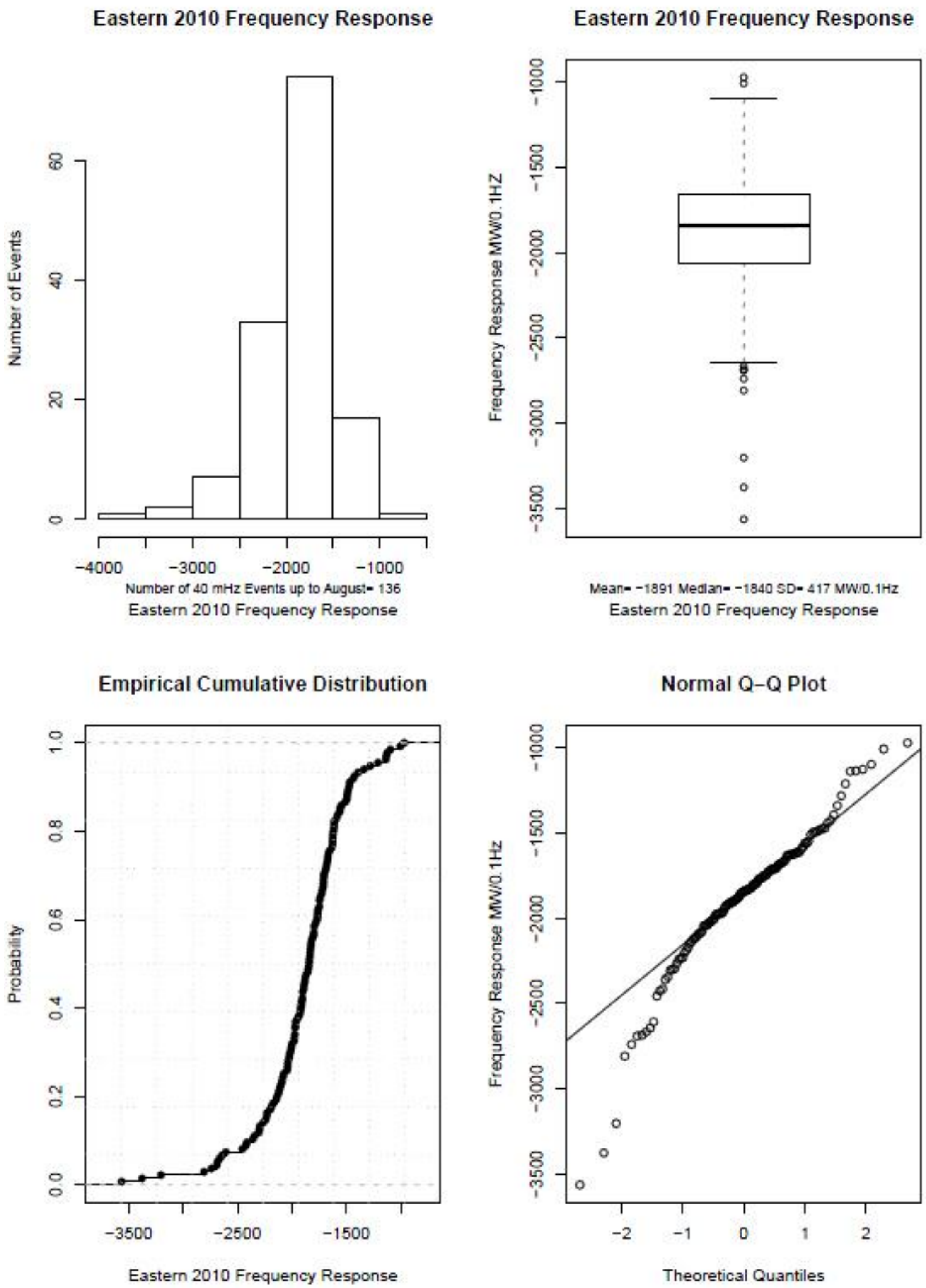


Figure 17 – Eastern Interconnection 40-MHz Frequency Deviation Statistics for January – August 2010

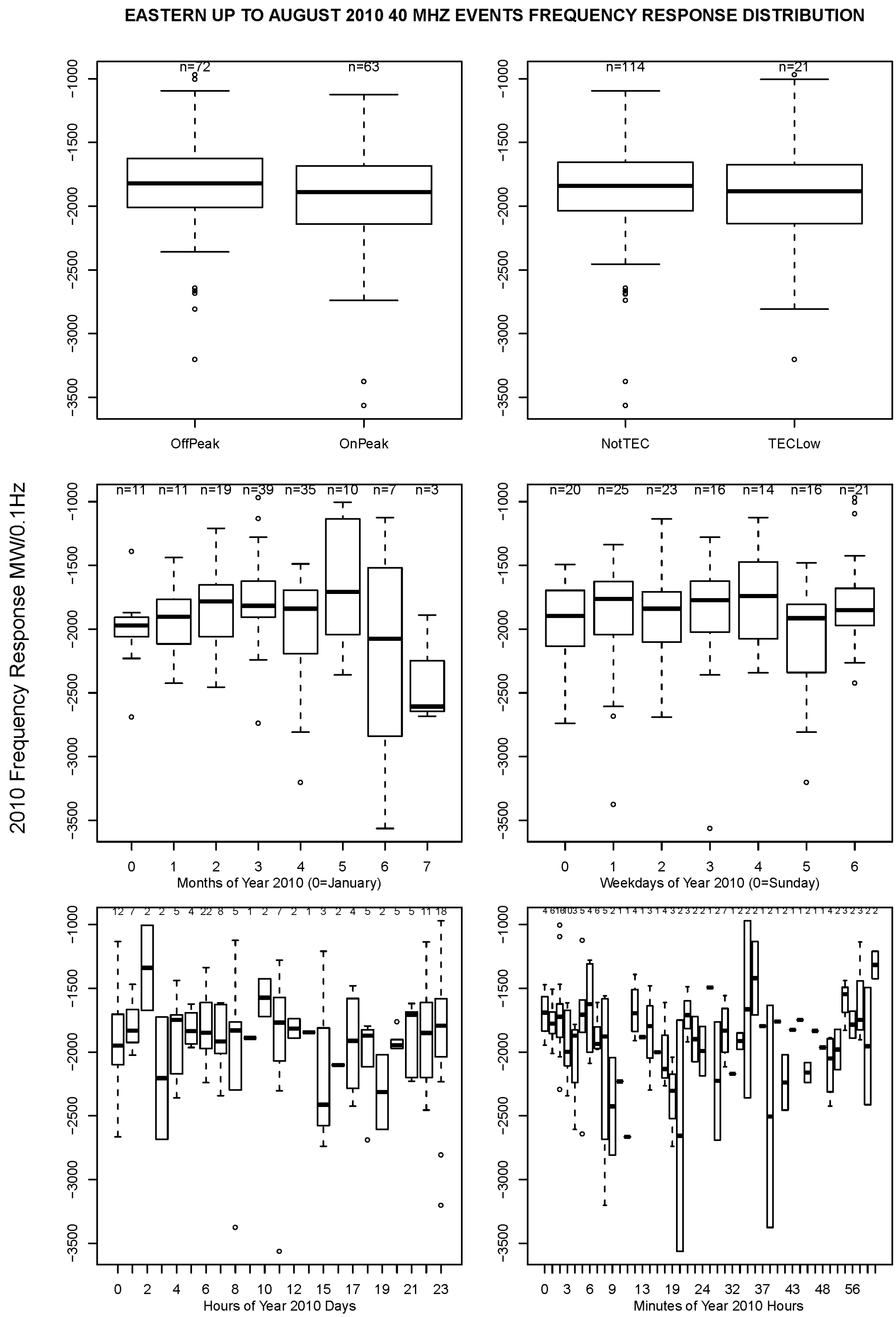


Figure 18 – Eastern Interconnection Frequency Event Correlation to On- versus Off-peak, TEC to non-TEC, Month of Year, Day of Week, Hour of Day, Minute of Hour – January - August 2010 data

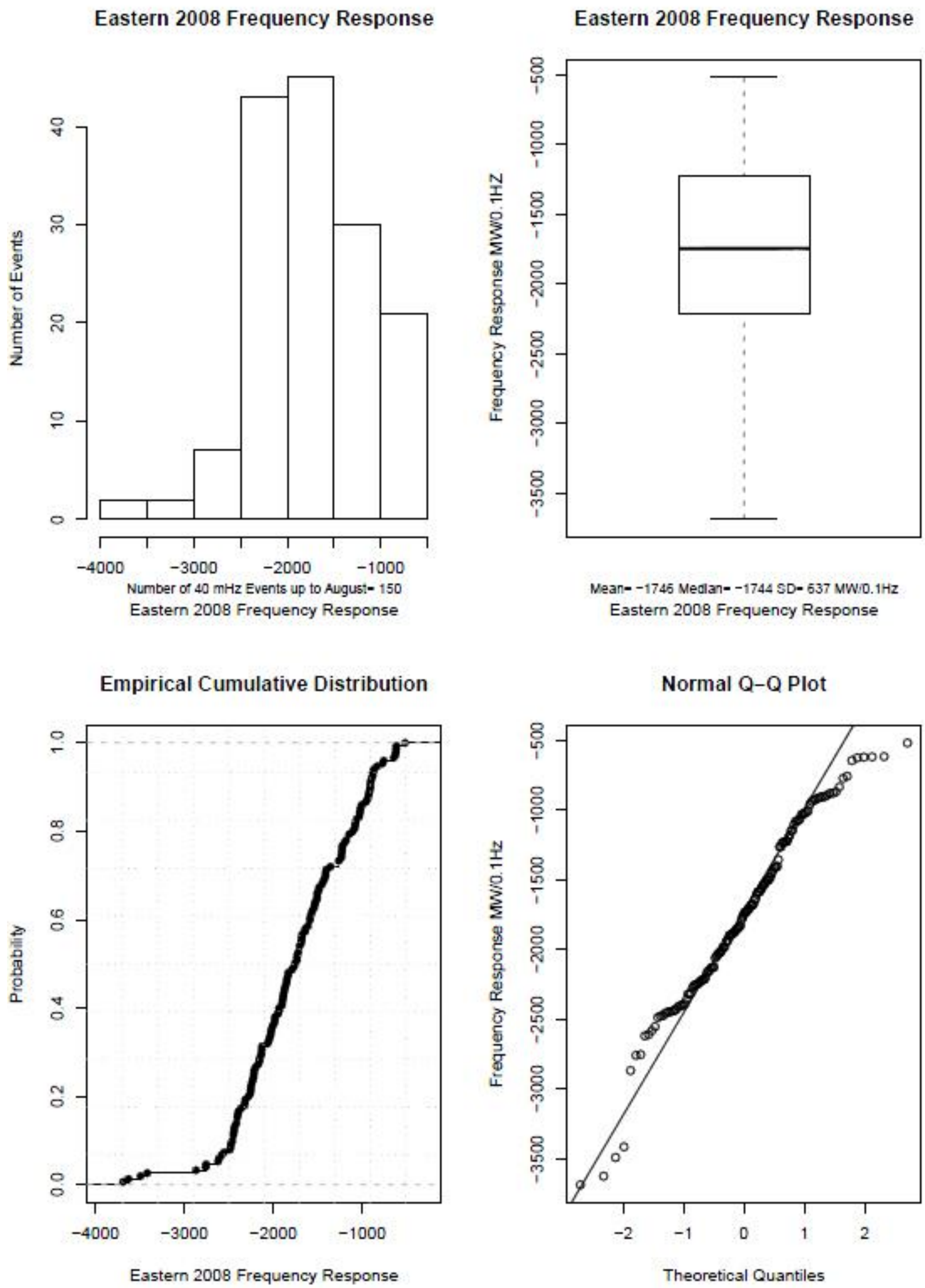


Figure 19 – Eastern Interconnection 40-MHz Frequency Deviation Statistics for 2008

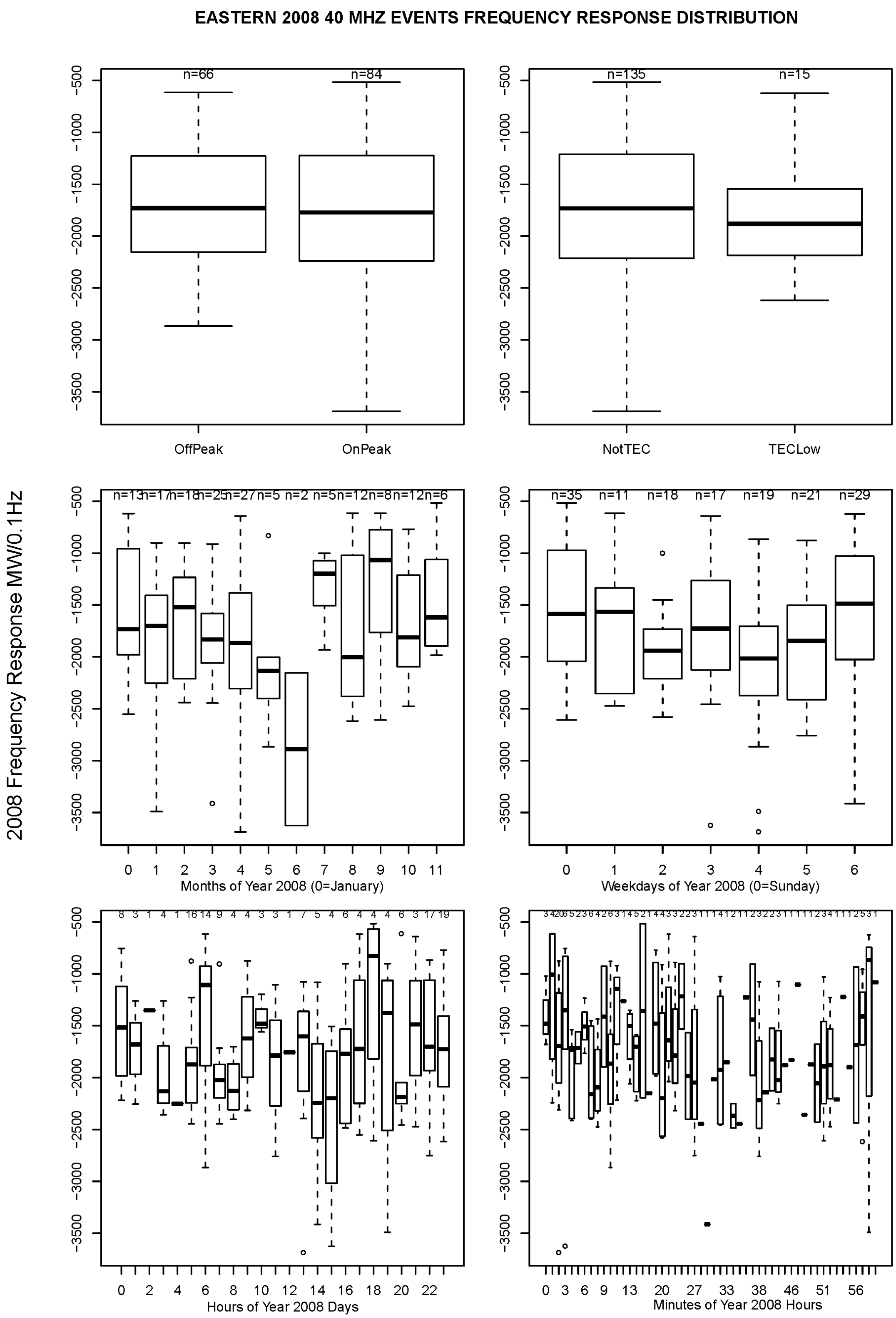


Figure 20 – Eastern Interconnection Frequency Event Correlation to On- versus Off-peak, TEC to non-TEC, Month of Year, Day of Week, Hour of Day, Minute of Hour – 2008 data

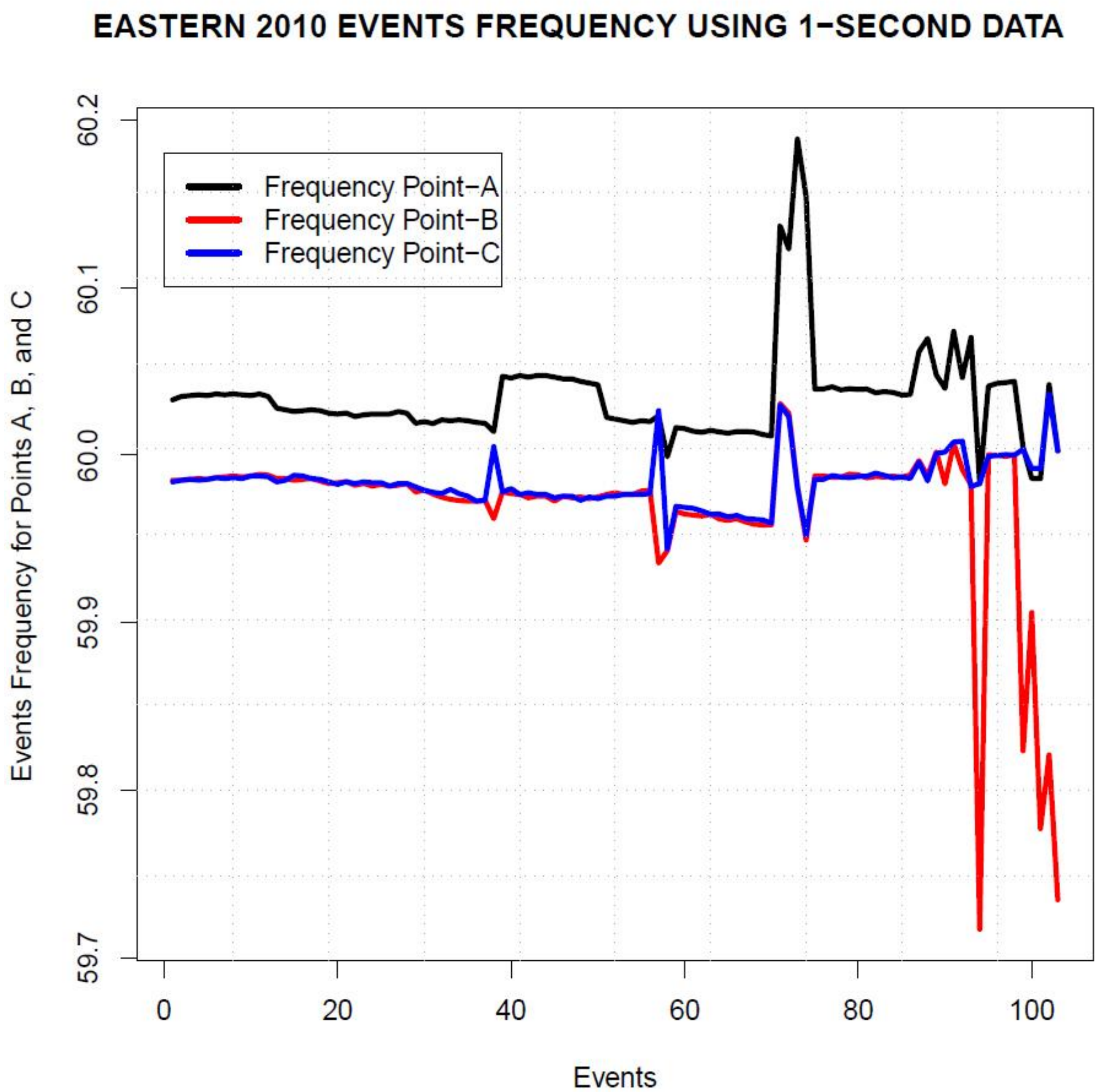


Figure 21 – Eastern Interconnection Frequency Events comparing Frequency Points A, B, and C using January - August 2010 One-second Data

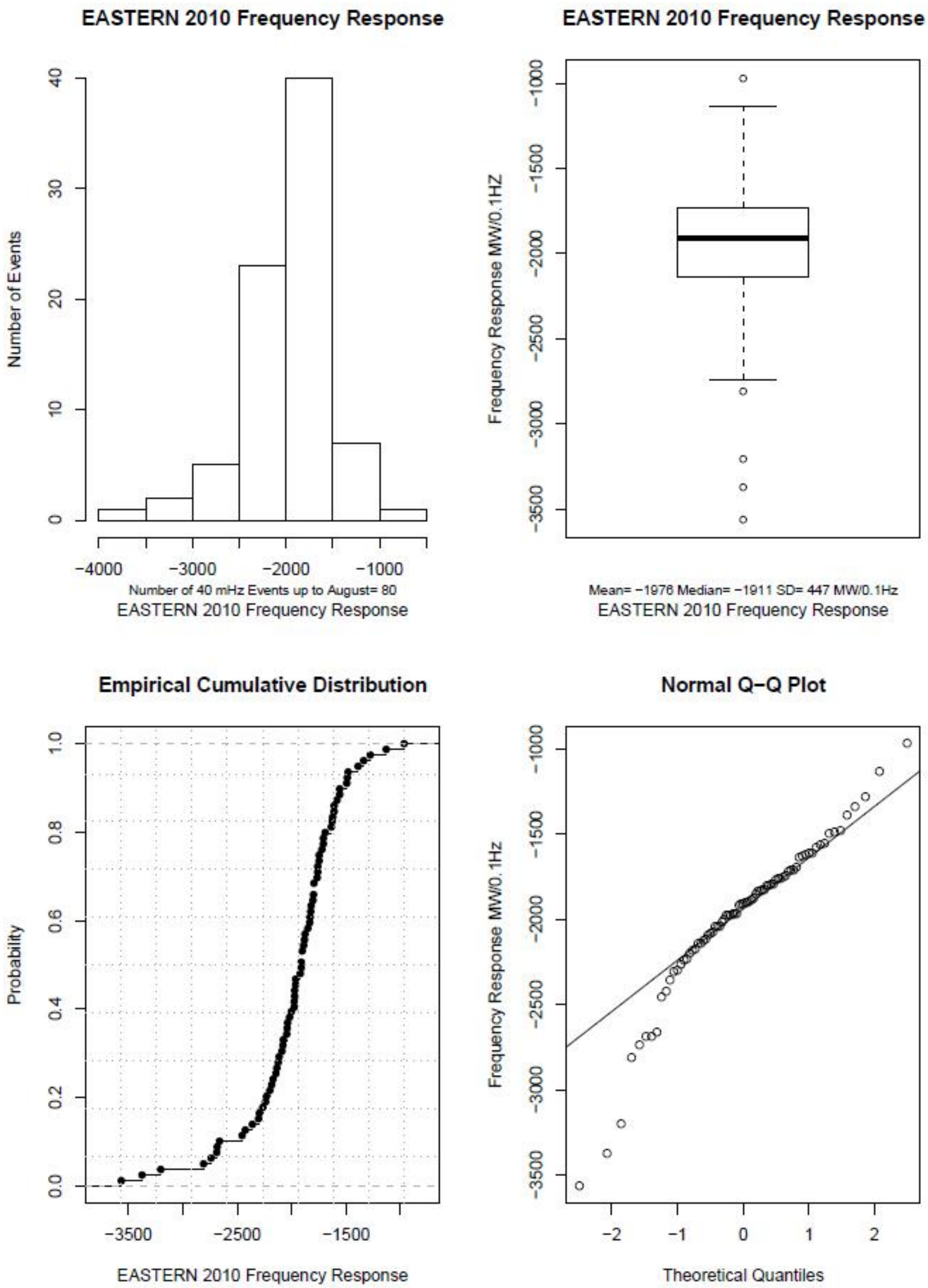


Figure 22 – Eastern Interconnection 40-MHz Frequency Deviation Statistics for January -August 2010 with "Top of Hour" Frequency Events Removed

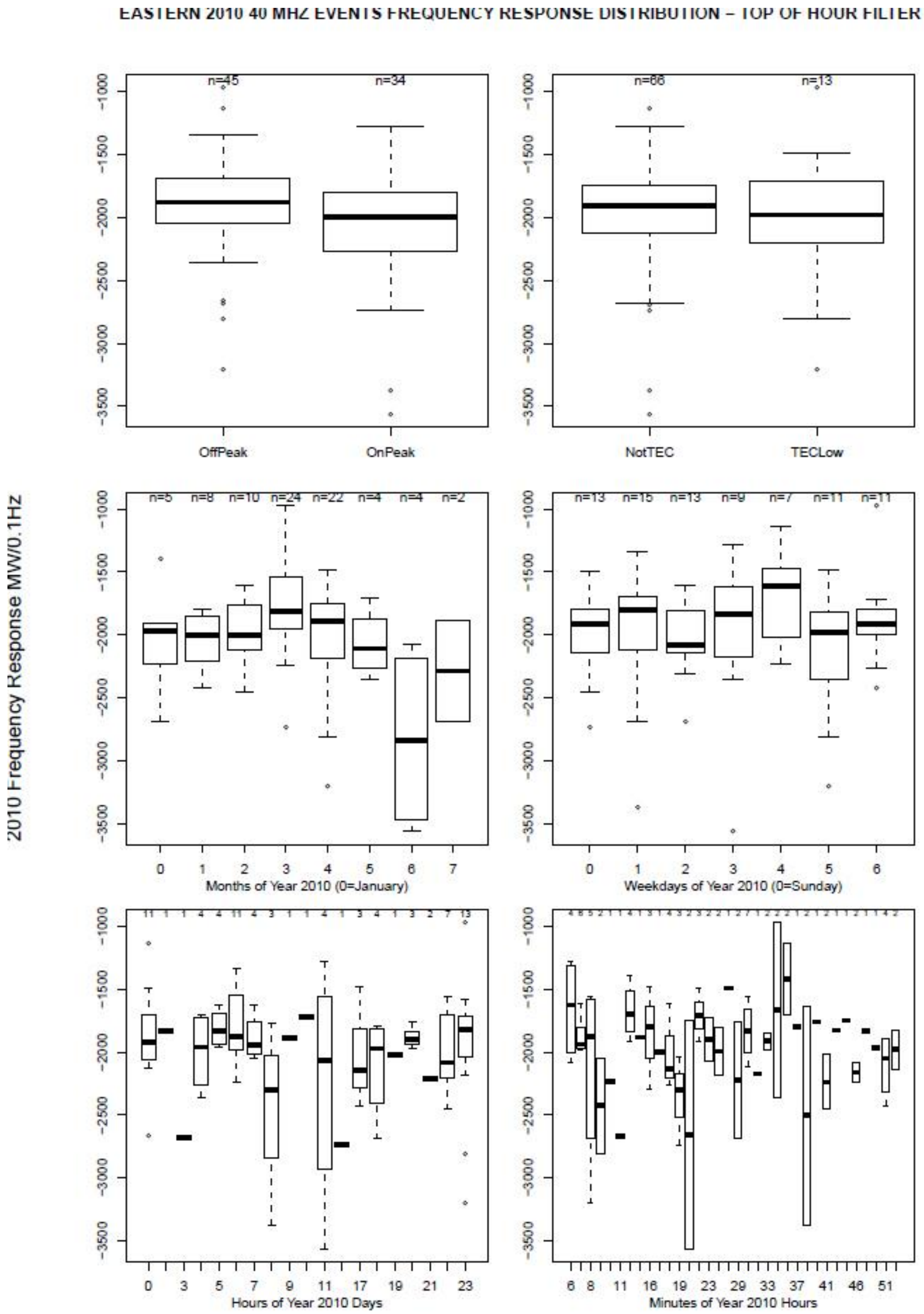


Figure 23 – Eastern Interconnection Frequency Event Correlation to On- versus Off-peak, TEC to non-TEC, Month of Year, Day of Week, Hour of Day, Minute of Hour – January - August 2010 data with "Top of Hour" Frequency Events Removed

10.2 Statistical Performance, Patterns, and Charts for Significant Events and Frequency Response for Western Interconnection, 2010 and 2008

To achieve the third Phase-3 objective, the research team selected frequency deviations of 40 MHz in the Western Interconnection. This analysis uses available NERC data and averages 10-second "scan cycle" data over one-minute intervals, estimating frequency response from calculation of MW loss as determined using methodologies identified in previous sections of this report.

The team used high-speed frequency data (10 samples per second) to produce one-second average data to compare with one-minute average data used in this analysis. Figure 28 shows a one-hour comparison. The figure demonstrates that one-minute averages are suitable for identifying frequency events and can be used to calculate frequency because the MW loss calculations are based on one-minute ACE values. However, the chart demonstrates that one-minute averages do not capture the full extent of frequency deviations, raising concerns if one-minute averages are considered for addressing Frequency Point C issues such as coordination with underfrequency load-shed relay points, etc.

Arguably, this understating of frequency deviation for a frequency event affects calculation of the associated frequency response. However, several factors mitigate such concerns. Because frequency response is calculated based on Frequency Point B, there is better agreement between one-second and one-minute averages as the frequency is more stable. In addition, as long as measurements are made consistently, the calculated frequency response should be comparable among events and entities within the same interconnection. Finally, and most importantly, other values used to calculate frequency response are not available with one-second updates. Therefore, it is not necessary or possible to improve the accuracy by using one-second frequency data to calculate frequency response. These limitations must be remembered as the industry moves forward.

Observations

From January to August of 2010, 68 events resulted in a mean, median, and standard deviation of calculated frequency response of -817, -758, and 335 MW/0.1Hz, respectively, compared to 136 events in 2008 that result in a mean, median, and standard deviation of -823, -779, and 381 MW/0.1Hz, respectively. These results demonstrate the variability associated with calculation of frequency response for individual events although the statistical values from 2010 and 2008 were remarkably consistent.

Variability in key statistics when correlating events by month of year, day of week, hour of day, and minute of hour suggest that it is preferable to determine frequency response using mean, median, etc. of calculated values from larger sample sizes rather than using a calculation from a single event or small number of events.

However, these statistics appear to be stable for on-peak versus off-peak and for TEC periods compared to non-TEC events. Observed variability for TEC versus non-TEC is believed to result from the small number of events (2) rather than from a correlation with TECs. The mean and median between on- and off-peak do not appear large enough to warrant disregarding measurement of frequency response for off-peak events. Surprisingly, 2010 data showed calculated frequency response for off-peak events to be better than for on-peak events although they were not significantly different. Western Interconnection 2008 data suggest that this was an anomaly.

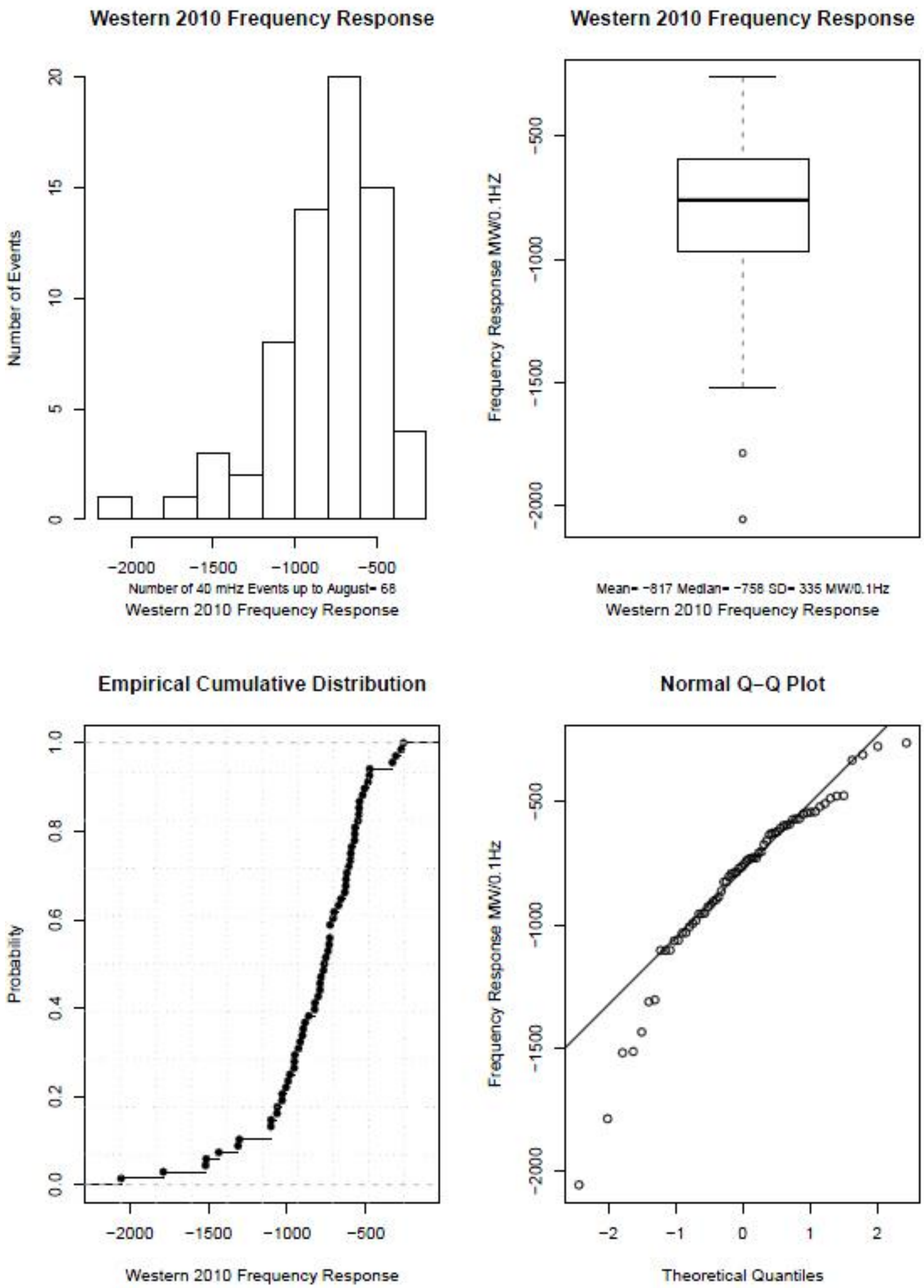


Figure 24 – Western Interconnection 40-MHz Frequency Deviation Statistics for January-August 2010

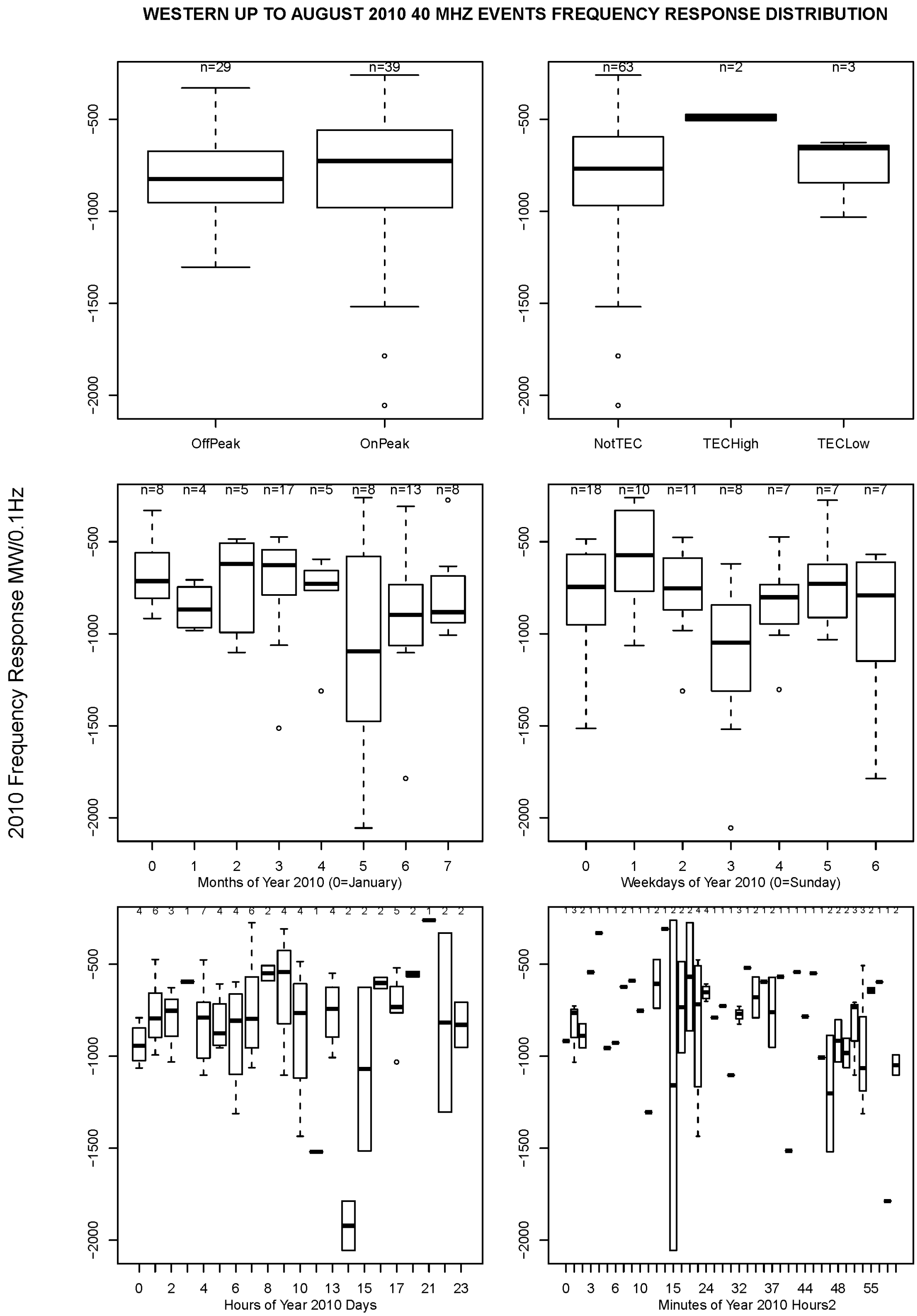


Figure 25 – Western Interconnection Frequency Event Correlation to On- versus Off-peak, TEC to non-TEC, Month of Year, Day of Week, Hour of Day, Minute of Hour – January - August 2010 data

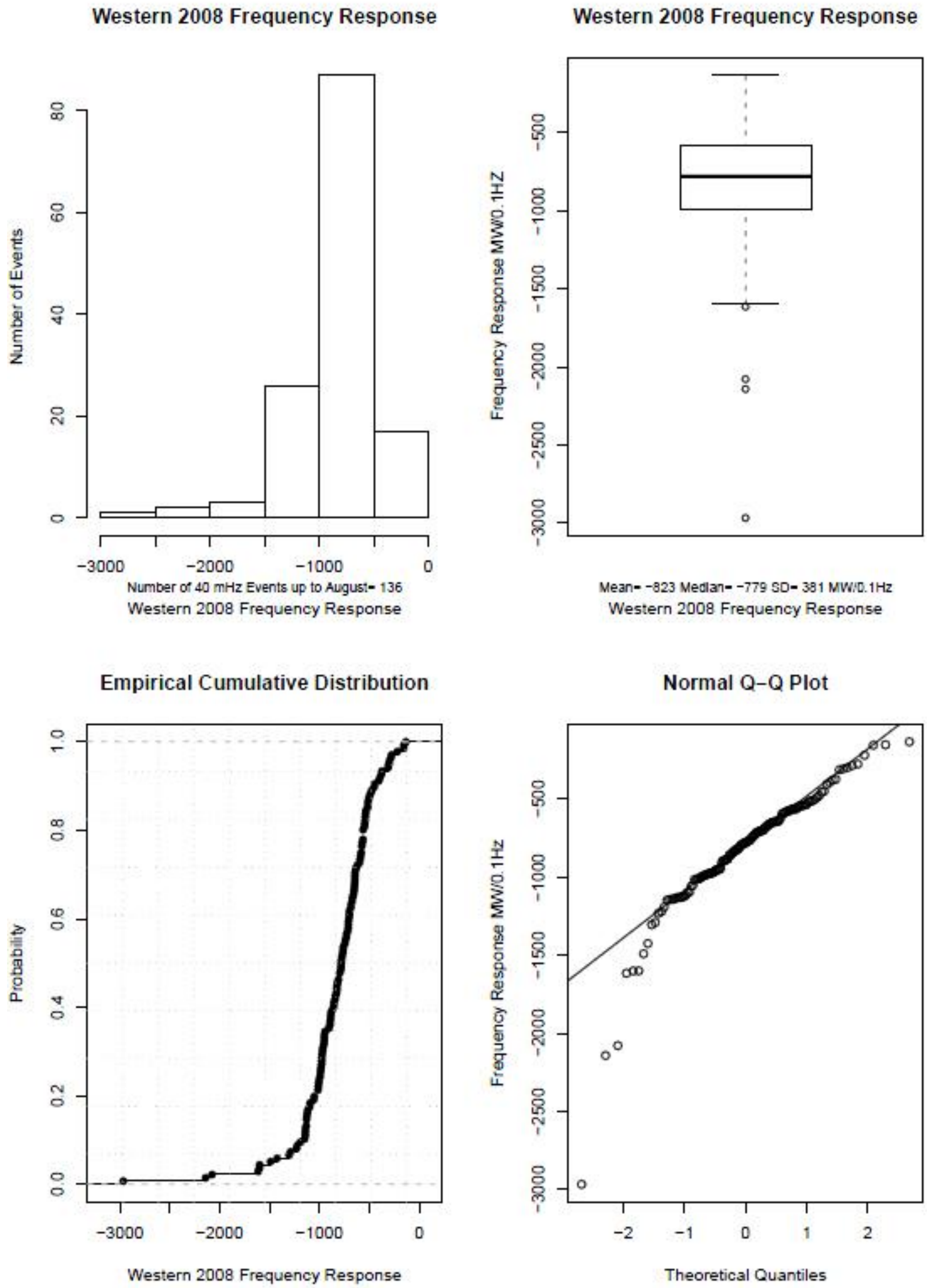


Figure 26 – Western Interconnection 40-MHz Frequency Deviation Statistics for 2008

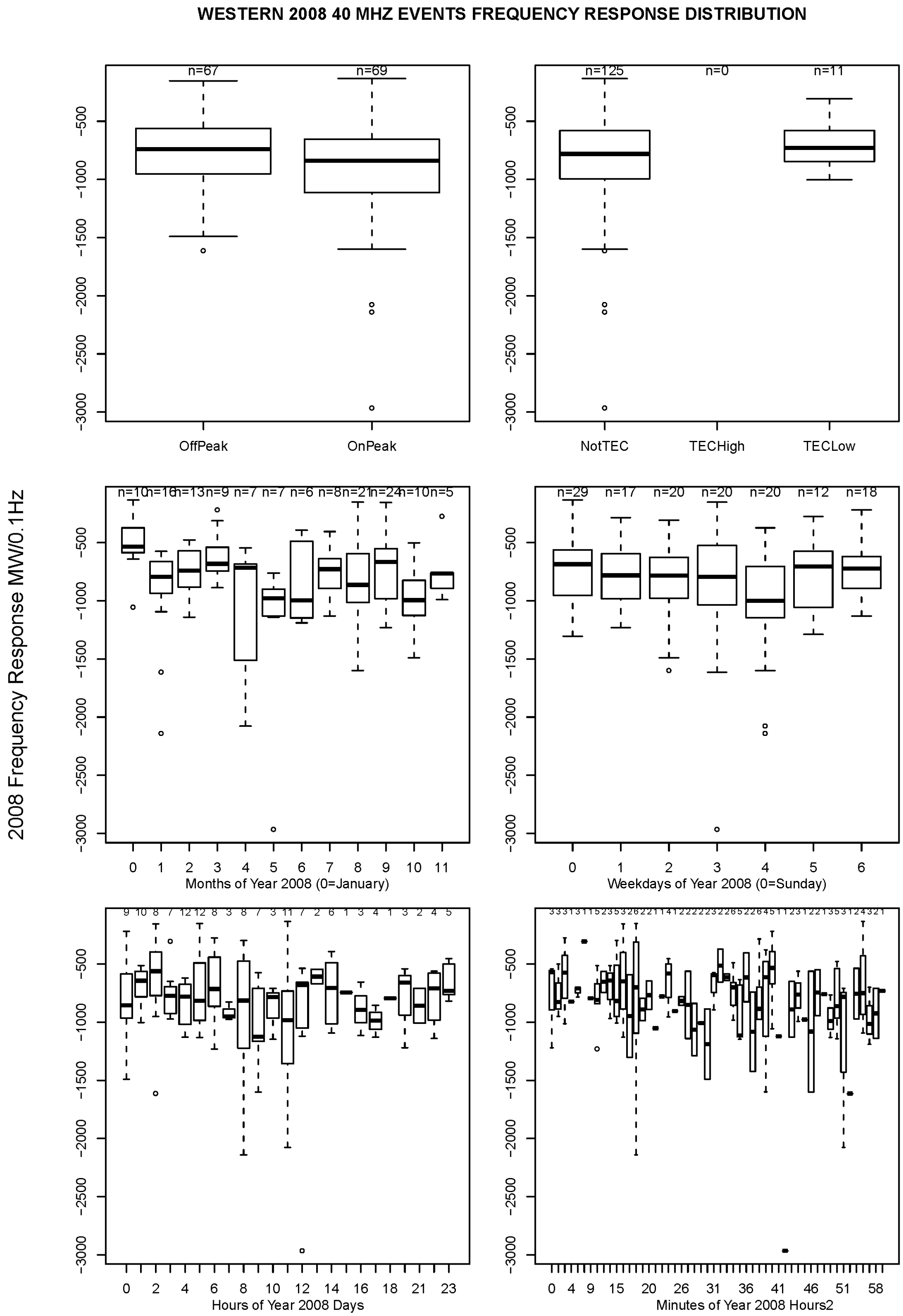


Figure 27 – Western Interconnection Frequency Event Correlation to On- versus Off-peak, TEC to non-TEC, Month of Year, Day of Week, Hour of Day, Minute of Hour – 2008 data

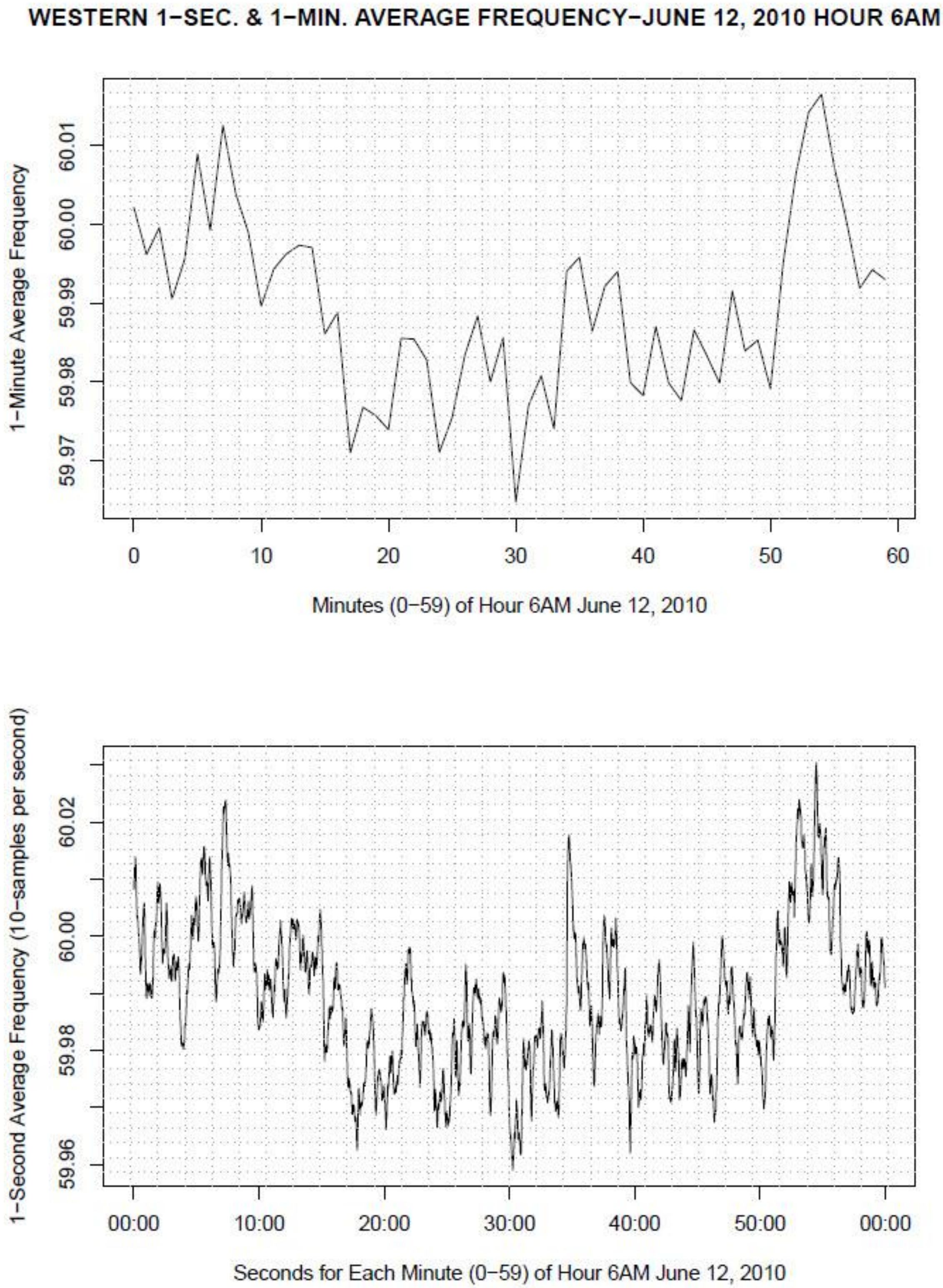


Figure 28 – Western Interconnection Frequency Comparing One-minute Averages to One-second Averages for June 12, 2010 from 6 AM to 7 AM

10.3 Statistical Performance, Patterns, and Charts for Significant Events and Frequency Response for ERCOT Interconnection, 2010 and 2009

To achieve the third Phase-3 research objective, the team selected frequency deviations of 70 MHz in the ERCOT Interconnection. This analysis uses available NERC data and averages 10-second "scan cycle" data over one-minute intervals, estimating frequency response from calculation of MW loss as determined using methodologies identified in previous sections of this report.

Observations

From January to August, 2010, 120 events result in a mean, median, and standard deviation of calculated frequency response of -725, -729, and 100 MW/0.1Hz, respectively, compared to 158 events in 2009 that result in a mean, median, and standard deviation of -704, -712, and 74 MW/0.1Hz, respectively. These results demonstrate lesser variability associated with calculation of frequency response for individual events than is the case for other interconnections and the values from 2010 and 2009 are remarkably consistent.

Variability in key statistics when correlating events by month of year, day of week, hour of day, and minute of hour suggest that it is preferable to determine frequency response using mean, median, etc. of calculated values from larger sample sizes rather than using a calculation from a single event or small number of events.

However, these statistics appear to be stable for on-peak versus off-peak periods and TEC periods compared to non-TEC events. Observed variability for TEC versus non-TEC periods is believed to result from the small number of events (0 – 4) rather than from a correlation with TECs. The mean and median between on- and off-peak do not appear large enough to warrant disregarding measurement of frequency response for off-peak events.

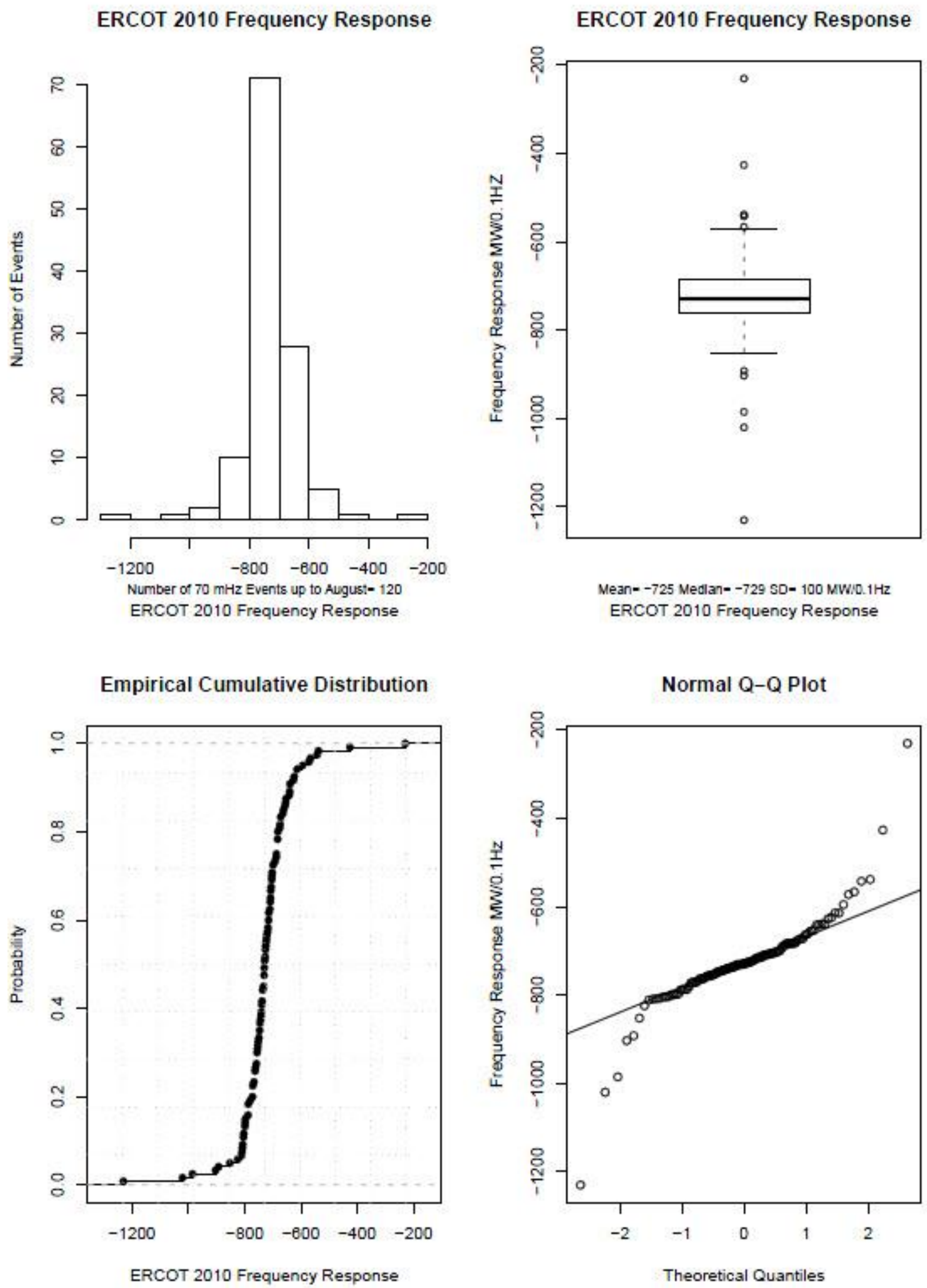


Figure 29 – ERCOT Interconnection 70-MHz Frequency Deviation Statistics for January - August 2010

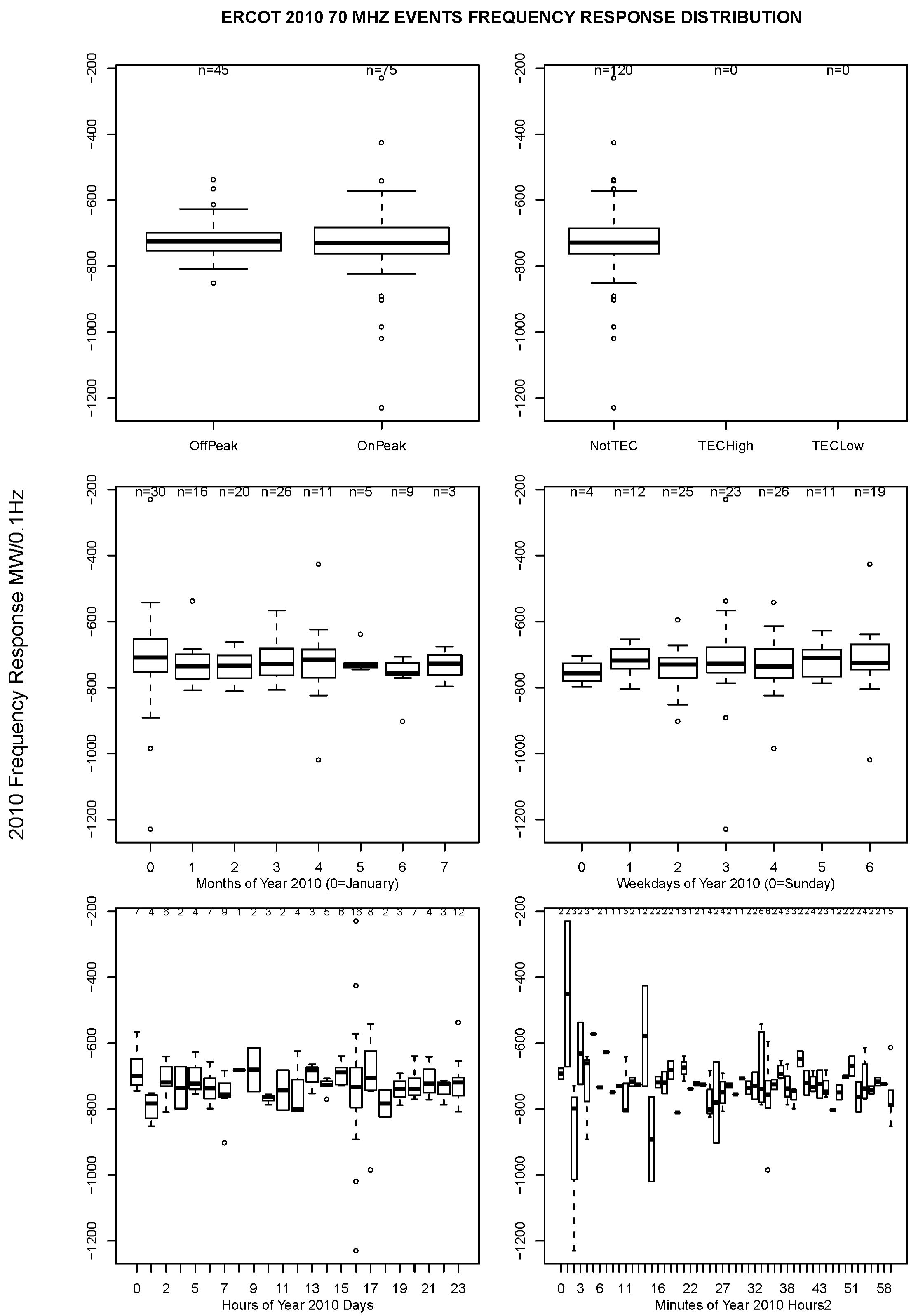


Figure 30 – ERCOT Interconnection Frequency Event Correlation to On- versus Off-peak, TEC to non-TEC, Month of Year, Day of Week, Hour of Day, Minute of Hour – January - August 2010 data

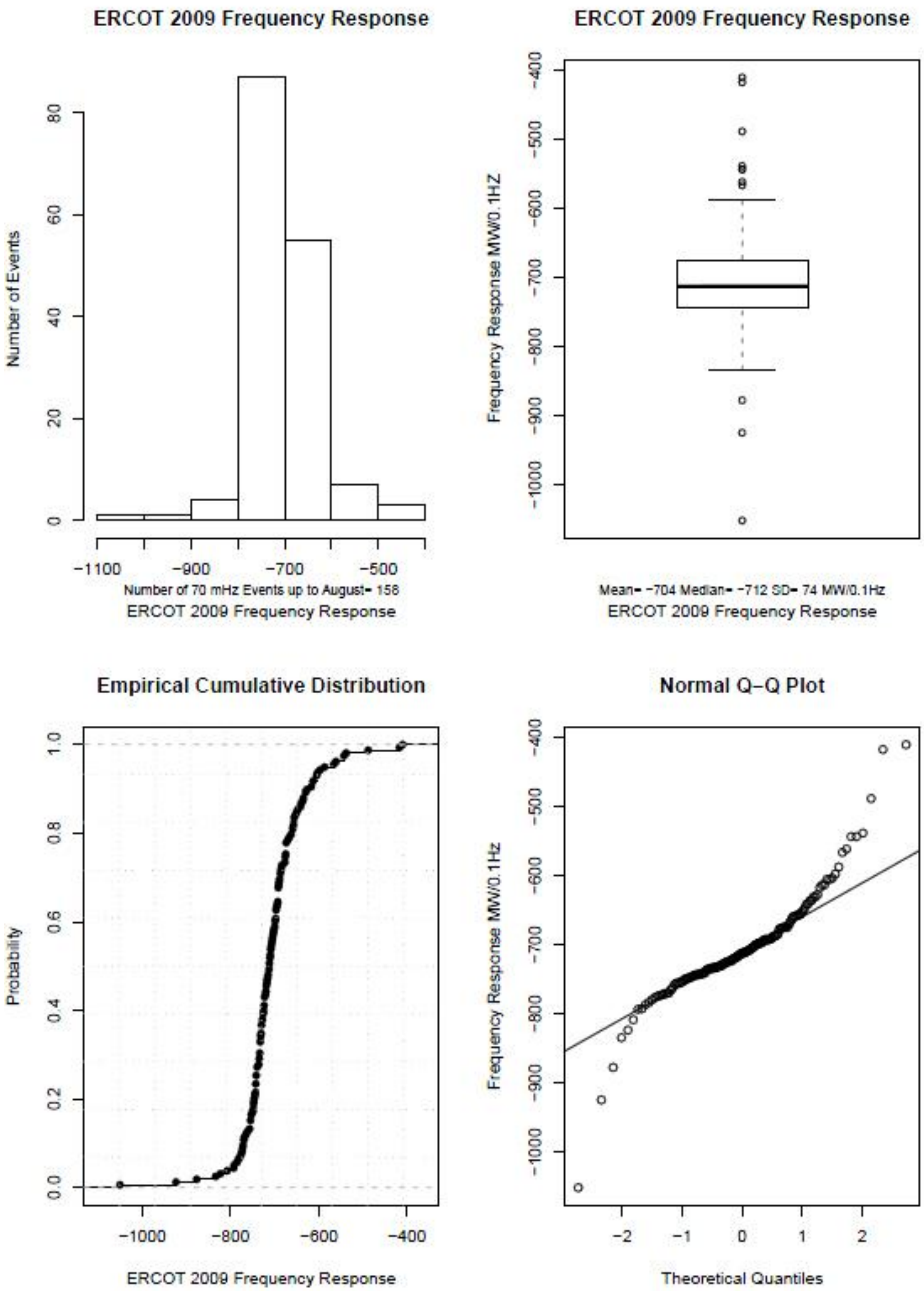


Figure 31 – ERCOT Interconnection 70-MHz Frequency Deviation Statistics for 2009

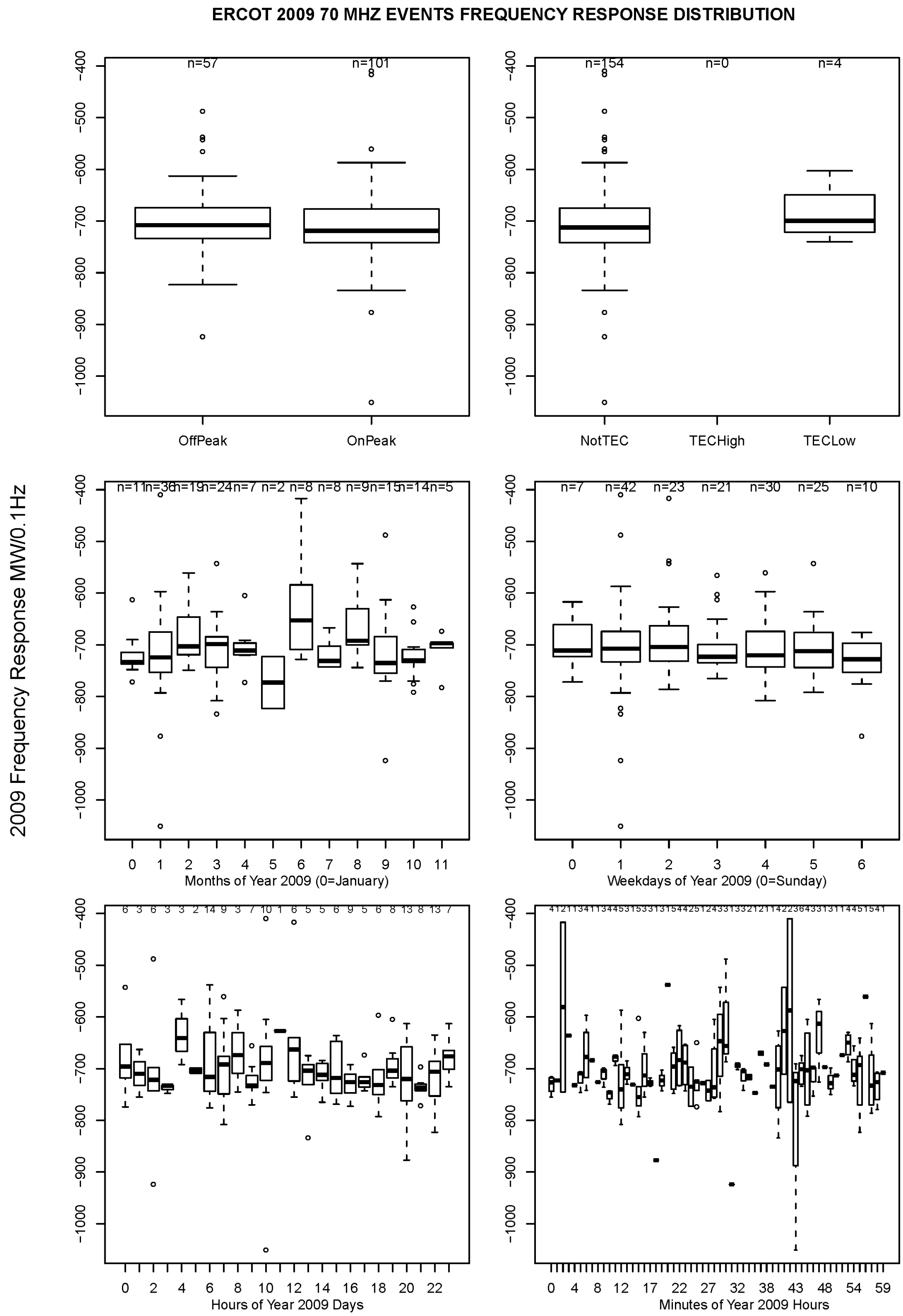


Figure 32 – ERCOT Interconnection Frequency Event Correlation to On- versus Off-peak, TEC to non-TEC, Month of Year, Day of Week, Hour of Day, Minute of Hour – 2009 data

10.4 Preliminary Estimates of Probability of Eastern Interconnection Events Larger Than 5,000 MW

For the preliminary estimates of probability of Eastern Interconnection frequency events larger than 5,000 MW, the team used event data reported to DOE by Eastern BAs from 2000 to 2010 and a methodology for assessing the probabilities of rare events.[5]

Results based on 2000 to 2010 DOE data and the probability of rare events methodology indicates that there could be two events larger than 5,000 MW in five years on the Eastern Interconnection. However, the team considers the DOE events database incomplete and not fully adequate for this type of probability calculation. A more complete and reliable database of events would increase the accuracy of the calculations of probability of significant events.

11. Conclusions/Recommendations

The industry is developing frequency response requirements to maintain and/or enhance reliable operation. This NERC effort must determine the minimum interconnection frequency response needed for reliability and how to ensure that appropriate entities provide that response. Critical components to support this NERC effort are identifying frequency events of interest, calculating frequency response for those events, and providing a viable and reliable methodology to measure frequency response for interconnections and BA areas. All three objectives researched in this report apply directly to NERC efforts to identify frequency events, calculate frequency response, and inform methodologies to measure frequency response. The research team for this report is working closely with the industry to ensure that research addresses appropriate issues within the framework of stated research objectives.

One key NERC task is to identify an appropriate list of frequency events for each interconnection that will be used by all BAs as a basis for consistently calculating their frequency response. To this end, 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 that was recommended by Florida Region representatives during the January 2010 NERC RS meeting in Tucson and that uses 2007 to 2009 one-second phasor frequency data for each interconnection. The team concluded that the parameters recommended by the Florida Region 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.

The team used historical 2007 to 2009 one-second phasor frequency data and one-minute ACE data currently available in NERC wide-area reliability monitoring applications databases to meet the objectives of investigating automatic methods and processes to identify frequency events on each interconnection and validating frequency response estimates for the events identified by the first objective. The team reviewed these 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 among the interconnections, compared to developing a methodology that is unique to each interconnection.
- Frequency events should correlate well with reliability concerns.

[5] Alemi, Farrokh, Ph.D. Most recent revision 09/29/2008. Part of a course lecture on Assessing Probability of Rare Events, George Mason University.

- The number of frequency events identified should be large enough to provide reasonable calculation accuracy but should be minimized so as not to burden entities beyond the data required for accuracy.
- 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 increase reliability concerns for high frequency events compared to what has been the case for historic operation.
- Sufficient data of reasonable quality must be available before a magnitude of frequency change should be considered a possible candidate to be labeled 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 are missing, data quality is insufficient, 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 among interconnections. This suggests using a common time window for events in all interconnections and using comparably sized frequency changes. The team did not have sufficient time to research all possibilities for frequency changes; however, it is essential to ensure that an appropriate number of events is identified (see next bullet). Therefore, proposed frequency changes are roughly 2, 3, and 3 times the published epsilons for the Eastern, Western, and ERCOT Interconnections, respectively, because frequency changes of this size provided a manageable number of events per month and per year.
- Calculating frequency response as described in Section 3 of this report requires roughly four (4) to seven (7) events per month for reasonable accuracy. This number could likely be reduced if data quality improves.

The following table summarizes the recommended parameters for automatically identifying frequency events for the three interconnections. Research results indicate that using the recommended parameters results in 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	Criterion Removed	Criterion Removed
Western	70 MHz	15	Criterion Removed	Criterion Removed
ERCOT	90 MHz	15	Criterion Removed	Criterion Removed

Related to the above conclusions, the team recommends the following:

- Frequency excursion 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).
- Data quality should be improved because 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, the improvements will minimize concerns regarding "garbage in – garbage out." Data quality improvements will also allow reduced sample sizes as described below for Objective 3.

To achieve the third objective, the research team selected frequency deviations of 40 MHz, 40 MHz, and 70 MHz in the Eastern, Western, and Texas Interconnections, respectively, to provide a sample size of roughly 100 of the largest frequency events. This analysis uses data that have been averaged over one-minute intervals and estimates frequency response from calculation of MW loss as determined using methodologies identified in Objectives 1 and 2. In other words, the team is calculating frequency response from NERC data using the same formulas accepted for use by NERC FMA and ARR applications.

Related to Objective 3, the team concluded the following:

- The analysis demonstrates the viability of automatically identifying frequency events and calculating frequency response using data that are currently available. Although statistical analysis suggests that data accuracy needs to improve, the variability of calculated frequency response for individual events can be mitigated by using larger sample sizes (more events) and prudently selecting statistical values to determine frequency response, such as using the median, mean, etc.
- As noted in Objective 2, there is significant uncertainty associated with frequency response estimates on all three interconnections as indicated by the standard deviations of the calculated frequency response. 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 calculation methodology is valid.

Related to these Objective 3 conclusions, the team recommends the following:

- Ongoing evaluation of the determination methodology as more data and more accurate data are collected and adjustments are made in event selection, evaluation, and measurement processes. The team recognizes the value of selecting events with appropriate frequency characteristics.
- Using data from 2002 to 2010 from the NERC databases to improve the accuracy of the probability-of-occurrence calculations for events larger than the specific MW criterion (5,000 MW for Eastern) for each interconnection.
- Using scan-rate data in the short term and one-second synchronized data in the long term for frequency response calculations because preliminary comparisons of interconnection frequency data between one-second resolution and one-minute resolution indicate there could be significant differences in frequency response estimates using these two data rates.
- Researching and quantifying the following issue using interconnection synchronized frequency phasor data, and reporting the findings: for a same-interconnection frequency event, there could be significant differences in the delta frequency between the frequency at points A and B between two distant Reliability Regions, which could impact frequency response comparisons.
- Conducting further research to identify whether any correlations exist between interconnection TECs and frequency response.
- Carefully reviewing any event selection process to ensure that it 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.
- Related to the above recommendation, applying statistical analysis to samples of calculated frequency response for long-term determination of frequency response, rather than using a single or a small number of frequency events, and using synchronized frequency phasor one-second data.
    - In support of the above two recommendations, the team observed that sufficient numbers of events occur off peak to warrant unbiased inclusion in event samples.
    - Further, while estimated frequency response is somewhat degraded for off-peak compared to on-peak events, differences do not appear significant.

- Surprisingly, the number of events occurring during TECs is much lower than expected, and, except for 2010 in the Western Interconnection, frequency response is comparable and perhaps improved during TECs. We believe the 2010 WECC results may be a result of having only 2 to 3 events during TECs during that year because the 2008 data did not show similar results.
- The large number of events occurring during transition hours and off-peak seasons suggests caution regarding excluding such events from data samples.
- For 2010, the day-of-week analysis showed surprising consistency regardless of the day of the week. Results were different using 2008 data, again suggesting that the benefits of including such events in sample data outweigh the detriments and simplify selection criteria.
- Comparing 2008 data to 2010 results for month of year, hour of day, and minute of hour, the team found insufficient data or trends to identify further recommendations beyond the ones previously described. However, the variability of calculated frequency response for events correlated as described supports the need for robust statistical analysis and large sample sizes if reasonable results are to be achieved.