

**2014 Frequency Response Annual Analysis**

December 2014



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# Preface

The North American Electric Reliability Corporation (NERC) is a not-for-profit international regulatory authority whose mission is to ensure the reliability of the bulk power system (BPS) in North America. NERC develops and enforces Reliability Standards; annually assesses seasonal and long‐term reliability; monitors the BPS through system awareness; and educates, trains, and certifies industry personnel. NERC’s area of responsibility spans the continental United States, Canada, and the northern portion of Baja California, Mexico. NERC is the electric reliability organization (ERO) for North America, subject to oversight by the Federal Energy Regulatory Commission (FERC) and governmental authorities in Canada. NERC’s jurisdiction includes users, owners, and operators of the BPS, which serves more than 334 million people.

The North American BPS is divided into eight Regional Entities (RE), as shown in the map and corresponding table below.

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| **FRCC** | Florida Reliability Coordinating Council |
| **MRO** | Midwest Reliability Organization |
| **NPCC** | Northeast Power Coordinating Council |
| **RF** | ReliabilityFirst  |
| **SERC** | SERC Reliability Corporation |
| **SPP-RE** | Southwest Power Pool Regional Entity |
| **TRE** | Texas Reliability Entity |
| **WECC** | Western Electricity Coordinating Council |

## This Report

This report is the 2014 annual analysis of Frequency Response performance for the administration and support of NERC Reliability Standard BAL-003-1 – Frequency Response and Frequency Bias Setting. It provides an update to the statistical analyses and calculations contained in the *2012 Frequency Response Initiative Report* approved by the NERC Resources Subcommittee and Operating Committee, and accepted by the NERC Board of Trustees. No changes are proposed to the procedures recommended in that report.

This report, prepared by the NERC staff,[[1]](#footnote-1) contains the analysis and annual recommendations for the calculation of the Interconnection Frequency Response Obligation (IFRO) for each of the four electrical interconnections of North America for the operational year 2015 (December 2014 through November 2015). This includes:

* Statistical analysis of the interconnection frequency characteristics for the period January 1, 2011 through December 31, 2013.[[2]](#footnote-2)
* Analysis of the interconnection frequency response performance for frequency events occurring between January 1, 2011, and May 31, 2014 to determine appropriate adjustment factors for calculating the IFROs.
* Dynamics analysis of the recommended IFROs.

This report also includes:

* Analysis of frequency anomalies discovered in the 1-second frequency data used as the basis for calculating starting frequencies.
* Analysis of outlier events in frequency response performance contained in the *State of Reliability 2014* report for the Eastern Interconnection.
* Recommendations for additional frequency analysis and proposed changes to the detection and selection of frequency events for the ALR 1-12 Frequency Response metric.

*This report was approved by the Resources Subcommittee on January \_\_\_\_\_\_\_, 2015, via e-mail vote.*

*This report was approved by the Operating Committee Executive Committee on January\_\_\_\_\_\_\_\_\_\_\_, 2015, via conference call/e-mail vote.*

# Executive Summary

## Recommendations

The following are the recommended parameters and adjustments to use when calculating the IFROs for the 2015 Frequency Response period (December 2014 through November 2015) during the BAL-003-1 Field Trial.

In accordance with the BAL-003-1 detailed implementation plan (and as a condition of approval by the Resources Subcommittee and the Operating Committee), these analyses are to be performed annually and the results published by November 15 each year, starting in 2015.

1. No changes are proposed to the procedures recommended in the *2012 Frequency Response Initiative Report*.
2. The IFROs for operating year 2015 (December 2014 through November 2015) are calculated as shown in Table A.

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| **Table A: Recommended IFROs** |
|  | Eastern(EI) | Western(WI) | ERCOT(TI) | Québec(QI) | Units |
| Starting Frequency | 59.974 | 59.968 | 59.965 | 59.968 | Hz |
| Max. Allowable Delta Frequency | 0.444 | 0.273 | 0.391 | 0.927 | Hz |
| Resource Contingency Protection Criteria  | 4,500 | 2,626 | 2,750 | 1,700 | MW |
| Credit for LR | – | 150 | 909 | – | MW |
| **IFRO[[3]](#footnote-3)** | **-1,014** | **-907** | **-471** | **-183** | **MW/0.1Hz** |
| **Absolute Value of IFRO** | **1,014** | **907** | **471** | **183** | **MW/0.1Hz** |
| Absolute Value of Current Interconnection Frequency Response Performance[[4]](#footnote-4) | 2,309 | 1,491 | 810 | 603 | MW/0.1Hz |
| 2015 IFRO as a % of Interconnection Load[[5]](#footnote-5) | 0.16% | 0.58% | 0.68% | 0.48% |  |

1. A Value B to Point C prime adjustment (BC'ADJ) of 17.4 mHz should continue to be made to the Eastern Interconnection allowable delta frequency to compensate for the predominant withdrawal of primary frequency response exhibited in that interconnection. The BC'ADJ was introduced in the 2012 *Frequency Response Initiative Report* analysis of the Eastern Interconnection frequency response. Analysis of the frequency events for that interconnection from January 2011 through May 2014 showed a lower nadir (Point C') for the events that typically occur in the T+52 to T+65 second time frame, beyond the measurements of Point C or Value B. Similar analysis of frequency events in the Western, ERCOT, and Québec Interconnections showed that any later nadirs occurred within the time frames of the measurements of Point C or Value B. Therefore, no BC'ADJ is necessary for those interconnections.
2. Monthly processing of 1-second data and weekly review of frequency event candidates for both ALR 1-12 and BAL-003-1 are recommended to discover problems sooner and ensure consistency in event selection.
3. The frequency event detection triggers and selection criteria be modified to remove restrictions that tend to skew the statistical analysis of interconnection frequency response performance.[[6]](#footnote-6)

## Findings

1. The Frequency Response performance exhibits stable trends for all four interconnections from 2011 through 2013.
2. Frequency event selection errors during 2013 were found in the ALR 1-12 Frequency Response metric presented in the *State of Reliability 2014* report. This resulted in 19 Eastern Interconnection events being eliminated from the ALR 1-12 events. The analysis for the Eastern Interconnection is corrected in this report and that correction has been made to the NERC Reliability Indicators dashboard.[[7]](#footnote-7)
3. Frequency step-change[[8]](#footnote-8) anomalies were found in the 2013 1-second Eastern Interconnection frequency data used to determine the starting frequency for the IFRO calculations. The problem was traced back to toggling back and forth between two data sources in the calculation of the 1-second averaged data. The entire 2013 1-second database was recalculated to correct the problem.
4. An error was discovered in several start times for frequency events in the Eastern, Western, ERCOT, and Québec Interconnections starting in July 2013.[[9]](#footnote-9) The problem arose from a sign error in an adjustment factor used to remove a time skew inherent in the high-speed metrology; instead of removing the time skew, the adjustment factor was doubling it. This impacted several of the adjustment factors used in the IFRO calculation related to Point C. The error was corrected and all timing of frequency events have been recalculated for this and future analyses.
5. Several sources of sub-second data were determined to be in maintenance/offline mode, which resulted in the provision of inaccurate sub-second frequency data. The sub-second data was corrected by replacing the erroneous sources with data from operational data sources available during frequency events.
6. For the ERCOT Interconnection IFRO calculation, credit for load resources was increased from 895 MW used in the 2013 calculations to a statistically determined 909 MW. This represents the amount of contractual 1,400 MW load resource that is available 95 percent of the time. Additionally, the ERCOT CBR ratio increased significantly due to changes in the interconnection’s frequency response performance in 2013. That change increased the ERCOT Interconnection IFRO by 58 MW/0.1 Hz. ERCOT has been experiencing a displacement of coal-fired generation by gas-fired combined cycle units in their dispatch due to lower prices for natural gas. While the combined cycle units are responsive in the Value B calculation timeframe (+20 to +52 seconds), they are slower than the steam units to respond in the arresting power timeframe (+0 to +20 seconds). This results in a similar Value B response but a lower Point C nadir, increasing the CBR ratio, as the performance in 2013-2014 displaces the older performance characteristics.
7. Dynamics simulations of the Eastern, Western, and ERCOT Interconnections for the recommended IFROs showed those levels of primary frequency response to be adequate to avoid tripping of the first stage of the interconnection UFLS systems. Light-load cases were used for all three of these analyses.

# Frequency Response Performance Analysis

Every year, NERC analyzes the Frequency Response performance of the four interconnections in the *State of Reliability* report. The following charts and statistics are drawn from the *State of Reliability 2014* report and the Interconnection Frequency Response from the NERC Reliability Indicators dashboard.[[10]](#footnote-10) The 2013 frequency response performance values for each interconnection are used to compare the IFROs calculated in 2013 for the 2014 operating year to (December 2013 through November 2014).

## Eastern Interconnection

The analysis below reflects the corrected data, showing steady frequency response performance for the Eastern Interconnection.

NOTE: Frequency response performance data from the Eastern Interconnection in the *State of Reliability 2014* report were reviewed in detail due to outliers that appeared to show a statistically significant decrease of frequency response in 2013 compared to 2011. Nineteen inappropriate frequency events were found to have been included in error.

Revised statistical analysis of the annual changes in Eastern Interconnection Frequency Response concluded that there were no other statistically significant changes in the expected frequency response by year for the Eastern Interconnection.



Figure : Eastern Interconnection Frequency Response Trend 2009–2013

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| **Table 1: Eastern Interconnection Frequency Response Statistics** |
| **Year** | **Number of Events** | **MW/0.1 Hz** | **Number of Events with****FR below the****|IFRO=1,014[[11]](#footnote-11)|** |
| **Mean of Frequency Response** | **Std. Dev. of Frequency Response** | **Min.** | **Max.**  |
| 2009–2013 | 238 | 2,349.2 | 582.3 | 1,102.5 | 4,335.9 | 0 |
| 2009 | 44 | 2,258.4 | 522.5 | 1,404.8 | 3,625.0 | 0 |
| 2010 | 49 | 2,335.7 | 697.6 | 1,102.5 | 4,335.9 | 0 |
| 2011 | 65 | 2,467.8 | 593.7 | 1,210.0 | 3,815.2 | 0 |
| 2012 | 28 | 2,314.3 | 523.6 | 1,374.0 | 3,921.4 | 0 |
| 2013 | 52 | 2,309.2 | 523.3 | 1,491.0 | 3,696.3 | 0 |

## Western Interconnection

It was not possible to statistically analyze the annual changes in the Western Interconnection Frequency Response due to the small sample sizes for each year.



Figure : Western Interconnection Frequency Response Trend 2009–2013

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| **Table 2: Western Interconnection Frequency Response Statistics** |
| **Year** | **Number of Events** | **MW/0.1 Hz** | **Number of Events with****FR below the****|IFRO=949[[12]](#footnote-12)|** |
| **Mean of Frequency Response** | **Std. Dev. of Frequency Response** | **Min.** | **Max.**  |
| 2009–2013 | 119 | 1,514.0  | 422.9 | 816.7 | 3,125.0 | 3 |
| 2009 | 25 | 1,513.6 | 295.7 | 1,000.0 | 2,027.0 | 0 |
| 2010 | 29 | 1,572.2 | 512.3 | 816.7 | 3,125.0 | 2 |
| 2011 | 25 | 1,496.5 | 391.9 | 1,078.6 | 2,894.6 | 0 |
| 2012 | 12 | 1,466.8 | 557.2 | 997.0 | 3,123.5 | 0 |
| 2013 | 28 | 1,491.2 | 404.3 | 821.9 | 2,851.0 | 1 |

## ERCOT Interconnection

Statistical analysis of the annual changes in ERCOT Interconnection Frequency Response found four statistically significant improvements in the expected frequency response (between 2009 and 2013, between 2010 and 2013, between 2011 and 2013, and between 2012 and 2013).



Figure : ERCOT Interconnection Frequency Response Analysis for 2009–2013

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| **Table 3: ERCOT Interconnection Frequency Response Statistics** |
| **Year** | **Number of Events** | **MW/0.1 Hz** | **Number of Events with****FR below the****|IFRO=413[[13]](#footnote-13)|** |
| **Mean of Frequency Response** | **Std. Dev. of Frequency Response** | **Min.** | **Max.**  |
| 2009–2013 | 298 | 612.2  | 240.8 | 228.0 | 2,552.8 | 34 |
| 2009 | 51 | 595.2 | 185.0 | 263.5 | 1,299.1 | 5 |
| 2010 | 67 | 609.7 | 164.8 | 367.6 | 1,152.5 | 3 |
| 2011 | 65 | 509.6 | 131.3 | 228.0 | 993.0 | 15 |
| 2012 | 63 | 571.2 | 191.9 | 290.4 | 1,417.9 | 9 |
| 2013 | 52 | 809.8 | 383.2 | 378.7 | 2,552.8 | 2 |

Several factors contributed to the frequency response performance improvement in the ERCOT Interconnection in 2012 and 2013.

* During 2013 generators continued to improve their delivery of Primary Frequency Response as they completed process control improvements as a result of the 2012 TRE investigations into Primary Frequency Response performance of generators.
* Approval and implementation of Regional Standard BAL-001-TRE-1 - Primary Frequency Response in the ERCOT Region has begun. This regional standard sets specific Governor droop and dead-band settings and provides performance measures to assure delivery of Primary Frequency Response from generators. Generators and the Balancing Authority are actively working to meet the implementation deadlines set in this regional standard.

## Québec Interconnection

Statistical analysis of the annual changes in Québec Interconnection Frequency Response found there are no statistically significant changes in the expected frequency response by year for Québec Interconnection.



Figure : Québec Interconnection Frequency Response Analysis for 2011–2013

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| **Table 4: Québec Interconnection Frequency Response Statistics** |
| **Year** | **Number of Events** | **MW/0.1 Hz** | **Number of Events with****FR below the****|IFRO=180[[14]](#footnote-14)|** |
| **Mean of Frequency Response** | **Std. Dev. of Frequency Response** | **Min.** | **Max.**  |
| 2011–2013 | 85 | 575.3 | 202.9 | 214.7 | 1,228.0 | 0 |
| 2011 | 20 | 499.1 | 153.6 | 214.7 | 829.9 | 0 |
| 2012 | 28  | 592.7 | 212.4 | 305.9 | 1,202.1 | 0 |
| 2013 | 37 | 603.3 | 213.3 | 250.9 | 1,227.8 | 0 |

# Interconnection Frequency Characteristic Analysis

## Frequency Variation Statistical Analysis

NERC staff annually performs a statistical analysis[[15]](#footnote-15) of the variability of frequency for each of the four interconnections using a three-year window of one-second measured frequency. For this report’s analysis, frequency data from 2011–2013 was used and summarized in Table 5.

This variability accounts for items such as time-error correction; variability of load, interchange, and frequency over the course of a normal day; and other uncertainties, including all frequency events.

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| **Table 5: Interconnection Frequency Variation Analysis** |
| Value | Eastern | Western | ERCOT | Québec |
| Time Frame | 2011-2013 | 2011-2013 | 2011-2013 | 2011-2013 |
| Number[[16]](#footnote-16) of Samples | 91,199,012 | 91,520,116 | 88,907,597 | 87,201,647 |
| Expected Value (Hz) | 60.000 | 59.994 | 59.992 | 59.982 |
| Variance of Frequency (σ²) (Hz²) | 0.00024 | 0.00844 | 0.01448 | 0.03360 |
| Standard Deviation (σ) (Hz) | 0.01543 | 0.09189 | 0.12032 | 0.18331 |
| 2σ (Hz) | 0.03086 | 0.18377 | 0.24065 | 0.36662 |
| 3σ (Hz) | 0.04629 | 0.27566 | 0.36097 | 0.54992 |
| Starting Frequency (FStart)5% of lower tail samples (Hz) | **59.974** | **59.968** | **59.965** | **59.968** |

Those starting frequencies encompass all variations in frequency, including changes to the target frequency during time-error correction (TEC). That eliminates the need to expressly evaluate TEC as a variable in the IFRO calculation. Therefore, the starting frequency for the calculation of IFROs should remain the frequency calculated at 5% of the lower tail of samples from the statistical analysis, which represents a 95% chance that frequencies will be at or above that value at the start of any frequency event.

Figures 5–8 show the probability density function of frequency for each interconnection.



Figure : Eastern Interconnection 2011–2013 Probability Density Function of Frequency



Figure : Western Interconnection 2011–2013 Probability Density Function of Frequency



Figure : ERCOT Interconnection 2011–2013 Probability Density Function of Frequency

Note that the ERCOT frequency probability density still displays some minor influence of the “flat-top” profile that was common to that interconnection prior to 2008. That phenomenon was caused by a standardized ±36 mHz deadband with a step-function implementation. This is significantly less pronounced than it was in the 2012 analysis as the impacts of migration toward a ±16.7 mHz deadband with a proportional response implementation became more pronounced in the 2011 and 2012 data.



Figure : Québec Interconnection 2011–2013 Probability Density Function of Frequency

### Changes in Starting Frequency

Comparing the results of the 2014 frequency variability analysis for the 2011–2013 data with those conducted in 2013 (Table 6) shows only slight variations in the starting frequencies.

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| **Table 6: Comparison of Interconnection Frequency Statistics(Hz)** |
| Expected Frequencies |
|  | 2013 Analysis | 2014 Analysis | Change |
| Eastern  | 60.000 | 60.000 | – |
| Western | 59.996 | 59.994 | -0.002 |
| ERCOT | 59.994 | 59.992 | -0.002 |
| Québec  | 59.980 | 59.982 | 0.002 |
| Starting Frequencies |
| Eastern  | 59.974 | 59.974 | – |
| Western | 59.971 | 59.968 | -0.003 |
| ERCOT | 59.964 | 59.965 | 0.001 |
| Québec  | 59.968 | 59.968 | – |

# Determination of Interconnection Frequency Response Obligations (IFROs)

## Tenets of IFRO

The IFRO is the minimum amount of Frequency Response that must be maintained by an interconnection. Each Balancing Authority (BA) in the interconnection should be allocated a portion of the IFRO that represents its minimum responsibility. To be sustainable, BAs that may be susceptible to islanding may need to carry additional frequency-responsive reserves to coordinate with their underfrequency load shedding (UFLS) plans for islanded operation.

A number of methods to assign the Frequency Response targets for each interconnection can be considered. Initially, the following tenets should be applied:

1. A frequency event should not trip the first stage of regionally approved UFLS systems within the interconnection.
2. Local tripping of first-stage UFLS systems for severe frequency excursions, particularly those associated with protracted faults or on systems on the edge of an interconnection, may be unavoidable.
3. Other frequency-sensitive loads or electronically coupled resources may trip during such frequency events (as is the case for photovoltaic inverters in the Western Interconnection).
4. It may be necessary in the future to consider other susceptible frequency sensitivities (e.g., electronically coupled load common-mode sensitivities).

UFLS is intended to be a safety net to prevent system collapse from severe contingencies. Conceptually, that safety net should not be violated for frequency events that happen on a relatively regular basis. As such, the resource loss protection criteria were selected through the Frequency Response Initiative 2012 analysis to avoid violating regionally approved UFLS settings.

## IFRO Formulae

The following are the formulae that comprise the calculation of the IFROs.

$$DF\_{Base}= F\_{Start}- UFLS$$

$$DF\_{CC}= DF\_{Base}- CC\_{Adj}$$

$$DF\_{CBR}= \frac{DF\_{CC}}{CB\_{R}}$$

$$MDF= DF\_{CBR}- BC'\_{Adj}$$

$$ARLPC=RLPC-CLR$$

$$IFRO= \frac{ARLPC}{MDF}$$

Where:

* DFBase is the base delta frequency.
* FStart is the starting frequency determined by the statistical analysis.
* UFLS is the highest UFLS trip set point for the interconnection.
* CCADJ is the adjustment for the differences between one-second and sub-second Point C observations for frequency events. A positive value indicates that the sub-second C data is lower than the one-second data.
* DFCC is the delta frequency adjusted for the differences between one-second and sub-second Point C observations for frequency events.
* CBR is the statistically determined ratio of the Point C to Value B.
* DFCBR is the delta frequency adjusted for the ratio of Point C to Value B.
* BC'ADJ is the statistically determined adjustment for the event nadir occurring below the Value B (Eastern Interconnection only) during primary frequency response withdrawal.
* MDF is the maximum allowable delta frequency.
* RLPC is the resource loss protection criteria.
* CLR is the credit for load resources.
* ARLPC is the adjusted resource loss protection criteria adjusted for the credit for load resources.
* IFRO is the interconnection Frequency Response obligation.

## Determination of Adjustment Factors

### Adjustment for Differences between Value B and Point C (CBR)

All of the calculations of the IFRO are based on avoiding instantaneous or time-delayed tripping of the highest set point (step) of UFLS, either for the initial nadir (Point C), or for any lower frequency that might occur during the frequency event. The frequency variance analysis in the previous section of this report is based on one-second data from January 2011 through May 2014.

As a practical matter, the ability to measure the tie line and loads for the BAs is limited to supervisory control and data acquisition (SCADA) scan-rate data of 1–6 seconds. Therefore, the ability to measure Frequency Response of the BAs is still limited by the SCADA scan rates available to calculate Value B.

Candidate events from the ALR1-12 Interconnection Frequency Response selection process for Frequency Response analysis were used to analyze the relationship between Value B and Point C for the significant frequency disturbances from January 2011 through May 2014. This sample set was selected because data was available for the analysis on a consistent basis. This resulted in the number of events shown in Table 7.

#### Analysis Method

The IFRO is the minimum performance level that the BAs in an interconnection must meet through their collective Frequency Response to a change in frequency. This response is also related to the function of the Frequency Bias Setting in the area control error (ACE) equation of the BAs for the longer term. The ACE equation looks at the difference between scheduled frequency and actual frequency, times the Frequency Bias Setting to estimate the amount of megawatts that are being provided by load and generation within the BA. If the actual frequency is equal to the scheduled frequency, the Frequency Bias component of ACE must be zero.

When evaluating some physical systems, the nature of the system and the data resulting from measurements derived from that system do not fit the standard linear regression methods that allow for both a slope and an intercept for the regression line. In those cases, it is better to use a linear regression technique that represents the system correctly.

Since the IFRO is ultimately a projection of how the interconnection is expected to respond to changes in frequency related to a change in megawatts (resource loss or load loss), there should be no expectation of Frequency Response without an attendant change in megawatts. It is this relationship that indicates the appropriateness of using regression with a forced fit through zero.

#### Determination of C-to-B Ratio (CBR)

The evaluation of data to determine the C-to-B ratio (CBR) to account for the differences between arrested Frequency Response (to the nadir, Point C) and settled Frequency Response (Value B) is also based on a physical representation of the electrical system. Evaluation of this system requires investigation of the meaning of an intercept. The CBR is defined as the difference between the pre-disturbance frequency and the frequency at the maximum deviation in post-disturbance frequency, divided by the difference between the pre-disturbance frequency and the settled post-disturbance frequency.

$$CB\_{R}= \frac{Value A-Point C}{Value A-Value B}$$

A stable physical system requires the ratio to be positive; a negative ratio indicates frequency instability or recovery of frequency greater than the initial deviation. The CBR adjusted for confidence (Table 7) should be used to compensate for the differences between Point C and Value B.

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| **Table 7: Analysis of Value B and Point C (CBR)** |
| Interconnection | Events Analyzed | Mean | Standard Deviation | CBR95% Confidence | CBR Adjusted for Confidence |
| Eastern | 158 | 0.954 | 0.193 | 0.025 | 1.000 (0.979)[[17]](#footnote-17) |
| Western | 79 | 1.607 | 0.348 | 0.065 | 1.672 |
| ERCOT | 169 | 1.548 | 1.200 | 0.153 | 1.700 |
| Québec[[18]](#footnote-18) | N/A | N/A | N/A | N/A | 1.550 |

This statistical analysis was completed using one-second averaged data that does not accurately capture Point C, which is better measured by high-speed metering (PMUs or FDRs). Therefore, a separate correction must be used to account for the differences between the Point C in the one-second data and the Point C values measured with sub-second measurements from the FNet[[19]](#footnote-19) (Frequency monitoring Network) FDRs.

The CBR value for the Eastern Interconnection indicates that Value B is generally below the Point C value. Therefore, no adjustment is necessary for that interconnection, and the CBR value is set to 1.000.

The Québec Interconnection’s resources are predominantly hydraulic and are operated to optimize efficiency, typically at about 85 percent of rated output. Consequently, most generators have about 15 percent headroom to supply primary frequency response. This results in a robust response to most frequency events, exhibited by high rebound rates between Point C and the calculated Value B. For the 67 frequency events in their event sample, Québec’s CBR value would be 4.161, or 2 to 4 times the CBR values of other interconnections. Using the same calculation method for CBR would effectively penalize Québec for their rapid rebound performance and make their IFRO artificially high. Therefore, the method for calculating the Québec CBR was modified.

Québec operates with an operating mandate for frequency responsive reserves to prevent tripping their 58.5 Hz (300 millisecond trip time) first step UFLS for their largest hazard at all times, effectively protecting against tripping for Point C frequency excursions. Québec also protects against tripping a UFLS step set at 59.0 Hz that has a 20-second time delay, which protects them from any sustained low frequency Value B and primary frequency response withdrawals. This results in a Point C to Value B ratio of 1.5. To account for the confidence interval, 0.05 is then added, making the CBR = 1.550.

### Point C Analysis – One-Second versus Sub-Second Data (CCADJ)

The basic statistical analysis of the frequency events was performed for the differences between Point C and Value B, calculated as a ratio of Point C to Value B, using one-second data for events from January 2011 through May 2014. Although the one-second data sample is robust, it does not necessarily ensure the nadir of the event was accurately captured. To do so requires sub-second measurements that can only be provided by phasor measurement units (PMUs) or frequency disturbance recorders (FDRs). Therefore, a “C to C” adjustment component (CCADJ) for the IFRO calculation was designed to account for the differences observed between the one-second Point C and high-speed Point C measurements. The value used is the CCADJ adjusted for confidence from Table 8.

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| **Table 8: Analysis of One-Second and Sub-Second Data for Point C (CCADJ)** |
| Interconnection | Events Analyzed | Mean(Hz) | Standard Deviation(Hz) | CCADJ(95% Quantile)(Hz) | CCADJAdjusted for Confidence (Hz) |
| Eastern | 158 | 0.011 | 0.014 | 0.032 | 0.013 |
| Western | 78 | 0.009 | 0.010 | 0.018 | 0.011 |
| ERCOT | 154 | -0.006 | 0.050 | 0.035 | 0.001 |
| Québec | 19 | 0.026 | 0.013 | 0.067 | 0.031 |

The CCADJ should be made to the allowable frequency deviation value before it is adjusted for the ratio of Point C to Value B.

### Adjustment for Primary Frequency Response Withdrawal (BC’ADJ)

At times, the nadir for a frequency event occurs after Point C—defined in BAL-003-1 as occurring in the T+0 to T+12 second period, during the Value B averaging period (T+20 through T+52 seconds), or later. For purposes of this report, that later-occurring nadir is termed Point C’. This lower nadir is symptomatic of primary frequency response withdrawal, or squelching, by unit or plant-level outer-loop control systems. Withdrawal is most prevalent in the Eastern Interconnection.

Primary frequency response withdrawal can become important depending on the type and characteristics of the generators in the resource dispatch, especially during light-load periods. Therefore, an additional adjustment to the maximum allowable delta frequency for calculating the IFROs was statistically developed. This adjustment should be used whenever withdrawal is a prevalent feature of frequency events.

Table 9 shows the number of events for each interconnection where the C’ value was lower than Value B (averaged from T+20 through T+52 seconds) for the period of January 2011 through May 2014. A sample of T+300 one-second data was used for this analysis.

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| **Table 9: Statistical Analysis of the Adjustment for C’ Nadir (BC’ADJ)** |
| Interconnection | EventsAnalyzed | Events W/C’Lower than B | Mean | Standard Deviation | BC’ADJ(95% Quantile) |
| Eastern | 160 | 159 | 7.3 mHz | 5.5 mHz | 17.4 mHz |
| Western[[20]](#footnote-20) | 79 | 79 | 30.5 mHz | 15.5 mHz | 48.6 mHz |
| ERCOT20 | 169 | 169 | 26.7 mHz | 21.9 mHz | 68.9 mHz |
| Québec20 | 67 | 67 | 223.1 mHz | 91.2 mHz | 408.7 mHz |

Table 10 shows when Point C’ occurred after T+0. For the Western, ERCOT, and Québec Interconnections, the occurrences of Point C’ were before or within the Value B time frame, indicating that a Point C’ adjustment to Value B is not needed in those interconnections.

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| **Table 10: Seconds from T+0 to C’ Nadir** |
| Interconnection | TotalEvents | Events W/C’Lower than B | Mean | Point C’ Time(Confidence Adjusted) |
| Eastern | 160 | 159 | 58 | 52 s to 65 s |
| Western | 79 | 79 | 15 | 12 s to 19 s |
| ERCOT | 169 | 169 | 26 | 21 s to 31 s |
| Québec | 67 | 67 | 12 | 12 s |

Note that the expected time for the Point C’ nadir to occur in the Eastern Interconnection is 52 to 65 seconds after the start of the event, which is beyond the Value B time frame. Therefore, a BC’ADJ of 17.4 mHz is appropriate for the Eastern Interconnection. No BC’ADJ is used for the other three interconnections.

The 95 percent quantile value is used for the Eastern Interconnection BC’ADJ to account for the statistically expected Point C’ value of a frequency event.

### Variables in Determination of IFRO

To determine the IFROs, a number of other variables must be taken into consideration.

#### Low-Frequency Limit

The low-frequency limit to be used for the IFRO calculations should be the highest step in the interconnection for regionally approved UFLS systems.

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| **Table 11: Low-Frequency Limits (Hz)** |
| Interconnection | Highest UFLS Trip Frequency |
| Eastern | 59.5 |
| Western | 59.5 |
| ERCOT | 59.3 |
| Québec | 58.5 |

Note that the highest UFLS set point in the Eastern Interconnection is 59.7 Hz in FRCC, while the prevalent highest set point in the rest of that interconnection is 59.5 Hz. The FRCC 59.7 Hz first UFLS step is based on internal stability concerns and for preventing the separation of the Florida peninsula from the rest of the interconnection. FRCC concluded that the IFRO starting point of 59.5 Hz for the Eastern Interconnection is acceptable in that it imposes no greater risk of UFLS operation for an interconnection resource loss event than for an internal FRCC event.

Protection against tripping the highest step of UFLS does not ensure that generation that has frequency-sensitive boiler or turbine control systems will not trip. Severe system conditions might drive the frequency and voltage to levels that may present a combination of conditions to control systems that may cause the generation to trip. Severe rate-of-change in voltage or frequency, which might actuate volts-per-hertz relays, could trip the unit. Similarly, some combustion turbines may not be able to sustain operation at frequencies below 59.5 Hz.

Also, electronically-coupled resources are susceptible to extremes in frequency. Southern California Edison’s recent laboratory testing of inverters used on residential and commercial scale photovoltaic (PV) systems revealed a propensity to trip at about 59.4 Hz, which is 200 mHz above the expected 59.2 Hz prescribed in IEEE Standard 1547 for distribution-connected PV systems rated at or below 30 kW (57.0 Hz for larger installations). This could become problematic in the future in areas of high penetration of PV resources.

#### Credit for Load Resources (CLR)

The ERCOT Interconnection depends on contractually interruptible demand that automatically trips at 59.7 Hz to help arrest frequency declines. A load resource credit of up to 1,400 MW (formerly called Load acting as a Resource – LaaR) may be included against the resource contingency for the ERCOT Interconnection. The actual amount of CLR available at any given time varies. Therefore, NERC performed a statistical analysis on hourly available CLR for the period of January 2011 through May 2014. That analysis indicated that at least 909 MW of CLR is available 95 percent of the time. Therefore, a CLR adjustment of 909 MW should be applied in the calculation of the ERCOT IFRO instead of the contractual 1,400 MW, handled in the calculation of the IFRO as a reduction to the loss of resources. This is 14 MW higher than the 895 MW adjustment used in the 2013 IFRO calculations.

### Determination of Maximum Allowable Delta Frequencies

Because of the measurement limitation of the BA-level Frequency Response performance using Value B, the IFROs must be calculated in “Value B space.” Protection from tripping UFLS for the interconnections based on Point C , Value B , or any nadir occurring after point C, within Value B, or after T+52 seconds, must be reflected in the maximum allowable delta frequency for IFRO calculations expressed as a Value B.

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| **Table 12: Determination of Maximum Allowable Delta Frequencies** |
|  | Eastern | Western | ERCOT | Québec | Units |
| Starting Frequency | 59.974 | 59.968 | 59.965 | 59.968 | Hz |
| Minimum Frequency Limit | 59.500 | 59.500 | 59.300 | 58.500 | Hz |
| Base Delta Frequency | 0.474 | 0.468 | 0.665 | 1.468 | Hz |
| CCADJ[[21]](#footnote-21) | 0.013 | 0.011 | 0.001 | 0.031 | Hz |
| Delta Frequency (DFCC) | 0.461 | 0.457 | 0.664 | 1.437 | Hz |
| CBR[[22]](#footnote-22) | 1.000[[23]](#footnote-23) | 1.672 | 1.700 | 1.550[[24]](#footnote-24) | Ratio |
| Delta Frequency (DFCBR)[[25]](#footnote-25) | 0.461 | 0.273 | 0.391 | 0.927 | Hz |
| BC’ADJ[[26]](#footnote-26) | 0.017 | N/A | N/A | N/A | Hz |
| Max. Allowable Delta Frequency | 0.444 | 0.273 | 0.391 | 0.927 | Hz |

Table 12 shows the calculation of the maximum allowable delta frequencies for each of the interconnections. All adjustments to the maximum allowable change in frequency are made to include:

* Adjustments for the differences between one-second and sub-second Point C observations for frequency events;
* Adjustments for the differences between Point C and Value B; and
* Adjustments for the event nadir being below Value B (Eastern Interconnection only) due to primary frequency response withdrawal.

#### Comparison of Maximum Allowable Delta Frequencies

The following is a comparison of the 2014 maximum allowable delta frequencies with those presented in the 2013 *Frequency Response Annual Analysis* report.

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| **Table 13a: Maximum Delta Allowable Frequency Comparison** |
| **Eastern** | **2013** | **2014** | **Change** | **Units** |
| Starting Frequency | 59.974 | 59.974 | – | Hz |
| Min. Frequency Limit | 59.500 | 59.500 | – | Hz |
| Base Delta Frequency | 0.474 | 0.474 | – | Hz |
| CCADJ | 0.009 | 0.013 | 0.004 | Hz |
| Delta Frequency (DFCC) | 0.465 | 0.461 | -0.004 | Hz |
| CBR | 1.000 | 1.000 | – | Ratio |
| Delta Freq. (DFCBR) | 0.465 | 0.461 | -0.004 | Hz |
| BC’ADJ | 0.021 | 0.017 | -0.004 | Hz |
| Max. Allowable Delta Frequency | 0.444 | 0.444 | – | Hz |
| **Western** | **2013** | **2014** | **Change** | **Units** |
| Starting Frequency | 59.971 | 59.968 | -0.003 | Hz |
| Min. Frequency Limit | 59.500 | 59.500 | – | Hz |
| Base Delta Frequency | 0.471 | 0.468 | -0.003 | Hz |
| CCADJ | 0.008 | 0.011 | 0.003 | Hz |
| Delta Frequency (DFCC) | 0.463 | 0.457 | -0.006 | Hz |
| CBR | 1.774 | 1.672 | -0.102 | Ratio |
| Delta Freq. (DFCBR) | 0.261 | 0.273 | 0.012 | Hz |
| BC’ADJ | N/A | N/A | – | Hz |
| Max. Allowable Delta Frequency | 0.261 | 0.273 | 0.012 | Hz |

In the Eastern Interconnection, the 4 mHz increase in CCADJ is offset by the 4 mHz decrease in BC'ADJ, resulting in no change to the Maximum Allowable Delta Frequency.

There is an increase of 12 mHz in the Western Interconnection maximum allowable delta frequency caused by:

* 0.003 Hz decrease in the starting frequency;
* 0.003 Hz increase in the CCADJ; and
* 0.102 decrease in the CBR ratio.

These changes are caused by the changes in the interconnection's frequency characteristics and changes to the Frequency Response performance in the analyzed events.

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| **Table 13b: Maximum allowable delta Frequency Comparison** |
| **ERCOT** | **2013** | **2014** | **Change** | **Units** |
| Starting Frequency | 59.964 | 59.965 | 0.001 | Hz |
| Min. Frequency Limit | 59.300 | 59.300 | – | Hz |
| Base Delta Frequency | 0.664 | 0.665 | 0.001 | Hz |
| CCADJ | 0.000 | 0.001 | 0.001 | Hz |
| Delta Frequency (DFCC) | 0.664 | 0.664 | – | Hz |
| CBR | 1.478 | 1.700 | 0.222 | Ratio |
| Delta Freq. (DFCBR) | 0.449 | 0.391 | -0.059 | Hz |
| BC’ADJ | N/A | N/A | – | Hz |
| Max. Allowable Delta Frequency | 0.449 | 0.391 | -0.059 | Hz |
| **Québec** | **2013** | **2014** | **Change** | **Units** |
| Starting Frequency | 59.968 | 59.968 | – | Hz |
| Min. Frequency Limit | 58.500 | 58.500 | – | Hz |
| Base Delta Frequency | 1.468 | 1.468 | – | Hz |
| CCADJ | 0.000 | 0.031 | 0.031 | Hz |
| Delta Frequency (DFCC) | 1.468 | 1.437 | -0.031 | Hz |
| CBR | 1.550 | 1.550 | – | Ratio |
| Delta Freq. (DFCBR) | 0.947 | 0.927 | -0.020 | Hz |
| BC’ADJ | N/A | N/A | – | Hz |
| Max. Allowable Delta Frequency | 0.947 | 0.927 | -0.020 | Hz |

There is a significant reduction of 59 mHz in the ERCOT Interconnection maximum allowable delta frequency caused by:

* The 0.001 Hz increase in the starting frequency;
* a 0.001 Hz increase in the CCADJ; and
* the 0.222 increase in the CBR ratio, caused by significant changes to the ERCOT Frequency Response performance in the analyzed events.

ERCOT has experiencing a displacement of coal-fired generation by gas-fired combined cycle units in their dispatch due to lower prices for natural gas. While the combined cycle units are responsive in the Value B calculation timeframe (+20 to +52 seconds), they are slower than the steam units to respond in the arresting power timeframe (+0 to +20 seconds). This results in a similar Value B response but a lower Point C nadir, increasing the CBR ratio. The performance in 2013-2014 displaces the older performance characteristics.

There is a reduction of 20 mHz in the Québec Interconnection maximum allowable delta frequency resulting from the first-time application of a CCADJ adjustment (no data was available in previous years).

## Recommended IFROs

Table 14 shows the determination of IFROs for operating year 2015 (December 2014 through November 2015) under standard BAL-003-1 based on a resource loss equivalent to the recommended criteria in each interconnection. The maximum allowable delta frequency values have already been modified to include the adjustments for: the differences between Value B and Point C (CBR); the differences in measurement of Point C using one-second and sub-second data (CCADJ); and the event nadir being below the Value B (BC’ADJ).

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| **Table 14: Recommended IFROs** |
|  | Eastern | Western | ERCOT | Québec | Units |
| Starting Frequency | 59.974 | 59.968 | 59.965 | 59.968 | Hz |
| Max. Allowable Delta Frequency | 0.444 | 0.273 | 0.391 | 0.927 | Hz |
| Resource Contingency Protection Criteria  | 4,500 | 2,626 | 2,750 | 1,700 | MW |
| Credit for LR | – | 150 | 909 | – | MW |
| **IFRO[[27]](#footnote-27)** | **-1,014** | **-907** | **-471** | **-183** | **MW/0.1Hz** |
| **Absolute Value of IFRO** | **1,014** | **907** | **471** | **183** | **MW/0.1Hz** |
| Absolute Value of Current Interconnection Frequency Response Performance[[28]](#footnote-28) | 2,309 | 1,491 | 810 | 603 | MW/0.1Hz |
| 2015 IFRO as a % of Interconnection Load[[29]](#footnote-29) | 0.16% | 0.58% | 0.68% | 0.48% |  |

### Comparison to Previous IFRO Values

The IFROs were first calculated and presented in the 2012 *Frequency Response Initiative* *Report*. Recommendations from that report called for an annual analysis and recalculation of the IFROs. The following is a comparison of the current IFROs and their key component values to those presented in the 2013 *Frequency Response Annual Analysis* report.

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| **Table 15a: Interconnection IFRO Comparison** |
| **Eastern** | **2013** | **2014** | **Change** | **Units** |
| Starting Frequency | 59.974 | 59.974 | – | Hz |
| Max. Allowable Delta Frequency | 0.444 | 0.444 | – | Hz |
| Resource Contingency Protection Criteria  | 4,500 | 4,500 | – | MW |
| Credit for LR | – | – | – | MW |
| Absolute Value of IFRO | 1,014 | 1,014 | – | MW/0.1Hz |
| **Western** | **2013** | **2014** | **Change** | **Units** |
| Starting Frequency | 59.971 | 59.968 | -0.003 | Hz |
| Max. Allowable Delta Frequency | 0.261 | 0.273 | 0.012 | Hz |
| Resource Contingency Protection Criteria  | 2,626 | 2,626 | – | MW |
| Credit for LR | 150 | 150 | – | MW |
| Absolute Value of IFRO | 949 | 907 | -42 | MW/0.1Hz |

There is no change to the IFRO for the Eastern Interconnection.

There is a 42 MW decrease in the Western Interconnection IFRO caused by:

* The 3 mHz reduction in the Western Interconnection starting frequency; and
* The 12 mHz increase in the Maximum Allowable Delta Frequency attributable to a decrease in the CBR ratio[[30]](#footnote-30).

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| **Table 15b: Interconnection IFRO Comparison** |
| **ERCOT** | **2013** | **2014** | **Change** | **Units** |
| Starting Frequency | 59.964 | 59.965 | 0.001 | Hz |
| Max. Allowable Delta Frequency | 0.449 | 0.391 | -0.059 | Hz |
| Resource Contingency Protection Criteria  | 2,750 | 2,750 | – | MW |
| Credit for LR | 895 | 909 | 14 | MW |
| Absolute Value of IFRO | 413 | 471 | 58 | MW/0.1Hz |
| **Québec** | **2013** | **2014** | **Change** | **Units** |
| Starting Frequency | 59.968 | 59.968 | – | Hz |
| Max. Allowable Delta Frequency | 0.947 | 0.927 | -0.020 | Hz |
| Resource Contingency Protection Criteria  | 1,700 | 1,700 | – | MW |
| Credit for LR | – | – | – | MW |
| Absolute Value of IFRO | 180 | 183 | 3 | MW/0.1Hz |

There is a 58 MW increase in the ERCOT Interconnection IFRO caused by:

* The 59 mHz reduction in the ERCOT Interconnection maximum allowable delta frequency; offset only slightly
* The 14 MW increase in the load resources credit, as discussed in the Credit for Load Resources (CLR) section of this report.

There is only a minor change to the Québec Interconnection IFRO caused by the 0.020 Hz decrease in the maximum allowable delta frequency due to the first-time application of a CCADJ adjustment (no data was available in previous years).

# Dynamics Analysis of Recommended IFROs

Off-peak dynamics analysis was performed for the recommended IFROs for the Eastern, Western, and ERCOT Interconnections to determine if those levels of primary frequency response are adequate to avoid tripping of the first stage of regionally approved UFLS systems in the interconnection. Light-load cases prepared by each of the interconnections were used for the analyses. In each case, the dynamic governor responses were de-tuned until the primary frequency response of the interconnection matched the recommended IFRO value for the prescribed resource loss. In all three simulations, the effects of automatic generation control (AGC), which typically starts to influence Frequency Response in the 30-45 second time frame, were not modeled. This causes the modeled withdrawal of primary frequency response to be exaggerated (see Figure 9).

For the Eastern Interconnection, a 2014 light-load case was for the analysis that reflects models of the actual governors and a best estimate of units participating in response. That case was created by the Eastern Interconnection Reliability Assessment Group (ERAG) Multiregional Modeling Working Group (MMWG). In the 2013 analysis, a 2013 light-load “generic” dynamics case was used, created by replacing the turbine governor models in the case with a generic governor model. A comparison is shown in this Figure 9.

In all three interconnections analyzed, the recommended Frequency Response maintained frequency above the highest UFLS set point. Figures 9–11 show the results of the dynamics analyses.



Figure : Eastern Interconnection Frequency Response Simulation



Figure : Western Interconnection Frequency Response Simulation

Dynamic simulation of the Western Interconnection 906 MW/0.1 Hz IFRO shows a resulting 59.63 Hz Point C. Similarly, simulation of the ERCOT Interconnection 471 MW/0.1 Hz IFRO shows a resulting 59.39 Hz Point C.



Figure : ERCOT Interconnection Frequency Response Simulation

# Data Problems and Corrective Action Taken

Several data problems were discovered and corrected during the 2014 analysis of frequency characteristics and frequency response performance.

1. Frequency event selection errors during 2013 were found in the ALR 1-12 Frequency Response metric presented in the *State of Reliability 2014* report. This resulted in 19 Eastern Interconnection events being eliminated from the ALR 1-12 events. The analysis for the Eastern Interconnection is corrected in this report and that correction has been made to the NERC Reliability Indicators dashboard.[[31]](#footnote-31)
2. Frequency step-change[[32]](#footnote-32) anomalies were found in the 2013 1-second Eastern Interconnection frequency data used to determine the starting frequency for the IFRO calculations. The problem was traced back to toggling back and forth between two data sources in the calculation of the 1-second averaged data. The entire 2013 1-second database was recalculated to correct the problem.
3. An error was discovered in several start times for frequency events in the Eastern, Western, ERCOT, and Québec Interconnections starting in July 2013.[[33]](#footnote-33) The problem arose from a sign error in an adjustment factor used to remove a time skew inherent in the high-speed metrology; instead of removing the time skew, the adjustment factor was doubling it. This impacted several of the adjustment factors used in the IFRO calculation related to Point C. The error was corrected and all timing of frequency events have been recalculated for this and future analyses.
4. Several sources of sub-second data were determined to be in maintenance/offline mode, which resulted in the provision of inaccurate sub-second frequency data. The sub-second data was corrected by replacing the erroneous sources with data from operational data sources available during frequency events.

**Recommendation**: Monthly processing of 1-second data and weekly review of frequency event candidates for both ALR 1-12 and BAL-003-1 are recommended to discover problems sooner and ensure consistency in event selection.

# Recommendations for ALR 1-12 Frequency Event Detection and Selection Process Changes

In examining the frequency event selection process for ALR 1-12, the NERC Resources Subcommittee and NERC staff found that process to be too restrictive in event selection, potentially skewing the statistical analysis results of frequency response performed for the annual *State of Reliability* report. The selection process discounted events that started above 60 Hz and did not fall below certain thresholds. Doing so tends to corrupt any analysis of the statistical relationship between frequency response performance and starting frequency or ending frequency, and potentially eliminates events of high frequency response performance for large events or low frequency response for large MW changes in an interconnection.

Table 16 details the event detection and selection triggers.

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| **Table 16: ALR 1-12 Frequency Event Candidate Triggers** |
| **Interconnection** | **Detection** | **Selection** |
| **MW Load Loss[[34]](#footnote-34)** | **MW Resource Loss** | **MW Load Loss34** | **MW Resource Loss** |
| Eastern | 800 | 750 | 800 | 800 |
| Western | 700 | 650 | 700 | 700 |
| ERCOT  | 450 | 400 | 450 | 450 |
| Québec | 450 | 400 | 450 | 450 |

The Resources Subcommittee and NERC staff are recommending the following:

* All BAL-003-1 frequency events should be a subset of the ALR 1-12 event set.
* All event detection windows are to remain at 15 second rolling windows.
* No change is recommended to the BAL-003-1 event selection process.
* Actual net MW loss will be verified for each MW loss event. MW changes for load loss or pumped storage load rejection events will rely on FNet estimates until better data sources become available.
* Data for all candidate events will be collected from the FNet system (Values A and B, Point C, Point C’, and 300 seconds of high-speed frequency data surrounding the event). These data will be stored in a database for use in the annual analysis.
* Events could be triggered from several sources:
	+ The FNet[[35]](#footnote-35) system alarms
	+ Reliability Coordination Information System (RCIS) messages
	+ E-mail
	+ Telephone calls
* Screen only actual MW change against the MW criteria.
* No criteria will be applied on frequency change parameters allowing for purer statistical analysis of interconnection performance.
* Weekly reviews will be conducted by NERC staff to screen candidate events for ALR 1-12 selection.
* Investigate the potential for applying a T=+0 to Point C slope (arresting slope) criteria to eliminate shallow slopes that may not be reflective of primary frequency response.

Several statistical additional correlation analyses be conducted against the ALR 1-12 frequency events in beyond those currently performed for the *State of Reliability* analysis, including but not limited to:

* Crossing of typical frequency dead-bands
* Time of day
* Day of week
* Seasonal
* On-peak / off-peak

Some of these analyses should be used to provide a feedback loop to the FNet MW change estimates to improve those estimates.

1. Prepared by the Reliability Initiatives and System Analysis (RISA) and Performance Analysis (PA) sections of the Reliability Assessment and Performance Analysis group (RAPA). [↑](#footnote-ref-1)
2. From the *State of Reliability 2014* report, available at: http://www.nerc.com/pa/RAPA/PA/Pages/default.aspx. [↑](#footnote-ref-2)
3. Refer to the IFRO Formulae section of this report for further details on the calculation [↑](#footnote-ref-3)
4. Based on 2014 Interconnection Frequency Response Performance from Appendix B of the *State of Reliability 2014* report, reflecting corrections to the ALR 1-12 metric events in the Eastern Interconnection. By interconnection:
EI = -2,349 MW / 0.1Hz, WI = -1,514 MW / 0.1Hz, TI = -612 MW / 0.1Hz, and QI = -575 MW/0.1 Hz. [↑](#footnote-ref-4)
5. Interconnection projected Total Internal Demands from the *2014 NERC Long-Term Reliability Assessment* (2015 summer demand):
EI = 617,372 MW, WI = 156,423 MW, TI = 69,057 MW, and QI (2014-2015 winter demand) = 38,316 MW. [↑](#footnote-ref-5)
6. Details are included in the Recommendations for ALR 1-12 Frequency Event Detection and Selection Process Changes section of this report. [↑](#footnote-ref-6)
7. Located at: http://www.nerc.com/pa/RAPA/ri/Pages/InterconnectionFrequencyResponse.aspx [↑](#footnote-ref-7)
8. Abrupt changes in frequency. [↑](#footnote-ref-8)
9. This problem did not affect the 2013 IFRO calculations because it began after the time frame used in those calculations. [↑](#footnote-ref-9)
10. Located at: http://www.nerc.com/pa/RAPA/ri/Pages/InterconnectionFrequencyResponse.aspx [↑](#footnote-ref-10)
11. Based on the *2013 Frequency Response Annual Analysi*s. [↑](#footnote-ref-11)
12. Based on the *2013 Frequency Response Annual Analysi*s. [↑](#footnote-ref-12)
13. Based on the *2013 Frequency Response Annual Analysi*s. [↑](#footnote-ref-13)
14. Based on the *2013 Frequency Response Annual Analysi*s. [↑](#footnote-ref-14)
15. Refer to the 2012 *Frequency Response Initiative* report for details on the statistical analyses used. [↑](#footnote-ref-15)
16. Numbers of samples vary due to exclusion of data drop-outs and other obvious observation anomalies. [↑](#footnote-ref-16)
17. CBR value limited to 1.000 because values lower than that indicate the Value B is lower than Point C and does not need to be adjusted. The calculated value is 0.979. [↑](#footnote-ref-17)
18. Based on Québec UFLS design between their 58.5 Hz UFLS with 300 millisecond operating time (responsive to Point C) and 59.0 Hz UFLS step with a 20-second delay (responsive to Value B or beyond) with a 0.05 Hz confidence interval. See the adjustment for differences between Value B and Point C section of this report for further details. [↑](#footnote-ref-18)
19. Operated by the Power Information Technology Laboratory at the University of Tennessee, FNet is a low-cost, quickly deployable GPS-synchronized wide-area frequency measurement network. High dynamic accuracy Frequency Disturbance Recorders (FDRs) are used to measure the frequency, phase angle, and voltage of the power system at ordinary 120 V outlets. The measurement data are continuously transmitted via the Internet to the FNet servers hosted at the University of Tennessee and Virginia Tech. [↑](#footnote-ref-19)
20. No BC’ADJ used. [↑](#footnote-ref-20)
21. Adjustment for the differences between one-second and sub-second Point C observations for frequency events. [↑](#footnote-ref-21)
22. Adjustment for the differences between Point C and Value B. [↑](#footnote-ref-22)
23. CBR value for the Eastern Interconnection limited to 1.000 because values lower than that indicate the Value B is lower than Point C and does not need to be adjusted. The calculated value is 0.979. [↑](#footnote-ref-23)
24. Based on Québec UFLS design between their 58.5 Hz UFLS with 300 millisecond operating time (responsive to Point C) and 59.0 Hz UFLS step with a 20-second delay (responsive to Value B or beyond). [↑](#footnote-ref-24)
25. DFCC/CBR [↑](#footnote-ref-25)
26. Adjustment for the event nadir being below the Value B (Eastern Interconnection only) due to primary frequency response withdrawal. [↑](#footnote-ref-26)
27. Refer to the IFRO Formulae section of this report for further details on the calculation [↑](#footnote-ref-27)
28. Based on 2014 Interconnection Frequency Response Performance from Appendix B of the *State of Reliability 2014* report, reflecting corrections to the ALR 1-12 metric events in the Eastern Interconnection. By interconnection:
EI = -2,349 MW / 0.1Hz, WI = -1,514 MW / 0.1Hz, TI = -612 MW / 0.1Hz, and QI = -575 MW/0.1 Hz. [↑](#footnote-ref-28)
29. Interconnection projected Total Internal Demands from the *2014 NERC Long-Term Reliability Assessment* (2015 summer demand):
EI = 617,372 MW, WI = 156,423 MW, TI = 69,057 MW, and QI (2014-2015 winter demand) = 38,316 MW. [↑](#footnote-ref-29)
30. See Tables 12 and 13a for details [↑](#footnote-ref-30)
31. Located at: http://www.nerc.com/pa/RAPA/ri/Pages/InterconnectionFrequencyResponse.aspx [↑](#footnote-ref-31)
32. Abrupt changes in frequency. [↑](#footnote-ref-32)
33. This problem did not affect the 2013 IFRO calculations because it began after the time frame used in those calculations. [↑](#footnote-ref-33)
34. Or Pumped-Storage Load Rejection. [↑](#footnote-ref-34)
35. Operated by the Power Information Technology Laboratory at the University of Tennessee, FNet is a low-cost, quickly deployable GPS-synchronized wide-area frequency measurement network. High dynamic accuracy Frequency Disturbance Recorders (FDRs) are used to measure the frequency, phase angle, and voltage of the power system at ordinary 120 V outlets. The measurement data are continuously transmitted via the Internet to the FNet servers hosted at the University of Tennessee and Virginia Tech. [↑](#footnote-ref-35)