December 16, 2015

VIA ELECTRONIC FILING

Ms. Kimberly D. Bose
Secretary
Federal Energy Regulatory Commission
888 First Street, NE
Washington, D.C. 20426

Re: Informational Filing, Frequency Response Annual Analysis
Docket No. RM13-11-000

Dear Ms. Bose:

The North American Electric Reliability Corporation ("NERC") hereby submits its 2015 Frequency Response Annual Analysis report for the administration and support of Reliability Standard BAL-003-1 – Frequency Response and Frequency Bias Setting ("Report"). The Report attached hereto provides an update to the statistical analyses and calculations contained in the 2012 Frequency Response Initiative Report included as Exhibit F to the March 29, 2013 NERC petition for approval of proposed Reliability Standard BAL-003-1, and the 2014 Report submitted in this docket on March 20, 2015.

Specifically, the attached Report contains the analysis and annual recommendations for the calculation of the Interconnection Frequency Response Obligations (IFROs). The Report also analyzes: (i) frequency events and interconnection frequency characteristics for the period between January 1, 2012 through December 31, 2014, in order to determine appropriate adjustment factors for calculating the IFROs for the 2016 operational year (December 2015 through November 2016); and (ii) trends in primary Frequency Response sustainability or withdrawal throughout frequency events.

Dynamic 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 the analyses, as proposed in Paragraph 41 of the NOPR.[1] Evaluation of field trial data regarding the use of a linear regression method for calculating the Balancing Authority Frequency Response Measure is not included in the Report, but is continuing.

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[1] *Frequency Response and Frequency Bias Setting Reliability Standard*, Notice of Proposed Rulemaking, 144 FERC ¶ 61,057 (2013) (NOPR).

As underscored in the NERC State of Reliability 2015 report, Frequency Response performance for all four interconnections from 2012 through 2014 exhibits stable trends.[2] That trend analysis is not included in the attached report, as publication of more detailed performance analysis is being pursued and developed for inclusion as part of the 2016 Frequency Response Annual Analysis.[3]

NERC is not requesting any Commission action on the instant filing. NERC respectfully requests that the Commission accept this filing for informational purposes only.

Respectfully submitted,

/s/ Holly A. Hawkins
Holly A. Hawkins

Counsel for North American Electric Reliability Corporation

cc: Official service list in Docket No. RM13-11-000

[2] *State of Reliability 2015 Report*, at p. 9 (May 2015), *available at*, http://www.nerc.com/pa/RAPA/PA/Performance%20Analysis%20DL/2015%20State%20of%20Reliability.pdf.
[3] *See e.g.*, Report, at p. iv.

NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

2015 Frequency Response Annual Analysis

September 16, 2015

RELIABILITY | ACCOUNTABILITY

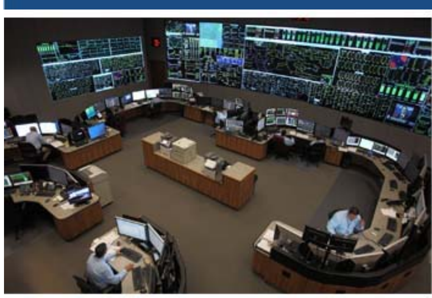


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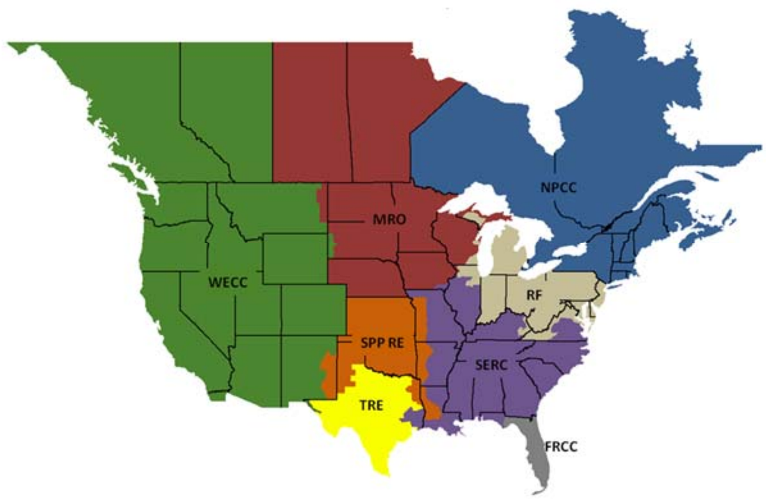
Table of Contents

Preface

The North American Electric Reliability Corporation (NERC) is a not-for-profit international regulatory authority whose mission is to assure 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.



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

Note: Capitalized terms in this document are defined terms in the *NERC Glossary of Terms Used in NERC Reliability Standards.*

This Report

This report is the 2015 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 NERC staff,[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 2016 (December 2015 through November 2016). This includes:

- Statistical analysis of the interconnection frequency characteristics for the period January 1, 2012, through December 31, 2014.[2]
- Dynamics analysis of the recommended IFROs.
- Frequency Response Performance Analysis
- The frequency response performance analysis normally included in this report will be published in a separate, expanded analysis including performance for BAL-003 frequency events and ALR1-12 frequency events separately. This is being done to produce a more comprehensive analysis. All of the adjustment factors used in the IFRO calculations are derived from the BAL-003 frequency events.

This report was accepted by the Resources Subcommittee on September 10, 2015.

This report was approved by the Operating Committee on September 16, 2015.

[1] Prepared by the Reliability Initiatives and System Analysis (RISA) and Performance Analysis (PA) sections of the Reliability Assessment and Performance Analysis group (RAPA).
[2] From the *State of Reliability 2015* report, available at: http://www.nerc.com/pa/RAPA/PA/Pages/default.aspx.

Executive Summary

Recommendations

The following are the recommended parameters and adjustment factors to use when calculating IFROs for the 2016 operational year (December 2015 through November 2016).

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 performed annually and the results published by November 15 each year, starting in 2015.

Interconnection Frequency Response Obligation (IFRO)
The IFROs calculated and presented in this report should be considered to be the minimum frequency response necessary for the interconnections to maintain reliability and avoid tripping load through activating under frequency load shedding programs. It has no direct relationship to Frequency Bias setting used by Balancing Authorities to prevent withdrawal of primary frequency response by automatic generator control (AGC) action.

1. The IFROs for operating year 2016 (December 2015 through November 2016) are calculated as shown in Table A.

Table A: Recommended IFROs

	Eastern (EI)	Western (WI)	ERCOT (TI)	Québec (QI)	Units
Starting Frequency	59.974	59.967	59.966	59.969	Hz
Max. Allowable Delta Frequency	0.443	0.292	0.411	0.948	Hz
Resource Contingency Protection Criteria	4,500	2,626	2,750	1,700	MW
Credit for Load Resources	N/A	120[3]	1,181	N/A	MW
IFRO[4]	**-1,015**	**-858**	**-381**	**-179**	**MW/0.1Hz**
Absolute Value of IFRO	**1,015**	**858**	**381**	**179**	**MW/0.1Hz**
Absolute Value of Current Interconnection Frequency Response Performance[5]	2,488	1,419	810	592	MW/0.1Hz
2016 IFRO as a % of Interconnection Load[6]	0.165	0.548	0.544	0.463	

[3] Based on updated information about the amount of load shedding in place for the loss of 2 Palo Verde units, the amount of CLR for this contingency was revised to 120 MW from the 150 MW value used last year.

[4] Refer to the IFRO Formulae section of this report for further details on the calculation

[5] Based on 2015 Interconnection Frequency Response Performance from Appendix D of the *State of Reliability 2015* report. By interconnection:
EI = -2,488 MW / 0.1Hz, WI = -1,419 MW / 0.1Hz, TI = -810 MW / 0.1Hz, and QI = -592 MW/0.1 Hz.

[6] Draft Interconnection projected Total Internal Demands to be used in the *2015 NERC Long-Term Reliability Assessment* (2016 summer demand):
EI = 612,456 MW, WI = 156,507 MW, TI = 70,014 MW, and QI (2015-2016 winter demand) = 38,650 MW. NOTE: These values are not finalized for the 2015 LTRA, but draft numbers provided here for illustration purposes.

2. Withdrawal of primary frequency response continues to be a predominant characteristic in the Eastern Interconnection. The adjustment to account for Point C' being below Value B (BC'_{ADJ}) was introduced in the 2012 Frequency Response Initiative Report analysis of the Eastern Interconnection frequency response, and should continue to be made to the Eastern Interconnection allowable delta frequency. The BC'_{ADJ} for the 2015 *Frequency Response Annual Analysis* (FRAA) is 7 mHz and analysis of frequency events for the Eastern Interconnection from January 2012 through December 2014 showed a lower Point C' after Value B occurring between T+69 and T+82 seconds after the initiating event, with 95 percent confidence. Analysis of events in the Western, ERCOT, and Québec Interconnections showed a prevalence of Point C' occurring after the timeframe of Value B calculation (T+20 to T+52); however, no BC'_{ADJ} is applied because there were either no events with Point C' below Point C (requiring compensation for absolute minimum frequency) or there wasn't enough statistically significant data to make an adjustment. Therefore, no BC'_{ADJ} is necessary for those interconnections.
3. NERC should examine the use of gross megawatt loss for generators in determination of the Resource Contingency Protection Criteria in the calculation of IFROs. In both WECC and ERCOT, the resource loss is based on a loss of two nuclear generating units. When those units trip, their auxiliary loads do not necessarily trip. Therefore, the apparent loss is actually the gross output at the time of the trip. This is the only proposed change to the procedures recommended in the *2012 Frequency Response Initiative Report*.

Findings

Frequency Response Performance Analysis
The frequency response performance analysis normally included in this report will be published in a separate, expanded analysis including performance for BAL-003 frequency events and ALR1-12 frequency events separately. This is being done to produce a more comprehensive analysis. All of the adjustment factors used in the IFRO calculations are derived from the BAL-003 frequency events.

1. Errors found in 2014 in the one-second data have been eliminated. A new method for improving the quality of the calculated one-second data for all interconnections was implemented for this year's frequency analysis. This method included a simple deadband filter, data stagnancy alarms, and a residual analysis of fit vs. actual to detect flagrant "spikes" or other data anomalies. This new method was shown to improve the statistical analysis, and this resulted in minimal changes in the starting frequency (F_{start}).
2. All analysis of interconnection frequency events has been converted to using sub-second data from the frequency data recorders (FDRs) of the University of Tennessee Knoxville (UTK) FNet[7] system. Use of higher-resolution 10-sample-per-second data for all adjustment factor determinations enabled the elimination of the CC'_{ADJ} factor because the actual frequency nadir was able to be accurately captured.
3. Use of the Frequency Response Analysis Tool, developed by Pacific Northwest National Laboratory through U.S. Department of Energy (DOE) funding, significantly expedited and streamlined frequency response analysis. The tool provides and effective means of compiling frequency response events and generating a database of necessary values for adjustment factor calculations.
4. Use of the Frequency Response Analysis Tool and sub-second data collection from FNet also allowed for variance in the defined start time for frequency events in all interconnections. A data time shift was discovered starting in the July 2013 frequency data during the 2014 FRAA analysis. However, the time skew in the collection was mitigated by the Frequency Response Analysis Tool by automatically detecting the starting time and frequency, with an option for manual adjustment. The starting time T_0 used in the calculation of frequency

[7] 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 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.

response, as prescribed in BAL-003-1, is based on the limitations of lower-resolution supervisory control and data acquisition (SCADA) data necessary to measure Balancing Authority performance under the standard. However, since the calculation of interconnection performance during frequency events is intended to indicate the leading edge of the disturbance, use of high-speed data is not only possible, but desirable. Use of the high-resolution FNet data allows improved event detection, measurement of the Point C nadir, and more accurate interconnection performance measurement. It also allows for tracking a number of other performance measures to improve analysis of frequency events.

5. For the ERCOT Interconnection IFRO calculation, CLR was increased from the 909 MW used in the 2014 calculations to a statistically determined 1,181 MW. This represents the amount of contractual load resource that is available at least 95 percent of the time. Statistical analysis for this year's CLR determination omitted year 2012 data because ERCOT changed market rules related to Responsive Reserve Service (RSS) in April of that year. Prior to April 2012, ERCOT was procuring 2,300 MW of RSS; after April 2012, that number was increased to 2,800 MW, 50 percent of which can be provided by load resources with under-frequency relays. This change better reflects how ERCOT has historically procured CLR.
6. The ratio between Point C and Value B (CB_R) changed rather significantly for the Eastern, Western, and ERCOT Interconnections. The Eastern Interconnection experienced a CB_R ratio increase of 0.052, moving the CB_R above the 1.000 threshold value for calculation. This is slightly indicative of improving frequency response, with B value above C value. The Western and ERCOT Interconnections decreased by -0.074 and -0.081, respectively. This may be due to 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 time frame (+20 to +52 seconds), they are slower than the steam units to respond in the arresting power time frame (+0 to +20 seconds). This results in a similar Value B response but a lower Point C nadir, which increases the CB_R ratio.
7. Dynamics simulations of the Eastern, Western, and ERCOT Interconnections for the recommended IFROs showed levels of primary frequency response to be adequate to avoid tripping of the first stage of the interconnection underfrequency load shedding (UFLS) systems. Light-load cases were used for all three of these analyses.
8. ERCOT is undergoing mid-year changes during the 2015 operating year for their process in procuring frequency-responsive load resources which are used to calculate their credit for load resources (CLR). Analysis for calculating CLR for future years may need to be revised starting with the 2016 FRAA report.

Interconnection Frequency Characteristic Analysis

Frequency Variation Statistical Analysis

NERC staff performs a statistical analysis[8] annually 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 2012–2014 was used and is summarized in Table 1.

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

One-Second Frequency Data
One-second frequency data for the frequency variation analysis is provided by UTK. The data is sourced from three to five FDRs per interconnection. The median value among the higher resolution FDRs is then down-sampled to one sample per second, and filters are applied to ensure data quality.

Table 1: Interconnection Frequency Variation Analysis

Value	Eastern	Western	ERCOT	Québec
Time Frame	2012-2014	2012-2014	2012-2014	2012-2014
Number[9] of Samples	92,541,346	93,385,750	90,436,875	92,365,437
Expected Value (Hz)	60.000	59.999	59.999	59.999
Variance of Frequency (σ^2) (Hz^2)	0.00023	0.00037	0.00040	0.00079
Standard Deviation (σ) (Hz)	0.01530	0.01927	0.01989	0.02810
50% percentile (median)	59.999	59.999	60.000	59.998
Starting Frequency (F_{Start}) (Hz) (5% of lower tail samples)	**59.974**	**59.967**	**59.966**	**59.969**

Those starting frequencies encompass all variations in frequency, including changes to the target frequency during TEC. This 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 five percent of the lower tail of samples from the statistical analysis, which represents a 95 percent chance that frequencies will be at or above that value at the start of any frequency event.

Figures 1-4 show the probability density function of frequency for each interconnection.

[8] Refer to the 2012 *Frequency Response Initiative* report for details on the statistical analyses used.
[9] Numbers of samples vary due to exclusion of data drop-outs and other obvious observation anomalies.

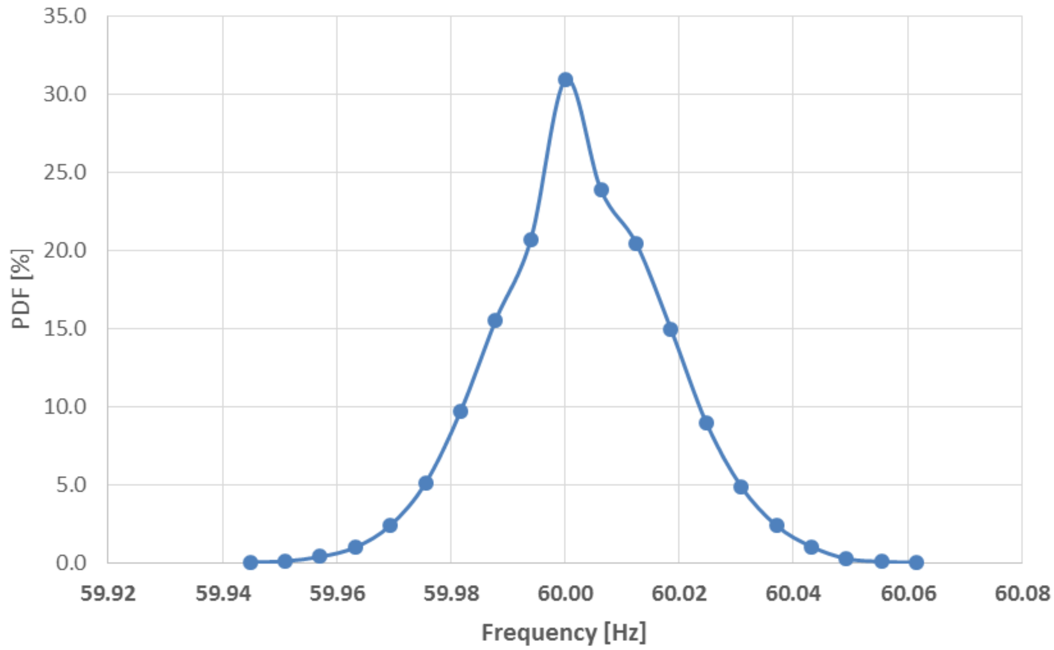


Figure 1: Eastern Interconnection 2012–2014 Probability Density Function of Frequency

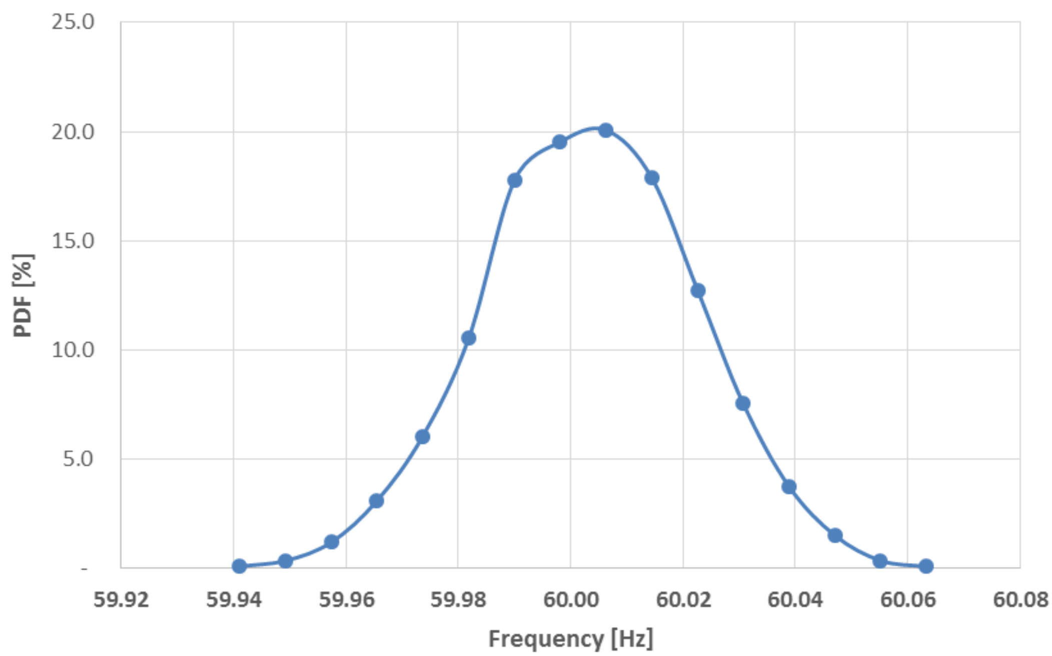


Figure 2: Western Interconnection 2012–2014 Probability Density Function of Frequency

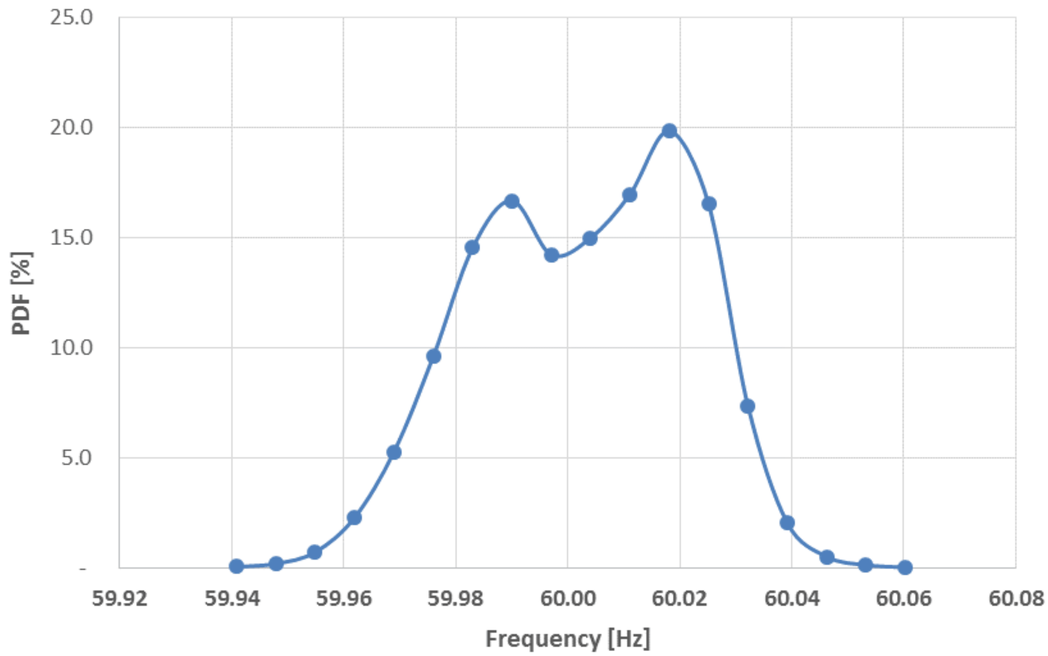


Figure 3: ERCOT Interconnection 2012–2014 Probability Density Function of Frequency

The probability density function for ERCOT frequency displays influence of the “flat-top” profile common to that interconnection prior to 2008. That phenomenon was caused by a standardized ±36 mHz deadband with step-function implementation. This is significantly less pronounced than it was in the 2012 analysis as generator governor settings migrate towards a ±16.7 mHz deadband with proportional response implementation.

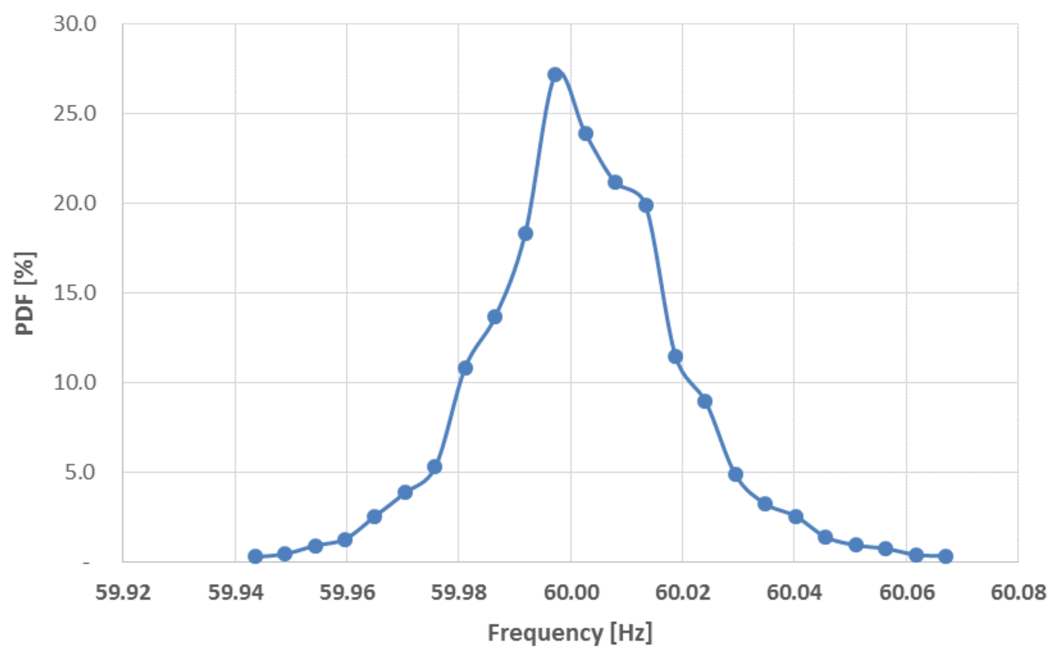


Figure 4: Québec Interconnection 2012–2014 Probability Density Function of Frequency

Changes in Starting Frequency

A comparison of expected frequencies and starting frequencies between the 2015 and 2014 frequency variability analyses is shown in Table 2. The results show variations in the starting frequencies of less than 0.001 Hz. Expected frequencies are unchanged for all interconnections except the Quebec Interconnection. The change in starting frequency in the Quebec Interconnection is attributed to improved data quality in this year's analysis, so the expected frequency is more reflective of nominal 60 Hz as expected.

Table 2: Comparison of Interconnection Frequency Statistics (Hz)

Expected Frequencies			
	2014 Analysis	2015 Analysis	Change
Eastern	60.000	60.000	–
Western	59.999	59.999	–
ERCOT	59.999	59.999	–
Québec	59.994	59.999	0.005
Starting Frequencies			
Eastern	59.974	59.974	–
Western	59.968	59.967	-0.001
ERCOT	59.965	59.966	0.001
Québec	59.969	59.969	–

Determination of Interconnection Frequency Response Obligations

Tenets of IFRO

The IFRO is the minimum amount of frequency response that must be maintained by an interconnection. Each Balancing Authority in the interconnection should be allocated a portion of the IFRO that represents its minimum responsibility. To be sustainable, Balancing Authorities that may be susceptible to islanding may need to carry additional frequency-responsive reserves to coordinate with their 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 (PV) inverters.
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:

$$DF_{Base} = F_{Start} - UFLS$$

$$DF_{CBR} = \frac{DF_{Base}}{CB_R}$$

$$MDF = DF_{CBR} - BC'_{Adj}$$

$$ARLPC = RLPC - CLR$$

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

Where:

- DF_{Base} is the base delta frequency.
- F_{Start} is the starting frequency determined by the statistical analysis.
- UFLS is the highest UFLS trip set point for the interconnection.
- CB_R is the statistically determined ratio of the Point C to Value B.

- DF_{CBR} 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.

Note: The CC_{ADJ} adjustment has been eliminated because of the use of sub-second data for this year's analysis of the interconnection frequency events. The CC_{ADJ} adjustment had been used to correct for the differences between one-second and sub-second Point C observations for frequency events. This also eliminates the DF_{CC} term from the formulae.

Determination of Adjustment Factors

Adjustment for Differences between Value B and Point C (CB_R)

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. However, as a practical matter, the ability to measure the tie line and loads for a Balancing Authority is limited to SCADA scan rates of one to six seconds. Therefore, the ability to measure frequency response at the Balancing Authority level is limited by the SCADA scan rates available to calculate Value B. To account for the issue of measuring frequency response as compared with the risk of UFLS tripping, an adjustment factor (CB_R) is calculated from the significant frequency disturbances from January 2012, which captures the relationship between Value B and Point C through December 2014. This resulted in the number of events shown in Table 3.

Sub-Second Frequency Data Source

Frequency data used for calculating all of the adjustment factors used in the IFRO calculation comes from the UTK FNet system. Six minutes of data is used for each frequency disturbance analyzed, 1 minute prior to the event and 5 minutes following the start of the event. All event data is provided at a higher resolution (10 samples-per-second) as a median frequency from all the available FDRs for that event.

Analysis Method

The IFRO is the minimum performance level that the Balancing Authorities 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 Balancing Authorities 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 Balancing Authority. 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 (CB_R)

The evaluation of data to determine the C-to-B ratio (CB_R) 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 CB_R 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 predisturbance 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 CB_R adjusted for confidence (Table 3) should be used to compensate for the differences between Point C and Value B.

Table 3: Analysis of Value B and Point C (CB_R)

Interconnection	Number of Events Analyzed	Mean	Standard Deviation	95% Confidence	CB_R Adjusted for Confidence
Eastern	76	1.027	0.132	0.025	1.052
Western	71	1.551	0.239	0.047	1.598
ERCOT	128	1.555	0.436	0.064	1.619
Québec	81	3.947	0.924	0.171	1.550

The Eastern Interconnection exhibits a frequency response characteristic that often has Value B below Point C, and the CB_R value for the Eastern Interconnection has historically been below 1.000, therefore the CB_R has been limited to 1.000. However, the calculated CB_R in this year's analysis indicates a value above 1.000, and no limitation is required.

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 81 frequency events in their event sample, Québec's CB_R value would be 4.12, or two to four times the CB_R values of other interconnections. Using the same calculation method for CB_R would effectively penalize Québec for their rapid rebound performance and make their IFRO artificially high. Therefore, the method for calculating the Québec CB_R was modified.

Québec has 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 Québec CB_R equal 1.550.

Point C Analysis – One-Second versus Sub-second Data (CC_{ADJ}) Eliminated

Calculation of all of the IFRO adjustment factors for the 2015 FRAA solely utilized sub-second measurements from FNet FDRs. Data at this resolution accurately reflect the Point C nadir; therefore, a CC_{ADJ} factor is no longer required and has been eliminated.

Statistical analysis of the calculated ratio of Point C to Value B for the FRAA analysis from January 2012 through December 2014 utilized the one-sample-per-second data. To ensure the nadir (Point C) of the event was accurately captured, a “C to C” adjustment component (CC_{ADJ}) for the IFRO calculation was designed to account for the differences observed between the one-second Point C and the high-speed Point C measurements using sub-second measurements provided by PMUs or FDRs. However, use of sub-second data for the analysis of interconnection events ensures that Point C is accurately captured, making the adjustment factor obsolete.

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, the later-occurring nadir is termed Point C’. This lower nadir is symptomatic of primary frequency response withdrawal, or squelching, by unit-level 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 is used whenever withdrawal is a prevalent feature of frequency events.

Table 4 shows a summary of the events for each interconnection where the C’ value was lower than Value B (averaged from T+20 through T+52 seconds) and Point C for the period of January 2012 through December 2014. The statistical analysis is performed on the events with C’ value lower than Value B to determine the adjustment factor BC'_{ADJ}.

Table 4 Statistical Analysis of the Adjustment for C' Nadir[10] (BC'_{adj})

Interconnection	Number of Events Analyzed	C' Lower than B	C' Lower than C	Mean Difference	Standard Deviation	BC'ADJ (95% Quantile)
Eastern	76	54	41	0.006	0.004	0.007
Western	71	28	0	N/A	N/A	N/A
ERCOT	128	26	3	N/A	N/A	N/A
Québec	81	31	0	N/A	N/A	N/A

Although events with C’ lower than C have been identified in the ERCOT Interconnection, there is only statistically significant data to apply this adjustment factor to the Eastern Interconnection. This will continue to be monitored moving forward to track these trends in C’ performance. Therefore, a BC'_{ADJ} is only needed for the Eastern Interconnection; no BC'_{ADJ} is needed for the other three interconnections. The 95 percent quantile value is used for the Eastern Interconnection BC'_{ADJ} of seven mHz (see Table 4) to account for the statistically expected Point C’ value of a frequency event.

[10] Point C’ is the absolute frequency nadir of a given frequency excursion event. Point C’ only occurs if frequency falls below Value B after the Value B measurement window of T+20 to T+52 seconds. Point C, on the other hand, is limited to the time between T=0 and T=+12 seconds.

In the Eastern Interconnection, the Point C' nadir occurs 69-82 seconds after the start of the event[11] 90 percent of the time, which is beyond the time frame for calculating Value B.

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.

Table 5: 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 is meant to prevent 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 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 present a combination of conditions to control systems that may cause some generation to trip. Severe rates-of-change occurring in voltage or frequency might actuate volts-per-hertz relays which would also trip some units. 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 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 with a high penetration of PV resources.

Credit for Load Resources

The ERCOT Interconnection depends on contractually interruptible (an Ancillary Service) demand response that automatically trips at 59.7 Hz by underfrequency relay to help arrest frequency declines. A credit for load resources[12] (CLR) is made for the resource contingency for the ERCOT Interconnection.

The actual amount of CLR available at any given time varies on different factors, including its usage in immediate past. NERC performed a statistical analysis on hourly available CLR for the period of January 2013 through December 2014. Data from 2012 was excluded from the analysis since prior to April 2012, ERCOT Interconnection was procuring 2,300 MW of Responsive Reserve Service (RRS) of which up to 50 percent could be provided by the load resources with under-frequency relays set at 59.70 Hz. Beginning April 2012 due to a change in market rules, the RRS requirement was increased from 2,300 MW to 2,800 MW for each hour, which means the load resources

[11] The timing of the C' occurrence is consistent with outer-loop plant and unit controls causing withdrawal of unit frequency response.
[12] Formerly called Load acting as a Resource, or LaaR.

could potentially provide up to 1,400 MW of RRS. The statistical analysis indicated that 1,181 MW of CLR is available 95 percent of the time. Therefore, a CLR adjustment of 1,181 MW is applied in the calculation of the ERCOT IFRO, as a reduction to the loss of resources.

The 2015 CLR for ERCOT is 272 MW higher than the 909 MW adjustment in the 2014 IFRO calculation. The primary reason for 909 MW CLR in the 2014 analysis was that the data utilized from 2011 and 2012 reflected the maximum participation limit on these resources of 1,150 MW during that period. IFRO analysis using only the data after 2012 should be used to capture the change in procuring these resources for frequency response purposes. This difference accounts for the substantial change in the ERCOT IFRO.

Determination of Maximum Allowable Delta Frequencies

Because of the measurement limitation of the BA-level frequency response performance using Value B, 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 in terms comparable to Value B.

Table 6 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 Point C and Value B.
- Adjustments for the event nadir being below Value C' (Eastern Interconnection only) due to primary frequency response withdrawal.

Table 6: Determination of Maximum Allowable Delta Frequencies

	Eastern	Western	ERCOT	Québec	Units
Starting Frequency	59.974	59.967	59.966	59.969	Hz
Minimum Frequency Limit	59.500	59.500	59.300	58.500	Hz
Base Delta Frequency	0.474	0.467	0.666	1.469	Hz
CB_R[13]	1.052	1.598	1.619	1.550	Ratio
Delta Frequency (DF_{CBR})[14]	0.450	0.292	0.411	0.948	Hz
BC'_{ADJ}[15]	0.007	N/A	N/A	N/A	Hz
Max. Allowable Delta Frequency	0.443	0.292	0.411	0.948	Hz

[13] Adjustment for the differences between Point C and Value B.
[14] DF_{CC}/CB_R
[15] Adjustment for the event nadir being below the Value B (Eastern Interconnection only) due to primary frequency response withdrawal.

Comparison of Maximum Allowable Delta Frequencies

The following is a comparison of the 2015 maximum allowable delta frequencies with the values from the 2014 *Frequency Response Annual Analysis* report.

Table 7a: Maximum Allowable Delta Frequency Comparison

Eastern	2014	2015	Change	Units
Starting Frequency	59.974	59.974	0.000	Hz
Min. Frequency Limit	59.500	59.500	0.000	Hz
Base Delta Frequency	0.474	0.474	0.000	Hz
CC_{ADJ}	0.013	N/A	-0.013	Hz
Delta Frequency (DF_{CC})	0.461	0.474	0.013	Hz
CB_R	1.000	1.052	0.052	Ratio
Delta Freq. (DF_{CBR})	0.461	0.450	-0.011	Hz
BC'_{ADJ}	0.017	0.007	-0.010	Hz
Max. Allowable Delta Frequency	0.444	0.443	-0.001	Hz
Western	**2014**	**2015**	**Change**	**Units**
Starting Frequency	59.968	59.967	-0.001	Hz
Min. Frequency Limit	59.500	59.500	0.000	Hz
Base Delta Frequency	0.468	0.467	-0.001	Hz
CC_{ADJ}	0.011	N/A	-0.011	Hz
Delta Frequency (DF_{CC})	0.457	0.467	0.010	Hz
CB_R	1.672	1.598	-0.074	Ratio
Delta Freq. (DF_{CBR})	0.273	0.292	0.019	Hz
BC'_{ADJ}	N/A	N/A	N/A	Hz
Max. Allowable Delta Frequency	0.273	0.292	0.019	Hz

In the Eastern Interconnection, the maximum allowable delta frequency value only changed by 1 mHz. The following are observations regarding maximum allowable delta frequency:

- CB_R increased from 1.00 (limited to 1.00 in 2014 FRAA) to 1.052, and therefore the delta frequency (DF_{CBR}) decreased by 11 mHz. The increase in CB_R demonstrates a relatively strong Point C frequency nadir.
- Delta frequency (DF_{CBR}) decreased by 11 mHz partially to the removal of the CC_{ADJ} factor.
- BC'_{ADJ} reduced by 10 mHz, illustrating less prevalence in governor response withdrawal.

In the Western Interconnection, the maximum allowable delta frequency value changed by 19 mHz. The following are observations regarding maximum allowable delta frequency:

- Delta frequency (DF_{CBR}) increased by 19 mHz partially due to the removal of the CC_{ADJ} factor, but the CB_R decreased by a factor of -0.074, primarily due to the decrease in Value B relative to Point C.

Table 7b: Maximum Allowable Delta Frequency Comparison				
ERCOT	**2014**	**2015**	**Change**	**Units**
Starting Frequency	59.965	59.966	0.001	Hz
Min. Frequency Limit	59.300	59.300	0.000	Hz
Base Delta Frequency	0.665	0.666	0.001	Hz
CC_{ADJ}	0.001	0.000	-0.001	Hz
Delta Frequency (DF_{CC})	0.664	0.666	0.002	Hz
CB_R	1.700	1.619	-0.081	Ratio
Delta Freq. (DF_{CBR})	0.391	0.411	0.020	Hz
BC'_{ADJ}	N/A	N/A	N/A	Hz
Max. Allowable Delta Frequency	0.391	0.411	0.020	Hz
Québec	**2014**	**2015**	**Change**	**Units**
Starting Frequency	59.968	59.969	0.001	Hz
Min. Frequency Limit	58.500	58.500	0	Hz
Base Delta Frequency	1.468	1.469	0.001	Hz
CC_{ADJ}	0.000	0.000	0	Hz
Delta Frequency (DF_{CC})	1.468	1.469	0.001	Hz
CB_R	1.550	1.550	0	Ratio
Delta Freq. (DF_{CBR})	0.927	0.948	0.021	Hz
BC'_{ADJ}	N/A	N/A	N/A	Hz
Max. Allowable Delta Frequency	0.927	0.948	0.021	Hz

In the ERCOT Interconnection, the maximum allowable delta frequency value changed by 20 mHz. The following are observations regarding maximum allowable delta frequency:

- Elimination of the CC_{ADJ} did not have a relative impact due to the 2014 CC_{ADJ} value of 0.001.
- The CB_R factor decreased by -0.081, and therefore the delta frequency (DF_{CBR}) increased by 20 mHz.

Changing Resource Mix in ERCOT
ERCOT continues to experience a displacement of coal-fired generation by gas-fired combined-cycle units in its dispatch due to lower prices for natural gas. While the combined-cycle units are responsive in the Value B calculation time frame (+20 to +52 seconds), they are slower than the steam units to respond in the arresting power time frame (+0 to +20 seconds). This results in a similar Value B response but a lower Point C nadir, increasing the CB_R ratio. The frequency response performance in 2013–2014 displaces the older performance characteristics.

In the Québec Interconnection, the maximum allowable delta frequency value changed by 21 mHz due to the removal of the CC_{ADJ} factor. Frequency response performance remained relatively unchanged compared to the 2014 FRAA performance analysis, and did not appreciably influence the maximum allowable delta frequency.

Recommended IFROs

Table 8 shows the determination of IFROs for operating year 2016 (December 2015 through November 2016) 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 (CB_R), the differences in measurement of Point C using one-second and sub-second data (CC_{ADJ}), and the event nadir being below the Value B (BC'_{ADJ}).

Table 8: Recommended IFROs

	Eastern (EI)	Western (WI)	ERCOT (TI)	Québec (QI)	Units
Starting Frequency	59.974	59.967	59.966	59.969	Hz
Max. Allowable Delta Frequency	0.443	0.292	0.411	0.948	Hz
Resource Contingency Protection Criteria	4,500	2,626	2,750	1,700	MW
Credit for Load Resources	N/A	120[16]	1,181	N/A	MW
IFRO[17]	**-1,015**	**-858**	**-381**	**-179**	**MW/0.1Hz**
Absolute Value of IFRO	**1,015**	**858**	**381**	**179**	**MW/0.1Hz**
Absolute Value of Current Interconnection Frequency Response Performance[18]	2,488	1,419	810	592	MW/0.1Hz
2016 IFRO as a % of Interconnection Load[19]	0.165	0.548	0.544	0.463	

[16] Based on updated information about the amount of load shedding in place for the loss of 2 Palo Verde units, the amount of CLR for this contingency was revised to 120 MW from the 150 MW value used last year.

[17] Refer to the IFRO Formulae section of this report for further details on the calculation

[18] 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 = -2,488 MW / 0.1Hz, WI = -1,419 MW / 0.1Hz, TI = -810 MW / 0.1Hz, and QI = -592 MW/0.1 Hz.

[19] Draft Interconnection projected Total Internal Demands to be used in the *2015 NERC Long-Term Reliability Assessment* (2016 summer demand):
EI = 612,456 MW, WI = 156,507 MW, TI = 70,014 MW, and QI (2015-2016 winter demand) = 38,650 MW. NOTE: These values are not finalized for the 2015 LTRA, but draft numbers provided here for illustration purposes.

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 2014 *Frequency Response Annual Analysis* report.

Table 9a: Interconnection IFRO Comparison				
Eastern	**2014**	**2015**	**Change**	**Units**
Starting Frequency	59.974	59.974	0.000	Hz
Max. Allowable Delta Frequency	0.444	0.443	-0.001	Hz
Resource Contingency Protection Criteria	4,500	4,500	0	MW
Credit for LR	N/A	N/A	N/A	MW
Absolute Value of IFRO	1,014	1,015	1	MW/0.1Hz
Western	**2014**	**2015**	**Change**	**Units**
Starting Frequency	59.968	59.967	-0.001	Hz
Max. Allowable Delta Frequency	0.273	0.292	0.019	Hz
Resource Contingency Protection Criteria	2,626	2,626	N/A	MW
Credit for LR	150	120	-30	MW
Absolute Value of IFRO	906	858	-48	MW/0.1Hz

The IFRO for the Eastern Interconnection increased by 1 MW/0.1 Hz, reflecting relatively no change to frequency response characteristics.

The IFRO for the Western Interconnection decreased by 48 MW/0.1 Hz. A number of factors influenced this change. In terms of frequency response performance, an increase in the maximum allowable delta frequency resulting from a decrease of 0.074 in the CB_R ratio[20] resulted in a prominent decrease in IFRO. However, a slight reduction in the CLR, from 150 MW to 120 MW, offset this change. The modification was based on updated information provided regarding the contingency definition for the loss of two Palo Verde units.

The Resource Contingency Protection Criteria (RCPC), as specified in the *2012 Frequency Response Initiative Report*, currently uses the net loss of MW for calculation of the IFRO. However, it is noted that the WECC and ERCOT resource loss events used for the RCPC include the loss of nuclear generating resources. When nuclear units trip, their auxiliary loads do not necessarily trip to ensure continuity of offsite power source. Therefore, the apparent loss of MW from a frequency response standpoint is actually the gross output of the units at the time of the trip. This is not captured in this year’s analysis (RCPC); but it will be explored in future analyses.

[20] See Tables 6 and 7a for details.

Table 9b: Interconnection IFRO Comparison				
ERCOT	**2014**	**2015**	**Change**	**Units**
Starting Frequency	59.965	59.966	0.001	Hz
Max. Allowable Delta Frequency	0.391	0.411	0.020	Hz
Resource Contingency Protection Criteria	2,750	2,750	0	MW
Credit for LR	909	1,181	272	MW
Absolute Value of IFRO	471	381	-90	MW/0.1Hz
Québec	**2014**	**2015**	**Change**	**Units**
Starting Frequency	59.969	59.969	0	Hz
Max. Allowable Delta Frequency	0.927	0.948	0.021	Hz
Resource Contingency Protection Criteria	1,700	1,700	0	MW
Credit for LR	N/A	N/A	N/A	MW
Absolute Value of IFRO	183	179	-4	MW/0.1Hz

The IFRO for the ERCOT Interconnection decreased by 90 MW/0.1 Hz. This is primarily due to the 272 MW increase in CLR based on the methodology that ERCOT used in 2013 and 2014 for carrying contractual load that will respond to underfrequency events, as discussed in the Credit for Load Resources section of this report. The increased CLR reduces the resource contingency protection impact and therefore reduces the IFRO.

The Québec Interconnection IFRO decreased by only 4 MW/0.1Hz. This is primarily attributed to the 21 mHz increase in maximum allowable delta frequency.[21]

[21] See Tables 6 and 7b for details.

Dynamics Analysis of Recommended IFROs

Off-peak dynamics analysis was performed of 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 5).

In all three interconnections analyzed, frequency remained above the highest UFLS set point even with Interconnection frequency response degraded to the IFRO value. Figures 5–7 show the results of the dynamics analyses.

For the Eastern Interconnection, a 2014 light-load case was used 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 Multiregional Modeling Working Group. In the 2013 analysis, a 2013 light-load "generic" dynamics case was used. It was created by replacing the turbine governor models in the case with a generic governor model. A comparison is also shown in Figure 9. Since the 2015 analysis resulted in only a 1 MW/0.1 Hz decrease in the IFRO, and a frequency-response-capable 2015 light load dynamics case for the Eastern Interconnection series of cases has not been finalized, the 2014 case was again used for testing the IFRO.

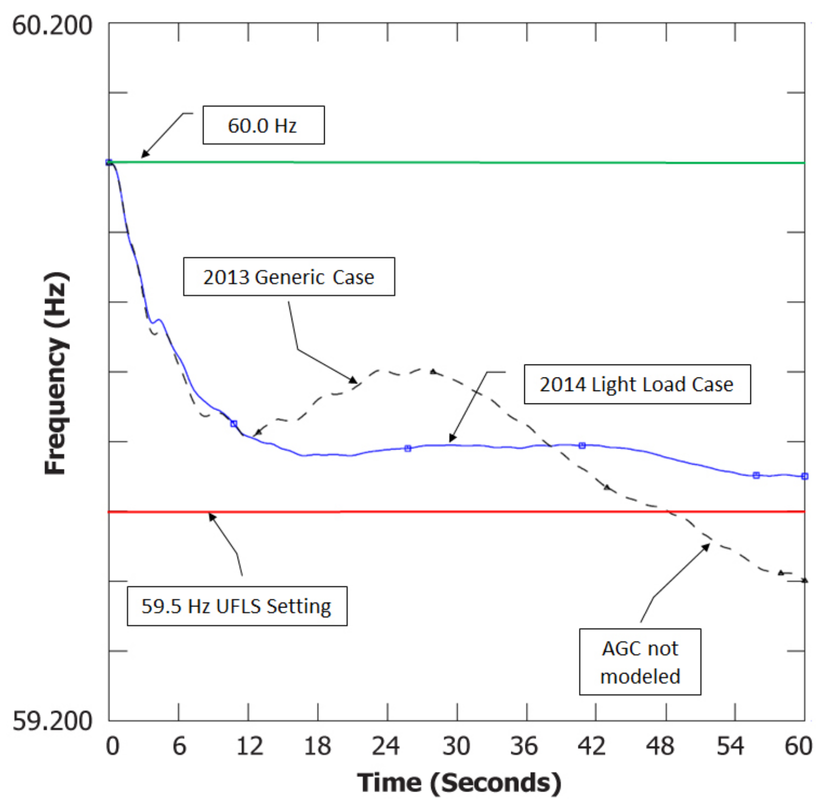


Figure 5: Eastern Interconnection Frequency Response Simulation

Dynamic simulation of the defined resource contingency for the Western Interconnection, with frequency response degraded to the IFRO value of 858 MW/0.1 Hz, shows a resulting value of 59.58 Hz for Point C.

This analysis used the same case employed last year. Although a new case for this year was provided by WECC, two significant issues were encountered with the 2015 case:

1. The interconnection frequency response reflected in the case, and particularly the frequency nadir (point C), were regarded as too optimistic (too high), and
2. The CB ratio for frequency events in this year's case was regarded as too high.

These determinations were made by comparing the behavior of this year's case to both the case used last year and actual observations of frequency response in the Western Interconnection in 2014.

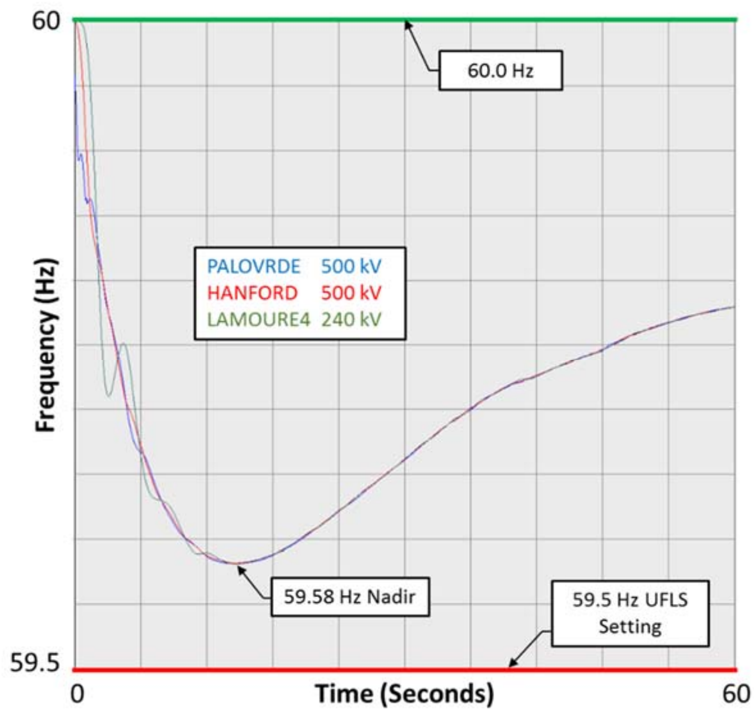


Figure 6: Western Interconnection Frequency Response Simulation

Simulation of the defined resource contingency for the ERCOT Interconnection with interconnection frequency response degraded to the IFRO value of 381 MW/0.1 Hz, shows a resulting value of 59.33 Hz for Point C. No new light load case was provided by ERCOT for this year's analysis; therefore, the analysis was performed using the most recent ERCOT light load dynamics case available.

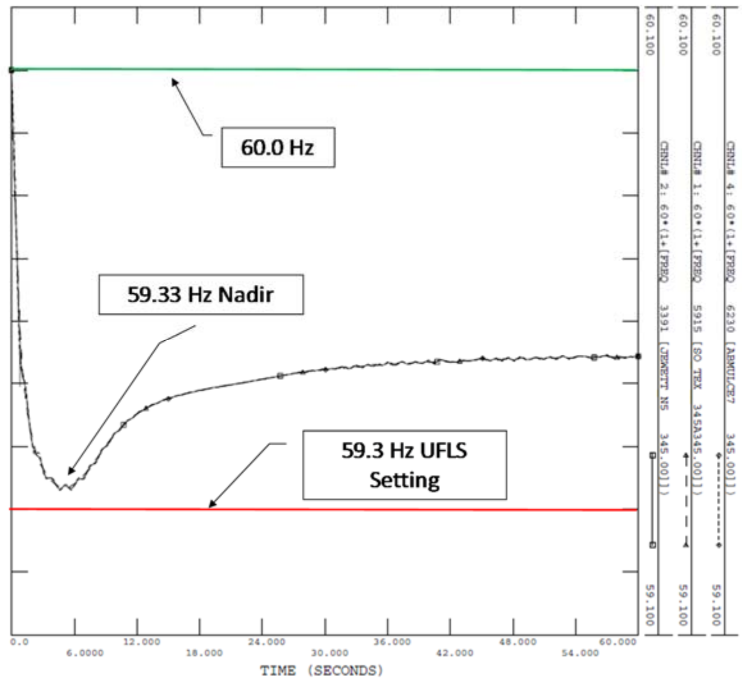


Figure 7: ERCOT Interconnection Frequency Response Simulation