NERC

NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

2017 Frequency Response Annual Analysis

November 2017

RELIABILITY | ACCOUNTABILITY

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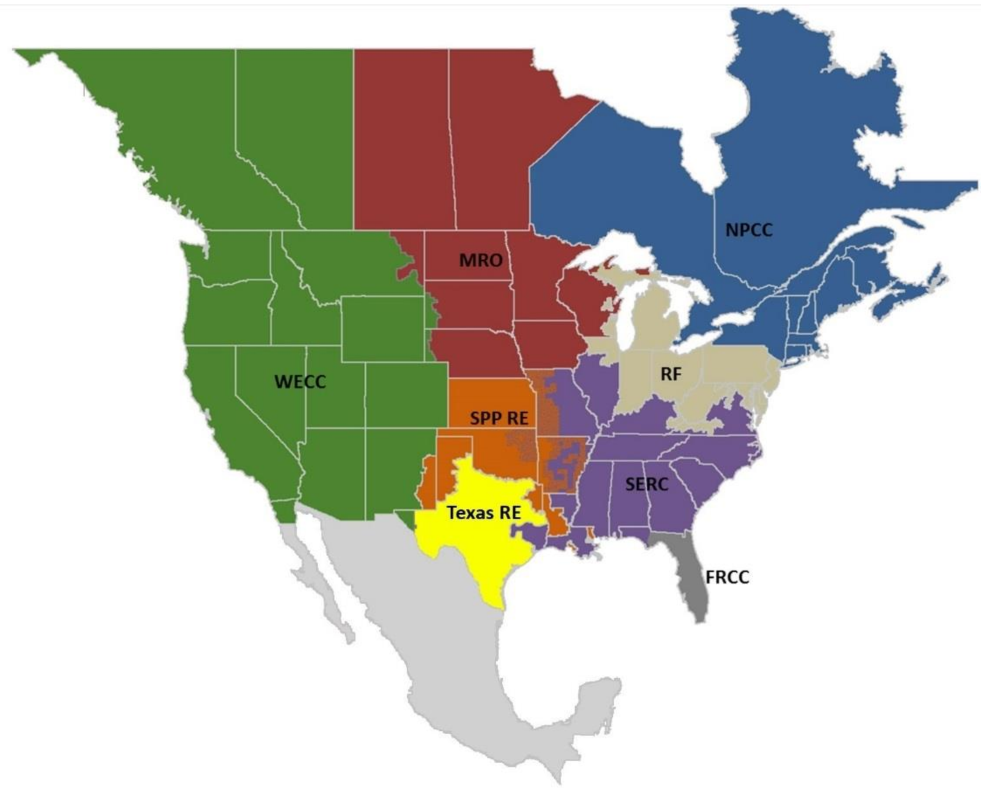
This report was approved by the Resources Subcommittee on October 16, 2017.

This report was accepted by the Operating Committee on November 3, 2017.

Preface

The North American Electric Reliability Corporation (NERC) is a not-for-profit international regulatory authority whose mission is to assure the reliability and security 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 Entity (RE) boundaries as shown in the map and corresponding table below.



The North American BPS is divided into eight RE boundaries. The highlighted areas denote overlap as some load-serving entities participate in one Region while associated transmission owners/operators participate in another.

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
Texas RE	Texas Reliability Entity
WECC	Western Electricity Coordinating Council

Executive Summary

This report is the 2017 annual analysis of frequency response performance for the administration and support of NERC Reliability Standard BAL-003-1 – Frequency Response and Frequency Bias Setting[1]. It provides an update to the statistical analyses and calculations contained in the *2012 Frequency Response Initiative Report*[2] approved by the NERC Resources Subcommittee (RS) and Operating Committee (OC) and accepted by the NERC Board of Trustees (Board). This report, prepared by NERC staff,[3] contains the annual analysis, calculation, and recommendations for the interconnection frequency response obligation (IFRO) for each of the four electrical interconnections of North America for the operational year 2018 (December 2016 through November 2017).

In accordance with the BAL-003-1 detailed implementation plan, and as a condition of approval by the RS and the OC, these analyses are performed annually, and the results published by November 15 each year.

Recommendations

The following recommendations are made for the administration of Standard BAL-003-1 for operating year 2018 (December 1, 2017 through November 30, 2018):

1. Due to inconsistencies detailed in Chapter 3: Analysis of IFRO Calculation Method of this report, NERC should develop a different method for adjusting for the difference between Value B and Point C in the calculation of IFROs.
2. The IFRO values for operating year 2018 (December 2017 through November 2018) shall remain the same values as calculated in the *2015 Frequency Response Annual Analysis* (FRAA) report for operating year 2016[4] and held constant through operating year 2017, as shown in Table 1.

Table 1: Recommended IFROs for Operating Year 2017					
	Eastern (EI)	Western (WI)	ERCOT (TI)	Québec (QI)	Units
Recommended IFROs[5]	**-1,015**	**-858**	**-381**	**-179**	**MW/0.1Hz**
Absolute Value of Mean Interconnection Frequency Response Performance for operating year 2016[6]	2,483	1,344	807	620	MW/0.1Hz

3. Frequency response withdrawal continues to be a characteristic of the Eastern Interconnection. The BC'_{ADJ} adjustment factor introduced in the *2012 Frequency Response Initiative Report* should continue to be tracked and used to adjust the IFRO for the Eastern Interconnection.
4. NERC should consider modifications to the IFRO calculation to change the method of handling the ERCOT Credit for Load Resources[7] (CLR) in the calculation. When the IFRO calculation was designed in 2012, the CLR was granted to account for a fixed value of load set to automatically trip at 59.7 Hz. Since that time,

[1] http://www.nerc.com/pa/Stand/Reliability%20Standards/BAL-003-1.1.pdf
[2] http://www.nerc.com/docs/pc/FRI_Report_10-30-12_Master_w-appendices.pdf
[3] Prepared jointly by the System Analysis and Performance Analysis departments.
[4] These IFROs were held constant through operating years 2016 and 2017.
[5] Initial calculated IFROs for Operating Year 2018 are: Eastern -1,071, Western -895, ERCOT -381, Québec -180. These are not to be used for Operating Year 2018, pursuant to Recommendation 1.
[6] Based on mean interconnection frequency response performance from Appendix E of the *2017 State of Reliability* report for operating year 2016.
[7] Formerly called Load acting as a Resource, or LaaR

the Responsive Reserve Service (RRS) has become a variable quantity procured by ERCOT as part of their frequency responsive resources. This differs from the CLR in the Western Interconnection for the loss of two Palo Verde units, where the load is automatically tripped by a Remedial Action Scheme (RAS).

Outstanding Recommendations from 2016 FRAA Report

Several recommendations from the *2016 FRAA* report[8] are currently being pursued through analysis by NERC staff and through the standards in the form of two standards authorization requests (SARs). Refer to that report for additional details.

[8] http://www.nerc.com/comm/OC/Documents/2016_FRAA_Report_2016-09-30.pdf

Introduction

This report is the 2017 annual analysis of frequency response performance for the administration and support of NERC Reliability Standard BAL-003-1 – Frequency Response and Frequency Bias Setting[9]. It provides an update to the statistical analyses and calculations contained in the *2012 Frequency Response Initiative Report*[10] that were approved by the NERC RS, the OC, and accepted by the Board. No changes are proposed to the procedures recommended in the 2012 report at this time.

This report, prepared by NERC staff,[11] contains the annual analysis, calculation, and recommendations for the IFRO for each of the four electrical interconnections of North America for the operational year 2018 (December 2016 through November 2017). This analysis includes the following:

- Statistical analysis of the interconnection frequency characteristics for the operating years 2013 through 2016 (December 1, 2012 through November 30, 2016)
- Calculation of adjustment factors from BAL-003-1 frequency response events
- Analysis of frequency profiles for each interconnection
- Dynamics analysis validation of the recommended IFROs

This year's frequency response analysis builds upon the work and experience from performing such analyses since 2013. As such, there are several important things that should be noted about this report:

- The University of Tennessee-Knoxville (UTK) FNET[12] data used in the analysis has seen significant improvement in data quality, simplifying and improving annual analysis of frequency performance and ongoing tracking of frequency response events. In addition, NERC uses data quality checks to flag additional bad one-second data, including a bandwidth filter, least squares fit, and derivative checking. This slightly modified data checking techniques resulted in no or minimal (+/- 0.001 Hz) change to starting frequency.
- As with the previous year's analysis, all frequency event analysis is using sub-second data from the FNET system frequency data recorders (FDRs). This eliminates the need for the CC_{ADJ} factor originally prescribed in the *2012 Frequency Response Initiative Report* because the actual frequency nadir was able to be accurately captured.
- The frequency response analysis tool[13] (FRAT) is being used by the NERC Bulk Power System Awareness (BPSA) group for frequency event tracking in support of the NERC Frequency Working Group (FWG). The tool has expedited and streamlined interconnection frequency response analysis. The tool provides an effective means of compiling frequency response events and generating a database of necessary values for adjustment factor calculations.
- Because the IFROs for the Western and ERCOT Interconnections have not changed from those prescribed for operating year 2017 (858 MW/0.1 Hz and 381 MW/0.1 Hz, respectively), additional dynamic validation analyses were not done for the 2017 FRAA report.

[9] http://www.nerc.com/pa/Stand/Reliability%20Standards/BAL-003-1.1.pdf
[10] http://www.nerc.com/docs/pc/FRI_Report_10-30-12_Master_w-appendices.pdf
[11] Prepared jointly by the System Analysis and Performance Analysis departments.
[12] 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.
[13] Developed by Pacific Northwest National Laboratory (PNNL).

For the Eastern Interconnection, an off-peak dynamics analysis was performed of the recommended 2018 operating year IFRO to determine if the prescribed 1,015 MW/0.1 Hz level of primary frequency response is adequate to avoid tripping of the first stage of regionally-approved under-frequency load shedding (UFLS) systems in the interconnection (59.5 Hz). This analysis was done using the 2017 light load dynamics case prepared by the Eastern Interconnection Reliability Assessment Group (ERAG)/Multiregional Modeling Working Group (MMWG).

Details of that analysis were contained in the *2017 Frequency Response of the Eastern Interconnection during Light Load Conditions* report provided to FERC in an informational filing[14] on June 30, 2017.

[14] http://www.nerc.com/FilingsOrders/us/NERC%20Filings%20to%20FERC%20DL/Eastern%20Interconnect%20Info%20Filing.pdf

Chapter 1: Interconnection Frequency Characteristic Analysis

Annually, NERC staff performs a statistical analysis[15] of the frequency characteristics for each of the four interconnections. That analysis is performed to monitor the changing frequency characteristics of the interconnections, and to statistically determine the starting frequencies for the IFRO calculations. For this report's analysis, one-second frequency data[16] from operating years 2013-2016 (December 1, 2012 through November 30, 2016) was used.

Frequency Variation Statistical Analysis

The 2017 frequency variation analysis was performed on one-second frequency data for operating years 2013–2016 and is summarized in Table 1.1. This analysis is used to determine the starting frequency to be used in the IFRO calculations for each of the interconnections.

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

Table 1.1: Interconnection Frequency Variation Analysis

Value	Eastern	Western	ERCOT	Québec
Time Frame (Operating Years)	2013–2016	2013–2016	2013–2016	2013–2016
Number of Samples	124,636,461	125,666,109	123,637,502	120,966,623
Filtered Samples (% of total)	98.7%	99.6%	97.9%	95.8%
Minimum Value (Hz)	59.909	59.676	59.710	59.792
Maximum Value (Hz)	60.114	60.114	60.197	60.199
Expected Value (Hz)	59.999	59.999	59.999	59.999
Variance of Frequency (σ^2)	0.00023	0.00037	0.00034	0.00040
Standard Deviation (σ)	0.01510	0.01916	0.01838	0.01999
50% percentile (median)	59.998	59.998	60.001	59.998
Starting Frequency (F_{START}) (Hz)	**59.974**	**59.966**	**59.968**	**59.967**

The starting frequency for the calculation of IFROs is the fifth-percentile lower tail of samples from the statistical analysis, representing a 95 percent chance that frequencies will be at or above that value at the start of any frequency event. Since the starting frequencies encompass all variations in frequency, including changes to the target frequency during TEC, the need to expressly evaluate TEC as a variable in the IFRO calculation is eliminated.

Figures 1.1 through 1.4 show the probability density function of frequency for each interconnection. The vertical red line is the fifth percentile frequency; the interconnection frequency will statistically be greater than that value 95 percent of the time. This value is used as the starting frequency.

[15] Refer to the 2012 *Frequency Response Initiative Report* for details on the statistical analyses used.

[16] One-second frequency data for the frequency variation analysis is provided by the University of Tennessee Knoxville (UTK). The data is sourced from FDRs in each interconnection. The median value among the higher-resolution FDRs is down-sampled to one sample per second, and filters are applied to ensure data quality.

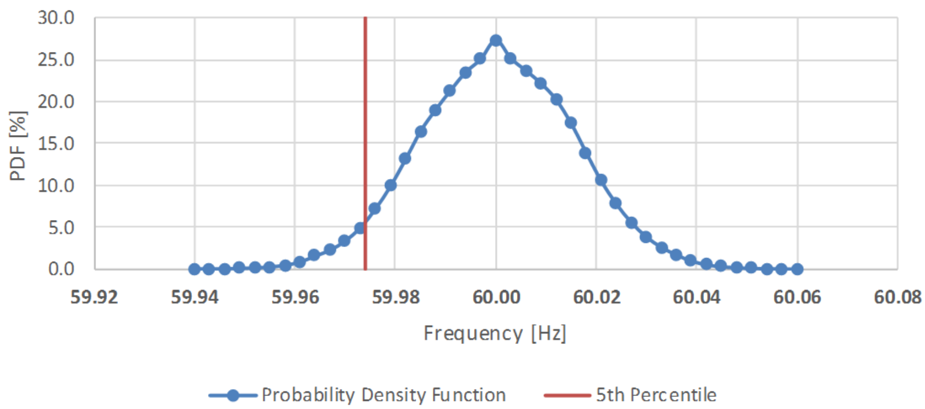


Figure 1.1: Eastern Interconnection 2013–2016 Probability Density Function of Frequency

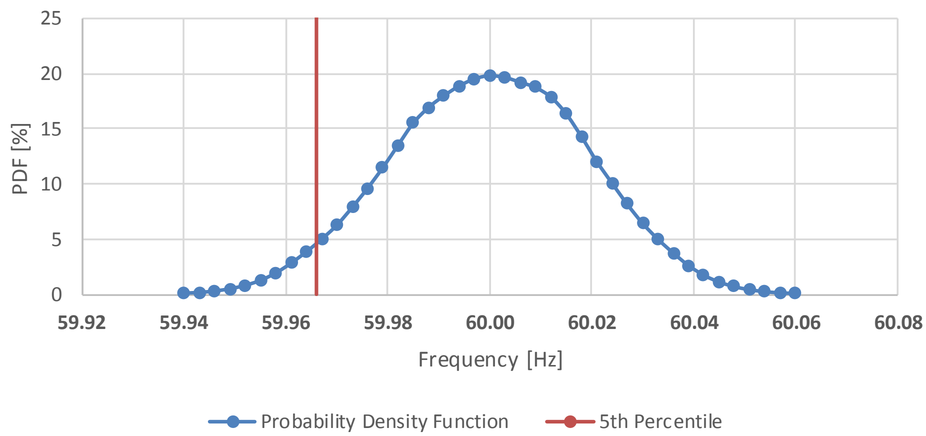


Figure 1.2: Western Interconnection 2013–2016 Probability Density Function of Frequency

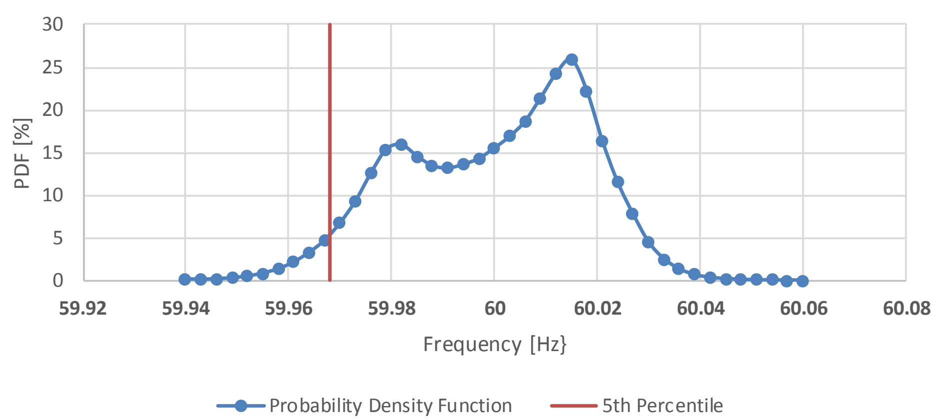


Figure 1.3: ERCOT Interconnection 2013–2016 Probability Density Function of Frequency

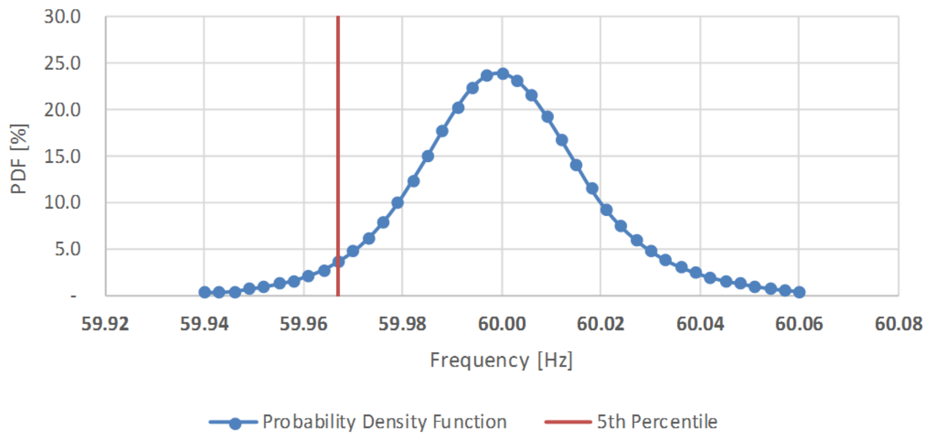


Figure 1.4: Québec Interconnection 2013–2016 Probability Density Function of Frequency

ERCOT's Frequency Characteristic Changes

Standard TRE BAL-001[17] went into full effect in April 2015 and caused a dramatic change in the probability density function of frequency for ERCOT in 2015 and 2016. That standard requires all resources in ERCOT to provide proportional, non-step primary frequency response with a ±16.7 mHz deadband. As a result, anytime frequency exceeds 60.017 Hz, resources automatically curtail themselves. That has resulted in far less operation in frequencies above the deadband since all resources, including wind, are backing down. It is exhibited in Figure 1.3 above as a probability concentration around 60.017 Hz. Similar behavior is not exhibited at the low deadband of 59.983 Hz because most wind resources are operated at maximum output and cannot increase when frequency falls below the deadband.

Figure 1.5 shows the progressive changes in ERCOT's frequency probability density function from 2013 through 2016. Also evident is a reduced probability of frequencies above 60.017 Hz deadband.

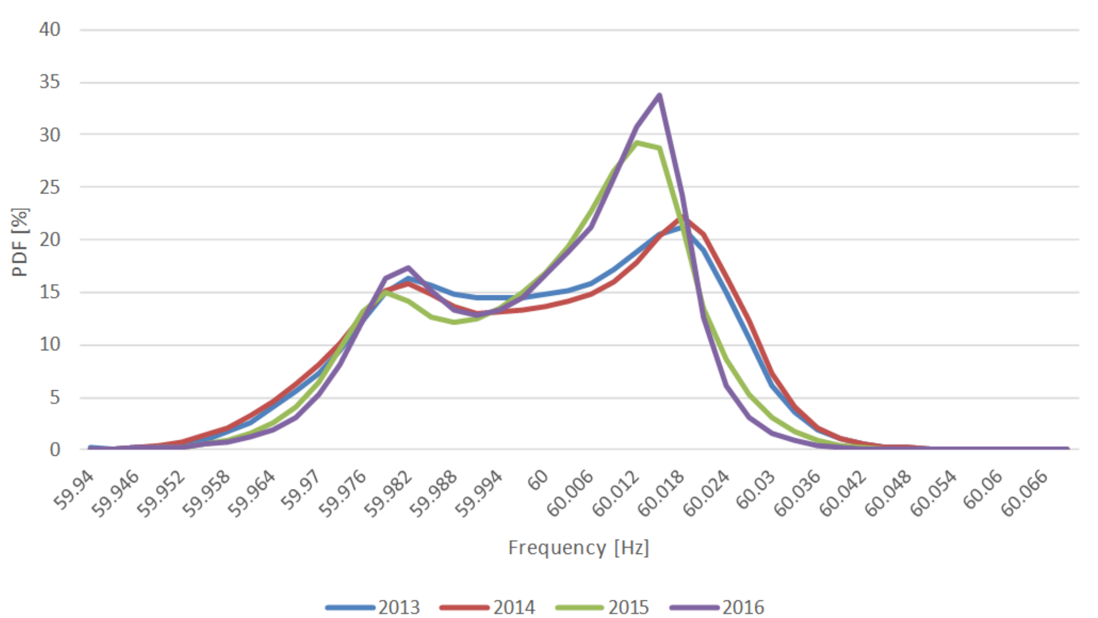


Figure 1.5: ERCOT Interconnection Frequency Probability Density Function by Year

[17] http://www.nerc.com/pa/Stand/Reliability%20Standards/BAL-001-TRE-1.pdf

Figure 1.6 compares the frequency probability density functions for the four interconnections for operating years 2013 through 2016.

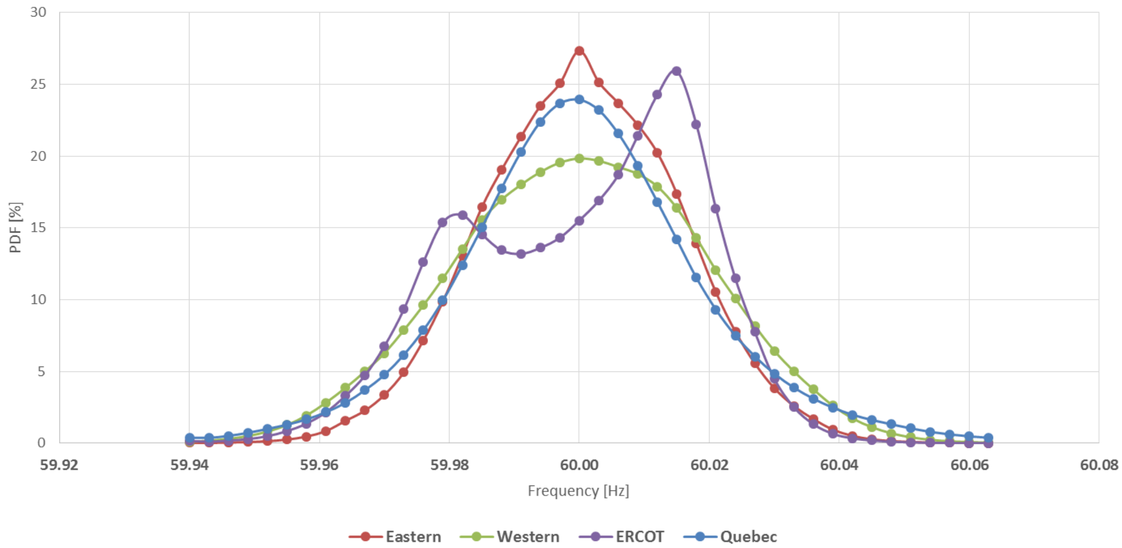


Figure 1.6: Comparison of 2013–2016 Interconnection Frequency Probability Density Functions

Changes in Starting Frequency

A comparison of expected frequencies and starting frequencies from the 2015 through 2017 frequency variability analyses is shown in Table 1.2. Expected frequencies are unchanged for all but the Eastern Interconnection. Starting frequencies dropped by 0.001 Hz for and Western and Québec Interconnections; the Eastern Interconnection starting frequency remained unchanged. The ERCOT Interconnection had an increase of 0.001 Hz, attributable to changes in the frequency characteristics of the interconnection.

Table 1.2: Comparison of Interconnection Frequency Statistics (Hz)				
	2015 Analysis	2016 Analysis	2017 Analysis	2016-2017 Change
Expected Frequencies				
Eastern	60.000	60.000	59.999	-0.001
Western	59.999	59.999	59.999	0.000
ERCOT	59.999	59.999	59.999	0.000
Québec	59.999	59.999	59.999	0.000
Starting Frequencies				
Eastern	59.974	59.974	59.974	0.000
Western	59.967	59.967	59.966	-0.001
ERCOT	59.966	59.967	59.968	0.001
Québec	59.969	59.968	59.967	-0.001

Chapter 2: Determination of Interconnection Frequency Response Obligations

The calculation of the IFROs is a multifaceted process that employs statistical analysis of past performance, analysis of the relationships between measurements of Value A, Point C, and Value B, and other adjustments to the allowable frequency deviations and resource losses used to determine the recommend IFROs. Refer to the *2012 Frequency Response Initiative Report* for additional details on the development of the IFRO and the adjustment calculation methods.[18]The chapter is organized to follow the flow of the IFRO calculation as it is performed for all four interconnections.

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 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:

- A frequency event should not activate the first stage of regionally approved UFLS systems within the interconnection.
- Local activation of first-stage UFLS systems for severe frequency excursions, particularly those associated with delayed fault-clearing or in systems on the edge of an interconnection, may be unavoidable.
- Other frequency-sensitive loads or electronically coupled resources may trip during such frequency events as is the case for photovoltaic (PV) inverters.
- 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 utilized for frequency events that are expected to happen on a relatively regular basis. As such, the resource loss protection criteria were selected as detailed in the *2012 Frequency Response Initiative Report* to avoid violating regionally approved UFLS settings.

IFRO Formulae

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

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

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

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

$$ARLPC = RLPC - CLR$$

[18] http://www.nerc.com/docs/pc/FRI_Report_10-30-12_Master_w-appendices.pdf

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

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 original 2012 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 BA is limited to SCADA scan rates of one to six seconds. Therefore, the ability to measure frequency response at the BA 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 selected for BAL-003-1 operating years 2013 through 2016 (between December 1, 2012 to November 30, 2016), which captures the relationship between Value B and Point C.

Sub-Second Frequency Data Source

Frequency data used for calculating all of the adjustment factors used in the IFRO calculation comes from the "FNet /GridEye system" hosted by UTK and the Oak Ridge National Laboratory. Six minutes of data is used for each frequency disturbance analyzed, one minute prior to the event and five 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 frequency data recorders (FDRs) for that event.

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 always 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 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 CB_R adjusted for confidence (Table 2.1) should be used to compensate for the differences between Point C and Value B. For this analysis, BAL-003-1 frequency events from operating years 2013 through 2016 (December 1, 2012 through November 30, 2016).

Table 2.1: 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	100	1.082	0.174	0.029	1.111
Western	74	1.603	0.347	0.067	1.670
ERCOT	156	1.583	0.490	0.065	1.648
Québec	113	3.876	1.079	0.168	1.550

The Eastern Interconnection historically exhibited a frequency response characteristic that often had Value B below Point C, and the CB_R value for the Eastern Interconnection has been below 1.000. In those instances, the CB_R had to be limited to 1.000. However, the calculated CB_R in this year's analysis[19] indicates a value above 1.000, and no such limitation is required. This is due to the improvement made to primary frequency response of the interconnection through the outreach efforts by the RS and the North American Generator Forum (NAGF).

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

[19] The same was true for the 2016 analysis.

high rebound rates between Point C and the calculated Value B. For the 113 frequency events in their event sample, Québec's CB_R value would be 4.13, 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, which limits the CB_R.

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 2017 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.

Adjustment for Primary Frequency Response Withdrawal (BC'_{ADJ})

At times, the actual frequency event nadir 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. 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.

In order to track frequency response withdrawal in this report, the later-occurring nadir is termed Point C', and is defined as occurring after the Value B averaging period, and must be lower than either Point C or Value B.

Primary frequency response withdrawal is 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.

The statistical analysis is performed on the events with C' value lower than Value B to determine the adjustment factor BC'_{ADJ}. Those results correct for the influence of frequency response withdrawal on setting the IFRO. Table 2.2 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 those where C' was below Point C for operating years 2013 through 2016 (December 1, 2012 through November 30, 2016).

Table 2.2: Statistical Analysis of the Adjustment for C' Nadir (BC'_{adj})

Interconnection	Number of Events Analyzed	C' Lower than B	C' Lower than C	Mean Difference	Standard Deviation	BC'ADJ (95% Quantile)
Eastern	100	62	37	0.005	0.004	0.007
Western	74	10	0	N/A	N/A	N/A
ERCOT	156	26	1	N/A	N/A	N/A
Québec	113	5	0	N/A	N/A	N/A

Only the Eastern Interconnection had a significant number of events were C' was below Point C. Although an event with C' lower than Point C was identified in the ERCOT Interconnection, there is only statistically significant data to apply this adjustment factor to the Eastern Interconnection. There were 62 out of 100 frequency events in the interconnection exhibiting a secondary nadir (Point C') below value B and 37 out of those had Point C' lower than the initial frequency nadir (Point C). These secondary nadirs occur 73 to 90 seconds after the start of the event.[20]

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 7 mHz to account for the statistically expected Point C' value of a frequency event. In the Eastern Interconnection, the Point C' nadir occurs 73 to 90 seconds after the start of the event,[21] which is well beyond the time frame for calculating Value B.

Recommendation:

NERC should continue to track and adjust for the withdrawal characteristics of the Eastern Interconnection.

Low-Frequency Limit

The low-frequency limits to be used for the IFRO calculations (Table 2.3) should be the highest step in the Interconnection for regionally approved UFLS systems. These values have remained unchanged since the *2012 Frequency Response Initiative Report*.

Table 2.3: Low-Frequency Limits (Hz)

Interconnection	Highest UFLS Trip Frequency
Eastern	59.5
Western	59.5
ERCOT	59.3
Québec	58.5

The highest UFLS set point in the Eastern Interconnection is 59.7 Hz in FRCC, while the highest set point in the rest of the 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, especially in electrical proximity to the loss of resources. Severe system conditions might drive the frequency and voltage to levels that present some generator and turbine control systems with a combination that may cause those systems to trip the generator. 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.

Electronically-coupled resources may also be susceptible to extremes in frequency. Laboratory testing by Southern California Edison 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

[20] The timing of the C' occurrence is consistent with outer-loop plant and unit controls causing withdrawal of unit frequency response.
[21] The timing of the C' occurrence is consistent with outer-loop plant and unit controls causing withdrawal of unit frequency response.

in the future in areas with a high penetration of PV resources; however, IEEE Standard 1547 is being revised and will include significantly wider voltage ride-through capability.

In addition to general frequency perturbations, inverter-coupled resources may be susceptible to tripping during transmission system fault conditions, both for very low voltages and during a fault and potential problems in accurately measuring frequency during a fault. This was evidenced by the tripping of a number of large transmission-connected (at 230 kV and 500 kV) solar farms in Southern California during faults caused by wild fires in the area. In the largest of those events,[22] the inverter controls[23] on about 1,200 MW of solar resources either tripped or went into momentary cessation (stopped injecting current to the system) at 26 separate solar installations over a fairly large area. About 700 MW "tripped" due to a perceived system frequency below 57 Hz, and about 450 MW inverters designed to "block" (momentary cessation of current injection) for voltages below 0.9 V per unit. There have been about 15 such instances observed since August of 2016.

NERC and WECC formed a joint task force to analyze those events. Their *1200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report* and an associated Industry Alert Recommendation *Loss of Solar Resources during Transmission Disturbances due to Inverter Settings* can be found on the Alerts page[24] on the NERC website.

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 relays to help arrest frequency declines. A CLR is made for the resource contingency for the ERCOT Interconnection.

The amount of CLR available any given time varies by different factors including its usage in the immediate past. NERC performed statistical analysis on hourly available CLR over a two-year period from January 2015 through December 2016, similar to the approach used in the 2015 and 2016 FRAA. Statistical analysis indicated that 1,209 MW of CLR is available 95 percent of the time. Therefore, a CLR adjustment of 1,209 MW is applied in the calculation of the ERCOT Interconnection IFRO as a reduction to the resource loss protection criteria (RLPC).

The 2015–2016 CLR for the ERCOT Interconnection is only 16 MW higher than the 1,193 MW adjustment in the 2016 IFRO calculation, and 20 MW above the 1,181 MW adjustment in the 2015 IFRO calculation, showing consistency in the procurement and availability load resources to arrest frequency response in ERCOT.

ERCOT Credit for Load Resources

Prior to April 2012, ERCOT was procuring 2,300 MW of 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, meaning load resources could potentially provide up to 1,400 MW of automatic primary frequency response. This differs from the CLR in the Western Interconnection for the loss of two Palo Verde units, where the load is automatically tripped by a RAS.

The current method of procurement and utilization of CLR has moved away from the original concept of a credit against the RLPC and more toward procurement of a frequency responsive reserve resource.

Recommendation

NERC should consider modifications to the IFRO calculation to change the method of handling the ERCOT CLR in the calculation. When the IFRO calculation was designed in 2012, the CLR was granted to account for a fixed value

[22] The fault was a line-to-line fault on a 500 kV circuit, cleared normally by primary protective relaying normally in 2.5 cycles (41.7 milliseconds).

[23] No protective relays operated or circuit breakers opened at the solar plants during the faults.

[24] http://www.nerc.com/pa/rrm/bpsa/Pages/Alerts.aspx

of load set to automatically trip at 59.7 Hz. Since that time, the RRS has become a variable quantity procured by ERCOT as part of their frequency responsive resources.

Determination of Maximum Allowable Delta Frequencies

Because of the measurement limitation[25] 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 2.4 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 the following:

- Adjustments for the differences between Point C and Value B.
- Adjustments for the event nadir being below Value C due to primary frequency response withdrawal measured by Point C'. Only the Eastern Interconnection exhibits statistically meaningful amounts of frequency response withdrawal.

Table 2.4: Determination of Maximum Allowable Delta Frequencies

	Eastern	Western	ERCOT	Québec	Units
Starting Frequency	59.974	59.966	59.968	59.967	Hz
Minimum Frequency Limit	59.500	59.500	59.300	58.500	Hz
Base Delta Frequency	0.474	0.467	0.667	1.468	Hz
CB_R[26]	1.111	1.670	1.648	1.550	Ratio
Delta Frequency (DF_{CBR})[27]	0.427	0.280	0.405	0.947	Hz
BC'_{ADJ}[28]	0.007	N/A	N/A	N/A	Hz
Max. Allowable Delta Frequency	0.420	0.280	0.405	0.947	Hz

Note: The adjustment for the differences one-second versus sub-second frequency data (CC_{ADJ}) is no longer required and has been eliminated. All Point C calculations for the 2017 FRAA utilized sub-second measurements from FNET FDRs.

Comparison of Maximum Allowable Delta Frequencies

Several factors account for the changes in the maximum allowable delta frequencies which have a direct bearing on the IFRO calculation. In the *2016 Frequency Response Annual Analysis* report, several inconsistencies with the behavior of the IFRO calculations for the relative changes in Values A and B and Point C.[29] Additional analysis of those inconsistencies is contained in the Findings section of this report.

CB_R is calculated as: $CB_R = \frac{Value\ A - Point\ C}{Value\ A - Value\ B}$

[25] Due to the use of 1 to 6 second scan-rate data in BA's EMS systems to calculate the BA's Frequency Response Measures for frequency events under BAL-003-1

[26] Adjustment for the differences between Point C and Value B

[27] Base Delta Frequency/CB_R

[28] Adjustment for the event nadir being below the Value B (Eastern Interconnection only) due to primary frequency response withdrawal.

[29] See Findings section of the *2016 Frequency Response Annual Analysis*.

Tables 2.5 through 2.8 compare the CB_R of the 2017 for each interconnection with the CB_R values from the *2016 Frequency Response Annual Analysis* report.

Table 2.5: Maximum Allowable Delta Frequency Comparison

Eastern Interconnection	OY 2017 In Use[30]	OY 2017 Calc.[31]	OY 2018 Calc.[32]	2017 Calc. to 2018 Calc. Change	Units
Starting Frequency	59.974	59.974	59.974	0.000	Hz
Min. Frequency Limit	59.500	59.500	59.500	0.000	Hz
Base Delta Frequency	0.474	0.474	0.474	0.000	Hz
CB_R	1.052	1.071	1.111	0.040	Ratio
Delta Freq. (DF_{CBR})	0.450	0.443	0.427	-0.016	Hz
BC'_{ADJ}	0.007	0.007	0.007	0.000	Hz
Max. Allowable Delta Frequency	**0.443**	**0.436**	**0.420**	**-0.016**	**Hz**
Average Value A	59.998	59.997	59.997	0.000	Hz
Average Value B	59.947	59.947	59.950	0.003	Hz
Average Point C	59.947	59.947	59.947	0.000	Hz

The Eastern Interconnection maximum allowable delta frequency value decreased by 16 mHz. This was driven by the following factors:

- The CB_R ratio increased by a factor of 0.040, from 1.071 to 1.111, reducing the maximum delta frequency (DF_{CBR}) by 16 mHz. This was caused by the following changes in the interconnection's frequency response performance from the 2012–2015 to the 2013–2016 evaluation period:
  - No change in the average Value A frequency
  - A 3 mHz increase in the average Value B
  - No change in the average Point C frequency.

  Since CB_R is calculated as noted above[33] with all other variables remaining the same, the larger Value B will make the denominator smaller, raising the CB_R and lowering the maximum allowable delta frequency.[34] This highlights the problem with the current IFRO calculation; despite an improvement in Value B frequency response performance, the lack of improvement in Point C performance results in a decreasing maximum allowable delta frequency, which would increase the interconnection's IFRO.
- BC'_{ADJ} remained unchanged at 0.007 Hz, indicating no change in frequency response withdrawal. However, the percentage of frequency events exhibiting C' below Point C withdrawal properties dropped from 44 percent to 37 percent in the BAL-003 events of the 2013–2016 operating years analyzed.[35]

[30] Calculated in the 2015 FRAA report. Average frequency values were for operating years 2012 through 2014.
[31] Calculated in the 2016 FRAA report. Average frequency values were for operating years 2012 through 2015.
[32] Calculated in the 2017 FRAA report. Average frequency values were for operating years 2013 through 2016.
[33] CB_R is calculated as: $CB_R = \frac{Value\ A - Point\ C}{Value\ A - Value\ B}$
[34] The DF_{CBR} is calculated by dividing the Base Delta Frequency by the CB_R.
[35] For 2013-2016 operating years, 37 events out of 100 events versus 37 out of 84 in operating years 2012-2015.

- The increase in average Value B and the reduction in percentage of C' events are the results of the outreach efforts by the NERC RS and the NAGF to improve generator governor performance and reduce frequency response withdrawal.

Table 2.6: Maximum Allowable Delta Frequency Comparison

Western Interconnection	OY 2017 In Use[36]	OY 2017 Calc.[37]	OY 2018 Calc.[38]	2017 Calc. to 2018 Calc. Change	Units
Starting Frequency	59.967	59.967	59.967	0.000	Hz
Min. Frequency Limit	59.500	59.500	59.500	0.000	Hz
Base Delta Frequency	0.467	0.467	0.467	0.000	Hz
CB_R	1.598	1.566	1.670	0.104	Ratio
Delta Freq. (DF_{CBR})	0.292	0.298	0.280	-0.018	Hz
BC'_{ADJ}	N/A	N/A	N/A	N/A	Hz
Max. Allowable Delta Frequency	**0.292**	**0.298**	**0.280**	**-0.018**	**Hz**
Average Value A	60.000	59.999	59.997	-0.002	Hz
Average Value B	59.923	59.928	59.929	0.001	Hz
Average Point C	59.887	59.894	59.893	-0.001	Hz

The Western Interconnection maximum allowable delta frequency value decreased by 18 mHz. This was driven by the following factors:

- The CB_R ratio increased by a factor of 0.104, from 1.566 to 1.670, reducing the maximum delta frequency (DF_{CBR}) by 18 mHz. This was caused by the following changes in the interconnection's frequency response performance from the 2012-2015 to the 2013-2016 evaluation period:
  - A 2 mHz decrease in the average Value A frequency
  - A 1 mHz increase in the average Value B
  - A 1 mHz decrease in average Point C frequency.

  Since CBR is calculated as noted above, the relationships between will result in raising the CBR and lowering the maximum allowable delta frequency.[39]

[36] Calculated in the 2015 FRAA report. Average frequency values were for operating years 2012 through 2014.
[37] Calculated in the 2016 FRAA report. Average frequency values were for operating years 2012 through 2015.
[38] Calculated in the 2017 FRAA report. Average frequency values were for operating years 2013 through 2016.
[39] The DF_{CBR} is calculated by dividing the Base Delta Frequency by the CB_R.

Table 2.7: Maximum Allowable Delta Frequency Comparison					
ERCOT Interconnection	**OY 2017 In Use[40]**	**OY 2017 Calc.[41]**	**OY 2018 Calc.[42]**	**2017 Calc. to 2018 Calc. Change**	**Units**
Starting Frequency	59.966	59.967	59.967	0.000	Hz
Min. Frequency Limit	59.300	59.300	59.300	0.000	Hz
Base Delta Frequency	0.666	0.667	0.667	0.000	Hz
CB_R	1.619	1.626	1.648	0.022	Ratio
Delta Freq. (DF_{CBR})	0.411	0.410	0.405	-0.005	Hz
BC'_{ADJ}	N/A	N/A	N/A	N/A	Hz
Max. Allowable Delta Frequency	**0.411**	**0.410**	**0.405**	**-0.005**	**Hz**
Average Value A	59.996	59.997	59.997	0.000	Hz
Average Value B	59.889	59.894	59.907	0.013	Hz
Average Point C	59.840	59.846	59.855	0.009	Hz

The ERCOT Interconnection maximum allowable delta frequency value decreased by 5 mHz. This was driven by the following factors:

- The CB_R ratio increased by a factor of 0.022, from 1.626 to 1.648, reducing the maximum delta frequency (DF_{CBR}) by 5 mHz. This was caused by the following changes in the interconnection's frequency response performance from the 2012–2015 to the 2013–2016 evaluation period:
  - No change in the average Value A frequency
  - A 13 mHz increase in the average Value B
  - A 9 mHz increase in average Point C frequency.

Since CBR is calculated as noted above, the relationships between will result in raising the CBR and lowering the maximum allowable delta frequency.[43]

Table 2.8: Maximum Allowable Delta Frequency Comparison					
Québec Interconnection	**OY 2017 In Use[44]**	**OY 2017 Calc.[45]**	**OY 2018 Calc.[46]**	**2017 Calc. to 2018 Calc. Change**	**Units**
Starting Frequency	59.969	59.968	59.968	0.000	Hz
Min. Frequency Limit	58.500	58.500	58.500	0.000	Hz
Base Delta Frequency	1.469	1.468	1.468	0.000	Hz

[40] Calculated in the 2015 FRAA report. Average frequency values were for operating years 2012 through 2014.
[41] Calculated in the 2016 FRAA report. Average frequency values were for operating years 2012 through 2015.
[42] Calculated in the 2017 FRAA report. Average frequency values were for operating years 2013 through 2016.
[43] The DF_{CBR} is calculated by dividing the Base Delta Frequency by the CB_R.
[44] Calculated in the 2015 FRAA report. Average frequency values were for operating years 2012 through 2014.
[45] Calculated in the 2016 FRAA report. Average frequency values were for operating years 2012 through 2015.
[46] Calculated in the 2017 FRAA report. Average frequency values were for operating years 2013 through 2016.

Table 2.8: Maximum Allowable Delta Frequency Comparison					
Québec Interconnection	**OY 2017 In Use**[44]	**OY 2017 Calc.**[45]	**OY 2018 Calc.**[46]	**2017 Calc. to 2018 Calc. Change**	**Units**
CB_R	1.550	1.550	1.550	0.000	Ratio
Delta Freq. (DF_{CBR})	0.948	0.947	0.947	0.000	Hz
BC'_{ADJ}	N/A	N/A	N/A	N/A	Hz
Max. Allowable Delta Frequency	**0.948**	**0.947**	**0.947**	**0.000**	**Hz**
Average Value A	60.003	60.003	60.001	-0.002	Hz
Average Value B	59.843	59.850	59.849	-0.001	Hz
Average Point C	59.433	59.462	59.463	0.001	Hz

In the Québec Interconnection, maximum allowable delta frequency value remained unchanged in the 2017 analysis. CB_R is a fixed quantity for Québec, so the only factor that has any influence on the maximum allowable delta frequency is the starting frequency, which did not change since last year's analysis.

Calculated IFROs

Table 2.9 shows the determination of IFROs for operating year 2018 (December 2017 through November 2018) 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 2.9: Initial Calculation of Operating Year 2018 IFROs					
	Eastern (EI)	**Western (WI)**	**ERCOT (TI)**	**Québec (QI)**	**Units**
Starting Frequency	59.974	59.967	59.967	59.968	Hz
Max. Allowable Delta Frequency	0.420	0.280	0.405	0.947	Hz
Resource Contingency Protection Criteria	4,500	2,626	2,750	1,700	MW
Credit for Load Resources	N/A	120[47]	1,209	N/A	MW
IFRO	**-1,071**	**-895**	**-381**	**-180**	**MW/0.1Hz**
Absolute Value of IFRO[48]	**1,071**	**895**	**381**	**180**	**MW/0.1Hz**

[47] Based on the most updated information regarding load shedding for loss of two Palo Verde units, with a Western Interconnection CLR = 120 MW.

[48] The values of IFRO calculated for operating year 2018 are shown here for reference. It is recommended that the IFROs for operating year 2018 remain the same as the values calculated in the 2015 FRAA report due to inconsistencies identified in the IFRO formulae, as described in the Recommendations and Findings sections of the report.

Table 2.9: Initial Calculation of Operating Year 2018 IFROs					
	Eastern (EI)	Western (WI)	ERCOT (TI)	Québec (QI)	Units
Absolute Value of Mean Interconnection Frequency Response Performance for operating year 2016[49]	2,483	1,344	807	620	MW/0.1Hz
2016 IFRO as a % of Interconnection Load[50]	0.175	0.546	0.514	0.469	%

Note: The operating year 2016 frequency response performance is significantly higher than the calculated IFROs for all four interconnections.

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. Tables 2.10 through 2.11 compare the current IFROs and their key component values to those presented in the *2016 Frequency Response Annual Analysis* report.

Table 2.10: Interconnection IFRO Comparison						
	OY 2017 In Use[51]	OY 2017 Calc.[52]	OY 2018 Calc.[53]	2017 Calc. to 2018 Calc. Change	OY 2017 In Use to 2018 Calc. Change	Units
Eastern Interconnection						
Starting Frequency	59.974	59.974	59.974	0.000	0.000	Hz
Max. Allowable Delta Frequency	0.443	0.435	0.420	-0.015	-0.023	Hz
Resource Contingency Protection Criteria	4,500	4,500	4,500	0	0	MW
Credit for Load Resources	N/A	N/A	N/A	N/A	N/A	MW
Absolute Value of IFRO	**1,015**	**1,034**	**1,071**	37	56	MW/ 0.1Hz
Average Value A	59.998	59.997	59.997	0.000	-0.001	Hz
Average Value B	59.947	59.947	59.950	0.003	0.003	Hz
Average Point C	59.947	59.947	59.947	0.000	0.000	Hz

[49] Based on mean interconnection frequency response performance from Appendix E of the *2017 State of Reliability* report for operating year 2016.

[50] Draft interconnection projected Total Internal Demands (2018 summer, 2018-2019 winter demand): to be used in the *2017 NERC Long-Term Reliability Assessment* EI = 610,438 MW, WI = 163,995 MW, TI = 74,149 MW, and QI (2016-2017 winter demand) = 38,184 MW. NOTE: These values are not yet finalized for the 2017 LTRA; draft numbers provided here for illustration purposes.

[51] Calculated in the 2015 FRAA report. Average frequency values were for operating years 2012 through 2014.

[52] Calculated in the 2016 FRAA report. Average frequency values were for operating years 2012 through 2015.

[53] Calculated in the 2017 FRAA report. Average frequency values were for operating years 2013 through 2016.

Table 2.10: Interconnection IFRO Comparison

	OY 2017 In Use[51]	OY 2017 Calc.[52]	OY 2018 Calc.[53]	2017 Calc. to 2018 Calc. Change	OY 2017 In Use to 2018 Calc. Change	Units
Western Interconnection						
Starting Frequency	59.967	59.967	59.967	0.000	0.000	Hz
Max. Allowable Delta Frequency	0.292	0.298	0.280	-0.018	-0.012	Hz
Resource Contingency Protection Criteria	2,626	2,626	2,626	0	0	MW
Credit for Load Resources	120	120	120	0	0	MW
Absolute Value of IFRO	**858**	**841**	**895**	54	27	MW/ 0.1Hz
Average Value A	60.000	59.999	59.997	-0.002	-0.003	Hz
Average Value B	59.923	59.928	59.929	0.001	0.006	Hz
Average Point C	59.887	59.894	59.893	-0.001	0.006	Hz

Table 2.11: Interconnection IFRO Comparison

	OY 2017 In Use[54]	OY 2017 Calc.[55]	OY 2018 Calc.[56]	2017 Calc. to 2018 Calc. Change	OY 2017 In Use to 2018 Calc. Change	Units
ERCOT Interconnection						
Starting Frequency	59.966	59.967	59.967	0.000	0.001	Hz
Max. Allowable Delta Frequency	0.411	0.410	0.405	-0.005	-0.006	Hz
Resource Contingency Protection Criteria	2,750	2,750	2,750	0	0	MW
Credit for Load Resources	1,181	1,193	1,209	16	28	MW
Absolute Value of IFRO	**381**	**380**	**381**	1	0	MW/ 0.1Hz
Average Value A	59.996	59.997	59.997	0.000	0.001	Hz
Average Value B	59.889	59.894	59.907	0.013	0.018	Hz
Average Point C	59.840	59.846	59.855	0.009	0.015	Hz
Québec Interconnection						
Starting Frequency	59.969	59.968	59.968	0.000	-0.001	Hz
Max. Allowable Delta Frequency	0.948	0.947	0.947	0.000	-0.001	Hz

[54] Calculated in the 2015 FRAA report. Average frequency values were for operating years 2012 through 2014.
[55] Calculated in the 2016 FRAA report. Average frequency values were for operating years 2012 through 2015.
[56] Calculated in the 2017 FRAA report. Average frequency values were for operating years 2013 through 2016.

Table 2.11: Interconnection IFRO Comparison						
	OY 2017 In Use[54]	OY 2017 Calc.[55]	OY 2018 Calc.[56]	2017 Calc. to 2018 Calc. Change	OY 2017 In Use to 2018 Calc. Change	Units
Resource Contingency Protection Criteria	1,700	1,700	1,700	0	0	MW
Credit for Load Resources	N/A	N/A	N/A	N/A	N/A	MW
Absolute Value of IFRO	**179**	**179**	**180**	0.001	0.001	MW/ 0.1Hz
Average Value A	60.003	60.003	60.001	-0.002	-0.002	Hz
Average Value B	59.843	59.850	59.849	-0.001	0.006	Hz
Average Point C	59.433	59.462	59.463	0.001	0.030	Hz

The calculated IFRO for the ERCOT Interconnection decreased by only 1 MW/0.1 Hz, and Québec Interconnection IFRO did not change, representing relatively stable frequency response characteristics over the time period of events analyzed.

Recommended IFROs for Operating Year 2018

Due to inconsistencies outlined in the Findings section of this report, the IFRO values for operating year 2018 (December 2017 through November 2018) shall remain the same values as calculated in the 2015 FRAA report for operating year 2016[57] and held constant through operating year 2017, shown in Table 2.12

Table 2.12: Recommended IFROs for Operating Year 2017					
	Eastern (EI)	Western (WI)	ERCOT (TI)	Québec (QI)	Units
IFRO	**-1,015**	**-858**	**-381**	**-179**	**MW/0.1Hz**

[57] These IFROs were held constant through operating years 2016 and 2017.

Chapter 3: Analysis of IFRO Calculation Method

The primary purpose of BAL-003 is to ensure that there is always sufficient primary frequency response to prevent frequency deviations from initiating activation of the UFLS safety net. That concern is mostly for mitigating the frequency dips in the first 20 seconds of the event, although there is always concern that subsequent withdrawal by outer loop generator controls (beyond 20 seconds) could also initiate UFLS action.

So the primary focus is on keeping Point C from impinging on the UFLS settings, but the frequency response obligations and the method for performance measurement and has to be linked to in some way to Value B because of the practical limitations of measurements using SCADA scan rate data. Therefore, the CBR adjustment was developed to account for the differences between the Point C nadir and Value B performance measures, calculated as:

$$CB_R = \frac{Value\ A - Point\ C}{Value\ A - Value\ B}$$

Therefore, the ratio is also affected by changes to Value A.

The analysis of the behavior of changes to the IFROs shows that it is primarily effected by the CB_R adjustment, making understanding of the relationship of movements of Values A and B and Point C crucial.

Measurement of Values A and B

Although the primary concern is for activation of UFLS for the Point C nadir, as a practical matter, the ability to measure the tie line and loads for the BAs is limited to 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 Point B.

The Value A frequency was initially defined as the average of the two scans immediately prior to the frequency event. All other averaging periods were then selected to be as consistent as possible with this 12-second average scan from the 6-second scan rate method. In addition, the “actual net interchange immediately before disturbance” was then defined as the average of the same period used for Value A.

The Value B frequency was then selected to be an average as long as the average of 6-second scan data as possible and would not begin until most of the hydro governor response had been delivered. It would end before significant automatic generation control (AGC) response had been initiated as indicated by a consistent frequency restoration slope. The “actual net interchange immediately after Disturbance” was then similarly defined as the average of the same period used for Value B.

However, the way the CB_R is applied in the IFRO calculations, by adjusting the allowable maximum delta frequency, creates unexpected and undesirable influences on the IFRO. The simplified[58] IFRO formulae are:

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

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

$$MDF = DF_{CBR}$$

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

[58] Adjustments for B-C’ and Credit for load resources are excluded here.

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.
- MDF is the maximum allowable delta frequency.
- RLPC is the resource loss protection criteria.
- IFRO is the interconnection frequency response obligation.

Table 3.1 shows how the IFRO calculation will change based on relative movement[59] of the differences between Value A and Point C and Value B (↑: increase, ↓: decrease, – : no change).For simplicity, Value A was kept constant.

Table 3.1: IFRO Movement in Relation to Point C and Values A and B

Case	Scenario	B	C	A-B	A-C	CB_R	Delta Freq	IFRO	Result
1	B – no change C – improving	–	↑	–	↓	↓	↑	↓	Lowering IFRO when A-C delta decreases
2	B – no change C – worsening	–	↓	–	↑	↑	↓	↑	Raising IFRO when A-C delta increases
3	B – improving C – no change	↑	–	↓	–	↑	↓	↑	Punishing B performance improvement
4	B – worsening C – no change	↓	–	↑	–	↓	↑	↓	Rewarding B performance worsening
5	B – worsening C – worsening	↓	↓	↑	↑	↓	↑	↓	Rewarding B & C performance worsening
6	B – improving C – improving	↑	↑	↓	↓	↓	↓	↑	Punishing B & C performance improvements

The original intent of CB_R adjustment in the IFRO calculation was to ensure Case 2 was covered, where an increasing difference between Point A and the frequency nadir would result in an increased IFRO. However, the calculation also causes Scenarios 3 through 6 to have an adverse effects on the IFRO calculation.

In Case 3, Value B is increasing, reflecting improved frequency response performance measured by Value B. However, that performance improvement results in a higher IFRO being set if Point C does not move. That sounds

[59] All movements were done in 5 millihertz increments, using generic frequency values.

counter intuitive, but because the Point C has not moved with Value B, there is no improvement in protecting against the Point C nadir impinging on the UFLS.

In Case 4, Value B is decreasing, reflecting poorer frequency response performance measured by Value B. The end result is a lowering of the IFRO, essentially rewarding the reduction in frequency response performance.

In Case 5, Value B and Point C are both decreasing by 5 mHz (59.950 to 59.945 and 59.940 to 59.935, respectively), but the relationship to Value A in the CB_R calculation results in a lowering of the IFRO, rewarding the reduction in frequency response performance.

In Case 6, Value B and Point C are both increasing by 5 mHz (59.950 to 59.955 and 59.940 to 59.945, respectively), but the relationship to Value A in the CB_R calculation results in an increase of the IFRO, punishing the improvement in frequency response performance.

These relationships and outcomes in the CB_R calculation results were not explored when the IFRO calculations were designed in 2012. A different method of adjustment for the difference between Value B and Point C is required for the calculation of IFROs.

Recommendation:

NERC should develop a different method for adjusting for the difference between Value B and Point C in the calculation of IFROs.

Chapter 4: Dynamics Analysis of Recommended IFROs

Because the IFROs for the Western and ERCOT Interconnections have not changed from those prescribed for operating year 2017 (858 MW/0.1 Hz and 381 MW/0.1 Hz, respectively), additional dynamic validation analyses were not done for the 2017 FRAA report. The IFRO validation from the *2016 Frequency Response Annual Analysis* report for those interconnections are repeated here for convenience. No analysis was performed for the Québec Interconnection.

For the Eastern Interconnection, an off-peak dynamics analysis was performed of the recommended 2018 operating year IFRO to determine if the prescribed 1,015 MW/0.1 Hz level of primary frequency response is adequate to avoid tripping of the first stage of regionally-approved UFLS systems in the interconnection (59.5 Hz). This analysis was done using the 2017 light load dynamics case prepared by the ERAG/ MMWG.

In all simulations, the effects of AGC, which typically starts to influence frequency response in the 30-45 second timeframe, were not modeled.

Eastern Interconnection[60]

The method used for performing the Eastern Interconnection evaluation was performed by detuning[61] the governor performance in the ERAG 2017-light-load base case in successive steps until it matched the prescribed 2018 Operating Year IFRO of 1,015 MW/0.1 Hz for loss of the RLPC of 4,500 MW. The resulting nadir was than compared to 59.5Hz UFLS, the Eastern Interconnection highest UFLS set point.

For this study, detuning was accomplished by disabling governors in several progressive steps with the "Detune case #5" mimicking the 1,015 MW/0.1 Hz IFRO. See Figure 4.1.

[60] The analysis for the Eastern Interconnection was originally published in the *2017 Frequency Response of the Eastern Interconnection during Light Load Conditions* report, published June 30, 2017 and subsequently filed with FERC. Additional detail on the analysis is contained in the report at:
http://www.nerc.com/FilingsOrders/us/NERC%20Filings%20to%20FERC%20DL/Eastern%20Interconnect%20Info%20Filing.pdf

[61] Detuning is a process of removing or reducing the frequency response capability for a given generation resource by changing the associated governor frequency response parameters, or by disabling the governor.

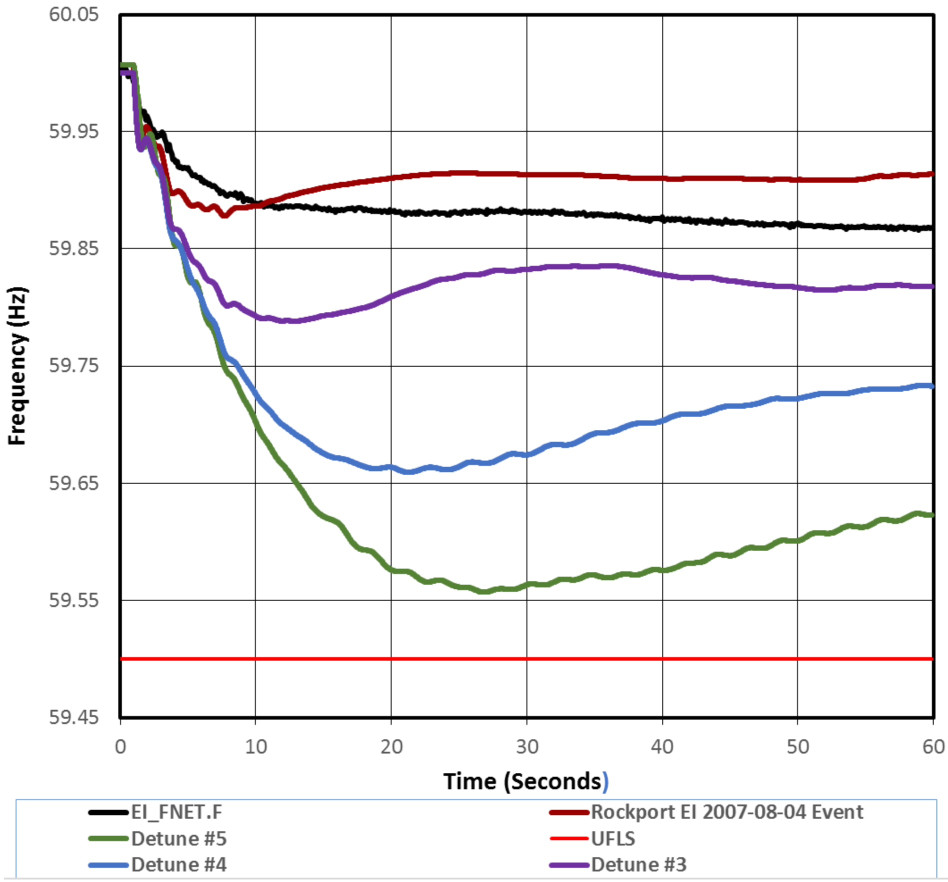


Figure 4.1: Eastern Interconnection Frequency Response for Detune #5 Scenario

This analysis is the first validation of the recommended IFRO of the Eastern Interconnection using actual governor data in the light load base case. This was the result of incorporating actual governor response data and modeling parameters obtained from the generator owners and operators through a number of surveys, and NERC's detailed review of governor models being used in the dynamics cases. Recommendations on changes to governor models and detailed setting data were provided to the ERAG/MMWG to be incorporated in the building process for the 2017-LL light load dynamics base case.

Previous IFRO validations in the 2012 FRI report and subsequent FRAA reports had to be performed with a dynamics case modified to contain only generic governor models.

The 1,015 MW/0.1 HZ IFRO prescribed for the 2018 Operating Year were validated to be adequate to maintain reliability of the Eastern Interconnection for the RLPC of 4,500 under the modeled light load conditions. The resultant nadir for that case is 59.564 Hz, about 64 mHz above the 59.5 Hz UFLS set point.

Western Interconnection[62]

Dynamic simulation of the defined resource contingency as per BAL-003-1 was performed for the Western Interconnection with frequency response degraded to at least the IFRO value of 841 MW/0.1 Hz. The analysis was performed on a WECC light load near-term planning case with the following modifications:

- The interconnection-wide demand level was reduced from 105 GW to a more representative light load condition of 97 GW.

[62] Analysis performed for the 2016 FRAA report.

- Interchanges between areas were held constant while reducing local generation for each area uniformly based on initial demand in the case.

The adjusted WECC case for the resource loss contingency gives the response shown in Figure 4.2. As the figure shows, frequency response is well above the first stage of UFLS at 59.5 Hz, and with an interconnection frequency response measure (IFRM) of 2,119 MW/0.1 Hz. The mean frequency has been used to obtain the representative points shown in the figure.

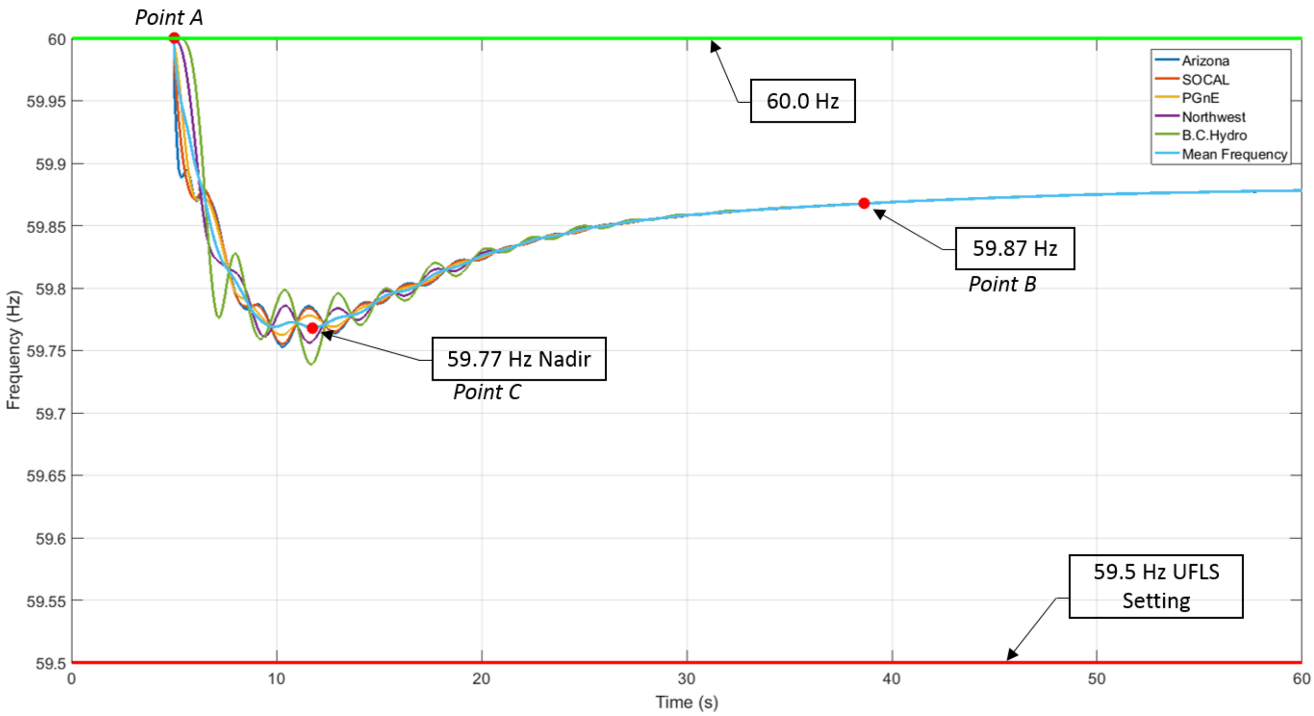


Figure 4.2: WECC Starting Case Simulation

Frequency response was degraded from this case to a worst-case scenario for the Western Interconnection of a response at the IFRO value of around 841 MW/0.1 Hz. This was accomplished by base-loading the majority of generation in certain areas, particularly Southern California and Arizona. Figure 4.3 shows the response for this case. The CB_R ratio in the simulation is relatively close to the statistically determined CB_R ratio from historical performance.

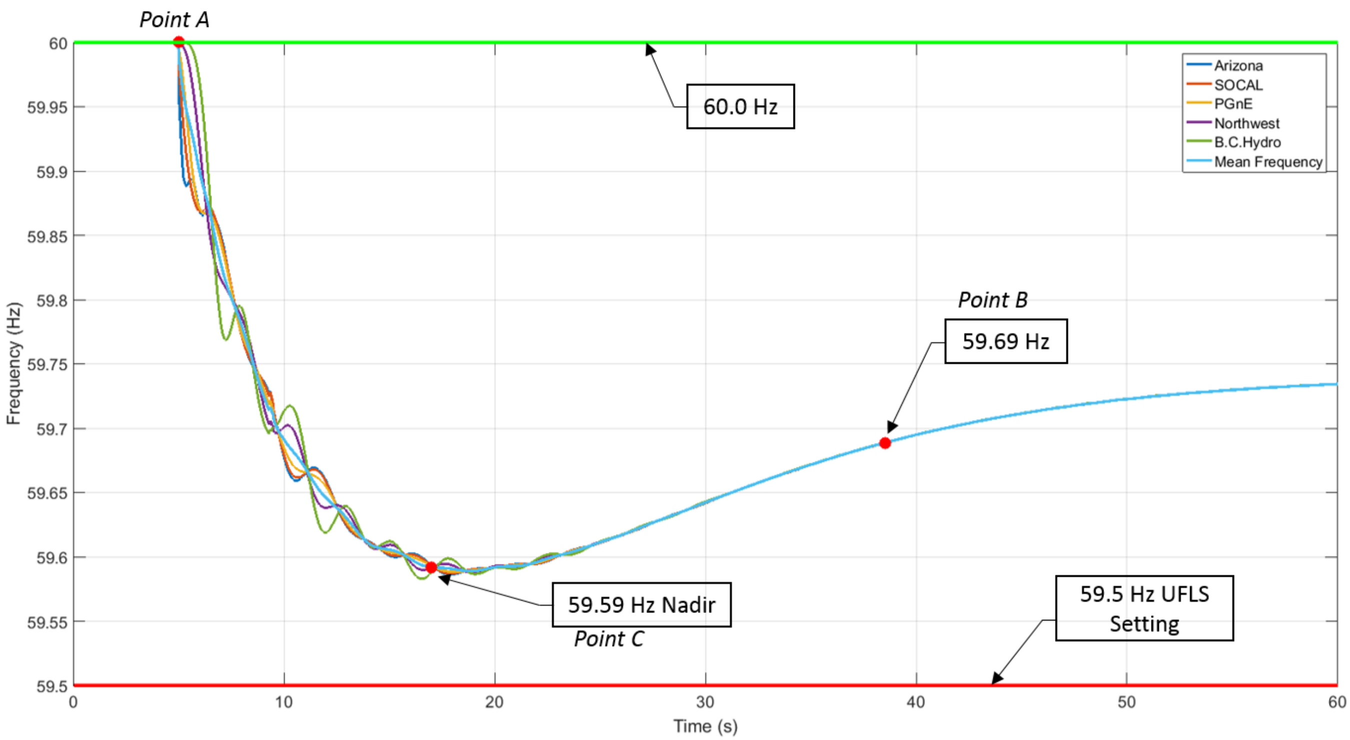


Figure 4.3: Western Interconnection Frequency Response Simulation

With a frequency response characteristic close to historical performance in the Western Interconnection the frequency nadir, for the defined resource loss protection criteria with response drastically degraded to obtain an IFRM equal to the determined IFRO of 841 MW/0.1 Hz, remains above the first stage UFLS at 59.5 Hz.

ERCOT Interconnection[63]

For the ERCOT Interconnection, the 2018 light-load high-wind case was used. Figure 4.4 shows the frequency response of the case as-is. It can be seen that the frequency response is well above the first stage of UFLS at 59.3 Hz, and with an IFRM of 1,833 MW/0.1 Hz. This case exhibited abnormal oscillatory behavior likely due to dynamics modeling issues; it is recommended that ERCOT and Texas RE investigate the cause of this simulation response in the post contingency steady state time frame of the simulation and correct any issues identified.

[63] Analysis performed for the 2016 FRAA report.

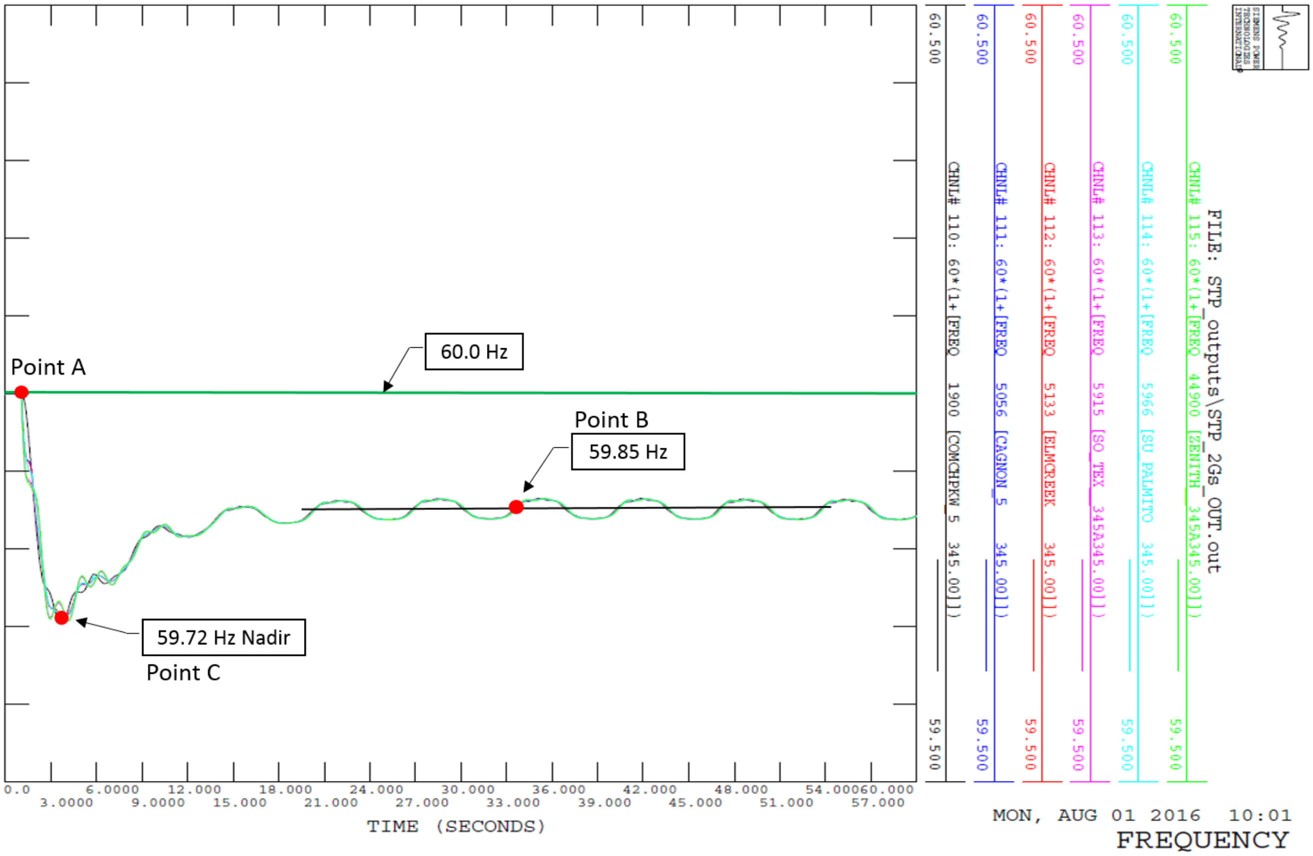


Figure 4.4: ERCOT Interconnection Starting Case Simulation

Frequency response was degraded from this case to a worst case scenario for a response at the IFRO value of around 380 MW/0.1 Hz. This was accomplished by switching off many of the governors arbitrarily on units across the interconnection (as for other interconnections' worst case simulations). Figure 4.5 shows the response for this case. The CB_R ratio in the simulation is relatively close to the statistically determined CB_R ratio from historical performance.

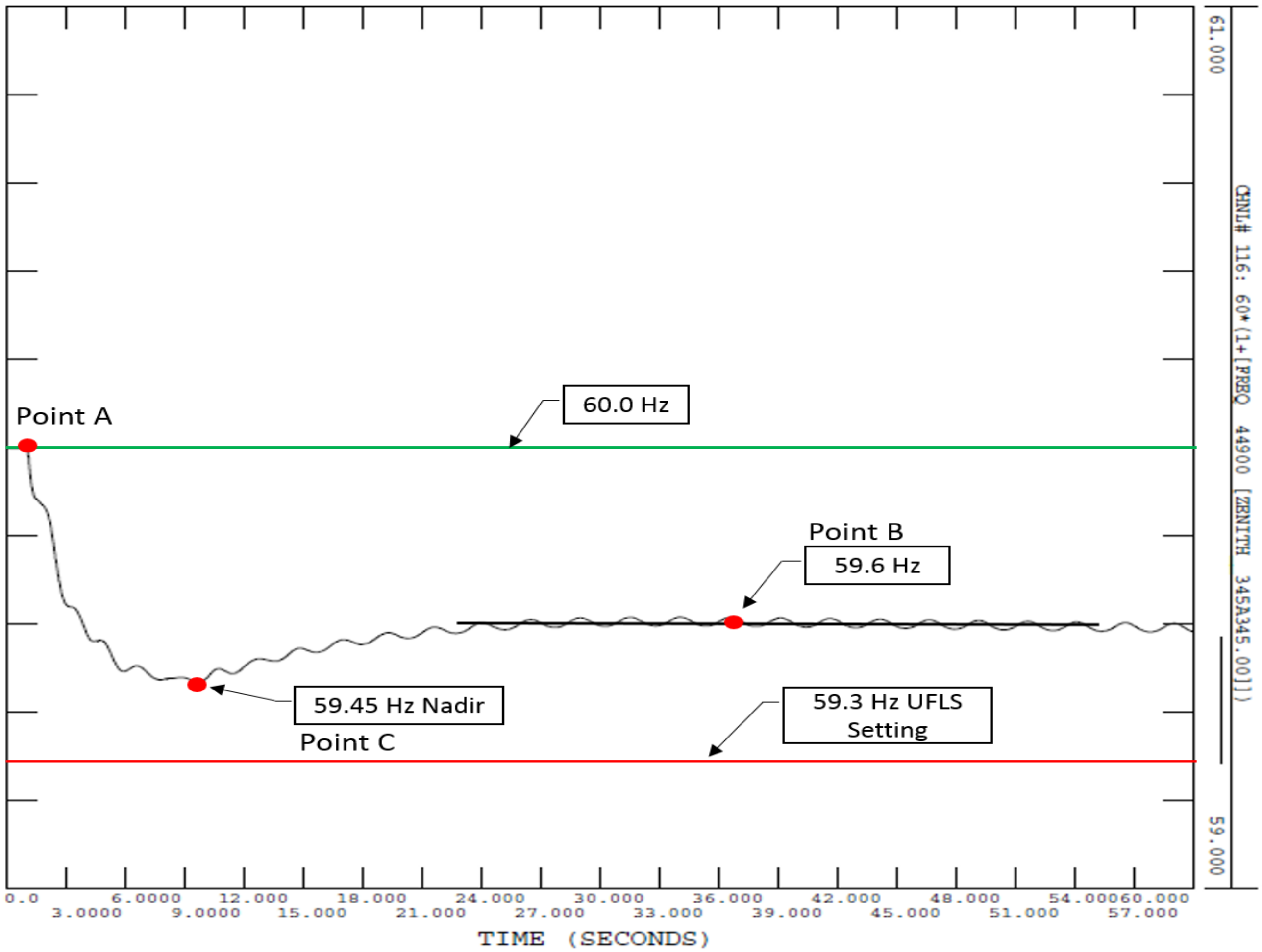


Figure 4.5: ERCOT Interconnection Frequency Response Simulation

With a frequency response characteristic close to historical performance in ERCOT Interconnection, the frequency nadir for the defined resource loss protection criteria with response drastically degraded to obtain an IFRM equal to the determined IFRO of around 380 MW/0.1 Hz, remains above the first stage UFLS at 59.3 Hz. It can be seen that the post contingency steady state oscillatory behavior still exists as it did in the root case obtained from ERCOT.