November 29, 2018

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 2018 Frequency Response Annual Analysis report for the administration and support of Reliability Standard BAL-003-1.1 – Frequency Response and Frequency Bias Setting ("Report"). The Report updates statistical analyses and calculations in the 2012 Frequency Response Initiative Report included with NERC's petition for approval of Reliability Standard BAL-003-1 and subsequent reports in this docket.[1]

The attached Report uses data from operating years 2014-2017 (December 1, 2013 through November 30, 2017) to: (i) analyze frequency events and interconnection frequency characteristics for BAL-003; and (ii) determine adjustment factors for calculating Interconnection Frequency Response Obligations ("IFROs"). This information is provided for consistency of the IFRO calculation, although, as noted below, the Report recommends application of 2016 IFRO values for operating year 2019.[2]

In particular, the Report references inconsistencies in IFRO calculations under BAL-003-1.1 that were detailed in last year's report. Due to these inconsistencies, IFRO values for operating year 2019 remain as calculated in 2015 for operating year 2016.[3] Frequency Response Obligations ("FROs") for individual Balancing Authorities will be allocated using 2017 generation and load data, consistent with BAL-003-1.1. Dynamic IFRO validations were not performed in this Report, as those IFROs did not change from those prescribed last year.[4]

The Report recommends that the current Project 2017-01 Standard Drafting Team ("SDT") continue to address the issues with BAL-003-1.1 included in the consolidated Standards Authorization

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[1] *See generally*, filings in the above captioned docket (these materials commonly refer to the standard as BAL-003-1, although BAL-003-1.1 is the latest version and currently effective). The 2012 Frequency Response Initiative Report was attached as Exhibit F to the original petition submitted on March 20, 2015.
[2] *Id.*
[3] *See, e.g.*, Report, at p. iv.
[4] *Id.*, at p. 18.

Request for the project.[5] As stated in the Report, "[s]everal recommendations from the 2016 and 2017 FRAA reports are currently being pursued through analysis by NERC staff and through the standards development process by multi-phase revisions to the BAL-003-1.1 Standard."[6] As further discussed in the Report, NERC will also continue tracking frequency response performance across interconnections.

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/ Candice Castaneda
Candice Castaneda

Counsel for North American Electric Reliability Corporation

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

5 SAR posted at, https://www.nerc.com/pa/Stand/Pages/Project201701ModificationstoBAL00311.aspx.
6 Report, at p. iv.

CERTIFICATE OF SERVICE

I hereby certify that I have served a copy of the foregoing document upon all parties listed on the official service list compiled by the Secretary in this proceeding.

Dated at Washington, D.C. this 29th day of November 2018.

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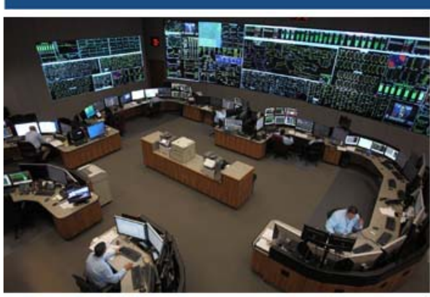
NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

2018 Frequency Response Annual Analysis

November 2018

RELIABILITY | ACCOUNTABILITY

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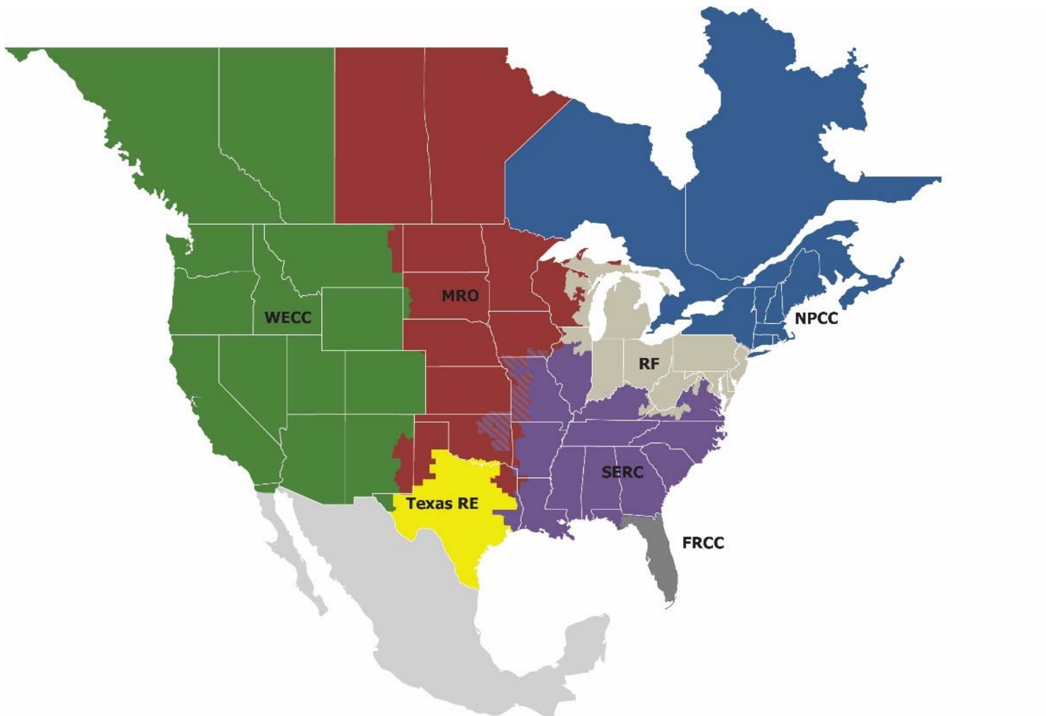
This report was approved by the Resources Subcommittee on November 2, 2018.

This report was endorsed by the Operating Committee on November 15, 2018.

Preface

The vision for the Electric Reliability Organization (ERO) Enterprise, which is comprised of the North American Electric Reliability Corporation (NERC) and the seven Regional Entities (REs), is a highly reliable and secure North American bulk power system (BPS). Our mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid.

The North American BPS is divided into seven RE boundaries as shown in the map and corresponding table below. The multicolored area denotes 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
Texas RE	Texas Reliability Entity
WECC	Western Electricity Coordinating Council

Executive Summary

This report is the 2018 annual analysis of frequency response performance for the administration and support of NERC reliability *Standard BAL-003-1.1 – 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] which was 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 operating year 2019 (December 2018 through November 2019).

In accordance with the BAL-003-1 detailed implementation plan, and as a condition of approval by the RS and endorsement by the OC, these analyses are performed annually, and the results are published no later than November 20 each year.

Recommendations

The following recommendations are made for the administration of Standard BAL-003-1 for operating year 2019 (December 1, 2018 through November 30, 2019):

1. The IFRO values for operating year 2019 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 years 2017 and 2018 as shown in **Table ES.1**.

Table ES.1: Recommended IFROs for Operating Year 2019

	Eastern (EI)	Western (WI)	ERCOT (TI)	Québec (QI)	Units
Recommended IFROs	**-1,015**	**-858**	**-381**	**-179**	**MW/0.1 Hz**
Absolute Value of Mean Interconnection Frequency Response Performance for Operating Year 2017[5]	2,257	1,836	835	748	MW/0.1 Hz

2. 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 as appropriate.

Outstanding Recommendations from the 2016 and 2017 FRAA Reports

Several recommendations from the *2016 and 2017 FRAA* reports[6] are currently being pursued through analysis by NERC staff and through the standards development process by multi-phase revisions to the BAL-003-1.1 Standard. Refer to those reports for additional details.

[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 the NERC Standards and Engineering organization.
[4] These IFROs were held constant through operating years 2016, 2017, and 2018.
[5] Based on mean Interconnection frequency response performance from Appendix E of the *2018 State of Reliability* report for operating year 2017.
[6] http://www.nerc.com/comm/OC/Documents/2016_FRAA_Report_2016-09-30.pdf and https://www.nerc.com/comm/OC/BAL0031_Supporting_Documents_2017_DL/2017_FRAA_Final_20171113.pdf

Introduction

This report is the 2018 annual analysis of frequency response performance for the administration and support of NERC Reliability Standard BAL-003-1 – Frequency Response and Frequency Bias Setting.[7] It provides an update to the statistical analyses and calculations contained in the *2012 Frequency Response Initiative Report*[8] 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,[9] contains the annual analysis, calculation, and recommendations for the IFRO for each of the four electrical Interconnections of North America for the operating year 2019 (December 2018 through November 2019). This analysis includes the following:

- Statistical analysis of the interconnection frequency characteristics for the operating years 2014 through 2017 (December 1, 2013 through November 30, 2017)
- Analysis of frequency profiles for each Interconnection
- Calculation of adjustment factors from BAL-003-1 frequency response events
- A review of the dynamic analyses of each Interconnection performed in 2016 and 2017 for the recommended IFRO values.

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[10] 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. These 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 accurately captured.
- The frequency response analysis tool[11] is being used by the NERC Bulk Power System Awareness group for frequency event tracking in support of the NERC Frequency Working Group. 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.

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

Chapter 1: Interconnection Frequency Characteristic Analysis

Annually, NERC staff performs a statistical analysis[12] 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[13] from operating years 2014–2017 (December 1, 2013 through November 30, 2017) was used.

Frequency Variation Statistical Analysis

The 2018 frequency variation analysis was performed on one-second frequency data for operating years 2014–2017 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 Interconnection.

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)	2014–2017	2014–2017	2014–2017	2014–2017
Number of Samples	125,230,343	126,020,370	124,767,853	122,225,057
Filtered Samples (% of total)	99.7%	99.68%	98.8%	96.8%
Expected Value (Hz)	59.999	59.999	59.999	59.999
Variance of Frequency (σ^2)	0.00023	0.00036	0.00031	0.00041
Standard Deviation (σ)	0.01532	0.01890	0.01758	0.02019
50% percentile (median)	59.998	59.998	60.002	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 **Figures 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.

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

[13] 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.

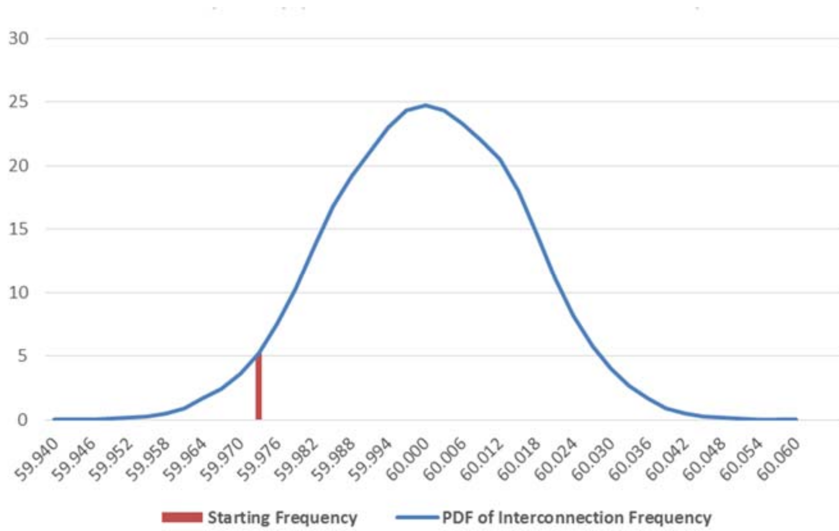

Figure 1.1: Eastern Interconnection 2014–2017 Probability Density Function of Frequency

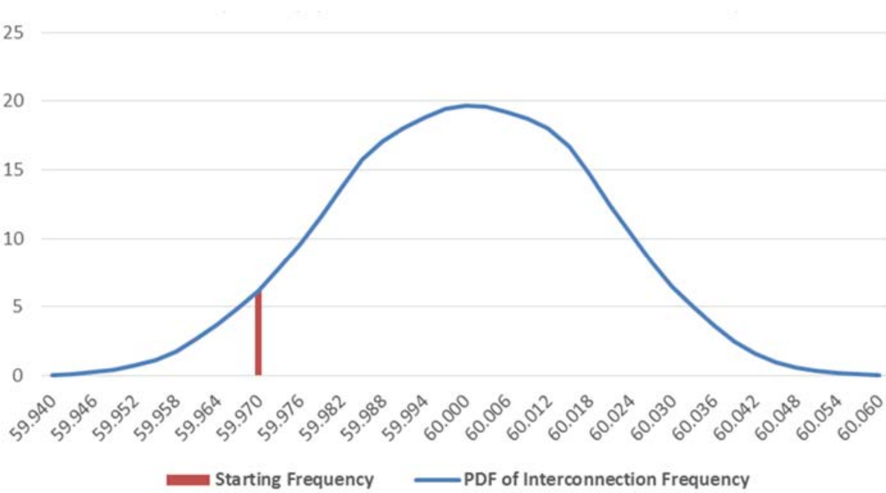

Figure 1.2: Western Interconnection 2014–2017 Probability Density Function of Frequency

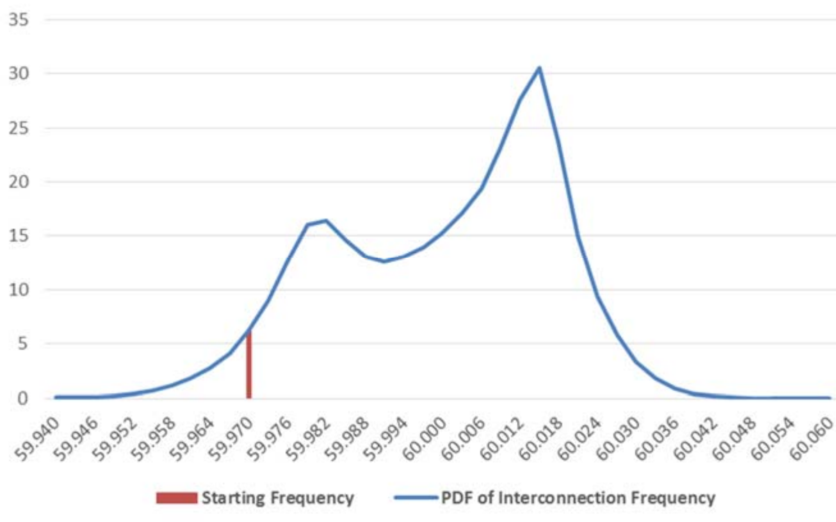

Figure 1.3: ERCOT Interconnection 2014–2017 Probability Density Function of Frequency

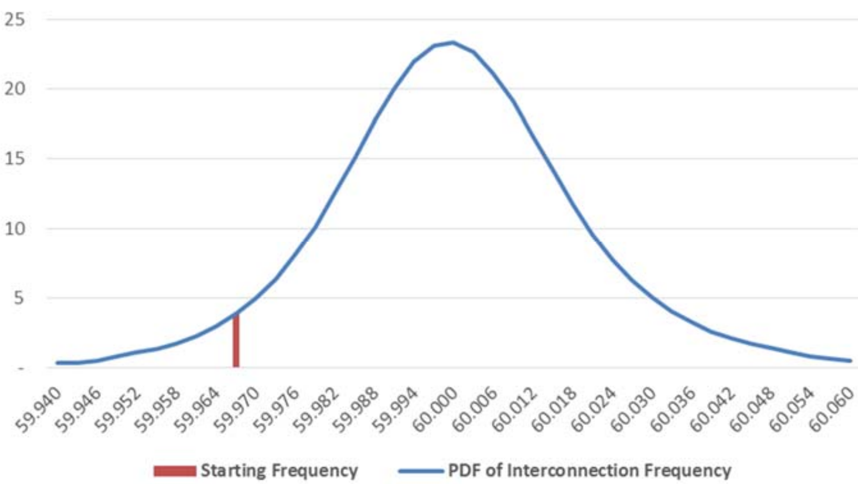

Figure 1.4: Québec Interconnection 2014–2017 Probability Density Function of Frequency

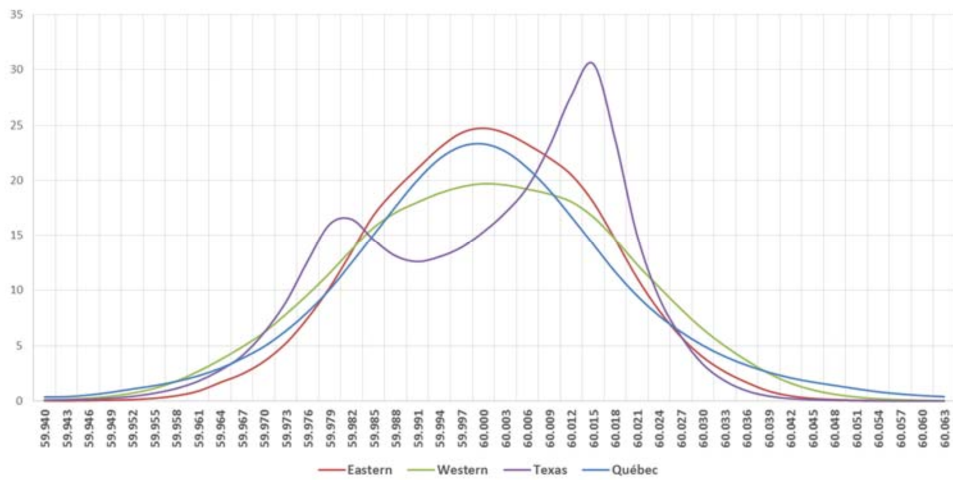

Figure 1.5: Comparison of 2014–2017 Interconnection Frequency Probability Density Functions

Variations in Probability Density Functions

The following is an analysis of the variations in probability density functions of the annual distributions of Interconnection frequency for years 2014 to 2017. Table 1.2 lists the standard deviation of the annual Interconnection frequencies.

Table 1.2: Interconnection Standard Deviation by Year				
Interconnection	**2014**	**2015**	**2016**	**2017**
Eastern	0.016	0.014	0.016	0.016
Western	0.019	0.019	0.019	0.019
ERCOT	0.020	0.017	0.016	0.016
Québec	0.020	0.020	0.020	0.020

For the Eastern Interconnection, the standard deviation in 2016 and 2017 increased compared to 2015 while in other interconnections standard deviations have been flat (Western and Québec) or decreasing (ERCOT). As a standard deviation is a measure of dispersity of values around the mean value, the decreasing standard deviation indicates tighter concentration around the mean value and more stable performance of the interconnection frequency in ERCOT. Changes in annual frequency profiles are further illustrated in **Figures 1.6 through 1.9**.

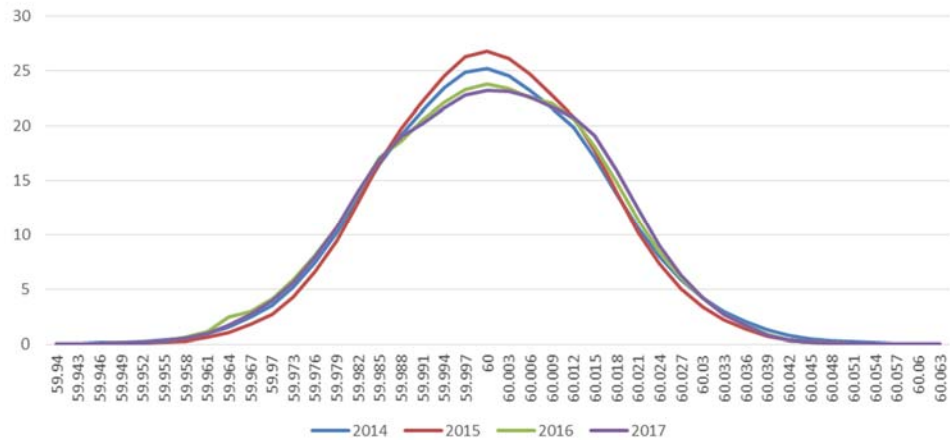

Figure 1.6: Eastern Interconnection Frequency Probability Density Function by Year

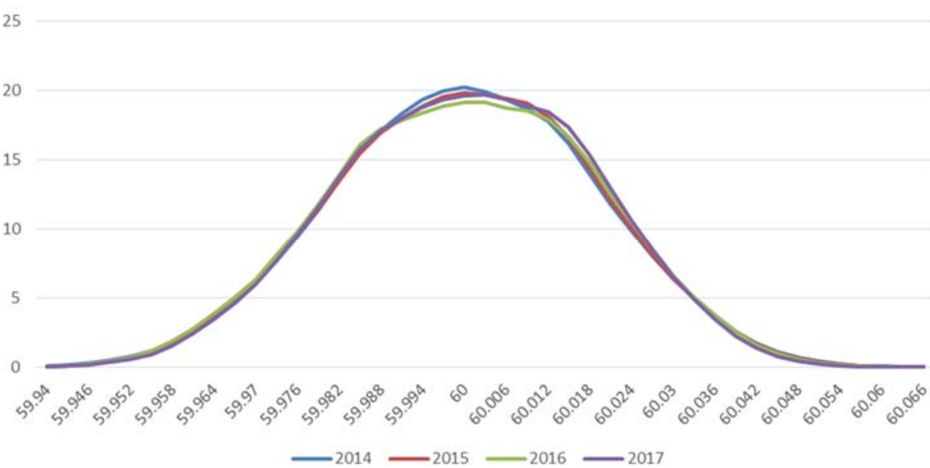

Figure 1.7: Western Interconnection Frequency Probability Density Function by Year

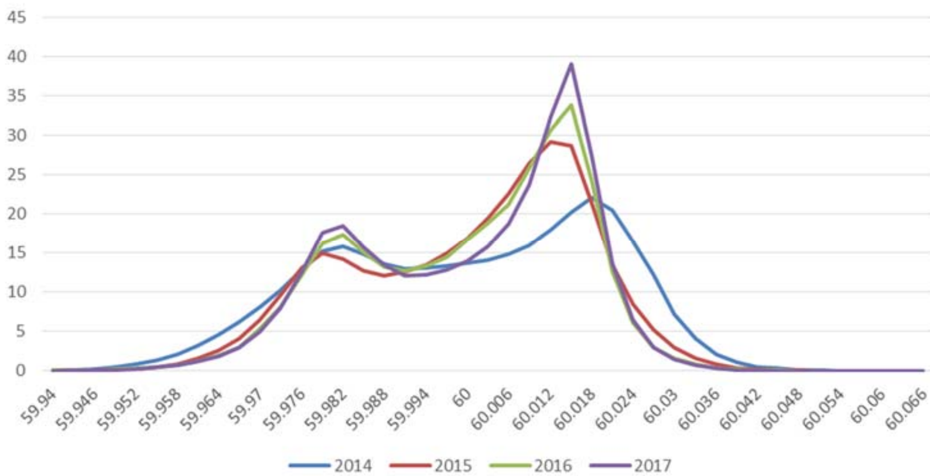

Figure 1.8: ERCOT Interconnection Frequency Probability Density Function by Year

ERCOT's Frequency Characteristic Changes

Standard TRE BAL-001[14] 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 dead-band. As a result, anytime frequency exceeds 60.017 Hz, resources automatically curtail themselves. That has resulted in far less operation in frequencies above the dead-band since all resources, including wind, are backing down. It is exhibited in **Figure 1.8** above as a probability concentration around 60.017 Hz. Similar behavior is not exhibited at the low dead-band of 59.983 Hz because most wind resources are operated at maximum output and cannot increase output when frequency falls below the dead-band.

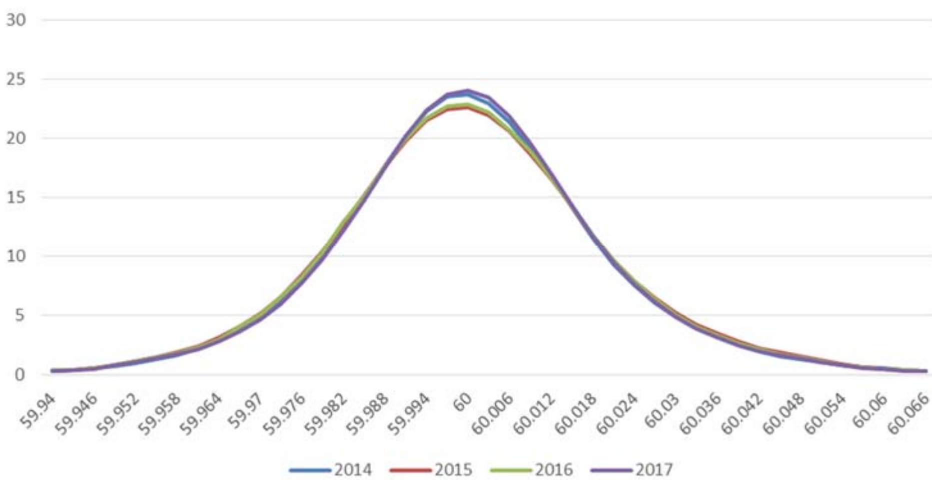

Figure 1.9: Québec Interconnection Frequency Probability Density Function by Year

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

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 recommended IFROs. Refer to the *2012 Frequency Response Initiative Report* for additional details on the development of the IFRO and the adjustment calculation methods.[15] 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 BA in the Interconnection should be allocated a portion of the IFRO that represents its minimum annual median performance 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:

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

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

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

$$ARLPC = RLPC - CLR$$

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

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

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.
- Resource loss protection criteria (RLPC) is the resource loss protection criteria.
- CLR is the credit for load resources.
- An RLPC is the adjusted resource loss protection criteria adjusted for the credit for load resources.
- IFRO is the interconnection frequency response obligation expressed in MW/0.1 Hz.

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 2014 through 2017 (between December 1, 2013 to November 30, 2017), 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 and 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 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 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 2014 through 2017 (December 1, 2013 through November 30, 2017) were used.

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	112	1.107	0.169	0.027	1.134
Western	86	1.755	0.692	0.124	1.879
ERCOT	143	1.700	0.536	0.074	1.774
Québec	135	4.353	1.383	0.197	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[16] indicates a value above 1.000, and no such limitation is required. This is due in large part to the improvement made to primary frequency response of the Interconnection through the outreach efforts by the NERC RS and the North American Generator Forum.

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

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

high rebound rates between Point C and the calculated Value B. For the 135 frequency events in their event sample, Québec's CB_R value would be 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 this *2018 FRAA* utilized sub-second measurements from FNET FDRs. Data at this resolution accurately reflects 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} to account for the statistically expected Point C' value of a frequency event. 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 2014 through 2017 (December 1, 2013 through November 30, 2017).

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	112	66	34	0.005	0.003	0.006
Western	86	45	0	N/A	N/A	N/A
ERCOT	143	61	2	N/A	N/A	N/A
Québec	135	31	12	-0.019	0.028	-0.004

Only the Eastern Interconnection had a significant number of resource-loss events where C' was below Point C or Value B for those events. The 12 events detected for Québec are for load-loss events, indicated by the negative values for the Mean Difference and the BC'_{ADJ}; the adjustment is not intended to be used for load-loss events.

Although an event with C' lower than Point C was identified in the ERCOT Interconnection, it does not warrant an adjustment factor; only the adjustment factor of 6 mHz for the Eastern Interconnection is necessary. There were 66 out of 112 frequency events in that Interconnection exhibiting a secondary nadir (Point C') below value B and 34 out of those had Point C' lower than the initial frequency nadir (Point C). These secondary nadirs occur 72 to 90 seconds after the start of the event,[17] which is well beyond the time frame for calculating Value B.

Therefore, a BC'_{ADJ} is only needed for the Eastern Interconnection; no BC'_{ADJ} is needed for the other three Interconnections. This will continue to be monitored moving forward to track these trends in C' performance.

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 faults or the loss of resources. Severe system conditions might drive the combination of frequency and voltage to levels that present some generator and turbine control systems to trip the generator. Similarly, severe rates-of-change occurring in voltage or frequency might actuate volts-per-hertz relays, which would also trip some generators, and some combustion turbines may not be able to sustain operation at frequencies below 59.5 Hz.

Inverter-based resources may also be susceptible to extremes in frequency. Laboratory testing by Southern California Edison of inverters used on residential and commercial scale photovoltaic (PV) systems revealed a propensity to trip at about 59.4 Hz, which is 200 mHz above the expected 59.2 Hz prescribed in IEEE Standard

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

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 inverter-based 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 relays to help arrest frequency declines. A credit for load resources (CLR) is made for the resource contingency for the ERCOT Interconnection.

The amount of CLR available at 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 RLPC.

The 2016–2017 CLR for the ERCOT Interconnection was 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.

CLR credit in future IFRO calculations for ERCOT is being reviewed by the BAL-003 Standard Drafting Team.

ERCOT Credit for Load Resources

Prior to April 2012, ERCOT 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, 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 remedial action scheme.

Determination of Maximum Allowable Delta Frequencies

Because of the measurement limitation[18] 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 B or Point C due to primary frequency response withdrawal measured by Point C'

Only the Eastern Interconnection exhibits a meaningful amounts of frequency response withdrawal. Frequency response withdrawal will continue to be monitored.

[18] 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

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	0.466	0.668	1.467	Hz
CB_R[19]	1.134	1.879	1.774	1.550	Ratio
Delta Frequency (DF_{CBR})[20]	0.418	0.248	0.377	0.946	Hz
BC'_{ADJ}[21]	0.006	N/A	N/A	N/A	Hz
Max. Allowable Delta Frequency	0.412	0.248	0.377	0.946	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 this *2018 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 that have a direct bearing on the IFRO calculation. In the 2016 and 2017 *Frequency Response Annual Analysis* reports, several inconsistencies with the behavior of the IFRO calculations for the relative changes in Values A and B and Point C.[22] Additional analysis of those inconsistencies is contained in this report.

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

Table 2.5 through **Table 2.8** compare the CB_R values for 2018 for each Interconnection with the CB_R values from the *2017 Frequency Response Annual Analysis* report.

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

[20] Base Delta Frequency/CB_R

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

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

Table 2.5: Maximum Allowable Delta Frequency Comparison					
Eastern Interconnection	**OY 2018 In Use[23]**	**OY 2018 Calc.[24]**	**OY 2019 Calc.[25]**	**2018 Calc. to 2019 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	1.111	1.134	0.023	Ratio
Delta Freq. (DF_{CBR})	0.450	0.427	0.418	-0.009	Hz
BC'_{ADJ}	0.007	0.007	0.006	-0.001	Hz
Max. Allowable Delta Frequency	**0.443**	**0.420**	**0.412**	**-0.008**	**Hz**

Table 2.6: Maximum Allowable Delta Frequency Comparison					
Western Interconnection	**OY 2018 In Use[24]**	**OY 2018 Calc.[25]**	**OY 2019 Calc.[26]**	**2018 Calc. to 2019 Calc. Change**	**Units**
Starting Frequency	59.967	59.967	59.966	-0.001	Hz
Min. Frequency Limit	59.500	59.500	59.500	0.000	Hz
Base Delta Frequency	0.467	0.467	0.466	-0.001	Hz
CB_R	1.598	1.670	1.879	0.209	Ratio
Delta Freq. (DF_{CBR})	0.292	0.280	0.248	-0.032	Hz
BC'_{ADJ}	N/A	N/A	N/A	N/A	Hz
Max. Allowable Delta Frequency	**0.292**	**0.280**	**0.248**	**-0.032**	**Hz**

[23] Calculated in the 2015 FRAA report. Average frequency values were for operating years 2012 through 2014.
[24] Calculated in the 2017 FRAA report. Average frequency values were for operating years 2013 through 2016.
[25] Calculated in the 2018 FRAA report. Average frequency values were for operating years 2014 through 2017.

Table 2.7: Maximum Allowable Delta Frequency Comparison					
ERCOT Interconnection	OY 2017 In Use[26]	OY 2017 Calc.[27]	OY 2018 Calc.[28]	2017 Calc. to 2018 Calc. Change	Units
Starting Frequency	59.966	59.967	59.968	0.001	Hz
Min. Frequency Limit	59.300	59.300	59.300	0.000	Hz
Base Delta Frequency	0.666	0.667	0.668	0.001	Hz
CB_R	1.619	1.648	1.774	0.126	Ratio
Delta Freq. (DF_{CBR})	0.411	0.405	0.377	-0.028	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**

Table 2.8: Maximum Allowable Delta Frequency Comparison					
Québec Interconnection	OY 2017 In Use[27]	OY 2017 Calc.[28]	OY 2018 Calc.[29]	2017 Calc. to 2018 Calc. Change	Units
Starting Frequency	59.969	59.968	59.967	-0.001	Hz
Min. Frequency Limit	58.500	58.500	58.500	0.000	Hz
Base Delta Frequency	1.469	1.468	1.467	-0.001	Hz
CB_R	1.550	1.550	1.550	0.000	Ratio
Delta Freq. (DF_{CBR})	0.948	0.947	0.946	0.000	Hz
BC'_{ADJ}	N/A	N/A	N/A	N/A	Hz
Max. Allowable Delta Frequency	**0.948**	**0.947**	**0.946**	**0.000**	**Hz**

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

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

[28] Calculated in the 2018 FRAA report. Average frequency values were for operating years 2014 through 2017.

Calculated IFROs

Table 2.9 shows the determination of IFROs for operating year 2019 (December 2018 through November 2019) 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 2019 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	0.418	0.248	0.377	0.946	Hz
Resource Contingency Protection Criteria	4,500	2,626	2,750	1,700	MW
Credit for Load Resources	N/A	120[29]	1,209	N/A	MW
IFRO	**-1,092**	**-1,010**	**-409**	**-180**	**MW/0.1 Hz**
Absolute Value of IFRO[30]	**1,092**	**1,010**	**409**	**180**	**MW/0.1 Hz**
Absolute Value of Mean Interconnection Frequency Response Performance for Operating Year 2017[31]	2,257	1,836	835	748	MW/0.1 Hz

Note: The operating year 2017 frequency response performance was significantly higher than the 2019 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. Table 2.10 through Table 2.11 compare the current IFROs and their key component values to those presented in the *2016 Frequency Response Annual Analysis* report.

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

[30] The values of IFRO calculated for operating year 2018 are shown here for reference. It is recommended that the IFROs for operating year 2019 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.

[31] Based on mean Interconnection frequency response performance from Appendix E of the *2018 State of Reliability* report for operating year 2017.

Table 2.10: Interconnection IFRO Comparison						
	OY 2018 In Use[32]	OY 2018 Calc.[33]	OY 2019 Calc.[34]	2018 Calc. to 2019 Calc. Change	OY 2018 In Use to 2019 Calc. Change	Units
Eastern Interconnection						
Starting Frequency	59.974	59.974	59.974	0	0	Hz
Max. Allowable Delta Frequency	0.443	0.420	0.412	-0.008	-0.031	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**	**1,071**	**1,092**	21	77	MW/0.1 Hz
Western Interconnection						
Starting Frequency	59.967	59.967	59.968	0.001	0.002	Hz
Max. Allowable Delta Frequency	0.292	0.280	0.248	-0.028	-0.034	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**	**895**	**1010**	115	152	MW/0.1 Hz
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	1,209	1,209	28	0	MW
Absolute Value of IFRO	**381**	**380**	**381**	1	0	MW/0.1 Hz
Québec Interconnection						
Starting Frequency	59.969	59.968	59.967	-0.001	-0.002	Hz
Max. Allowable Delta Frequency	0.948	0.947	0.946	-0.001	-0.002	Hz
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**	**180**	**180**	0	1	MW/0.1 Hz

[32] Calculated in the 2015 FRAA report. Average frequency values were for operating years 2012 through 2014.
[33] Calculated in the 2017 FRAA report. Average frequency values were for operating years 2013 through 2016.
[34] Calculated in the 2018 FRAA report. Average frequency values were for operating years 2014 through 2017.

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 this report, the IFRO values for operating year 2019 (December 2018 through November 2019) shall remain the same values as calculated in the *2015 FRAA* report for operating year 2016[35] and held constant through operating years 2017 and 2018, shown in **Table 2.11**.

Table 2.11: Recommended IFROs for Operating Year 2017					
	Eastern (EI)	**Western (WI)**	**ERCOT (TI)**	**Québec (QI)**	**Units**
IFRO	**-1,015**	**-858**	**-381**	**-179**	**MW/0.1 Hz**

[35] These IFROs were held constant through operating years 2016, 2017, and 2018.

Chapter 3: Dynamics Analysis of Recommended IFROs

Because the IFROs for the Eastern, Western, and ERCOT Interconnections have not changed from those prescribed for operating year 2018 (1,015 MW/0.1 Hz, 858 MW/0.1 Hz, and 381 MW/0.1 Hz, respectively), additional dynamic validation analyses were not done for this report.

Refer to the dynamics validation in the *2017 Frequency Response Annual Analysis* report for details. No analysis was performed for the Québec Interconnection.