NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

2019 Frequency Response Annual Analysis

November 2019

This report was approved by the Resources Subcommittee on October 18, 2019.

This report was endorsed by the Operating Committee on October 30, 2019.

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Preface

Electricity is a key component of the fabric of modern society and the Electric Reliability Organization (ERO) Enterprise serves to strengthen that fabric. The vision for the ERO Enterprise, which is comprised of the North American Electric Reliability Corporation (NERC) and the six 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.

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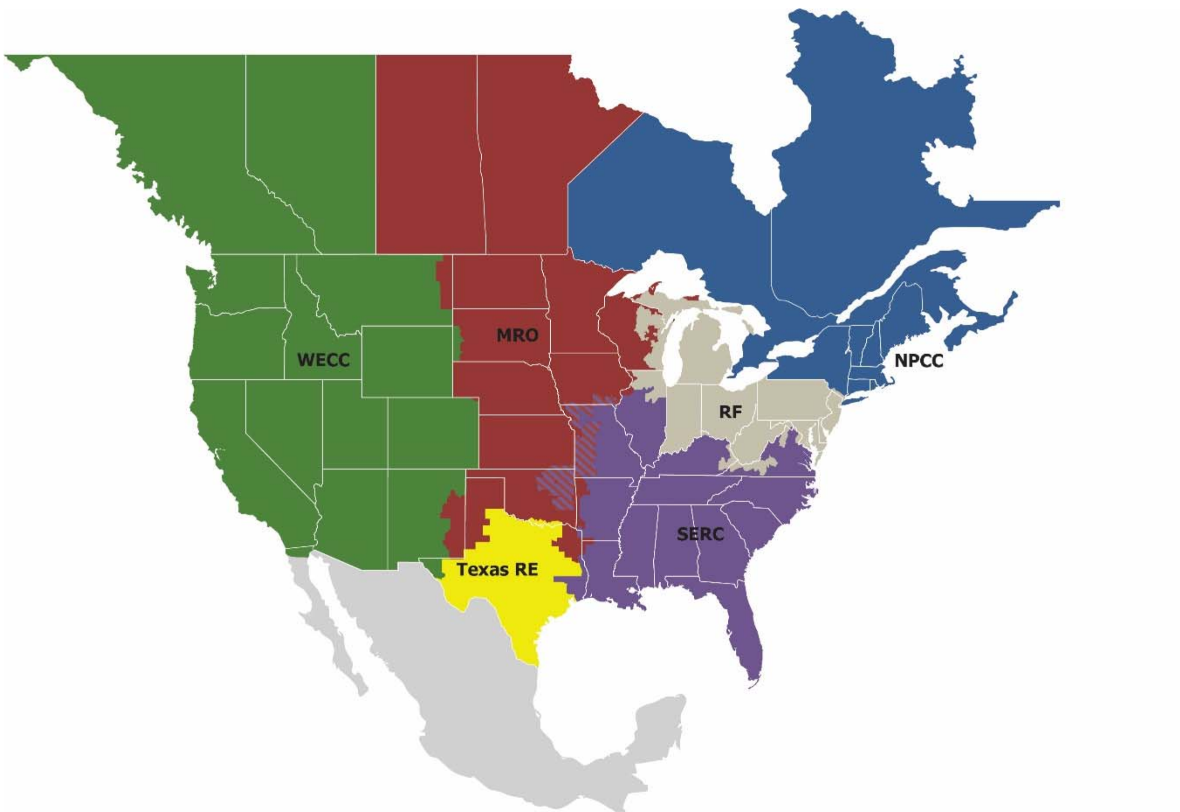
Because nearly 400 million citizens in North America are counting on us

The North American BPS is divided into six 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.



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 2019 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] that was approved by the NERC Resources Subcommittee (RS), the Operating Committee (OC), and accepted by the NERC Board of Trustees (Board).

This report is prepared by NERC staff[3] and 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 2020 (December 2019 through November 2020).

In accordance with the *BAL-003-1* detailed implementation plan and as a condition of approval by the NERC RS and endorsement by the OC, these analyses are performed annually, and the results are published no later than November 20 of each year. Below are the key findings and recommendations contained in this report.

Key Findings

Starting Frequency

The starting frequency for the calculation of IFROs, shown in **Table 1.1,** is the fifth-percentile lower-tail of samples from the statistical analysis, representing a 95% chance that frequencies will be at or above that value at the start of any frequency event. The starting frequency for the Eastern Interconnection (EI) decreased slightly from 59.974 to 59.973, increased slightly for the Western Interconnection (WI) from 59.966 to 59.967, increased for the Texas Interconnection (TI) from 59.968 to 59.971, and remained the same for the Québec Interconnection (QI) at 59.967.

Frequency Probability Density Functions

Analysis of the frequency probability density functions show that in the EI the standard deviation in 2016 and 2017 increased compared to 2015. The standard deviation further increased in 2018. The EI experienced a coincidental increase in fast time error in 2018. The EI frequency probability density function for 2018 as compared to previous years is shown in **Figure 1.6**. In the other Interconnections, standard deviations have been flat (Québec) or decreasing (Western and Texas). As the standard deviation is a measure of dispersity of values around the mean value, a decreasing standard deviation indicates tighter concentration around the mean value and more stable performance of the interconnection frequency. Comparisons of annual frequency profiles for each Interconnection are shown in **Figure 1.6–1.9**.

Interconnection Performance and the Point C to Value B Ratio (CBr)

Table 2.8 shows a comparison of mean Value A, mean Value B, and mean Point C that is illustrative of Interconnection performance during low frequency events over the previous operating year and as compared to the 2016 operating year in which the IFRO values were frozen; loss of load events have been excluded from the data in **Table 2.6**. All four Interconnections show an increase in mean Value B and a decrease in the mean (A-B) indicating improved performance during the stabilizing period of frequency events. All four Interconnections show either an increase or no change in mean Point C as well as a decrease or no change in mean (A-C) indicating improved performance during the arresting period of frequency events. This performance data demonstrates that the increases in year-over-year CBr that result in higher calculated IFROs are due to improved stabilizing period performance and not due to a decline in the performance of the Point C nadir.

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[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.

IFRO Calculation Inconsistencies

The ratio between CBr is a multiplicative factor in the IFRO formulae that couples these two quantities together in the formulation of the IFRO. The original intent of the IFRO calculation was to ensure that a declining frequency nadir (as demonstrated by an increasing A-C) would result in an increase in the IFRO. However, the calculation also results in an increase in IFRO when stabilizing period performance improves (as demonstrated by a decreasing A-B) while Point C remains relatively stable. Using the current method for calculating IFRO an increase in the CBr, when all other variables remain unchanged, results in an increase in IFRO. The IFRO should not penalize an Interconnection for improved performance of Value B during the stabilizing period. For these reasons, absent a decline in the mean Point C frequency nadirs, the IFROs since the 2016 operating year have been frozen at the levels recommended in the *2015 Frequency Response Annual Analysis* (FRAA).[4] **Table 2.7** shows the year-over-year comparison of adjusted CBr for all Interconnections and demonstrates the trend of higher CBr values that have resulted in higher calculated IFROs.

Recommendations

NERC provides the following recommendations for the administration of *Standard BAL-003-1* for operating year (OY) 2020 (December 1, 2019, through November 30, 2020):

1. The IFRO values for the EI, WI, and QI shall remain the same values as calculated in the *2015 FRAA* report for operating year 2016 and held constant through operating years 2017, 2018, and 2019 as shown in **Table ES.1**.
2. The IFRO value for the TI will increase by -44 MW / 0.1 Hz due to a reduction in the credit for load resources (CLR). The statistically derived available CLR decreased by 72 MW from the 2018 to 2019 FRAA calculations, but the decrease was only 44 MW from the 2015 FRAA calculations that established the IFRO values currently in effect. Therefore, the recommended IFRO for TI is -425 MW / 0.1 Hz, an increase of -44 MW / 0.1 Hz.
3. NERC should, in coordination with NERC technical committees, evaluate the causes of increasing standard deviation and asymmetry in EI frequency distribution and identify possible impacts, if any, to frequency response.
4. Recommendations from previous FRAA reports are currently being pursued through the standards development process, including analysis by the BAL-003-2 Standards Drafting Team (SDT) and NERC staff.

Table ES.1: Recommended IFROs for Operating Year 2019

	Eastern (EI)	Western (WI)	Texas (TI)	Québec (QI)	Units
Recommended IFROs	**-1,015**	**-858**	**-425**	**-179**	**MW/0.1 Hz**
Mean Interconnection Frequency Response Performance ($IFRM_{A-B}$) for Operating Year 2018[5]	-2,539	-1,823	-945	-673	MW/0.1 Hz

[4] https://www.nerc.com/comm/OC/RS%20Landing%20Page%20DL/Related%20Files/2015_FRAA_Report_Final.pdf

[5] Mean interconnection frequency response performance $IFRM_{A-B}$ for BAL-003 events for the operating year 2018.

Introduction

This report, prepared by NERC staff,[6] contains the annual analysis, calculation, and recommendations for the IFRO for each of the four Interconnections of North America for the operating year 2020 (December 2019 through November 2020). This analysis includes the following information:

- Statistical analysis of Interconnection frequency characteristics for the operating years 2015 through 2018 (December 1, 2014, through November 30, 2018)
- 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[7] 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 bandwidth filtering, least squares fit, and derivative checking.
- 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 (FRAT)[8] is being used by the NERC Power System Analysis group for frequency event tracking in support of the NERC Frequency Working Group (FWG) and RS. The tool has streamlined interconnection frequency response analysis. The tool provides an effective means of determining frequency event performance parameters and generating a database of values necessary for calculation of adjustment factors.

This report contains numerous references to Value A, Value B, and Point C, which are defined in NERC *BAL-003-1.1*. As such it is important to understand the relationship between these variables and the basic tenants of primary and secondary frequency control.

The Arresting, Rebound, Stabilizing, and Recovery Periods of a frequency event following the loss of a large generation resource is shown in **Figure I.1**. Value A and Value B are average frequencies from t-16 to t-2 seconds and t+20 to t+52 seconds, respectively, as defined in NERC *BAL-003-1.1*. Point C is the lowest frequency experienced in the first 12 seconds following the start of a frequency event. A Point C' value may exist if frequency falls below the original Point C nadir or Value B after the end of the 20 to 52 second stabilizing period.

[6] Prepared by the Power System Analysis and Advanced System Analytics & Modeling departments.
[7] Operated by the Power Information Technology Laboratory at the University of Tennessee, FNET is a low-cost, quickly deployable GPS-synchronized wide-area frequency measurement network. High-dynamic accuracy FDRs are used to measure the frequency, phase angle, and voltage of the power system at ordinary 120 V outlets. The measurement data are continuously transmitted via the Internet to the FNET servers hosted at the University of Tennessee and Virginia Tech.
[8] Developed by Pacific Northwest National Laboratory.

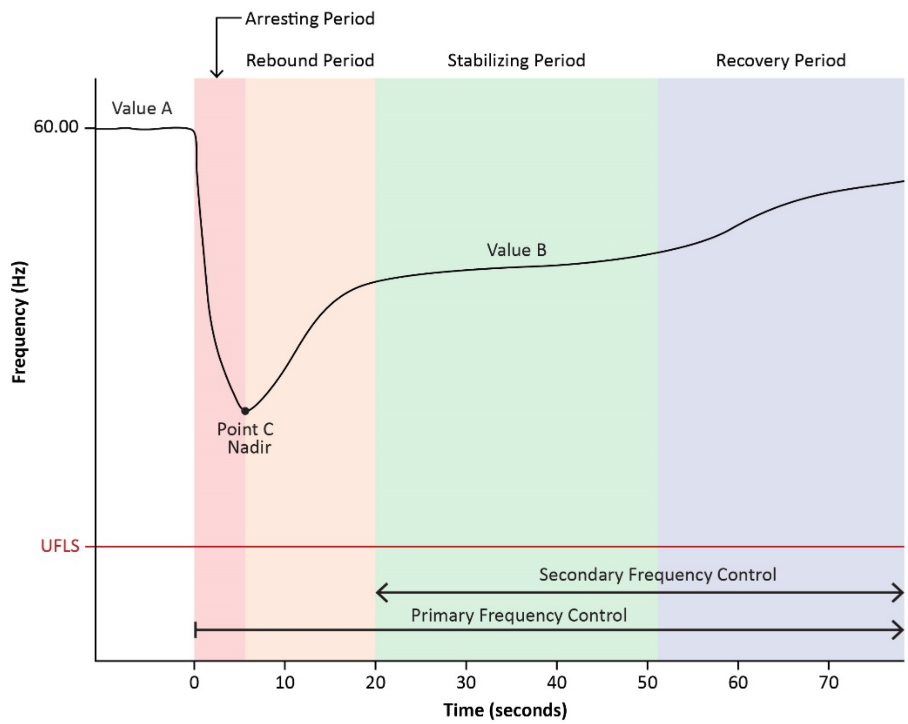

Figure I.1: Primary and Secondary Frequency Control

Primary Frequency Control: This is the action by the Interconnection to arrest and stabilize frequency in response to frequency deviations and has three time components; the Arresting Period, Rebound Period, and Stabilizing Period.

Arresting Period: This is the time from time zero (Value A) to the time of the nadir (Point C) and is the combination of system inertia, load damping, and the initial primary control response of resources acting together to limit the duration and magnitude of frequency change. It is essential that the decline in frequency is arrested during this period to prevent activation of automatic under-frequency load shedding (UFLS) schemes in the Interconnection.

Rebound Period: This includes the effects of governor response in sensing the change in turbine speed as frequency increases or declines, causing an adjustment to the energy input of the turbine's prime mover. The Rebound Period can also be impacted by end-user customer or other loads that are capable of self-curtailment due to local frequency sensing and control during frequency deviations.

Stabilizing Period: This is the third component of primary frequency control following a disturbance when the frequency stabilizes following a frequency excursion. Value B represents the interconnected system frequency at the point immediately after the frequency stabilizes primarily due to governor action but before the contingent control area takes corrective automatic generation control action.

Chapter 1: Interconnection Frequency Characteristic Analysis

Annually, NERC staff performs a statistical analysis, as detailed in the *2012 Frequency Response Initiative Report*[9], 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 each interconnection's starting frequency for the respective IFRO calculations. For this report's analysis, one-second frequency data[10] from operating years 2015–2018 (December 1, 2014, through November 30, 2018) was used.

Frequency Variation Statistical Analysis

The 2019 frequency variation analysis was performed on one-second frequency data for 2015–2018 and is summarized in **Table 1.1**. This analysis is used to determine the starting frequency and is also used in the IFRO calculations for each Interconnection.

This variability accounts for items like 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 2015–2018				
Value	**Eastern**	**Western**	**Texas**	**Québec**
Number of Samples	125,871,176	126,004,170	125,476538	122,239,837
Filtered Samples (% of total)	99.7%	99.8%	99.4%	96.8%
Expected Value (Hz)	59.999	59.999	59.999	59.999
Variance of Frequency (σ^2)	0.00024	0.00034	0.00027	0.00041
Standard Deviation (σ)	0.01545	0.01855	0.01658	0.02021
50% percentile (median)	59.999	59.999	60.002	59.998
Starting Frequency (F_{START}) (Hz)	**59.973**	**59.967**	**59.971**	**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% 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 TECs, the need to expressly evaluate TEC as a variable in the IFRO calculation is eliminated.

Figures 1.1–1.4 show the probability density function (PDF) of frequency for each Interconnection. The vertical red line is the 5th percentile frequency; the interconnection frequency will statistically be greater than that value 95% of the time; this value is used as the starting frequency.

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

[10] One-second frequency data for the frequency variation analysis is provided by 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.

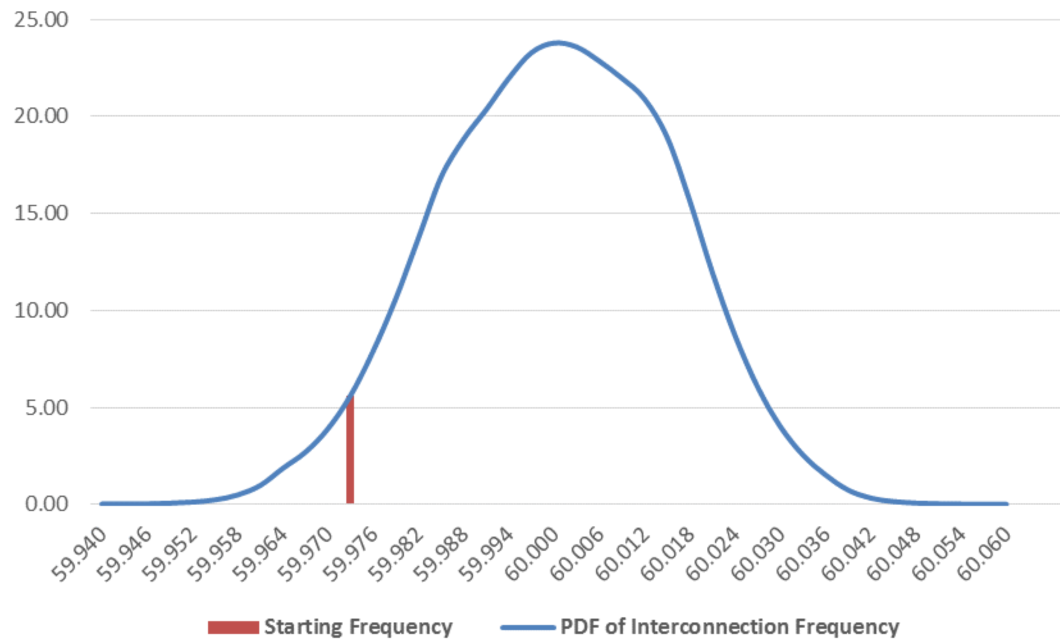

Figure 1.1: Eastern Interconnection 2015–2018 Probability Density Function of Frequency

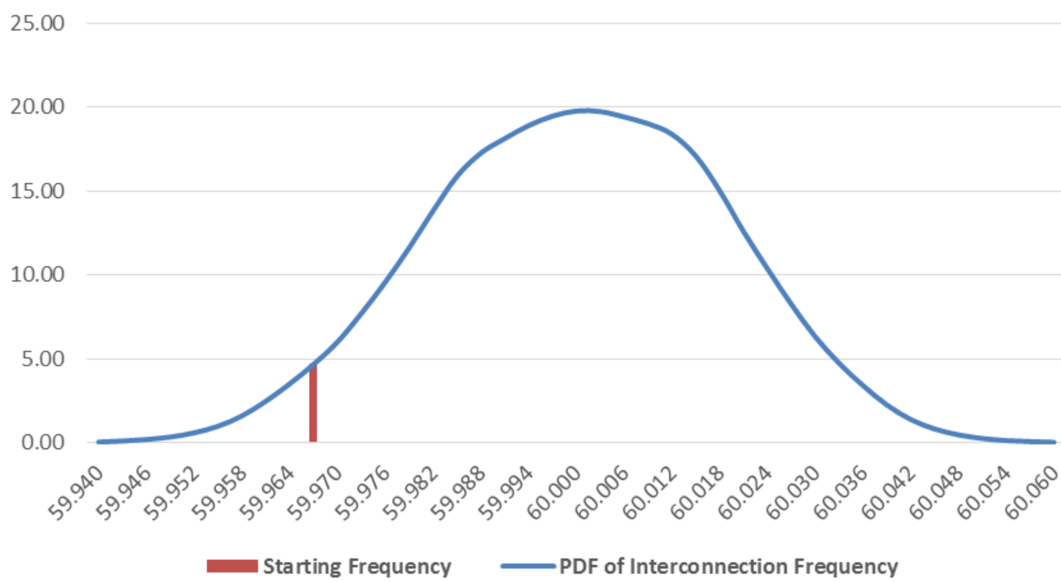

Figure 1.2: Western Interconnection 2015–2018 Probability Density Function of Frequency

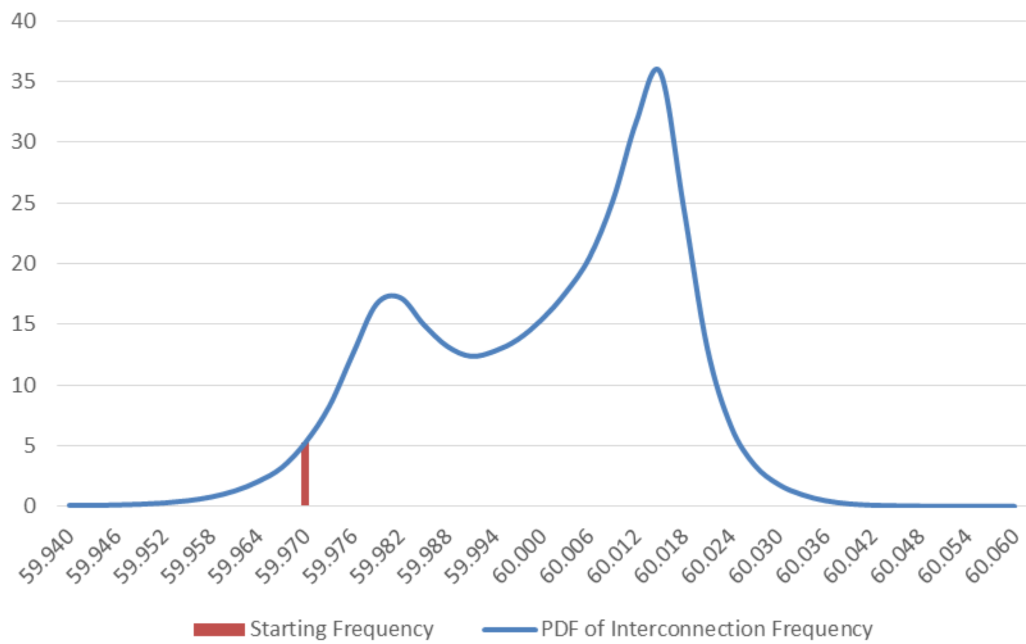

Figure 1.3: Texas Interconnection 2015–2018 Probability Density Function of Frequency

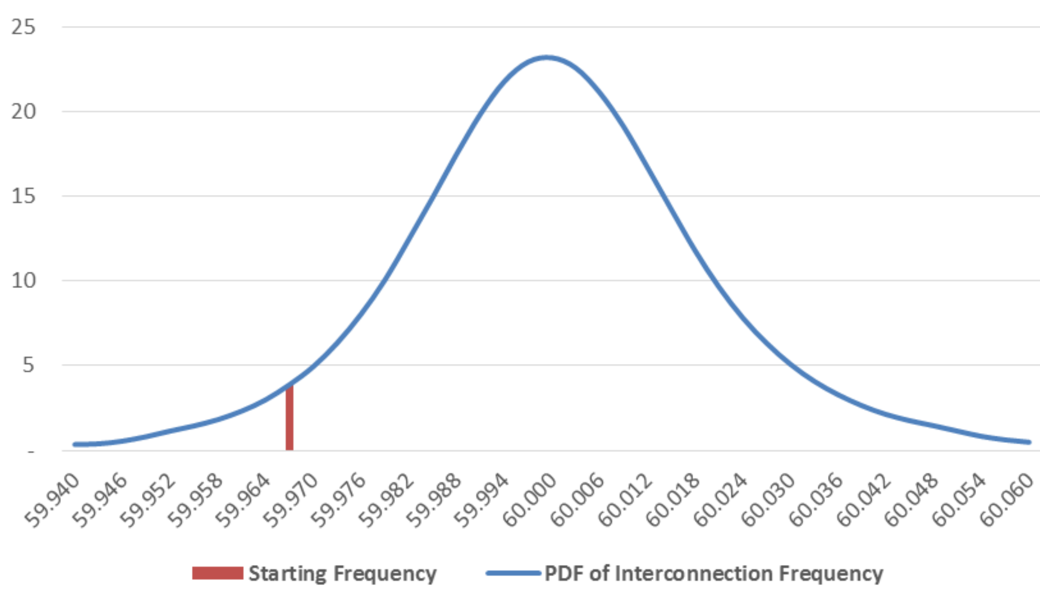

Figure 1.4: Québec Interconnection 2015–2018 Probability Density Function of Frequency

The starting frequency for the calculation of IFROs is the fifth-percentile lower-tail of samples from the statistical analysis, representing a 95% 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 TECs, the need to expressly evaluate TEC as a variable in the IFRO calculation is eliminated.

Figures 1.1–1.4 show the PDF of frequency for each Interconnection. The interconnection frequency will statistically be greater than that value 95% of the time; this value is used as the starting frequency. **Figure 1.5** shows a comparison of the PDF for all Interconnections.

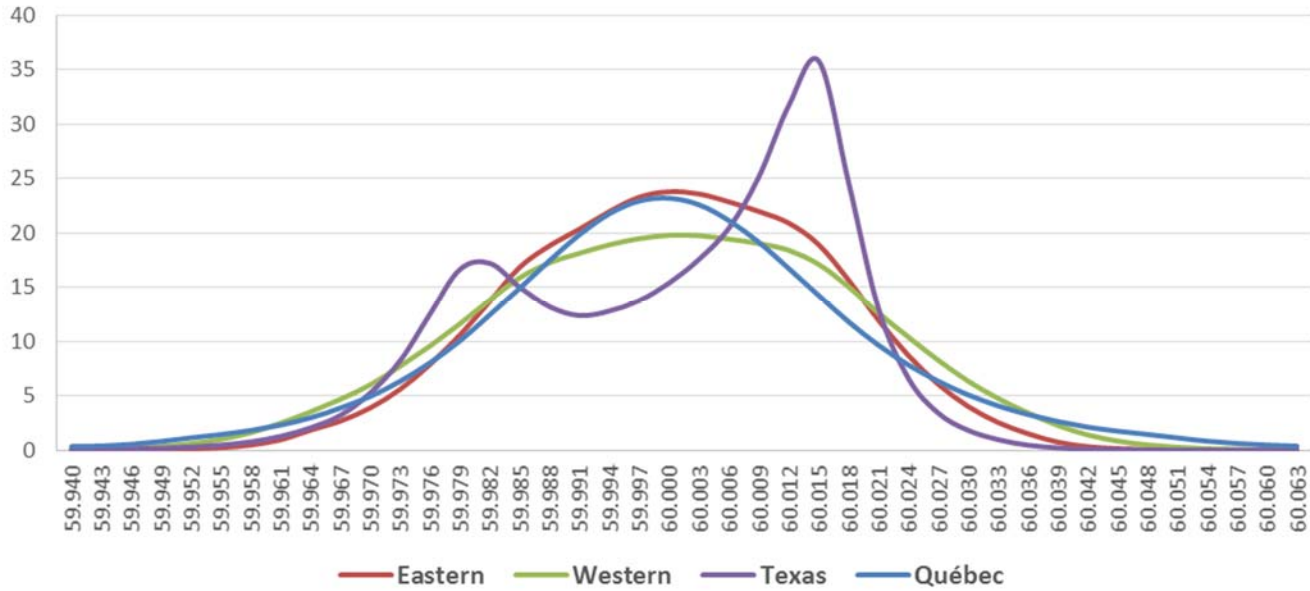

Figure 1.5: Comparison of 2015–2018 Interconnection Frequency PDFs

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 2015 to 2018. **Table 1.2** lists the standard deviation of the annual Interconnection frequencies.

Table 1.2: Interconnection Standard Deviation by Year				
Interconnection	**2015**	**2016**	**2017**	**2018**
Eastern	0.0144	0.0157	0.0156	0.0161
Western	0.0190	0.0190	0.0186	0.0186
Texas	0.0172	0.0165	0.0165	0.0162
Québec	0.0204	0.0203	0.0198	0.0203

In the Eastern Interconnection, the standard deviation in 2016 and 2017 increased compared to 2015. The standard deviation further increased in 2018. In the other Interconnections, standard deviations have been flat (Québec) or decreasing (Western and Texas). 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. Comparisons of annual frequency profiles for each Interconnection are shown in **Figures 1.6–1.9.**

Eastern Interconnection Frequency Characteristic Changes

The increase in standard deviation for the EI frequency characteristic in 2018 is shown in **Figure 1.6**. Statistical skewness (S) also increased in 2018 (S = -0.16) as compared to 2015, 2016, and 2017 (S = 0.00, -0.08, and -0.08;

respectively). The absolute value of S measures the asymmetry of the distribution.[11] The 2015 EI frequency had a very small S, so it was almost perfectly symmetric. In 2018, the absolute value of EI frequency skewness increased so the frequency became less symmetric. The EI experienced a coincidental increase in fast time error in 2018.

Recommendation:

NERC should, in coordination with NERC technical committees, evaluate the causes of increased standard deviation and asymmetry in EI frequency distribution and identify possible impacts, if any, to frequency response.

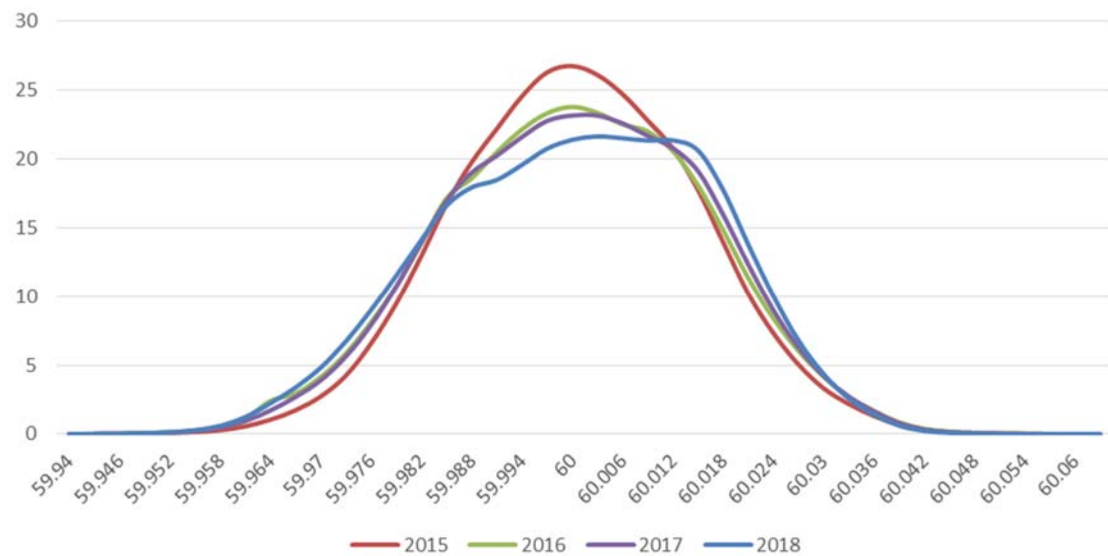

Figure 1.6: Eastern Interconnection Frequency Probability Density Function by Year

Western Interconnection Frequency Characteristic Changes

There were no observable changes in the frequency distributions for the WI as shown in **Figure 1.7**.

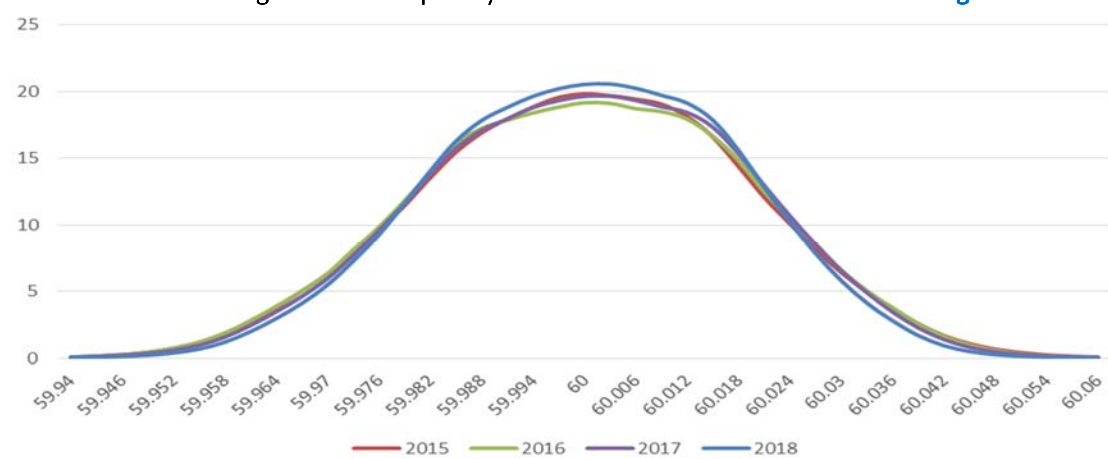

Figure 1.7: Western Interconnection Frequency Probability Density Function by Year

[11] The skewness (S) is a measure of asymmetry of a distribution. A perfectly symmetric distribution has S=0. The sign indicates where a longer tail of the distribution is. The negatively-skewed distribution has a longer left tail and its curve leans to the opposite direction (to the right). Algebraically, it means that the frequency values that are smaller than its mean are spread farther from the mean than the values greater than the mean or that there is more variability in lower values of the frequency than in higher values of the frequency.

Texas Interconnection Frequency Characteristic Changes

Standard TRE BAL-001[12] 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. This standard requires all resources in ERCOT to provide proportional, non-step primary frequency response with a ±17 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** 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.

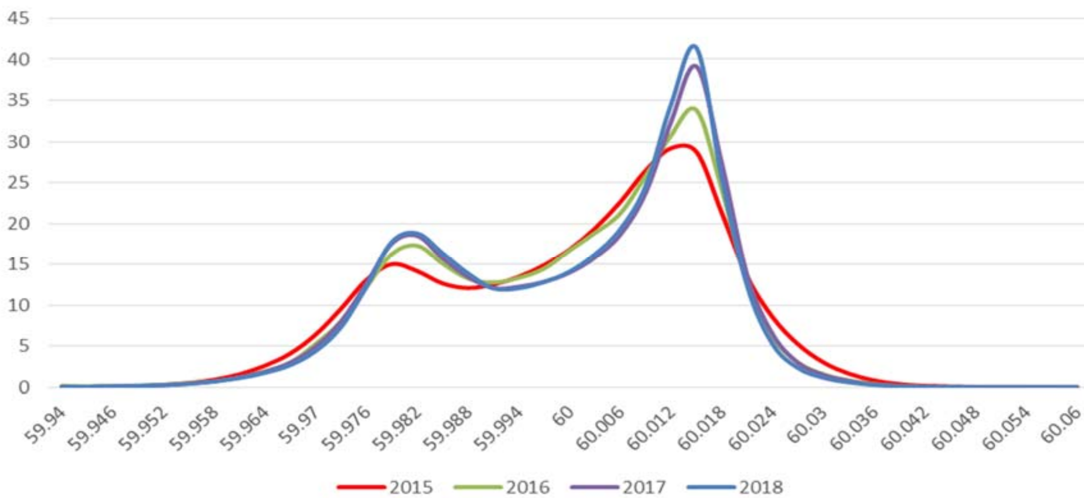

Figure 1.8: Texas Interconnection Frequency Probability Density Function by Year

Quebec Interconnection Frequency Characteristic Changes

There were no observable changes in the shape of the distribution for the QI as shown in **Figure 1.9**.

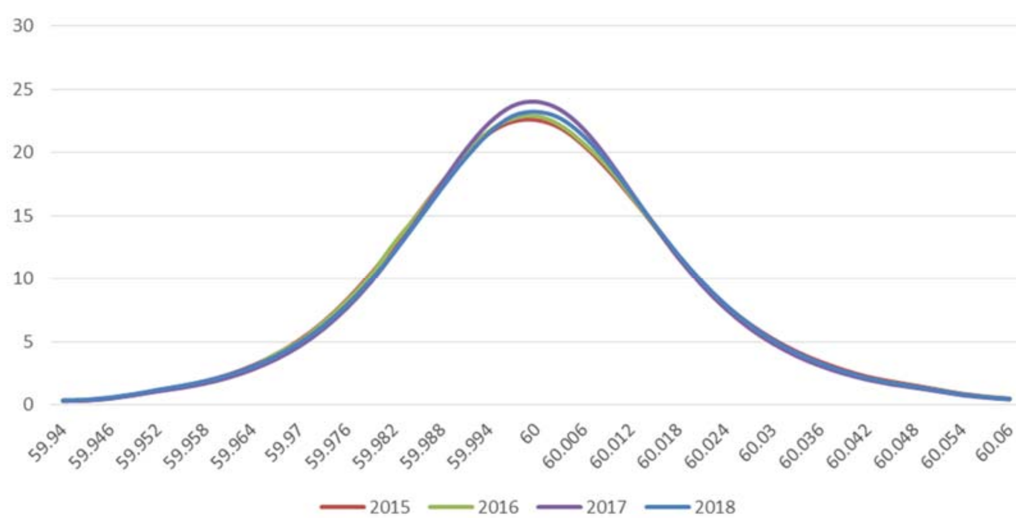

Figure 1.9: Québec Interconnection Frequency Probability Density Function by Year

[12] 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.[13] This 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 is 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 due to 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:

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

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

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

$$ARLPC = RLPC - CLR$$

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

[13] 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 (EI 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.
- A resource loss protection criterion is the adjusted resource loss protection criteria adjusted for the CLR.
- 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 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 the calculations in 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 supervisory control and data acquisition (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 2015 through 2018 that capture the relationship between Value B and Point C.

Sub-Second Frequency Data Source
Frequency data used for calculating all 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 the five most perturbed 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 multiplied by the frequency bias setting to estimate the 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

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 shown in **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 2014–2017 (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	108	1.121	0.170	0.027	1.148
Western	93	1.888	0.671	0.116	2.004
Texas	132	1.748	0.540	0.078	1.826
Québec	169	4.699	1.480	0.188	1.550

The EI historically exhibited a frequency response characteristic that often had Value B below Point C, and the CB_R value for the EI 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[14] indicates a value above 1.000, so no such limitation is required. This is due in large part to the improvement made to primary frequency response of the Interconnection through the continued outreach efforts by the NERC RS and the North American Generator Forum (NAGF).

The QI's resources are predominantly hydraulic and are operated to optimize efficiency, typically at about 85% of rated output. Consequently, most generators have about 15% headroom to supply primary frequency response. This results in a robust response to most frequency events, exhibited by high rebound rates between Point C and the calculated Value B. For the 169 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, limiting CB_R.

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

Québec has an operating mandate for frequency responsive reserves to prevent tripping the 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, protecting the Interconnection 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 vs. Subsecond Data (CC_{ADJ}) Eliminated

Calculation of all of the IFRO adjustment factors for this *2019 FRAA Report* utilized subsecond 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 EI.

To track frequency response withdrawal in this report, the later-occurring nadir is termed Point C’, 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. These 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	108	57	27	0.005	0.004	0.007
Western	93	51	0	N/A	N/A	N/A
Texas	132	66	2	N/A	N/A	N/A
Québec	169	40	20	-0.017	0.023	-0.008

Only the EI had a significant number of resource-loss events where C’ was below Point C or Value B for those events. The 20 events detected for Québec are for load-loss events; this is 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 two events with C’ lower than Point C were identified in the TI, it does not warrant an adjustment factor; only the adjustment factor of 7 mHz for the EI is necessary. Of the 108 frequency events analyzed in the EI, there were 57 events exhibiting a secondary nadir where Point C’ was below Value B and 27 events where Point C’ was lower than the initial frequency nadir (Point C). These secondary nadirs beyond 52 seconds after the start of the event[15] which is the time frame for calculating Value B.

Therefore, a BC'_{ADJ} is only needed for the EI; 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.

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
Texas	59.3
Québec	58.5

The highest UFLS set point in the EI 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 EI 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; this 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 PV systems revealed a propensity to trip at about 59.4 Hz, which is 200 mHz above the expected 59.2 Hz prescribed in IEEE Standard 1547 for distribution-connected PV systems rated at or below 30 kW (57.0 Hz for larger installations). This could become problematic in the future in areas with a high penetration of inverter-based resources.

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

Credit for Load Resources

The TI depends on contractually interruptible (an ancillary service) demand response that automatically trips at 59.7 Hz by under-frequency relays to help arrest frequency declines. A CLR is made for the resource contingency for the TI.

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 2017 through December 2018, like the approach used in the 2015 and 2016 FRAA. Statistical analysis indicated that 1,137 MW of CLR is available 95% of the time. Therefore, a CLR adjustment of 1,137 MW is applied in the calculation of the TI IFRO as a reduction to the RLPC.

ERCOT Credit for Load Resources
Prior to April 2012, ERCOT was procuring 2,300 MW of responsive reserve service of which up to 50% 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 responsive reserve service 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.

Determination of Maximum Allowable Delta Frequencies

Because of the measurement limitation[16] 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'

Table 2.4: Determination of Maximum Allowable Delta Frequencies

	Eastern	Western	Texas	Québec	Units
Starting Frequency	59.973	59.967	59.971	59.967	Hz
Minimum Frequency Limit	59.500	59.500	59.300	58.500	Hz
Base Delta Frequency	0.473	0.467	0.671	1.467	Hz
CB_R[17]	1.148	2.004	1.826	1.550	Ratio
Delta Frequency (DF_{CBR})[18]	0.412	0.233	0.367	0.946	Hz
BC'_{ADJ}[19]	0.007	0	0	0	Hz
Max. Allowable Delta Frequency	0.405	0.233	0.367	0.946	Hz

[16] Due to the use of 1–6 second scan-rate data in BA's EMS systems to calculate the BA's Frequency Response Measures for frequency events under BAL-003-1
[17] Adjustment for the differences between Point C and Value B
[18] Base Delta Frequency/CB_R
[19] Adjustment for the event nadir being below the Value B (EI only) due to primary frequency response withdrawal.

Calculated IFROs

Table 2.5 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 2.5: Initial Calculation of Operating Year 2019 IFROs					
	Eastern (EI)	**Western (WI)**	**ERCOT (TI)**	**Québec (QI)**	**Units**
Starting Frequency	59.973	59.967	59.971	59.967	Hz
Max. Allowable Delta Frequency	0.405	0.233	0.367	0.946	Hz
Resource Contingency Protection Criteria	4,500	2,626	2,750	1,700	MW
Credit for Load Resources	N/A	120[20]	1,137	N/A	MW
IFRO	**-1,111**	**-1,075**	**-439**	**-180**	**MW/0.1 Hz**
Mean Interconnection Frequency Response Performance for Operating Year 2018[21]	-2,411	-1,789	-940	-862	MW/0.1 Hz

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 2.6 compares the current IFROs and their key component values to those presented in the *2016 FRAA* report.

Table 2.6: Interconnection IFRO Comparison						
	OY 2019 In Use[22]	**OY 2019 Calc.[23]**	**OY 2020 Calc.[24]**	**2019 Calc. to 2020 Calc. Change**	**OY 2019 In Use to 2020 Calc. Change**	**Units**
Eastern Interconnection						
Starting Frequency	59.974	59.974	59.973	-0.001	-0.001	Hz
Max. Allowable Delta Frequency	0.443	0.418	0.405	-0.013	-0.038	Hz
Resource Contingency Protection Criteria	4,500	4,500	4,500	0	0	MW
Credit for Load Resources	0	0	0	0	0	MW

[20] Based on the most updated information regarding load shedding for loss of two Palo Verde units with a WI CLR = 120 MW.
[21] Based on mean Interconnection frequency response performance from the *2019 State of Reliability* report for operating year 2018.
[22] Calculated in the 2015 FRAA report. Average frequency values were for operating years 2012 through 2014.
[23] Calculated in the 2018 FRAA report. Average frequency values were for operating years 2014 through 2017.
[24] Calculated in the 2019 FRAA report. Average frequency values were for operating years 2015 through 2018.

Table 2.6: Interconnection IFRO Comparison						
	OY 2019 In Use[22]	OY 2019 Calc.[23]	OY 2020 Calc.[24]	2019 Calc. to 2020 Calc. Change	OY 2019 In Use to 2020 Calc. Change	Units
Absolute Value of IFRO	**1,015**	**1,092**	**1,111**	19	96	MW/0.1 Hz
Western Interconnection						
Starting Frequency	59.967	59.967	59.967	0	0	Hz
Max. Allowable Delta Frequency	0.292	0.248	0.233	-0.015	-0.059	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**	**1,010**	**1,075**	65	217	MW/0.1 Hz
Texas Interconnection						
Starting Frequency	59.966	59.967	59.971	0.004	0.005	Hz
Max. Allowable Delta Frequency	0.411	0.377	0.367	-0.01	-0.044	Hz
Resource Contingency Protection Criteria	2,750	2,750	2,750	0	0	MW
Credit for Load Resources	1,181	1,209	1,137	-72	-44	MW
Absolute Value of IFRO	**381**	**409**	**439**	30	58	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	0.946	0.946	0	-0.002	Hz
Resource Contingency Protection Criteria	1,700	1,700	1,700	0	0	MW
Credit for Load Resources	0	0	0	0	0	MW
Absolute Value of IFRO	**179**	**180**	**180**	0	1	MW/0.1 Hz

Key Findings

Analysis of the characteristics of the IFRO calculations in response to trends in frequency response performance have identified inconsistencies in the IFRO calculation that have been identified and discussed beginning with the 2016 FRAA. The following findings are important to highlight.

The ratio between Point C and Value B (CBr) is a multiplicative factor in the IFRO formulae, which couples these two quantities together in the formulation of the IFRO. The original intent of the IFRO calculation was to ensure that a declining frequency nadir (as demonstrated by an increasing A-C) would result in an increase in the IFRO. However, the calculation also results in an increase in IFRO when stabilizing period performance improves (as demonstrated by a decreasing A-B) while Point C remains relatively stable. Using the current method for calculating IFRO an increase in the CBr, when all other variables remain unchanged, results in an increase in IFRO. The IFRO should not penalize an Interconnection for improved performance of Value B during the stabilizing period.

For these reasons, absent a decline in the mean Point C frequency nadirs, the IFROs since the 2016 operating year have been frozen at the levels recommended in the 2015 FRAA. Table 2.7 shows the year over year comparison of adjusted CBr for all interconnections and demonstrates the trend of higher CBr values that have resulted in higher calculated IFROs.

Table 2.7: Year over Year Comparison Adjusted CBr

Interconnection	OY2016	OY2017	OY2018	OY2019	OY2020	Difference OY2019 - OY2016
Eastern	1.052	1.071	1.111	1.134	1.148	0.096
Western	1.598	1.566	1.670	1.879	2.004	0.106
Texas	1.619	1.626	1.648	1.774	1.826	0.207
Québec	1.550	1.550	1.550	1.550	1.550	0

Table 2.8 shows a comparison of mean Value A, mean Value B, and mean Point C that is illustrative of Interconnection performance over the previous operating year and as compared to the 2016 operating year in which the IFRO values were frozen. Loss of load events have been excluded from the data in Table 2.8.

Table 2.8: Year over Year Comparison Value A, Value B, and Point C (Loss of Load Events Excluded)

	OY2016	OY2019	OY2020	Difference OY2019 - OY2016	Difference OY2020 - OY2019
Eastern Interconnection					
Mean Value A (Hz)	59.998	59.998	59.999	0.001	0.001
Mean Value B (Hz)	59.947	59.952	59.953	0.006	0.001
Mean Point C (Hz)	59.947	59.949	59.949	0.002	0
Mean A – B (Hz)	0.051	0.046	0.046	-0.005	0
Mean A – C (Hz)	0.051	0.049	0.050	-0.001	0.001
Western Interconnection					
Mean Value A (Hz)	60.000	59.996	59.995	-0.005	-0.001
Mean Value B (Hz)	59.923	59.927	59.934	0.011	0.007
Mean Point C (Hz)	59.887	59.886	59.887	0	0.001
Mean A – B (Hz)	0.076	0.069	0.061	-0.015	-0.08
Mean A – C (Hz)	0.112	0.112	0.108	-0.004	-0.004
Texas Interconnection					
Mean Value A (Hz)	59.996	59.997	59.997	0.001	0
Mean Value B (Hz)	59.889	59.914	59.918	0.029	0.004
Mean Point C (Hz)	59.840	59.862	59.865	0.025	0.003

Table 2.8: Year over Year Comparison Value A, Value B, and Point C (Loss of Load Events Excluded)					
	OY2016	**OY2019**	**OY2020**	**Difference OY2019 - OY2016**	**Difference OY2020 - OY2019**
Mean A – B (Hz)	0.107	0.083	0.079	-0.028	-0.004
Mean A – C (Hz)	0.156	0.135	0.132	-0.024	-0.003
Québec Interconnection					
Mean Value A (Hz)	60.003	60.003	60.003	0	0
Mean Value B (Hz)	59.843	59.864	59.876	0.033	0.012
Mean Point C (Hz)	59.433	59.505	59.533	0.100	0.028
Mean A – B (Hz)	0.160	0.139	0.127	-0.033	-0.012
Mean A – C (Hz)	0.570	0.498	0.469	-0.101	-0.029

All four Interconnections show an increase in mean Value B and a decrease in the mean Value A – Value B indicating improved performance during the stabilizing period of frequency events. All four interconnections show either an increase or no change in mean Point C as well as a decrease or no change in mean Value A – Point C indicating improved performance during the arresting period of frequency events. This performance data demonstrates that the increases in year over year CBr that result in higher calculated IFROs are due to improved stabilizing period performance and not due to a decline in the performance of Point C.

Recommended IFROs for Operating Year 2020

Due to the inconsistencies outlined in this and previous FRAA reports and the findings that demonstrate improved performance, the IFRO values shown in **Table 2.9** for operating year 2020 (December 2019 through November 2020) are recommended as follows:

1. For the operating year 2020 the IFRO values for the EI, WI, and QI shall remain the same values as calculated in the *2015 FRAA* report for operating year 2016[25] and held constant through operating years 2017, 2018, and 2019 as shown in **Table 2.9**.
2. For the operating year 2020, the IFRO value for the TI will increase by -44 MW / 0.1 Hz due to a reduction in the CLR. The statistically derived available CLR decreased by 72 MW from the 2018 to 2019 FRAA calculations but the decrease was only 44 MW from the 2015 FRAA calculations which established the IFRO values currently in effect. Therefore, the recommended IFRO for TI is -425 MW / 0.1 Hz, an increase of -44 MW / 0.1 Hz.

Table 2.9: Recommended IFROs for Operating Year 2020					
	Eastern (EI)	**Western (WI)**	**Texas (TI)**	**Québec (QI)**	**Units**
IFRO	**-1,015**	**-858**	**-425**	**-179**	**MW/0.1 Hz**

[25] These IFROs were held constant through operating years 2016, 2017, 2018, and 2019.

Chapter 3: Dynamics Analysis of Recommended IFROs

Because the IFROs for the EI, WI, and TI have not been reduced 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 FRAA*[26] report for details. No analysis was performed for the QI.

[26] https://www.nerc.com/comm/OC/Documents/2017_FRAA_Final_20171113.pdf