NERC

NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

2022 Frequency Response Annual Analysis

November 2022

This report was approved by the Resources Subcommittee on October 19, 2022.

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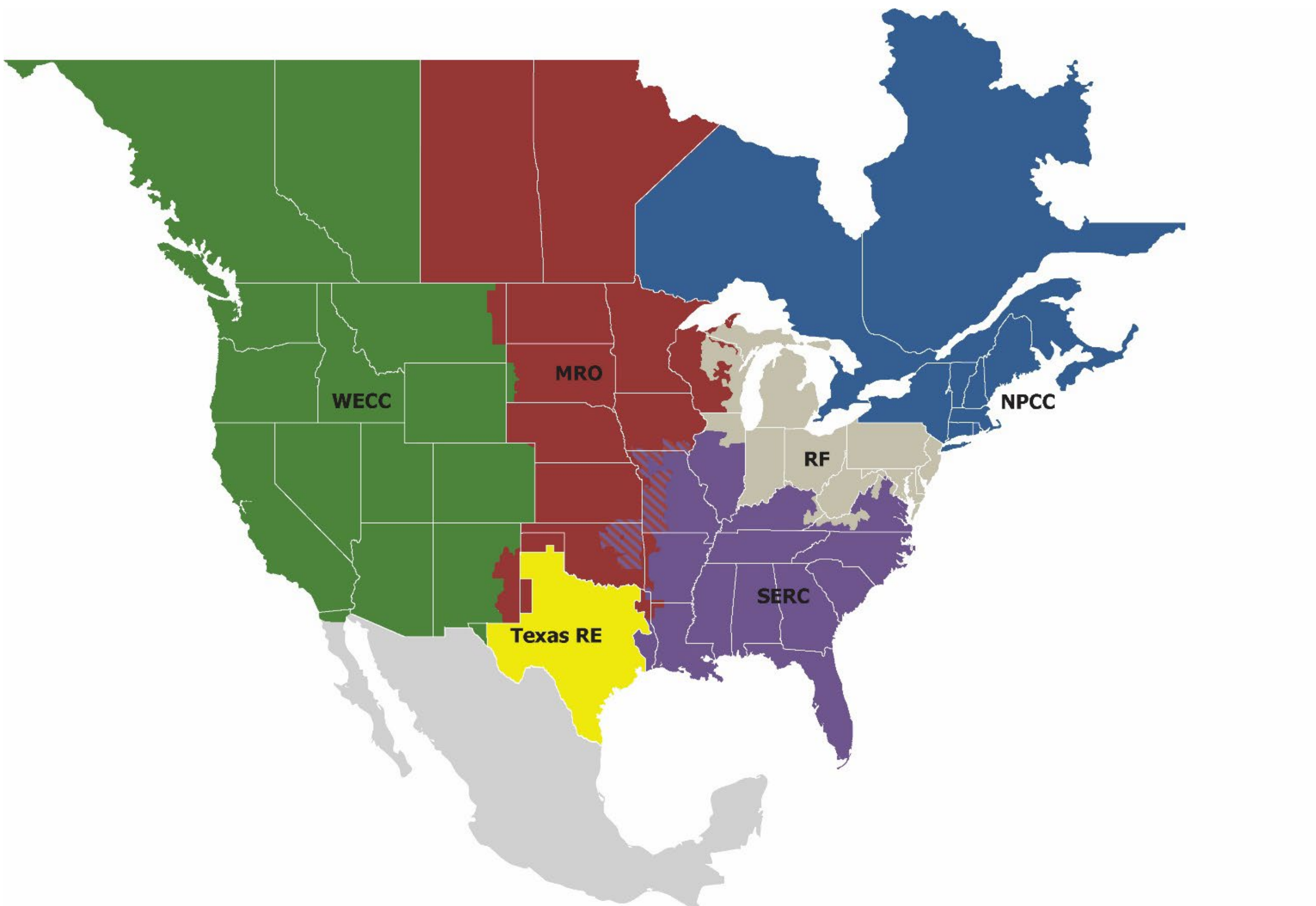
Preface

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 NERC and the six Regional Entities, is a highly reliable, resilient, 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.

Reliability | Resilience | Security

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

The North American BPS is made up of six Regional Entity boundaries as shown in the map and corresponding table below. The multicolored area denotes overlap as some load-serving entities participate in one Regional Entity 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	WECC

Executive Summary

This report is the 2022 annual analysis of frequency response performance for the administration and support of *NERC Reliability Standard BAL-003-2 – Frequency Response and Frequency Bias Setting,*[1] effective December 1, 2020. 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) and the technical committee, which predated the Reliability and Security Technical Committee (RSTC) and was 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 (OY) 2023 (December 2022 through November 2023). 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 decreased slightly from 59.972 to 59.971 for the Eastern Interconnection (EI), remained the same for the Western Interconnection (WI) at 59.969, decreased slightly from 59.971 to 59.97 for the Texas Interconnection (TI), and decreased slightly from 59.966 to 59.965 for the Québec Interconnection (QI).

Frequency Probability Density Functions

Analysis of the frequency probability density functions shows that the standard deviation in 2016 and 2017 increased compared to 2015 in the EI; the standard deviation further increased in 2019. The EI experienced a coincidental increase in fast time error in 2018. The EI frequency probability density function for 2019 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 the disparity of values around the mean value, a decreasing standard deviation indicates tighter concentration around the mean value and more stable performance of Interconnection frequency. Comparisons of annual frequency profiles for each Interconnection are shown in **Figures 1.6–1.9**.

Interconnection Performance and the Comparison of Mean Value A, B, and Point C

Table 2.6 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 OY and as compared to the 2016 OY 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 higher calculated IFROs are due to improved stabilizing period performance and not due to a decline in the performance of the Point C nadir.

[1] http://www.nerc.com/pa/Stand/Reliability%20Standards/BAL-003-2.pdf

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

[3] Prepared by the NERC Standards and Engineering organization.

Recommendations

NERC provides the following recommendation for the administration of *Standard BAL-003-2*[1] for OY 2023 (December 1, 2022, through November 30, 2023):

- The IFRO value for the TI will change by -51 MW/0.1 Hz due to a decrease in Credit for Load Resources (CLR). Therefore, the recommended IFRO for TI is -463 MW/ .1 Hz.
- NERC requests that the Recommended IFRO values calculated in this report in accordance with BAL-003-2 and shown in Table **ES.1** be approved for implementation in OY 2023. NERC, in collaboration with the RS, shall continue to monitor and evaluate the impacts on BPS reliability as a result of changes in IFRO values.

Table ES.1: Recommended IFROs for OY 2023

	Eastern (EI)	Western (WI)	Texas (TI)	Québec (QI)	Units
MDF[4]	0.420	0.280	0.405	0.947	Hz
RLPC[5]	3,740	3,069	2,805	2,000	MW
CLR	0	0	931	0	MW
Calculated IFRO	-890	-1096	-463	-211	MW/0.1 Hz
Recommended IFROs[6]	**-890**	**-1,096**	**-463**	**-211**	**MW/0.1 Hz**

[4] The Procedure for ERO Support of Frequency Response and Frequency Bias Setting Standard, Version II, provided in the approved ballot for BAL-003-2, specifies that, "MDF is the Maximum Delta Frequency for the specific interconnection as determined in the 2017 Frequency Response Annual Analysis (FRAA)."

[5] BAL-003-2, Attachment A specifies that Resource Loss Protection Criteria (RLPC) be based on the two largest potential resource losses in an interconnection. This value is required to be evaluated annually.

[6] BAL-003-2 requires that the EI IFRO will be stepped down to its calculated value over three years. The maximum reduction is limited to 100 MW/0.10 Hz annually.

Introduction

This report, prepared by NERC staff,[7] contains the annual analysis, calculation, and recommendations for the IFRO for each of the four Interconnections of North America for the OY 2023 (December 2022 through November 2023). This analysis includes the following information:

- Statistical analysis of Interconnection frequency characteristics for the OYs 2017 through 2021 (December 1, 2016, through November 30, 2021)
- Analysis of frequency profiles for each Interconnection
- Calculation of adjustment factors from BAL-003-2 frequency response events

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 FNET[8] 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 uses subsecond 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*[9] because the actual frequency nadir was accurately captured.
- The Frequency Response Analysis Tool[10] is being used by the NERC Power System Analysis group for frequency event tracking in support of the NERC Frequency Working Group 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-003-2.*[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 are 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-003-2*. Point C is the lowest frequency experienced within the first 20 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 20–52 second Stabilizing Period.

[7] Prepared by the Power System Analysis and Advanced System Analytics & Modeling departments

[8] 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.

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

[10] Developed by Pacific Northwest National Laboratory

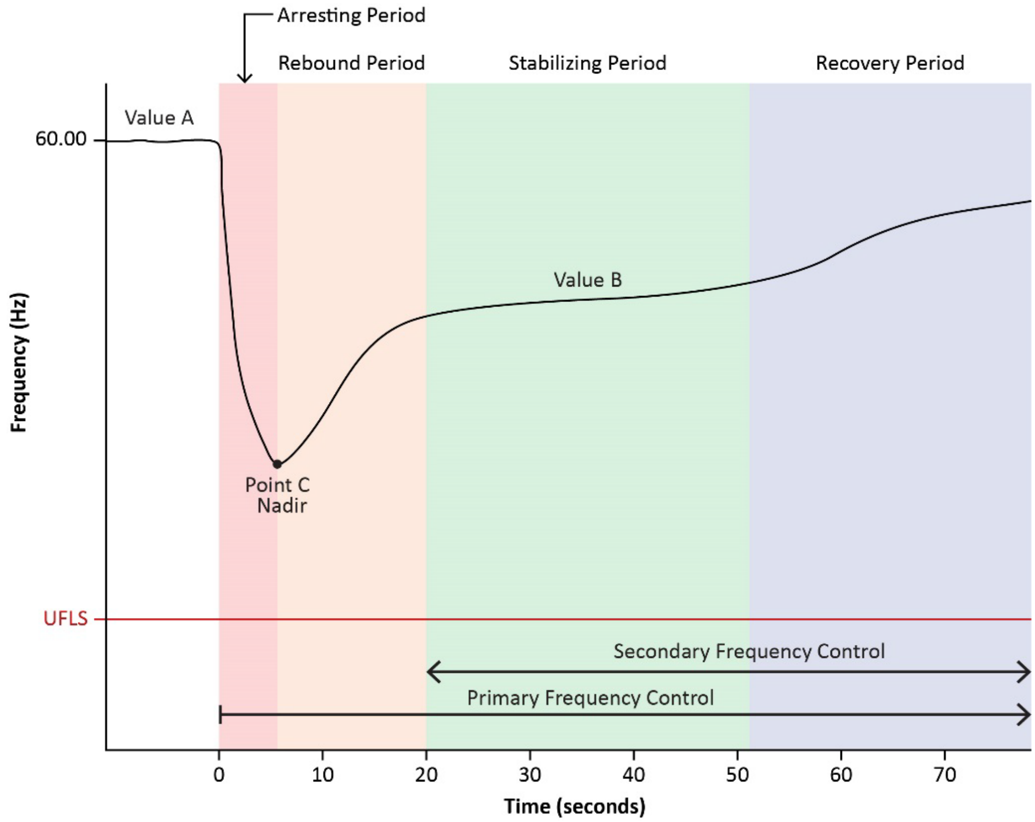


Figure I.1: Primary and Secondary Frequency Control

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. These terms are defined below:

- **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. This 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,*[11] 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[12] from OYs 2017–2021 (December 1, 2016, through November 30, 2021) was used.

Frequency Variation Statistical Analysis

The 2022 frequency variation analysis was performed on one-second frequency data for 2017–2021 and is summarized in **Table 1.1**. 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.

The starting frequency is calculated and published in this report for comparison and informational purposes. Starting frequencies are evaluated annually and indicate no need to change the Maximum Delta Frequency for OY 2023.

Table 1.1: Interconnection Frequency Variation Analysis 2017-2021

Value	Eastern	Western	Texas	Québec
Number of Samples	157,253,691	157,215,135	157,074,707	151,764,657
Filtered Samples (% of total)	99.7%	99.7%	99.6%	96.2%
Expected Value (Hz)	59.999	59.999	59.999	60.000
Variance of Frequency (σ^2)	0.00026	0.00031	0.00028	0.00043
Standard Deviation (σ)	0.01611	0.01773	0.01683	0.02072
50% percentile (median)[13]	59.999	59.999	60.003	59.998
Starting Frequency (F_{START}) (Hz)	**59.971**	**59.969**	**59.970**	**59.965**

The starting frequency 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 fifth-percentile frequency; the interconnection frequency will statistically be greater than that value 95% of the time; this value is used as the starting frequency.

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

[12] 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.

[13] Note regarding the EI median frequency that: with fast time error corrections the median value is around but slightly below 60 Hz. Without these corrections the median would be above 60 Hz.

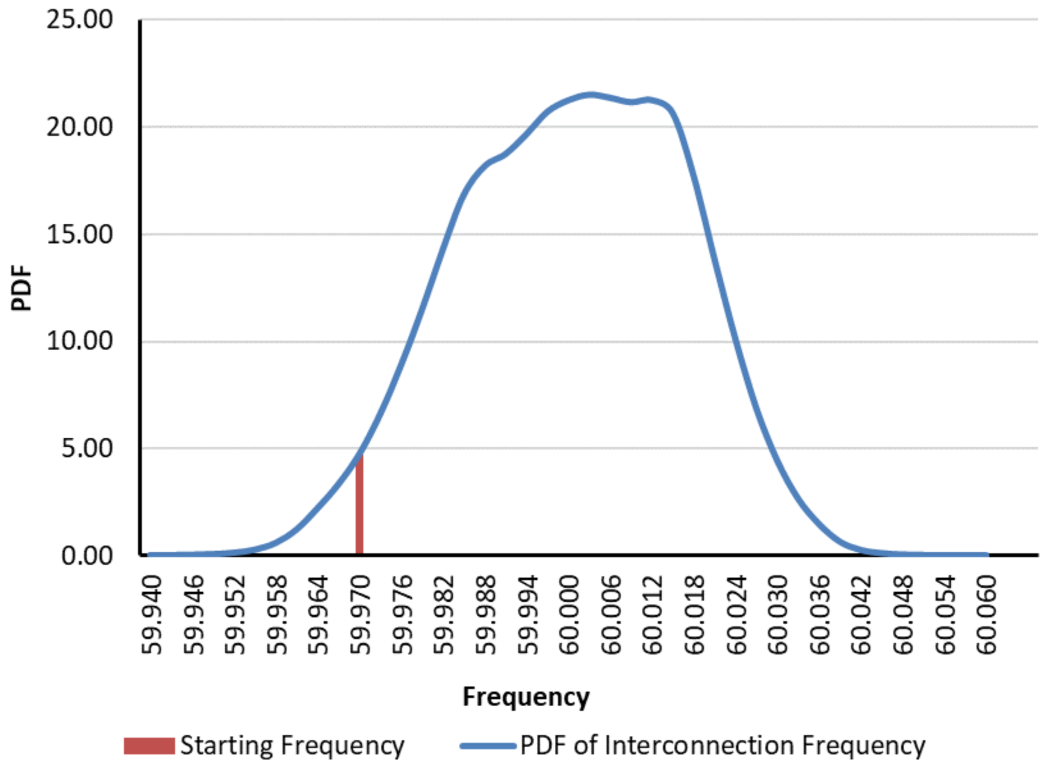


Figure 1.1: Eastern Interconnection 2017–2021 Probability Density Function of Frequency

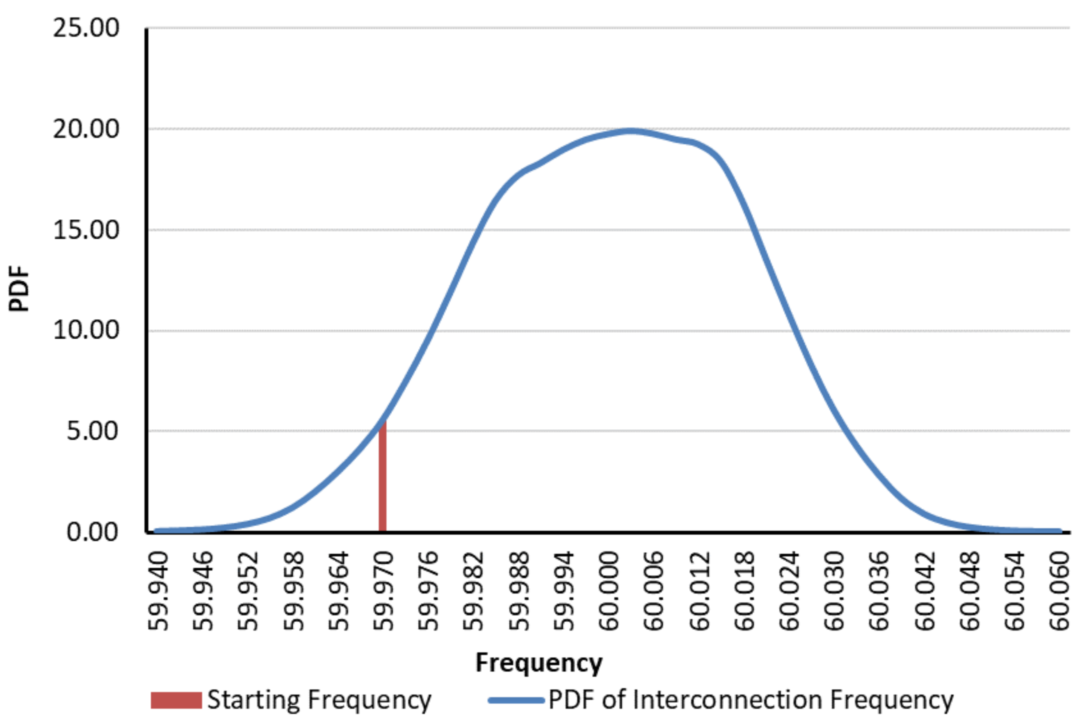


Figure 1.2: Western Interconnection 2017–2021 Probability Density Function of Frequency

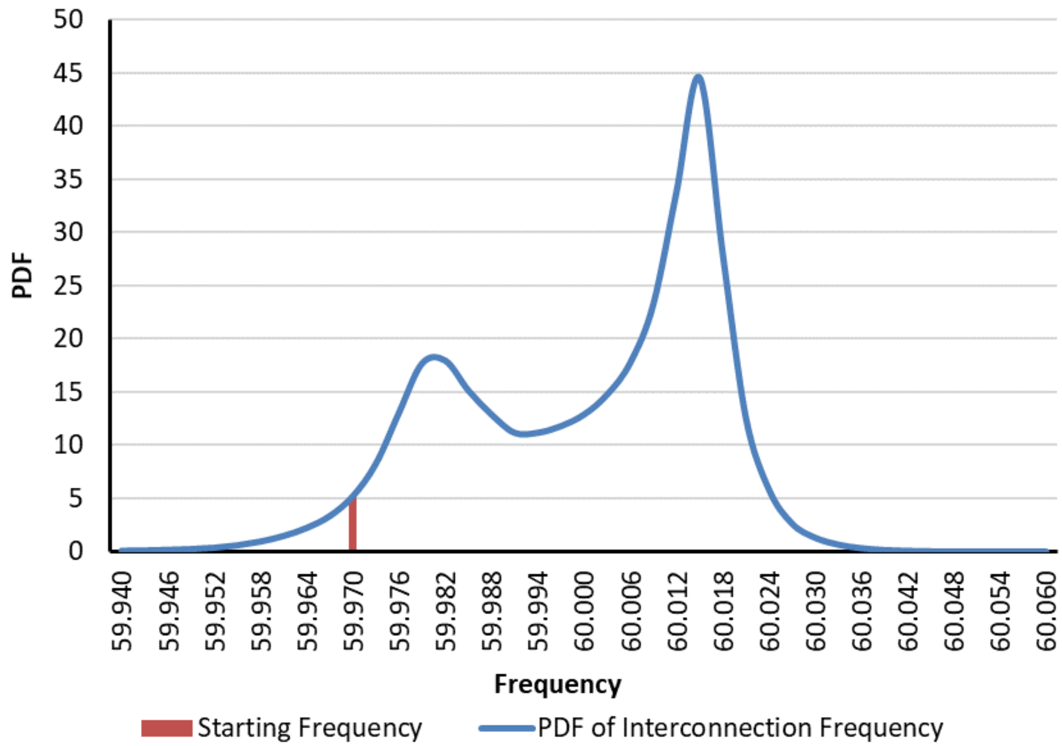


Figure 1.3: Texas Interconnection 2017–2021 Probability Density Function of Frequency

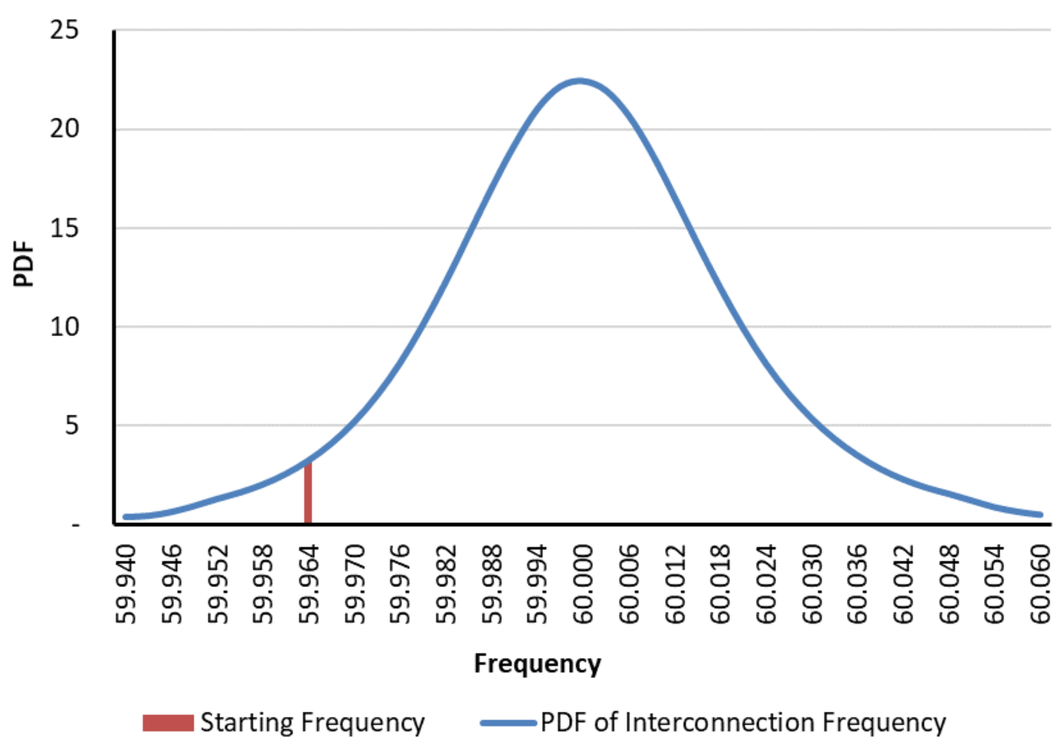


Figure 1.4: Québec Interconnection 2017–2021 Probability Density Function of Frequency

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.

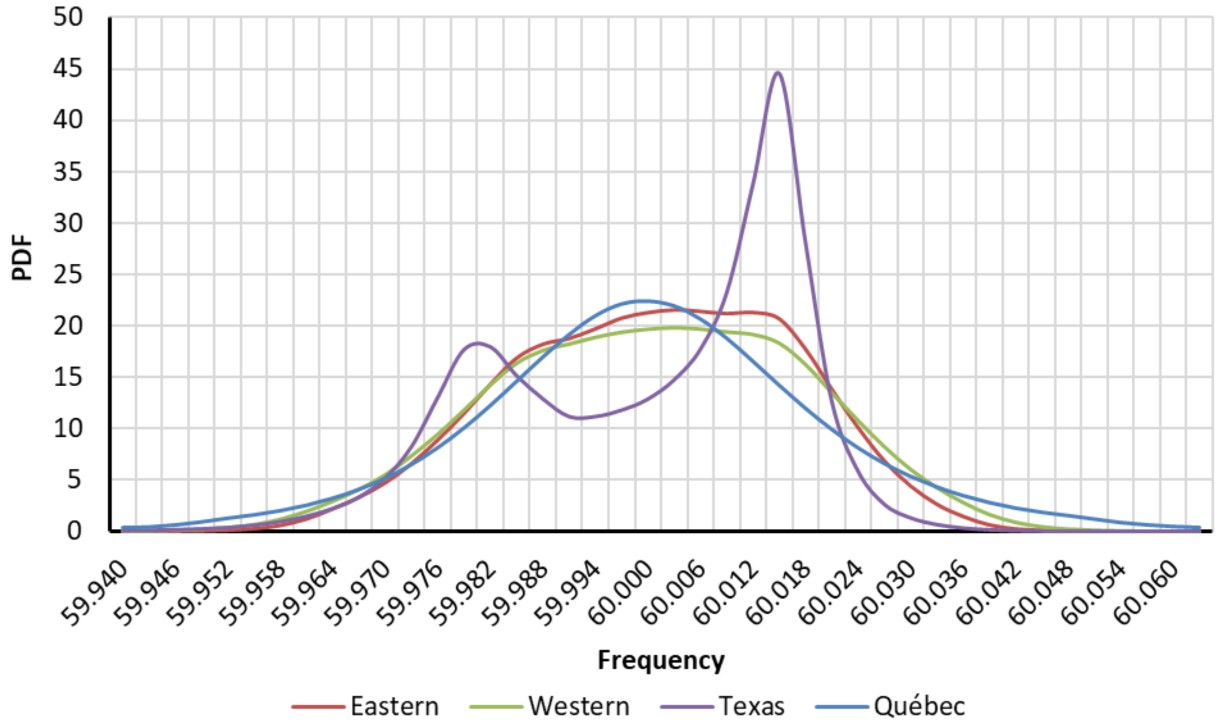


Figure 1.5: Comparison of 2017–2021 Interconnection Frequency PDFs

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 2017–2021. **Table 1.2** lists the standard deviation of the annual Interconnection frequencies.

Table 1.2: Interconnection Standard Deviation by Year

Interconnection	2017	2018	2019	2020	2021
Eastern	0.0156	0.0161	0.0162	0.0163	0.0164
Western	0.0186	0.0186	0.0174	0.0176	0.0174
Texas	0.0165	0.0162	0.0165	0.0174	0.0176
Québec	0.0198	0.0203	0.0204	0.0208	0.0223

In the EI, the standard deviation continued to increase in 2021 compared to 2017–2020. The standard deviation increased as well in the QI and the TI and decreased slightly the WI in 2021 compared to 2020. As standard deviation is a measure of dispersion of values around the mean value, the increasing standard deviations indicate reduced concentration around the mean value and less 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 2021 is shown in **Figure 1.6**. Statistical skewness (S)[14] continued to increase in 2021 (S = -0.16) as compared to 2016 and 2017 (S = -0.08 and -0.08, respectively). NERC, in coordination with its technical committees, continues to evaluate this phenomenon and its impact, if any, on BPS reliability.

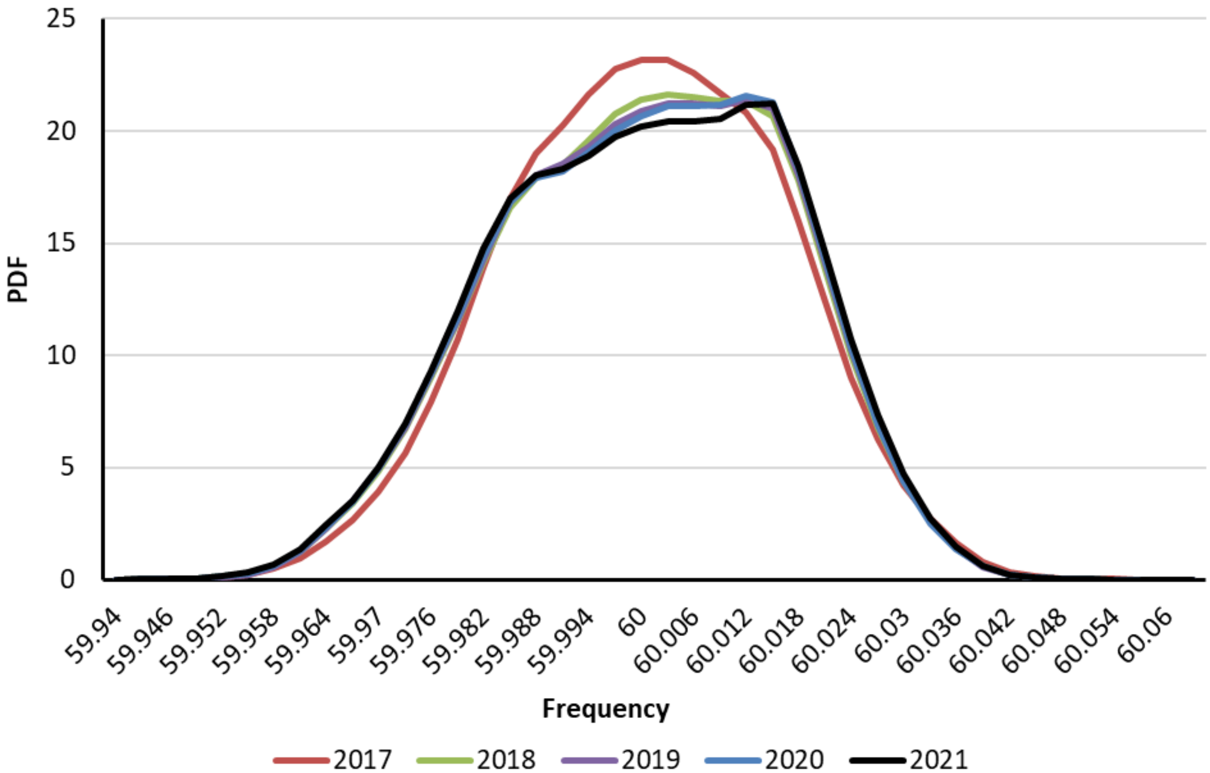


Figure 1.6: Eastern Interconnection Frequency Probability Density Function by Year

[14] 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.

Western Interconnection Frequency Characteristic Changes

There was an observable change in the frequency distribution for the WI in 2021 that includes some skewness as shown in **Figure 1.7**.

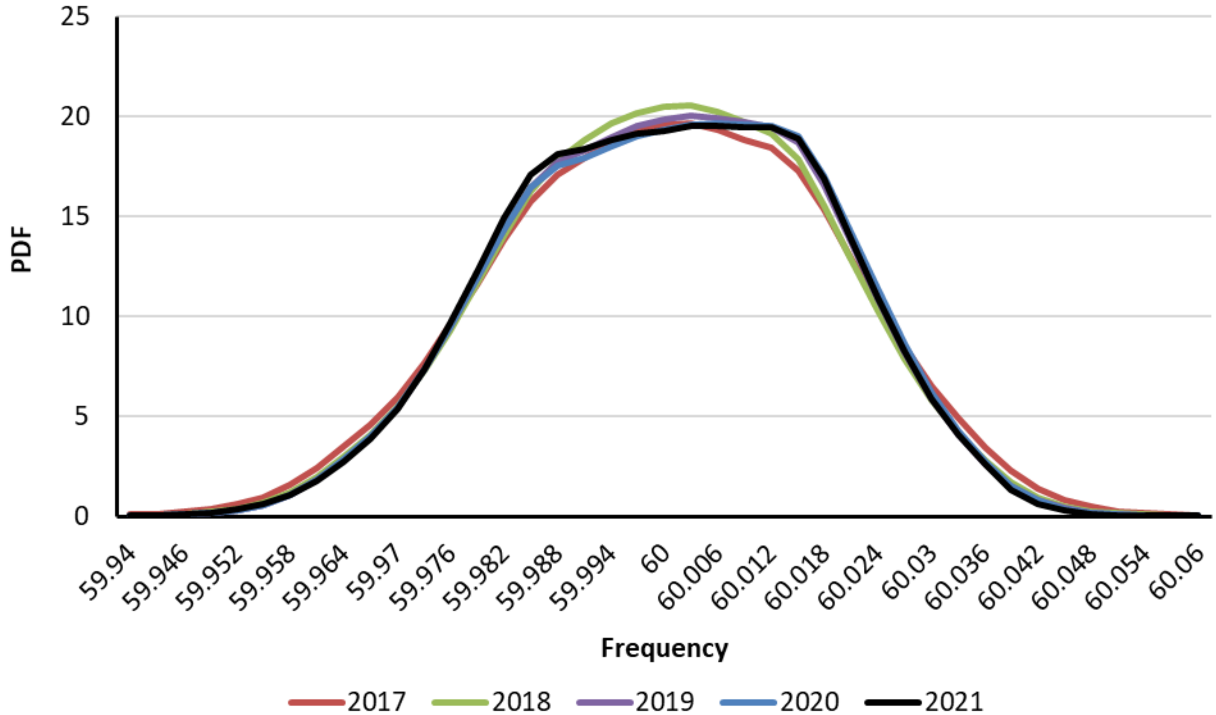


Figure 1.7: Western Interconnection Frequency Probability Density Function by Year

Texas Interconnection Frequency Characteristic Changes

Standard TRE BAL-001[15] went into full effect in April 2015 and caused a dramatic change in the probability density function of frequency for Texas Interconnection in 2015 and 2016. This standard requires all resources in Texas Interconnecton to provide proportional, nonstep primary frequency response with a ±17 mHz dead-band. As a result, any time 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 and solar, are backing down. It is exhibited in **Figure 1.8** as a probability concentration around 60.015 Hz. Similar behavior is not exhibited at the low dead-band of 59.983 Hz because most wind and solar resources are operated at maximum output and cannot increase output when frequency falls below the dead-band.

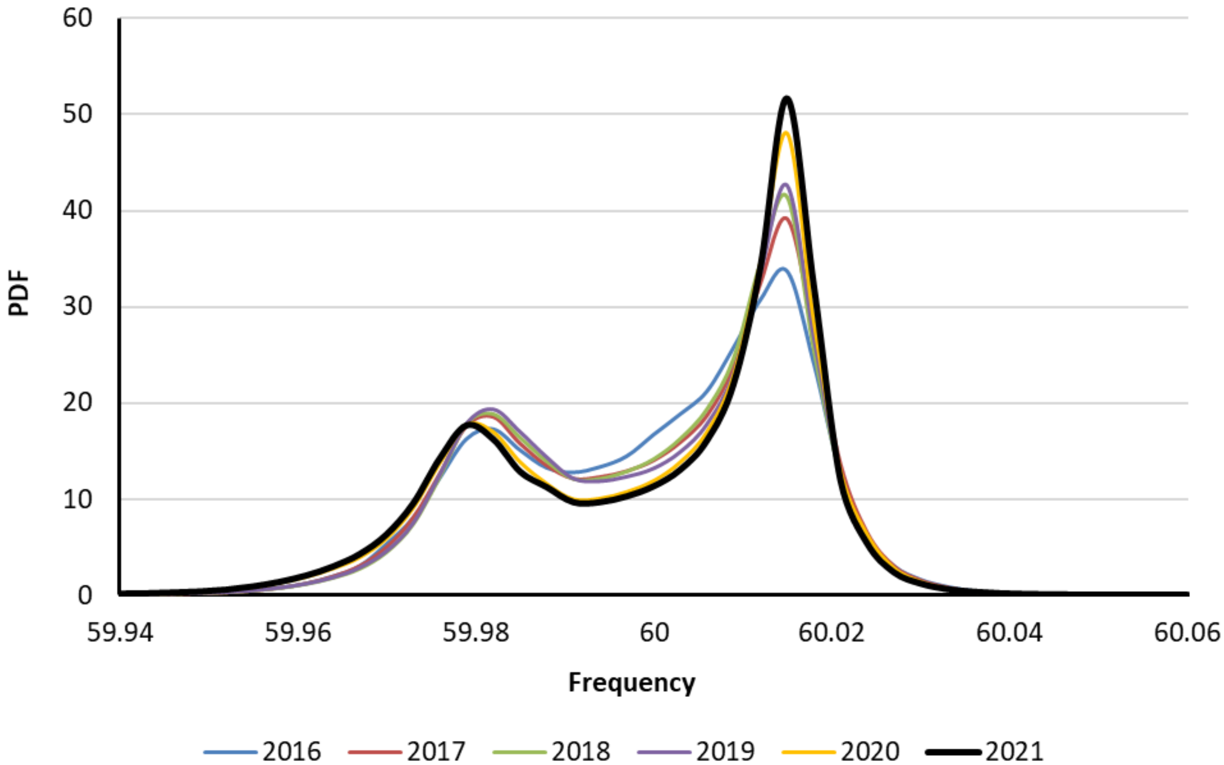


Figure 1.8: Texas Interconnection Frequency Probability Density Function by Year

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

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**.

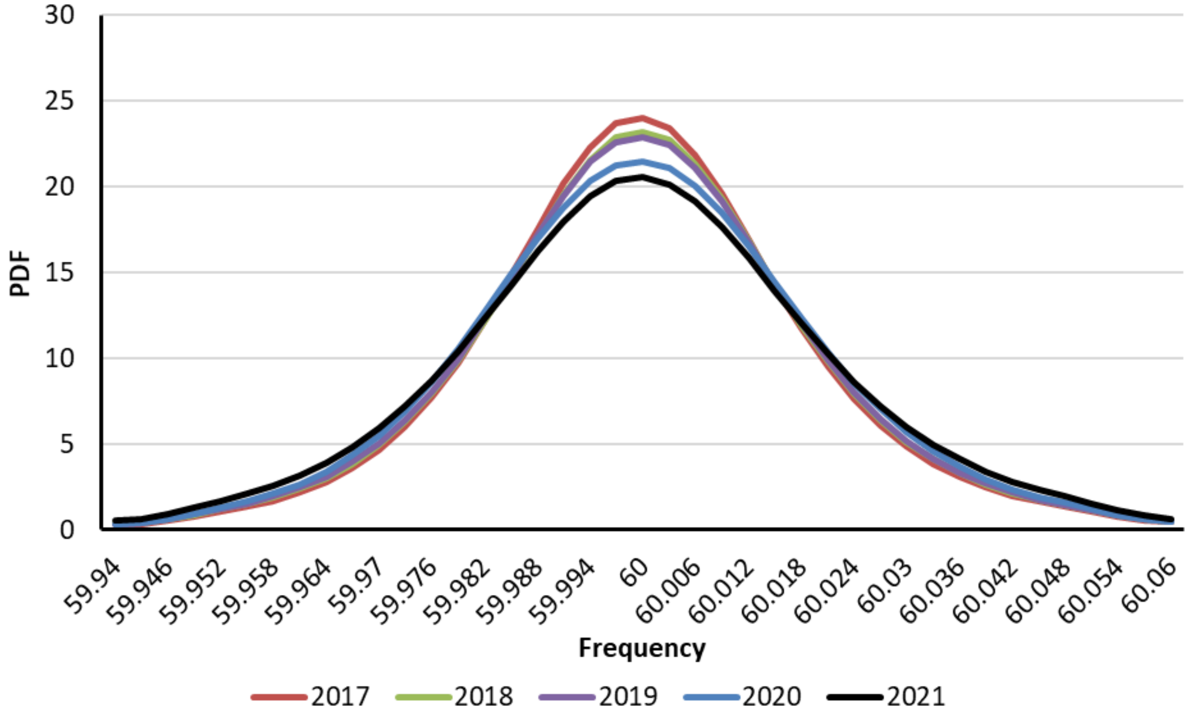


Figure 1.9: Québec Interconnection Frequency Probability Density Function by Year

Chapter 2: Determination of Interconnection Frequency Response Obligations

With this report the calculation of the IFROs is determined by recently approved BAL-003-2. Previously, the calculation involved a multifaceted process that employed 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.[16] This report includes information that serves to transition from the old to the new method.

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 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 in accordance with BAL-003-2 to avoid violating regionally approved UFLS settings.

Interconnection Resource Loss Protection Criteria (RLPC)

BAL-003-2 introduced the Interconnection Resource Loss Protection Criteria (RLPC) to replace the Resource Contingency Protection Criteria used previously. It is based on resource loss in accordance with the following process:

NERC will request BAs to provide their two largest resource loss values and largest resource loss due to an N-1 or N-2 remedial action scheme (RAS) event or largest resource as described above. This will facilitate comparison between the existing Interconnection RLPC values and the RLPC values in use. This data submission will be needed to complete the calculation of the RLPC and IFRO.

BAs determine the two largest resource losses for the next OY based on a review of the following items:

- The two largest balancing contingency events due to a single contingency identified using system models in terms of loss measured by megawatt loss in a normal system configuration (N-0) (An abnormal system configuration is not used to determine the RLPC).

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

- The two largest units in the BA area, regardless of shared ownership/responsibility
- The two largest RAS resource losses (if any) that are initiated by single (N-1) contingency events

The BA provides these two numbers determined above as Resource Loss A and Resource Loss B in the FR Form 1.

The BA should then provide the largest resource loss due to RAS operations (if any) that is initiated by a multiple contingency (N-2) event (RLPC cannot be lower than this value). If this RAS impacts more than a single BA, one BA is asked to take the lead and sum all resources lost due to the RAS event and provide that information.

The calculated RLPC should meet or exceed any credible N-2 resource loss event.

The host BA (or planned host BA) where jointly-owned resources are physically located should be the only BA to report that resource. The full ratings of the resource, not the fractional shares, should be reported.

Direct current (dc) ties to asynchronous resources (such as dc ties between Interconnections, or the Manitoba Hydro Dorsey bi-pole ties to their northern asynchronous generation) should be considered as resource losses. DC lines such as the Pacific DC Intertie, which ties two sections of the same synchronous Interconnection together, should not be reported. A single pole block with normal clearing in a monopole or bi-pole high-voltage direct current system is a single contingency.

Calculation of IFRO Values

The IFRO is calculated using the RLPC above (Table 1 from BAL-003-2).

$$IFRO = \frac{(RLPC-CLR)}{(MDF*10)} \text{ expressed as MW/0.1Hz}$$

As specified in the Procedure for ERO Support of Frequency Response and Frequency Bias Setting standard, “MDF is the Maximum Delta Frequency for the specific interconnection as determined in the 2017 Frequency Response Annual Analysis (FRAA).” The BAL-003-2 revision alleviated the adverse impacts of an improving CB_R.

The IFRO for each Interconnection is calculated in this report in **Table 2.5**; note that the calculated value for the EI IFRO is estimated by BAL-003-2 to be stepped down over three years with a reduction of IFRO not to exceed -100 MW/0.10 Hz per year in accordance with BAL-003-2. Collected RLPC data exceeded the estimate at the time BAL-003-2 balloted, and EI IFRO should meet the actual calculated value in only two OYs as a result. That determines the difference between the calculated EI IFRO in **Table 2.5** and the recommended IFRO shown in **Table ES-1** and **Table 2.9**.

Determination of Adjustment Factors

The C-to-B ratio (CB_R) is no longer used in the IFRO method 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+20 second period during the Value B averaging period (T+20 through T+52 seconds) or later.[17] 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,' which 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 2.1** 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 OYs 2017 through 2021 (December 1, 2016, through November 30, 2021).

Table 2.1: 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)
EI	117	25	10	0.007	0.005	0.010
WI	112	72	1	N/A	N/A	N/A
TI	96	50	1	N/A	N/A	N/A
QI	204	30	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 QI and 1 event for WI 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 one event with C' lower than Point C was identified in the TI, an adjustment factor is not warranted; only the adjustment factor of 7 mHz for the EI is necessary. Of the 117 frequency events analyzed in the EI, there were 25 events that exhibited a secondary nadir where Point C' was below Value B and 10 events where Point C' was lower than the initial frequency nadir (Point C). These secondary nadirs occur beyond 52 seconds after the start of the event,[18] 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.

[17] BAL-003-2 redefines Point C to occur within T+20 seconds.

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

Low-Frequency Limit

The low-frequency limits to be used for the IFRO calculations (**Table 2.2**) 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 2.2: Low-Frequency Limits (Hz)	
Interconnection	**Highest UFLS Trip Frequency**
EI	59.5
WI	59.5
TI	59.3
QI	58.5

The highest UFLS set point in the EI is 59.7 Hz in SERC-Florida Peninsula (FP), which was previously FRCC, while the highest set point in the rest of the Interconnection is 59.5 Hz. The SERC-FP 59.7 Hz first UFLS step is based on internal stability concerns and is meant to prevent the separation of the FP from the rest of the Interconnection. SERC-FP 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 SERC-FP 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, about 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.

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 December 2020 through November 2021, like the approach used in the *2015 FRAA* and in the *2016 FRAA*. Statistical analysis indicated that 931 MW of CLR is available 95% of the time. Therefore, a CLR adjustment of 931 MW is applied in the calculation of the TI IFRO as a reduction to the RLPC.

TI Credit for Load Resources

Prior to April 2012, the TI 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[19] of the BA-level frequency response performance, 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 2.3 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 2.3: Determination of Maximum Allowable Delta Frequencies

	EI	WI	TI	QI	Units
Starting Frequency	59.971	59.969	59.970	59.965	Hz
Minimum Frequency Limit	59.500	59.500	59.300	58.500	Hz
Base Delta Frequency	0.471	0.469	0.670	1.465	Hz
BC'_{ADJ}[20]	0.010	N/A	N/A	-0.008	-
Calculated Max. Allowable Delta Frequency	0.385	0.202	0.343	0.953	Hz
Max. Delta Frequency Per Procedure for ERO Support of Frequency Response and Frequency Bias Setting Standard	0.420	0.280	0.405	0.947	Hz

[19] 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

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

Calculated IFROs

Table 2.4 shows the determination of IFROs for OY 2023 (December 2022 through November 2023) under standard BAL-003-2 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 subsecond data (CC_{ADJ}), and the event nadir being below the Value B (BC'_{ADJ}).

Table 2.4: Initial Calculation of OY 2023 IFROs

	Eastern	Western	Texas	Québec	Units
Starting Frequency	59.972	59.969	59.971	59.966	Hz
Max. Delta Frequency Per Procedure for ERO Support of Frequency Response and Frequency Bias Setting Standard	0.420	0.280	0.405	0.947	Hz
Resource Loss Protection Criteria	3,740	3,069	2,805	2,000	MW
Credit for Load Resources	N/A	N/A	931	N/A	MW
Calculated IFRO using 2017 MDF	-890	-1,096	-463	-211	MW/0.1 Hz
Recommended IFRO					
IFRO per Procedure for ERO Support of Frequency Response and Frequency Bias Setting Standard	-890[21]	-1096	-463	-211	MW/0.10 Hz

21 EI IFRO decrease is limited to 100 MW/0.10 Hz annually from previous values. Calculated value without consideration of the limitation is -890 MW/0.10 Hz.

Comparison to Previous IFRO Values

The IFROs were first calculated and presented in the *2012 Frequency Response Initiative Report*. Table 2.5 compares the current IFROs and their key component values to those presented in the *2016 FRAA* report.

Table 2.5: Interconnection IFRO Comparison

	OY 2022 In Use[22]	OY 2022 Calc.[23]	OY 2023 Calc.[24]	2022 Calc. to 2023 Calc. Change	OY 2022 In Use to 2023 Calc. Change	Units
Eastern Interconnection						
Starting Frequency	59.974	59.972	59.971	-0.001	-0.003	Hz
Max. Allowable Delta Frequency	0.443	0.418	0.420	0.002	-0.023	Hz
Resource Contingency Protection Criteria	4500	4500	3740	-760	-760	MW
Credit for Load Resources	0	0	0	0	0	MW
Absolute Value of IFRO	**1015**	**1092**	**890**	-202	-125	MW/0.1 Hz
Western Interconnection						
Starting Frequency	59.967	59.968	59.969	0.001	0.002	Hz
Max. Allowable Delta Frequency	0.292	0.248	0.280	0.032	-0.012	Hz
Resource Loss Protection Criteria	2626	2626	3068.5	442.5	442.5	MW
Credit for Load Resources	0	120	0	-120	0	MW
Absolute Value of IFRO	**858**	**1010**	**1096**	86	238	MW/0.1 Hz
Texas Interconnection						
Starting Frequency	59.971	59.971	59.971	0	0	Hz
Max. Allowable Delta Frequency	0.405	0.405	0.405	0	0	Hz
Resource Loss Protection Criteria	2805	2805	2805	0	0	MW
Credit for Load Resources	1136	1136	931	-205	-205	MW
Absolute Value of IFRO	**412**	**412**	**463**	51	51	MW/0.1 Hz
Québec Interconnection						
Starting Frequency	59.969	59.966	59.965	-0.001	-0.004	Hz
Max. Allowable Delta Frequency	0.948	0.946	0.947	0.001	-0.001	Hz
Resource Loss Protection Criteria	1700	1700	2000	300	300	MW
Credit for Load Resources	0	0	0	0	0	MW

[22] Calculated in the 2015 FRAA report. Average frequency values were for OYs 2012–2014.
[23] Calculated in the 2021 FRAA report. Average frequency values were for OYs 2016–2020.
[24] Calculated in the 2022 FRAA report. Average frequency values were for OYs 2017–2021.

Table 2.5: Interconnection IFRO Comparison						
	OY 2022 In Use[22]	OY 2022 Calc.[23]	OY 2023 Calc.[24]	2022 Calc. to 2023 Calc. Change	OY 2022 In Use to 2023 Calc. Change	Units
Absolute Value of IFRO	**179**	**180**	**211**	31	32	MW/0.1 Hz

Key Findings

Table 2.6 shows a comparison of mean Value A, mean Value B, and mean Point C that is illustrative of Interconnection performance over the previous OY and as compared to the 2016 OY in which the IFRO values were frozen. Loss of load events have been excluded from the data in **Table 2.6**. The EI and WI maintained the trend of an increase in mean Value B and a decrease in the mean (A–B), indicating improved performance during the Stabilizing Period of frequency events. The TI maintained the trend of an increase in mean Value B and a decrease in mean (A-B), indicating improved performance during the Arresting Period of frequency events. QI had a decrease in mean Value B and increase in mean (A–B). The EI and WI show 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 CB_R 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. TI showed an increase or no change in the 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. QI showed decreasing mean Point C and increasing mean (A-C).

Table 2.6: Year over Year Comparison Value A, Value B, and Point C (Loss of Load Events Excluded)					
	OY2016	OY2022	OY2023	Difference OY 2022–2016	Difference OY 2023–2022
Eastern Interconnection					
Mean Value A (Hz)	59.998	59.999	60.000	0.001	0.001
Mean Value B (Hz)	59.947	59.954	59.955	0.007	0.001
Mean Point C (Hz)	59.947	59.949	59.949	0.002	0.000
Mean A – B (Hz)	0.051	0.045	0.045	-0.006	0.000
Mean A – C (Hz)	0.051	0.050	0.052	-0.001	0.002
Western Interconnection					
Mean Value A (Hz)	60	59.994	59.995	-0.0058	0.001
Mean Value B (Hz)	59.923	59.938	59.941	0.0147	0.003
Mean Point C (Hz)	59.887	59.890	59.888	0.0029	-0.002
Mean A – B (Hz)	0.076	0.057	0.053	-0.0195	-0.003
Mean A – C (Hz)	0.112	0.104	0.107	-0.0078	0.002
Texas Interconnection					
Mean Value A (Hz)	59.996	59.997	59.998	0.0009	0.001
Mean Value B (Hz)	59.889	59.916	59.921	0.0273	0.005
Mean Point C (Hz)	59.84	59.860	59.859	0.0198	-0.001
Mean A – B (Hz)	0.107	0.081	0.077	-0.0264	-0.003

Mean A – C (Hz)	0.156	0.137	0.139	-0.0188	0.002
Québec Interconnection					
Mean Value A (Hz)	60.003	60.003	60.005	0.0001	0.002
Mean Value B (Hz)	59.843	59.870	59.874	0.0269	0.005
Mean Point C (Hz)	59.433	59.516	59.519	0.0834	0.002
Mean A – B (Hz)	0.16	0.133	0.130	-0.0268	-0.003
Mean A – C (Hz)	0.57	0.487	0.486	-0.0833	-0.001

Recommended IFROs for OY 2023

Consistent with the requirements of BAL-003-2, the IFRO values shown in **Table 2.7** for OY 2023 (December 2022 through November 2023) are recommended as follows:

Table 2.7: Recommended IFROs for OY 2023

	EI	WI	TI	QI	Units
MDF[25]	0.420	0.280	0.405	0.947	Hz
RLPC[26]	3,740	3,069	2,805	2,000	MW
CLR	0	0	931	0	MW
Calculated IFRO	-890	-1096	-463	-211	MW/0.1 Hz
Recommended IFRO[27]	**-890**	**-1096**	**-463**	**-211**	MW/0.1 Hz

[25] The Procedure for ERO Support of Frequency Response and Frequency Bias Setting Standard, Version II, provided in the approved ballot for BAL-003-2, specifies that, "MDF is the Maximum Delta Frequency for the specific interconnection as determined in the 2017 Frequency Response Annual Analysis (FRAA).

[26] BAL-003-2, Attachment A specifies that Resource Loss Protection Criteria (RLPC) be based on the two largest potential resource losses in an interconnection. This value is required to be evaluated annually.

[27] BAL-003-2 requires that the EI IFRO will be stepped down to its calculated value over three years. The maximum reduction is limited to 915 MW/0.10 Hz annually.

Chapter 3: Dynamics Analysis of Recommended IFROs

Because the IFROs for the EI, WI, and TI have only upon issue of this report been changed as governed by BAL-003-2, additional dynamic validation analyses were not done for this report.

Refer to the dynamics validation in the *2017 FRAA*[28] report for details. No analysis was performed for the QI.

Further supporting dynamic studies accompanied the development and filing of BAL-003-2.

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