California ISO

Primary Frequency Response

Draft Technical Appendix

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1. Introduction

The Frequency Response initiative's goal is to propose an option that will reduce the risk of the ISO not complying with a new NERC standard requiring a defined amount of primary frequency response (PFR) within 52 seconds following a disturbance. The ISO is issuing this technical appendix to the Frequency Response straw proposal in order to clarify the obligation and the evaluation expected.

This technical appendix covers:

- Factors influencing the slope of a frequency excursion
- Impacts of technology type on primary frequency response
- NERC Process for Determining IFRO
- NERC Process for Allocating IFRO to BAA
- Measuring the ISO's actual performance for standard
- Determining Frequency Response Measure

2. Factors influencing the slope of a frequency excursion

As depicted visually in the straw proposal, the speed at which a frequency response drops after the disturbance event occurs is a function of the on-line inertia constant at that time. The speed is also a function of load damping and the change in power output[1].

$$Slope = \frac{\Delta P}{D + 2H}$$

$$\textbf{Where}: \Delta \mathrm{P} = P_{t+1} - P_t$$
$$\text{and } t = T_0$$

$Slope$	Frequency Excursion Slope.
ΔP	Magnitude of the imbalance.
D	Load damping factor ranging from 0 to 2 where 2 represents all-motor load.
H	Inertia Constant of system ranging from 2.5 to 6.5.
T_0	First SCADA scan showing change in frequency

[1] Frequency Response Initiative Report – October 2012 at 39.

3. Impacts of technology type on primary frequency response

Various technology types have diverse PFR capabilities. The various types of technology can provide different levels of PFR across the timeframe generally associated with primary frequency control. The ISO believes that while resources should be treated equivalently regardless of technology type from a requirement stance, it is important for the ISO to consider the frequency response characteristics by technology type.

Resources that are dispatched to full load cannot provide primary frequency response. Additionally, resources that have multiple configurations may have a different maximum capacity for each configuration.

Fossil-fuel steam resources can provide PFR with various characteristics depending on the control mode in which it is operating. The characteristics for each control mode are as follows:[2]

(1) Boiler-follow mode: prompt and sustained increase in power followed by long delay anywhere from 10 seconds to minutes until full increase in power is achieved.
(2) Turbine-follow mode: slower response relative to boiler-follow mode.
(3) Coordinate control: compromise between fast response of boiler-follow mode and sluggish response of turbine-follow mode while maintaining better control of boiler.
(4) Sliding-pressure control: sluggish response to PFR since it's relying on controlling boiler and fuel which respond more slowly than turbine control valves which are left open in this mode.

Combined cycle gas turbine (CCGT) resources similarly to hydro facilities are only expected to provide at most a small percentage (e.g. 5% to 10 %) of 2/3 of their maximum capacity within the first minute of an event. However, this estimate is based on the unit not being fully loaded or at a level of their capacity where temperature control loop is in effect. If either of these conditions exist, the CCGT will provide little to no PFR. The main reasons a CCGT typically only provides at most a percentage of 2/3 of its capacity is that only the gas turbine has an active governor and the sliding-pressure control mode frequently used has a sluggish response. The amount of frequency response could be increased if the steam turbines had active governors and allowed for some valve control. While this would improve frequency response it would affect overall plant efficiency. Additionally in order to extend the life of the gas turbines, CCGT do employ the use of a deadband so that the governor response is activated only when the change in frequency is outside the deadband.[3]

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[2] Interconnected Power System Response to Generation Governing: Present Practice and Outstanding Concerns, IEEE, May 2007 at 1-5.

[3] Interconnected Power System Response to Generation Governing: Present Practice and Outstanding Concerns, IEEE, May 2007 at 1-17.

Hydro facilities respond fairly predictably to a frequency excursion event since as a rule multiple unit hydro facilities are not fully loaded but are instead used as peaking or spinning reserve resources[4]. Their response is relatively slow with the beginning of their response expected by T_{30} and roughly 2/3 of their capacity by T_{60}[5]. Since the most reliability value is gained from response early in the period following an event, this type of technology would have less reliability value than faster responding types. The slowed power response rate is driven in part by the type of feedback signal used by the resources. Many older hydro resources use a mechanical signal that uses the wicket gate position as a proxy for the power signal. The response could be improved if electrical power signals were instead used as feedback.

A nuclear plant is typically operated at full load. Therefore it would generally not respond to an under-frequency event with a governor-like response, but does act to limit the severity of a frequency event by providing inertia. While the Lepreau Generating Station in New Brunswick provides primary frequency response,[6] this is not a widespread practice especially in the WECC.

4. NERC Process for Determining IFRO

The ISO's new frequency response obligation is the ISO's portion of a new obligation for the entire Western Interconnect, the Interconnection Frequency Response Obligation (IFRO). Federal Energy Regulatory Commission approved the Petition of the North American Electric Reliability Corporation (NERC) for approval of BAL-003-1, Frequency Response and Frequency Bias Setting on March 29, 2013 where this new standard requires the ISO to meet a BAA level Frequency Response Obligation (FRO) effective April 1, 2016.

The primary objective of Requirement 1 (R1) from BAL-003-1 is to determine whether a BA has sufficient frequency response for reliable operations[7]. The standard requires each interconnection to maintain a minimum amount of frequency response at any given time. The IFRO is the minimum MW/0.1 Hz frequency response necessary to protect against a loss of generation event that would result in the system frequency encroaching on the trip setting of the Under Frequency Load Shedding (UFLS) relays. An important goal of this standard is to avoid tripping the first block of the UFLS relays for a frequency event resulting in the actual system

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[4] This holds true unless units are needed for water flow control and then they will not be able to provide PFR.

[5] Interconnected Power System Response to Generation Governing: Present Practice and Outstanding Concerns, IEEE, May 2007 at 1-6.

[6] Interconnected Power System Response to Generation Governing: Present Practice and Outstanding Concerns, IEEE, May 2007 at 1-15.

[7] NERC Petition at 15.

frequency dipping to 59.5 Hz[8].

FERC approved NERC's recommended target resource loss protection criteria (RLPC) reflecting the simultaneous loss of resources without system adjustments for the largest reasonably expected contingency. The Western Interconnection needs to protect against the largest N-2 event, which is the loss of 2 Palo Verde units (2,626 MW). The Interconnection will be credited for 120 MW of load that trips by a Remedial Action Scheme (RAS) following this N-2 event. Thus, the Adjusted Resource Loss Protection Criteria (ARLPC) is 2,506 MW.

The maximum delta frequency (MDF) following an event is intended to ensure the interconnection frequency does not trip the first block of UFLS relays. For the Western Interconnection, the MDF, calculated by NERC to promote system reliability is 0.292 Hz[9].

NERC is required to analyze annually frequency response performance and update the statistical analyses and calculations. The updated Frequency Response Annual Analysis serves as the vehicle for communicating the recommended IFROs for a given compliance period. The statistical analysis will be performed over a three year period prior to the upcoming compliance period. For example, the statistical analysis for the 2014 frequency response period (December 2013 – November 2014) uses data points across 2010-2012.

The following are the formulae comprising the calculation of the IFRO and a table illustrating the results of these calculations for the Western Interconnection for the 2013 – 2016 periods[10].

$$DF_{BASE} = F_{START} - UFLS$$

$$DF_{CC} = DF_{BASE} - CC_{ADJ}$$

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

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

$$ARLPC = RLPC - CLR$$

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

[8] Frequency Response Initiative Report – October 2012 at 51 – 52.

[9] 2015 Frequency Response Annual Analysis.at 13.

[10] Frequency Response Initiative Report – October 2012 at 56 - 61.

TABLE 1: NERC RECOMMENDED IFRO FOR THE 2013 – 2016 EVALUATION PERIODS

Explanation of Calculations		2013[11]	2014[12]	2015[13]	2016[14]	Units
F_{START}	Starting Frequency is the 5% of the lower tail samples over three-year window representing 95% change frequency will be at or above value at start of an event.	59.976	59.971	59.968	59.967	Hz
$UFLS$	Prevailing UFLS First Step	59.500	59.500	59.500	59.500	Hz
DF_{BASE}	Base Delta Frequency from F_{START} to UFLS First Step	0.476	0.471	0.468	0.467	Hz
CC_{ADJ}	95% confidence interval adjustment for differences between Point C when comparing 1-second and sub-second measurements of Point C.	0.004	0.008	0.011	0.000	Hz
DF_{CC}	Delta frequency adjusted for differences between 1-second and sub-second Point C observations	0.472	0.463	0.457	0.467	Hz
CB_R	Statistically determined ratio of arrested frequency response (Point C) to settled frequency response (Value B) where CB_R is defined as expected Value A – Point C / Value A – Value B plus a 95% confidence adjustment.	1.625	1.774	1.672	1.598	Hz
DF_{CBR}	Delta frequency adjusted for the ratio of Point C to Value B	0.291	0.261	0.273	0.292	Hz
BC'_{ADJ}	Statistically determined adjustment in the event nadir occurs below settled frequency response only applying to the Eastern Interconnect.	N/A	N/A	N/A	N/A	Hz
MDF	Maximum allowable delta frequency	0.291	0.261	0.273	0.292	Hz
$RLPC$	Resource Loss Protection Criteria (Largest N-2 Event)	2,740	2,626	2,626	2,626	MW
CLR	Credit for load resources	300	150	150	120	MW
$ARLPC$	Adjusted Resource Loss Protection Criteria	2,440	2,476	2,440	2,506	MW
$IFRO$	Interconnection Frequency Response Obligation	-840	-949	-906	-858	MW/ 0.1Hz

The IFRO value will change from year to year primarily as the result of the changes to the

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[11] Frequency Response Initiative Report – October 2012 at 56 - 61.

[12] 2013 Frequency Response Annual Analysis.

[13] 2014 Frequency Response Annual Analysis.

[14] 2015 Frequency Response Annual Analysis.

following:

1. Statistical frequency variability over a three-year window of 1-second frequency measurements affecting Fs_{TART}.
2. Statistical "C-to-C" adjustment over a three-year window comparing 1-second and sub-second measurements of Point C.
3. Statistical "C-to-B" ratio adjustment over a three-year window comparing the Value A – Point C and Value A – Value B ratio.

NERC will collect data necessary to calculate the 2017 IFRO and allocate 2017 IFRO to individual BAs starting on January 1, 2015 through December 31, 2015. The ISO will provide the 2015 data from FERC Form 714 to NERC by fall 2016. NERC will approve the 2017 IFRO by September 2016 and allocate the IFRO to the BA level. The ISO expects to receive this FRO by October 2016 for implementation December 1, 2016 – November 30, 2017[15].

5. NERC Process for Allocating IFRO to BAA

The IFRO will be allocated to the BA level based on the BA's annual load[16] and annual generation[17] from the most recently reported FERC Form 714 values or other representative data.

FERC Form 714 is the Annual Electric Balancing Authority Area and Planning Area Report in which the ISO reports its BAA net energy for load and peak demand sources by month (Part II - Schedule C). These values are reported for each month and an annual total. The IFRO allocation will be determined using the annual total reported on these forms or a similar calculation for BAAs not reporting with FERC Form 714[18].

$$FRO_{BA} = IFRO \times \frac{Annual\ Gen_{BA} + Annual\ Load_{BA}}{Annual\ Gen_{INT} + Annual\ Load_{INT}}$$

FRO_{BA}	BAA frequency response obligation.

[15] BAL-003-1 Detailed Implementation Timeline, North American Electric Reliability Corporation, August 20, 2014.

[16] Annual Gen_{BA} is total annual BAA Net Generation (MWh) as reported on FERC Form 714, column c of Part 11 – Schedule 3.

[17] Annual $Load_{BA}$ is total annual BAA Net Energy for Load (MWh) as reported on FERC Form 714, column c of Part 11 – Schedule 3 which is the sum of the BAA Net Generation and Net Actual Interchange.

[18] BAL-003-1 Standard, Attachment A.

$IFRO$	Interconnection frequency response.
$Annual\ Gen_{BA}$	BAA net generation (MWH) annual total reported FERC Form 714, Part II – Schedule 3, Column C, line 13.
$Annual\ Load_{BA}$	BAA net energy for load (MWH) annual total reported FERC Form 714, Part II – Schedule 3, Column E, line 13 which is the sum of BAA net generation (MWH) and net h interchange (MWH).
$Annual\ Gen_{INT}$	The sum of all net generation (MWH) across all BAA in the Interconnection.
$Annual\ Load_{INT}$	The sum of all net energy for load (MWH) across all BAA in the Interconnection.

6. Measuring the ISO's actual performance for standard

Prior to the standard, NERC's guidance to a BA was to calculate frequency response by identifying interchange values "immediately before" and "immediately after" a frequency excursion event and use the difference to calculate MWs deployed for event[19]. While generally speaking this is calculated by showing change in net actual interchange measurements, with BAL-003-1 in place there is a more standardized approach to defining how this change is measured.

One of the challenges in measuring performance is no reasonable calculation can be made on the arresting frequency, Point C, using Energy Management System (EMS) scan rate data on 4 second intervals or tie-line flows. NERC determines Point C by using phasor measurement units (PMU) sub-second frequency data and makes an adjustment to compensate for slower EMS scans of Point C in order to calculate an IFRO. The standard attempts to standardize measurement given the Point C measurement using EMS scan data.

NERC analysis showed a single-event-based compliance measure is unsuitable for compliance evaluation when the data has a large degree of variability[20]. The analysis further demonstrated that a sampling of at least 20 events is sufficient to stabilize the results and alleviate the problem associated with outliers in the measurement of BAA frequency response performance[21]. Therefore, NERC decided to select the median value from all events sampled to designate as the Frequency Response Measure (FRM), calculated in units of MW/0.1Hz[22]. NERC selected the median because this measurement met the two most important factors:

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[19] Frequency Response Standard Background Document – November 2012 at 11.

[20] Frequency Response Initiative Report – October 2012 at 70.

[21] Frequency Response Initiative Report – October 2012 at 72.

[22] NERC Petition at 13.

reduce influence of outliers and noise

The actual frequency response performance for each candidate event will be calculated using the SEFRD data[23]. The performance is determined by calculating the change of a BA's net actual interchange on its tie lines with its adjacent balancing authorities adjusted for the loss of generation if the contingency occurred within the ISO BAA divided by the change in interconnection frequency[24]. The performance will be measured by comparing the average of discrete scans of net actual interchange (Ni_A) across the defined sampling periods. The sampling periods provide the Value A and Value B averages for 16 seconds prior to an event and 20 to 52 seconds after an event. The 20 – 52 second period following an event was selected because it begins measuring response after transient period completely settles and show squelched response during the recovery period[25].

The ISO will submit to NERC its performance measurements for each event using Frequency Response Survey (FRS) Form1 and Form 2[26] which provide a consistent, objective process for evaluating the Frequency Response Measure (FRM).

7. Determining Frequency Response Measure

NERC performed a field trial of SEFRD data to come to a recommendation for a sampling approach to the compliance of this standard instead of a single-event based compliance measure. The analysis showed a single-event based compliance measure is unsuitable for compliance evaluation when data has large degree of variability[27]. The analysis further demonstrated that a sampling of at least 20 events is sufficient to stabilize the results and alleviate the problem associated with outliers in the measurement of a BA's frequency response performance[28]. Out of this sampling, the median value of SEFRD data for actual frequency response performance described above expressed in MW/0.1Hz is selected as the FRM[29].

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[23] Single Event Frequency Response Data (SEFRD) is the individual sample of the event selections and actual performance measurements data from a Balancing Authority which represents the change in Net Actual Interchange (NIA), divided by the change in frequency, expressed in MW/0.1Hz.

[24] BAL-003-1 Standard, Attachment A.

[25] Frequency Response Standard Background Document – November 2012 at 13.

[26] MyBA FRS Forms 2.10 MultiBAInterconnection.

[27] Frequency Response Initiative Report – October 2012 at 70.

[28] Frequency Response Initiative Report – October 2012 at 72.

[29] BAL-003-1 Standard, Attachment A.

The FRM will be determined from a sampling of the largest (A-to-B) 20-35 events provided by NERC on FRS Form 1[30] where 2 or 3 events are from each calendar month[31]. If 20 events cannot be identified during the period, similar acceptable events from the next year will be used and the compliance period will be extended from 12 months to 24 months.

NERC detects a frequency event has occurred in the Western Interconnection if during a 15-second rolling time window the frequency deviation between Value A and Point C exceeds 40 mHz[32]. NERC will then select 2 or 3 events per month for the sample based in part on the following criteria[33]:

- Value A should be relatively steady around the scheduled frequency of 60.000Hz.
- The change in frequency as defined by the difference between Pre-event period, Value A, and arrested frequency Point C is greater than 0.04 Hz and Point C for a frequency dip is less than 59.95 Hz.
- Typically, the time from the start of the rapid change in frequency until the point the frequency stabilizes within a narrow range should be less than 18 seconds.
- If any data point in Value B period recovers to the Value A level, the event will not be considered as a candidate.
- Events that include 2 or more events not stabilizing within 18 seconds, during large ramping or load changes, within 5 minutes of the top of the hour will be excluded from consideration if other acceptable events are available.

The ISO will submit its 2017 Frequency Response Measure (FRM) by March 7, 2018. NERC will evaluate whether the ISO met the 2017 FRO at that time by comparing the percentage difference between the FRM and the FRO.

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[30] MyBA 2016 FRS Form 1.10 Western Interconnection.

[31] Procedure for ERO Support of Frequency Response and Frequency Bias Setting at 1-2.

[32] Frequency Event Detection Methodology, NERC, May 2012.

[33] Procedure for ERO Support of Frequency Response and Frequency Bias Setting Standard at 1 – 2.