Primary Frequency Response Reference Document

Texas Reliability Entity, Inc.
BAL-001-TRE-1
Performance Metric Calculations

I. Introduction

This Primary Frequency Response Reference Document provides a methodology for determining the Primary Frequency Response (PFR) performance of individual generating units/generating facilities in accordance with Requirements R9 and R10. Flowcharts A (Initial PFR) and B (Sustained PFR) show the logic and calculations in graphical form, and they are considered part of this Primary Frequency Response Reference Document. Several Excel spreadsheets implementing the calculations described herein for various types of generating units are available for reference and use in understanding and performing these calculations.

This Primary Frequency Response Reference Document is not considered to be a part of the regional standard. This document will be maintained by Texas RE and will be subject to modification as approved by the Texas RE Board of Directors, without being required to go through the formal Standard Development Process.

The following process will be used to revise the Primary Frequency Response Reference Document. A Primary Frequency Response Reference Document revision request may be submitted to the Texas RE Reliability Standards Manager, who will present the revision request to the Texas RE Reliability Standards Committee (RSC) for consideration. The revision request will be posted in accordance with RSC procedures. The RSC shall discuss the revision request in a public meeting, and will accept and consider verbal and written comments pertaining to the request. The RSC will make a recommendation to the Texas RE Board of Directors, which may adopt the revision request, reject it, or adopt it with modifications. Any approved revision to the Primary Frequency Response Reference Document shall be filed with NERC and FERC for informational purposes.

As used in this document the following terms are defined as shown:

High Sustained Limit (HSL) for a generating unit/generating facility: The limit established by the GO/GOP, continuously updatable in Real-Time, that describes the maximum sustained energy production capability of a generating unit/generating facility.

Low Sustained Limit (LSL) for a generating unit/generating facility: The limit established by the GO/GOP, continuously updatable in Real-Time, that describes the minimum sustained energy production capability of a generating unit/generating facility.

II. Initial Primary Frequency Response Calculations

Requirement 9

R9. Each GO shall meet a minimum 12-month rolling average initial Primary Frequency Response performance of 0.75 on each generating unit/generating facility, based on participation in at least eight FMEs. The performance of a combined-cycle facility will be determined using an expected performance droop of 5.78%.

9.1. The initial Primary Frequency Response performance shall be the ratio of the Actual Primary Frequency Response to the Expected Primary Frequency Response during the initial measurement period following the FME. The initial Primary Frequency Response performance for each FME shall be between 0.0 and 2.0.

9.2. If a generating unit/generating facility has not participated in a minimum of eight FMEs in a 12-month period, performance shall be based on a rolling eight-FME average response.

9.3. A generating unit/generating facility's Primary Frequency Response performance during an FME may be excluded from the rolling average calculation by the Compliance Enforcement Authority due to a legitimate operating condition that prevented normal Primary Frequency Response performance.

Initial Primary Frequency Response Performance Calculation Methodology

Initial Primary Frequency Response performance requirement:

$$Avg_{Period}[P.U.PFR_{Resource}] \geq 0.75,$$

where P.U. $PFR_{Resource}$ is the per unit measure of the Primary Frequency Response of a Resource during identified FMEs.

Each GO may submit to the BA unit-specific information used by the BA in this requirement to calculate initial PFR performance for each generating unit/generating facility.

$$P.U.PFR_{Resource} = \frac{Actual\ Primary\ Frequency\ Response\ (APFR)}{Expected\ Primary\ Frequency\ Response_{Final}}$$

where P.U. $PFR_{Resource}$ for each FME is between zero and 2.0.

The Actual Primary Frequency Response and the Expected Primary Frequency $Response_{Final}$ ($EPFR_{Final}$) are calculated as described below:

EPFR Calculations use droop and deadband values as stated in R6 with the exception of combined-cycle facilities while being evaluated as a single resource (MW production of the steam turbine generator is included in the evaluation) where the evaluation droop will be 5.78%.[1]

Ideal Expected Primary Frequency Response ($EPFR_{ideal}$)

The unadjusted expected MW change calculated when the frequency deviation exceeds the deadband for all generator types.

$$EPFR_{ideal} = \left[\frac{(HZ_{actual} - 60.0 \pm deadband_{max})}{(60 \times droop_{max} - deadband_{max})} \times (-1) \times (Capacity)\right]$$

Capacity and NDC are used interchangeably and the term Capacity will be used in this document. They are the official reported seasonal capacity of the generating unit/generating facility. The capacity for wind-powered generators is the cumulative nameplate capacity of all wind turbines in that facility that were on-line when the FME occurred.

For combined cycle facilities, ERCOT will calculate each generator's HSL using the submitted seasonal ratings, the telemetered individual net MW, and telemetered combined cycle HSL. As an alternative the GO/GOP may telemeter HSL values for each generator of the combined cycle facility.

In the numerator, the "+" is used for positive (above 60.000 Hz) frequency excursions and the "–" is used for negative (below 60.000 Hz) frequency excursions.

$EPFR_{final}$ for Combustion Turbine

First calculate the Adjusted EPFR:

$$EPFR_{Adj} = EPFR_{ideal} + (HZ_{actual} - 60.0) \times 10 \times 0.00276 \times Capacity$$

where

$$HZ_{Actual} = \frac{\sum_{T+20}^{T+52} HZ_{Actual}}{\#\ of\ Scans}$$

Note: The 0.00276 constant is MW/0.1 Hz change / MW Capacity and represents the MW change in generator output due to the change in mass flow through the combustion turbine due to the speed change of the turbine during the post-perturbation measurement period. (This factor is based on empirical data from a major 2003 event as measured on multiple combustion turbines in ERCOT.)

[1] The effective droop of a typical combined-cycle facility with governor settings per Requirement R6 is 5.78%, assuming a 2-to-1 ratio between combustion turbine capacity and steam turbine capacity.

Then add a ramp adjustment to determine $EPFR_{final}$:

$EPFR_{final} = EPFR_{adj} + RampMagnitude$

where

$RampMagnitude = (MW_{T-4} - MW_{T-60}) * 0.59$

Note: $(MW_{T-4} - MW_{T-60})$ represents the MW ramp of the generator resource/generator facility during the full minute prior to the event. The factor 0.59 adjusts this full minute ramp to represent the ramp that should have been achieved during the post-perturbation measurement period.

$EPFR_{final}$ for Steam Turbine

First calculate the adjusted EPFR:

$$EPFR_{Adj} = \left(EPFR_{ideal} + MW_{Adj}\right) \times \frac{Throttle\ Pressure}{Rated\ Throttle\ Pressure}$$

where:

$$MW_{Adj} = EPFR_{ideal} \times \frac{K}{Rated\ Throttle\ Pressure} \times HSL \times Steam\ Flow\ Pressure\ Change\ Factor$$

where:

$$\%Steam\ Flow = \frac{Post-perturbation\ Average\ MW_{actual}}{HSL}$$

$$Steam\ Flow\ Pressure\ Change\ Factor = \frac{\%Steam\ Flow}{0.5}^{x}$$

and where K is used to model the stored energy available to the resource and ranges between 0.0 and 0.6 psig/MW, measured at 50% output of the steam turbine. K is then adjusted based on rated throttle pressure and resource capacity. An additional sensitivity factor, based on resource loading (% steam flow) further modifies the MW adjustment. This sensitivity factor will decrease the adjustment at resource outputs below 50% and increase the adjustment at outputs above 50%. The GO should determine the fixed K factor for each resource that generally results in the best match between EPFR and APFR (resulting in the highest P.U. $PFR_{Resource}$). K will not change unless the steam generator is significantly reconfigured.

Throttle Pressure = Interpolation of Pressure curve at Post-perturbation Average MW_{Actual}.

Then add a ramp factor to determine $EPFR_{final}$:

$EPFR_{final} = EPFR_{adj} + RampMagnitude$

$EPFR_{final}$ for Other Generating Units/Generating Facilities

$$EPFR_{Adj} = EPFR_{ideal} + X * LF$$

$EPFR_{Final} = EPFR_{Adj}$ + RampMagnitude

where X and LF are the adjustment methods that properly model the delivery of PFR due to known and approved technical or physical limitations of the resource. X and LF may be adjusted by the BA and may be variable across the operating range of a resource.

Ramp Adjustment: The Final Expected Primary Frequency Response number that is used to calculate P.U.PFR is adjusted for the ramp magnitude of the generating unit/generating facility during the pre-perturbation minute. The ramp magnitude is added to $EPFR_{Adj}$.

Ramp Magnitude = $(MW_{T-4} - MW_{T-60})*0.59$

$(MW_{T-4} - MW_{T-60})$ represents the MW ramp of the generator resource/generator facility for a full minute prior to the event. The factor 0.59 adjusts this full minute ramp to represent the ramp that should have been achieved during the post-perturbation measurement period.

Expected Primary Frequency $Response_{Final} = EPFR_{Adj}$ + Ramp Magnitude

Actual Primary Frequency Response (APFR)

This is the difference between Post-perturbation Average MW and Pre-perturbation Average MW.

$$Actual\ Primary\ Frequency\ Response = MW_{post-perturbation} - MW_{pre-perturbation}$$

where

Pre-perturbation Average MW: Actual MW averaged from t(-16) to t(-2)

$$MW_{pre-perturbation} = \frac{\sum_{t(-16)}^{t(-2)} MW}{\#\ Scans}$$

Post-perturbation Average MW: Actual MW averaged from t(20) to t(52)

$$MW_{post-perturbation} = \frac{\sum_{t(20)}^{t(52)} MW}{\#\ Scans}$$

Limits on Calculation of Initial Primary Frequency Response Performance:

If the generating unit/generating facility is operating within 2% of HSL from its operating limits at the time an FME occurs (pre-perturbation), then that unit/facility's Primary Frequency Response performance is not evaluated for that FME.

For negative frequency deviations, if

$MW_{Pre-perturbation} \geq (HSL\ x\ 0.98)$

then Primary Frequency Response is not evaluated for this FME.

For positive frequency deviations, if

$MW_{Pre-perturbation} \leq [LSL + (HSL\ x\ 0.02)]$

then Primary Frequency Response is not evaluated for this FME.

Expected PFR greater than Operating Margin: When a generating unit/generating facility has greater than 2% pre-perturbation operating margin, but the Expected Primary Frequency Response is greater than the available operating margin and the generating unit/generating facility's actual $PFR_{Initial}$ response is in the correct direction, the P.U. $PFR_{Resource}$ will be set to 0.75 or the calculated P.U. $PFR_{Resource}$, whichever is greater.

III. Sustained Primary Frequency Response Calculations

Requirement 10

R10. The GO shall meet a minimum 12-month rolling average sustained Primary Frequency Response performance of 0.75 on each generating unit/generating facility, based on participation in at least eight FMEs. The performance of a combined cycle facility will be determined using an expected performance droop of 5.78%.

10.1. The sustained Primary Frequency Response performance shall be the ratio of the Actual Primary Frequency Response to the Expected Primary Frequency Response during the sustained measurement following the FME.

10.2. If a generating unit/generating facility has not participated in a minimum of eight FMEs in a 12-month period, performance shall be based on a rolling eight-FME average.

10.3. A generating unit/generating facility's Primary Frequency Response performance during an FME may be excluded from the rolling average calculation due to a legitimate operating condition that prevented normal Primary Frequency Response performance.

Sustained Primary Frequency Response Performance Calculation Methodology

Event Recovery Time (ERT): For low frequency events, the time at which frequency returns to pre-perturbation frequency or 59.984 Hz, whichever occurs first. For high frequency events, the time at which frequency returns to pre-perturbation frequency or 60.016 Hz, whichever occurs first.

Event Recovery Period (ERP): The period from T=0 to ERT expressed in seconds.

Each GO may submit to the BA any information used by the BA in this requirement to calculate sustained PFR performance for each generating unit/generating facility.

Sustained Primary Frequency Response performance requirement:

$$Avg_{Period}\,[P.U.PFR_{Resource}] \geq 0.75$$

RampMW Calculation (MW/scan)

$$RampMW_{pre-event} = \frac{MW_{(t-2)} - MW_{(t-60)} - EPFR_{delayed\,(t-2)} + EPFR_{delayed\,(t-60)}}{29}$$

Note: There are 29 two-second scans between t-2 and t-60. The terminology "$MW_{(t-2)}$" refers to MW output at 2 seconds before the Frequency Measurable Event (FME) occurs at t(0).

$$RampMW_{post-event} = \left[\frac{MW_{(ERT)} - MW_{(t-4)} + EPFR_{delayed(t-4)} - EPFR_{delayed(ERT)}}{\frac{ERP}{Seconds\ per\ Scan}} \right]$$

EPFR Calculations use droop and deadband values as stated in R6 with the exception of combined-cycle facilities while evaluated as a single resource (MW production of the steam turbine generator is included in the evaluation) where the evaluation droop will be 5.78%.

$EPFR_{ideal}$ Calculation

When the frequency is within the Governor deadband:

$EPFR_{ideal} = 0$

When the frequency is outside the Governor deadband and above 60 Hz:

$$EPFR_{ideal}[i] = \left[\frac{(HZ_{actual}[i] - 60 - Deadband)}{(Droop \times 60 - Deadband)} \times (Capacity) \times (-1) \right]$$

When the frequency is outside the Governor deadband and below 60 Hz:

$$EPFR_{ideal}[i] = \left[\frac{(HZ_{actual}[i] - 60 + Deadband)}{(Droop \times 60 - Deadband)} \times (Capacity) \times (-1) \right]$$

$EPFR_{delayed}$ Calculation

For every scan *i* from 70 seconds prior to the FME (t-70) to ERT:

$$EPFR_{delayed}[i] = (Time\ Constant \times EPFR_{ideal}[i]) + \big((1 - Time\ Constant) \times EPFR_{delayed}[i-1]\big)$$

Where *Time Constant* is a value in the range 0.05 to 1.0. This value is provided by the GO for each generating unit/generating facility. The GO should determine (and provide to the BA) the Time Constant for each unit or facility that generally results in the best match between sustained EPFR and sustained APFR (and the highest sustained P.U. $PFR_{Resource}$). The Time Constant will not change unless the unit or facility is significantly reconfigured. However, implementation of control modifications that significantly improve PFR performance may justify changing (increasing) the Time Constant.

TargetMW Calculation

TargetMW[i] at t = -2:

$$TargetMW_{(t-2)} = MW_{Actual(t-2)}$$

Pre-Event TargetMW[i] for every scan *i* from t-4 to t-60 (between 4 and 60 seconds before the FME):

$$TargetMW[i] = TargetMW[i+2] - RampMW_{pre-event} - (EPFR_{delayed}[i+2] - EPFR_{delayed}[i])$$

Recovery TargetMW[i] for every scan from t(0) to Event Recovery Time:

$$TargetMW[i] = TargetMW[i-2] + RampMW_{post-event} + (EPFR_{delayed}[i] - EPFR_{delayed}[i-2])$$

Note: If TargetMW[i] exceeds HSL or is less than LSL it is limited to the corresponding HSL or LSL.

$TargetMW_{avg}$

$$TargetMW_{avg} = \frac{\sum_{t(+2)}^{t(ERT)}(TargetMW[i])}{\#Scans}$$

$ActualMW_{avg}$

$$ActualMW_{avg} = \frac{\sum_{t(+2)}^{t(ERT)}(ActualMW[i])}{\#Scans}$$

P.U. PFR Calculations

Consideration of resource ramp direction during the ERP impacts the method of determining P.U. PFR. If the ramp during the ERP is opposite in direction to the $EPFR_{final}$, special tests must be performed to determine the impact of the ramp on performance.

For Low Frequency events:

When the $TargetMW_{avg}$ minus the $ActualMW_{(t-4)}$ is less than 0, the unit will be considered in a hard down ramp. To allow for this situation an assessment is done to determine if the $ActualMW_{avg}$ performed by the unit is greater than the $TargetMW_{avg}$ the unit was expected to achieve. If it was, then the unit will be contributing to the performance of the system and given a score of 1.0. If not, an additional assessment will be made to determine if the $ActualMW_{avg}$ was greater than the $RampMW_{avg}$. If it was, then the unit will be credited with a 0.75 indicating it was not a detriment to the system and appeared to make an effort to contribute. If it was not, then the unit will be credited with 0.0 for not providing Primary Frequency Response.

When the $TargetMW_{avg}$ minus the $ActualMW_{(t-4)}$ is greater than or equal to 0, the unit will not be considered to be in a hard down ramp. For this situation an assessment is done to determine if the $ActualMW_{avg} - ActualMW_{(t-4)}$ is greater than 0. If not, then a further assessment will be performed to determine if the $ActualMW_{avg}$ was greater than the $RampMW_{avg}$. If it was, then the unit will be credited with a 0.75 indicating it was not a detriment to the system and appeared to make an effort to contribute. If it was not, then the unit will be credited with 0.0 for not responding. If the $ActualMW_{avg} - ActualMW_{(t-4)}$ is greater than 0, then the unit P.U.PFR performance will be calculated as shown below.

Sustained P.U.PFR Calculation – Low Frequency Event

For generating unit/generating facility whose MW output value at ERT is higher than MW output at t-4.

$$P.U.PFR_{Resource} = \frac{ActualMW_{avg} - ActualMW_{(t-4)}}{TargetMW_{avg} - ActualMW_{(t-4)}}$$

For generating unit/generating facility whose MW output value at ERT is lower than or equal to MW output at t-4.

$$P.U.PFR_{Resource} = \frac{ActualMW_{avg} - ActualMW_{(ERT)}}{TargetMW_{avg} - ActualMW_{(ERT)}}$$

The maximum achievable score will be constrained at 2.0.

For High Frequency events:

When the $TargetMW_{avg}$ minus the $ActualMW_{(t-4)}$ is greater than 0, the unit will be considered in a hard up ramp. To allow for this situation an assessment is done to determine if the $ActualMW_{avg}$ performed by the unit is less than the $TargetMW_{avg}$ the unit was expected to achieve. If it was, then the unit will be contributing to the performance of the system and given a score of 1.0. If not, an additional assessment will be made to determine if the $ActualMW_{avg}$ was less than the $RampMW_{avg}$. If it was, then the unit will be credited with a score of 0.75, indicating it was not a detriment to the system and appeared to make an effort to contribute. If it was not, then the unit will be given a score of 0.0 for not responding.

When the $TargetMW_{avg}$ minus the $ActualMW_{(t-4)}$ is less than or equal to 0, the unit will not be considered to be in a hard up ramp. For this situation, an assessment is done to determine if the $ActualMW_{avg}$ – $ActualMW_{(t-4)}$ is less than 0. If not, then a further assessment will be performed to determine if the $ActualMW_{avg}$ was less than the $RampMW_{avg}$. If it was, then the unit will be credited with a score of 0.75 indicating it was not a detriment to the system and appeared to make an effort to contribute. If it was not, then it will be credited with 0.0 for not responding. If the $ActualMW_{avg}$ – $ActualMW_{(t-4)}$ is less than 0, then the unit P.U.PFR performance will be calculated as shown below.

Sustained P.U.PFR Calculation – High Frequency Event

For generating unit/generating facility whose MW output value at ERT is higher than MW output at t-4.

$$P.U.PFR_{Resource} = \frac{ActualMW_{avg} - ActualMW_{(ERT)}}{TargetMW_{avg} - ActualMW_{(ERT)}}$$

For generating unit/generating facility whose MW output value at ERT is lower than MW output at t-4.

$$P.U.PFR_{Resource} = \frac{ActualMW_{avg} - ActualMW_{(t-4)}}{TargetMW_{avg} - ActualMW_{(t-4)}}$$

Revision History

Version	Date	Action	Change Tracking
1	7-25-11	Approved by SDT and submitted to Texas RE RSC for approval to post for regional ballot	