

Attachment 1

Primary Frequency Response Reference Document

Texas Reliability Entity, Inc.
BAL-001-TRE-2
Requirements R2, R9, and R10
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 following Frequency Measurable Events (FMEs) in accordance with Requirements R2, R9 and R10. Flowcharts in Attachment A (Initial PFR) and Attachment 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 available¹ 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 is maintained by Texas RE and subject to modifications as approved by the Texas RE Board of Directors, without being required to go through the formal Standard Development Process.

Revision 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 Member Representatives Committee (MRC) for consideration. The MRC shall discuss the revision request in a public meeting, and will accept and consider verbal and written comments pertaining to the request. The MRC 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.

In this regional standard, the term “resource” is synonymous with “generating unit/generating facility”.

¹ These spreadsheets are available at www.TexasRE.org.

II. Initial Primary Frequency Response Calculations

Requirement 9

- R9.** Each Generator Owner 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.
- 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.
- 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 initial Primary Frequency Response performance during an FME may be excluded by the Balancing Authority from the rolling average calculation due to a legitimate operating condition that prevented normal Primary Frequency Response performance. Examples of legitimate operating conditions that may support exclusion of FMEs include, but are not limited to:
- Operation at or near auxiliary equipment operating limits (such as boiler feed pumps, condensate pumps, pulverizers, and forced draft fans);
 - Data telemetry failure. The Balancing Authority may request raw data from the Generator Owner as a substitute.

Initial Primary Frequency Response Performance Calculation Methodology

This portion of this PFR Reference Document establishes the process used to calculate initial Primary Frequency Response performance for each Frequency Measurable Event (FME), and then average the events over a 12-month period (or 8-event minimum) to establish whether a resource is compliant with Requirement R9.

This process calculates the initial Per Unit Primary Frequency Response of a resource $[P.U.PFR_{Resource}]$ as a ratio between the Adjusted Actual Primary Frequency Response ($APFR_{Adj}$), adjusted for the pre-event ramping of the unit, and the Final Expected Primary Frequency Response ($EPFR_{final}$) as calculated using the Pre-perturbation and Post-perturbation time periods of the initial measure.

This comparison of actual performance to a calculated target value establishes, for each type of resource, the initial Per Unit Primary Frequency Response $[P.U.PFR_{Resource}]$ for any Frequency Measurable Event (FME).

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 initial Primary Frequency Response of a resource during identified FMEs.

$$P.U.PFR_{Resource} = \frac{Actual\ Primary\ Frequency\ Response_{Adj}}{Expected\ Primary\ Frequency\ Response_{final}}$$

Where P.U.PFR_{Resource} for each FME is limited to values between 0.0 and 2.0.

The Adjusted Actual Primary Frequency Response (APFR_{Adj}) and the Final Expected Primary Frequency Response (EPFR_{final}) are calculated as described below.

EPFR Calculations use droop and deadband values as stated in Requirement R6 with the exception of combined-cycle facilities while being evaluated as a single resource (MW production of both the combustion turbine generator and the steam turbine generator are included in the evaluation) where the evaluation droop will be 5.78%.²

Actual Primary Frequency Response (APFR_{adj})

The adjusted Actual Primary Frequency Response (APFR_{adj}) is the difference between Post-perturbation Average MW and Pre-perturbation Average MW, including the ramp magnitude adjustment.

$$APFR_{adj} = MW_{post-perturbation} - MW_{pre-perturbation} - Ramp\ Magnitude$$

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

$$MW_{post-perturbation} = \frac{\sum_{T+20}^{T+52} MW}{\# Scans}$$

² 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. Use 5.78% effective droop in all combined-cycle performance calculations.

Ramp Adjustment: The Actual 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 subtracted from the APFR.

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

($MW_{T-4} - MW_{T-60}$) 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 (EPFR)

For all generator types, the *ideal* Expected Primary Frequency Response ($EPFR_{ideal}$) is calculated as the difference between the $EPFR_{post-perturbation}$ and the $EPFR_{pre-perturbation}$.

$$EPFR_{ideal} = EPFR_{post-perturbation} - EPFR_{pre-perturbation}$$

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

$$EPFR_{pre-perturbation} = \left[\frac{(HZ_{pre-perturbation} - 60.0 - deadband_{max})}{(60 \times droop_{max} - deadband_{max})} \times (-1) \times (HSL - PA \text{ Capacity}) \right]$$

$$EPFR_{post-perturbation} = \left[\frac{(HZ_{post-perturbation} - 60.0 - deadband_{max})}{(60 \times droop_{max} - deadband_{max})} \times (-1) \times (HSL - PA \text{ Capacity}) \right]$$

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

$$EPFR_{pre-perturbation} = \left[\frac{(HZ_{pre-perturbation} - 60.0 + deadband_{max})}{(60 \times droop_{max} - deadband_{max})} \times (-1) \times (HSL - PA \text{ Capacity}) \right]$$

$$EPFR_{post-perturbation} = \left[\frac{(HZ_{post-perturbation} - 60.0 + deadband_{max})}{(60 \times droop_{max} - deadband_{max})} \times (-1) \times (HSL - PA \text{ Capacity}) \right]$$

For each formula, when frequency is within the Governor deadband the appropriate EPFR value is zero. The $deadband_{max}$ and $droop_{max}$ quantities come from Requirement R6.

Where:

Pre-perturbation Average Hz: Actual Hz averaged from T-16 to T-2

$$Hz_{pre - perturbation} = \frac{\sum_{T-16}^{T-2} Hz}{\# Scans}$$

Post-perturbation Average Hz: Actual Hz averaged from T+20 to T+52

$$Hz_{post - perturbation} = \frac{\sum_{T+20}^{T+52} Hz}{\# Scans}$$

Capacity and NDC (Net Dependable Capacity) are used interchangeably and the term Capacity will be used in this document. Capacity is the official reported seasonal capacity of the generating unit/generating facility. The Capacity for wind-powered generators is the real time HSL of the wind plant at the time the FME occurred.

Power Augmentation: For Combined Cycle facilities, Capacity is adjusted by subtracting power augmentation (PA) capacity, if any, from the HSL. Other generator types may also have power augmentation that is not frequency responsive. This could be “over-pressure” operation of a steam turbine at valves wide open or operating with a secondary fuel in service. The GO should provide the BA with documentation and conditions when power augmentation is to be considered in PFR calculations.

EPFR_{final} for Combustion Turbines and Combined Cycle Facilities

$$EPFR_{final} = EPFR_{ideal} + (Hz_{post-perturbation} - 60.0) \times 10 \times 0.00276 \times (HSL - PA Capacity)$$

Note: The 0.00276 constant is the MW/0.1 Hz change per MW of 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.

EPFR_{final} for Steam Turbine

$$EPFR_{final} = (EPFR_{ideal} + MW_{adj}) \times \frac{Throttle Pressure}{Rated Throttle Pressure}$$

Where:

$$MW_{adj} = EPFR_{ideal} \times \frac{K}{\text{Rated Throttle Pressure}} \times (\text{HSL} - \text{PA Capacity}) \times \text{Steam Flow Change Factor} \times -1$$

Where:

$$\% \text{ Steam Flow} = \frac{MW_{\text{post-perturbation}}}{(\text{HSL} - \text{PA Capacity})}$$

$$\text{Steam Flow Change Factor} = \frac{\% \text{ Steam Flow}}{0.5}$$

Throttle Pressure = Interpolation of Pressure curve at MW_{pre-perturbation}

The Rated Throttle Pressure and the Pressure curve, based on generator MW output, are provided by the GO to the BA. This pressure curve is defined by up to six pair of Pressure and MW breakpoints where the Rated Throttle Pressure and MW output, where Rated Throttle Pressure is achieved, is the first pair and the Minimum Throttle Pressure and MW output, where the Minimum Throttle Pressure is achieved, as the last pair of breakpoints. If fewer breakpoints are needed, the pair values will be repeated to complete the six pair table.

The K factor is used to model the stored energy available to the resource. The value ranges between 0.0 and 0.6 psig per MW change when responding during a FME. The GO can measure the drop in throttle pressure when the resource is operating near 50% output of the steam turbine during a FME and provide this ratio of pressure change to the BA. K is then adjusted based on rated throttle pressure and resource capacity. An additional sensitivity factor, the Steam Flow Change Factor, is based on resource loading (% steam flow) and 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}). For any generating unit, K will not change unless the steam generator is significantly reconfigured.

EPFR_{final} for Other Generating Units/Generating Facilities

$$EPFR_{final} = EPFR_{ideal} + X$$

Where X is an adjustment factor that may be applied to properly model the delivery of PFR. The X factor will be based on known and accepted technical or physical limitations of the resource. X may be adjusted by the BA and may be variable across the operating range of a resource. X shall be zero unless the BA accepts an alternative value.

III. Sustained Primary Frequency Response Calculations

Requirement 10

R10. The Generator Owner 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.

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 period 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 sustained Primary Frequency Response performance during an FME may be excluded by the Balancing Authority from the rolling average calculation due to a legitimate operating condition that prevented normal Primary Frequency Response performance. Examples of legitimate operating conditions that may support exclusion of FMEs include, but are not limited to:

- Operation at or near auxiliary equipment operating limits (such as boiler feed pumps, condensate pumps, pulverizers, and forced draft fans);
- Data telemetry failure. The Balancing Authority may request raw data from the Generator Owner as a substitute.

Sustained Primary Frequency Response Performance Calculation Methodology

This portion of this PFR Reference Document establishes the process used to calculate sustained Primary Frequency Response performance for each Frequency Measurable Event (FME), and then average the events over a 12-month period (or 8-event minimum) to establish whether a resource is compliant with Requirement R10.

This process calculates the Per Unit Sustained Primary Frequency Response of a resource [P.U.SPFR_{Resource}] as a ratio between the maximum actual unit response at any time during the period from T+46 to T+60, adjusted for the pre-event ramping of the unit, and the *Final* Expected Primary Frequency Response (EPFR) value at time T+46.³

This comparison of actual performance to a calculated target value establishes, for each type of resource, the Per Unit Sustained Primary Frequency Response [P.U.SPFR_{Resource}] for any Frequency Measurable Event (FME).

Sustained Primary Frequency Response performance requirement:

The standard requires an average performance over a period of 12 months (including at least 8 measured events) that is ≥ 0.75 .

³ The time designations used in this section refer to relative time after an FME occurs. For example, "T+46" refers to 46 seconds after the frequency deviation occurred.

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

$Avg_{Period} [P.U.SPFR_{Resource}]$ is either:

- the average of each resource's sustained Primary Frequency Response performances $[P.U.SPFR_{Resource}]$ during all of the assessable Frequency Measurable Events (FMEs), for the most recent rolling 12 month period; or
- if the unit has not experienced at least 8 assessable FMEs in the most recent 12 month period, the average of the unit's last 8 sustained Primary Frequency Response performances when the unit provided frequency response during a Frequency Measurable Event.

Sustained Primary Frequency Response Calculation (P.U.SPFR)

$$P.U.SPFR_{Resource} = \frac{\text{Actual Sustained Primary Frequency Response}_{Adj}}{\text{Expected Sustained Primary Frequency Response}_{final}}$$

$P.U.SPFR_{Resource}$ is the per unit (P.U.) measure of the sustained Primary Frequency Response of a resource during identified Frequency Measurable Events. For any given event $P.U.SPFR_{Resource}$ for each FME will be limited to values between 0.0 and 2.0.

Actual Sustained Primary Frequency Response (ASPFR) Calculations

$$ASPFR = MW_{MaximumResponse} - MW_{pre-perturbation}$$

Where:

Pre-perturbation Average MW: Actual MW averaged from T-16 to T-2.

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

And:

$MW_{MaximumResponse}$ = maximum MW value telemetered by a unit from T+46 through T+60 during low frequency events and the minimum MW value telemetered by a unit from T+46 through T+60 during a high frequency event.

Actual Sustained Primary Frequency Response, Adjusted ($ASPFR_{Adj}$)

$$ASPFR_{Adj} = ASPFR - RampMW_{Sustained}$$

RampMW Sustained (MW) – The Standard requires a unit/facility to sustain its response to a Frequency Measureable Event. An adjustment available in determining a unit’s sustained Primary Frequency Response performance ($P.U.SPFR_{Resource}$) is to account for the direction in which a resource was moving (increasing or decreasing output) when the event occurred $T=t(0)$. This is the *RampMW Sustained* adjustment:

$$RampMW\ Sustained = (MW_{T-4} - MW_{T-60}) \times 0.821$$

Note: The terminology “ MW_{T-4} ” refers to MW output at 4 seconds before the Frequency Measurable Event (FME) occurs at $T=t(0)$.

By subtracting a reading at 4 seconds before, from a reading at 60 seconds before, the formula calculates the MWs a generator moved in the minute (56 seconds) prior to $T=t(0)$. The formula is then modified by a factor to indicate where the generator would have been at $T+46$, had the event not occurred: the “*RampMW Sustained*.” It does this by multiplying the MW change over 56 seconds before the event ($MW_{T-4} - MW_{T-60}$) by a modifier. This extrapolates to an equivalent number of MWs the generator would have changed if it had been allowed to continue on its ramp

$$\frac{46\ \text{seconds}}{56\ \text{seconds}} \text{ or } 0.821.$$

to $T+46$ unencumbered by the FME. The modifier is

Expected Sustained Primary Frequency Response (ESPFR) Calculations

The Expected Sustained Primary Frequency Response ($ESPFR_{final}$) is calculated using the actual frequency at $T+46$, HZ_{T+46} .

This $ESPFR_{final}$ is the MW value a unit should have responded with if it is properly sustaining the output of its generating unit/generating facility in response to an FME. Determination of this value begins with establishing where it would be in an ideal situation; considers proper droop and dead-band values established in Requirement R6, High Sustainable Limit (HSL), Low Sustainable Limit (LSL) and actual frequency. It then allows for adjusting the value to compensate for the various types of Limiting Factors each generating units / generating facilities may have and any Power Augmentation Capacity (PA Capacity) that may be included in the HSL/LSL.

Establishing the Ideal Expected Sustained Primary Frequency Response

For all generator types, the ideal Expected Sustained Primary Frequency Response ($ESPFR_{ideal}$) is calculated as the difference between the $ESPFR_{T+46}$ and the $EPFR_{pre-perturbation}$. The $EPFR_{pre-perturbation}$ is the same $EPFR_{pre-perturbation}$ value used in the Initial measure of R9.

$$ESPFR_{ideal} = ESPFR_{T+46} - EPFR_{pre-perturbation}$$

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

$$ESPFR_{T+46} = \left[\frac{(HZ_{T+46} - 60 - deadband_{max})}{(droop_{max} \times 60 - deadband_{max})} \times (HSL - PA\ Capacity) \times (-1) \right]$$

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

$$ESPFR_{T+46} = \left[\frac{(HZ_{T+46} - 60 + deadband_{max})}{(droop_{max} \times 60 - deadband_{max})} \times (HSL - PA Capacity) \times (-1) \right]$$

Capacity and Net Dependable Capability (NDC) are used interchangeably and the term Capacity will be used in this document. Capacity is the official reported seasonal capacity of the generating unit/generating facility. The capacity for wind-powered generators is the real-time HSL of the wind plant at the time the FME occurred. The $deadband_{max}$ and $droop_{max}$ quantities come from Requirement R6.

For Combined Cycle facilities, determination of Capacity includes subtracting Power Augmentation (PA) Capacity, if any, from the original HSL. Other generator types may also have Power Augmentation that is not frequency responsive. This could be “over-pressure” operation of a steam turbine at valves wide open or operating with a secondary fuel in service. The GO is required to provide the BA with documentation and identify conditions when this augmentation is in service.

ESPFR_{final} for Combustion Turbines and Combined Cycle Facilities

$$ESPFR_{final} = ESPFR_{ideal} + (HZ_{T+46} - 60) * 10 * 0.00276 * (HSL - PACapacity)$$

Note: The 0.00276 constant is the MW/0.1 Hz change per MW of 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 at HZ_{T+46} . (This is based on empirical data from a major 2003 event as measured on multiple combustion turbines in ERCOT.)

ESPFR_{final} for Steam Turbine

$$ESPFR_{final} = (ESPFR_{ideal} + MW_{Adj}) \times \frac{Throttle Pressure}{Rated Throttle Pressure}$$

Where:

$$MW_{Adj} = ESPFR_{ideal} \times \frac{K}{Rated Throttle Pressure} \times (HSL - PACapacity) \times Steam Flow Change Factor \times (-1)$$

Where:

$$\% Steam Flow = \frac{MW_{post-perturbation}}{(HSL - PA Capacity)}$$

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

Throttle Pressure = Interpolation of Pressure curve at $MW_{pre-perturbation}$

The Rated Throttle Pressure and the Pressure curve, based on generator MW output, are provided by the GO to the BA. This pressure curve is defined by up to six pair of Pressure and MW breakpoints where the Rated Throttle Pressure and MW output where Rated Throttle Pressure is achieved is the first pair and the Minimum Throttle Pressure and MW output where the Minimum Throttle Pressure is achieved as the last pair of breakpoints. If fewer breakpoints are needed, the pair values will be repeated to complete the six pair table.

The K factor is used to model the stored energy available to the resource and ranges between 0.0 and 0.6 psig per MW change when responding during a FME. The GO can measure the drop in throttle pressure, when the resource is operating near 50% output of the steam turbine during a FME and provide this ratio of pressure change to the BA. K is then adjusted based on rated throttle pressure and resource capacity. An additional sensitivity factor, the Steam Flow Change Factor, is based on resource loading (% steam flow) and 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 ESPFR and ASPFR (resulting in the highest P.U.SPFR_{Resource}). For any generating unit, K will not change unless the steam generator is significantly reconfigured.

ESPFR_{final} for Other Generating Units/Generating Facilities

$$ESPFR_{final} = ESPFR_{ideal} + X$$

Where X is an adjustment factor that may be applied to properly model the delivery of PFR. The X factor will be based on known and accepted technical or physical limitations of the resource. X may be adjusted by the BA and may be variable across the operating range of a resource. X shall be zero unless the BA accepts an alternative value.

IV. Limits on Calculation of Primary Frequency Response Performance (Initial and Sustained):

If the generating unit/generating facility is operating within 2% of its (HSL – PA Capacity) or within 5 MW (whichever is greater) from its applicable operating limit (high or low) at the time an FME occurs (pre-perturbation), then that resource's Primary Frequency Response performance is not evaluated for that FME.

For frequency deviations below 60 Hz (Hz_{Post-perturbation} < 60 if:

$$MW_{pre-perturbation} \geq \min([(HSL - PA Capacity] \times 0.98), [(HSL - PA Capacity] - 5 MW)]$$

then Primary Frequency Response is not evaluated for this FME.

For frequency deviations above 60 Hz (Hz_{Post-perturbation} > 60, if:

$$MW_{pre-perturbation} \leq \max[(LSL + [(HSL - PA Capacity] \times 0.02)], (LSL + 5 MW)]$$

then Primary Frequency Response is not evaluated for this FME.

Final Expected Primary Frequency Response (EPFR_{final}) is greater than Operating Margin:

Caps and limits exist for resources operating with adequate reserve margin to be evaluated (at least 2% of (HSL less PA Capacity) or 5 MW), but with Expected Primary Frequency Response_{final} greater than the actual margin available.

1. The P.U.PFR_{Resource} will be set to the greater of 0.75 or the calculated P.U.PFR_{Resource} if all of the following conditions are met:
 - a. The generating unit/generating facility's pre-perturbation operating margin (appropriate for the frequency deviation direction) is greater than 2% of its (HSL less PA Capacity) and greater than 5 MW; and
 - b. The Expected Primary Frequency Response_{final} is greater than the generating unit/generating facility's available frequency responsive Capacity⁴; and
 - c. The generating unit/generating facility's APFR_{adj} response is in the correct direction.
2. When calculation of the P.U.PFR_{Resource} uses the resource's (HSL less PA Capacity) as the maximum expected output, the calculated P.U.PFR_{Resource} will not be greater than 1.0.
3. When calculation of the P.U.PFR_{Resource} uses the resource's LSL as the minimum expected output, the calculated P.U.PFR_{Resource} will not be greater than 1.0.
4. If the APFR_{Adj} is in the wrong direction, then P.U.PFR_{Resource} is 0.0.
5. These caps and limits apply to both the Initial and Sustained Primary Frequency Response measures.

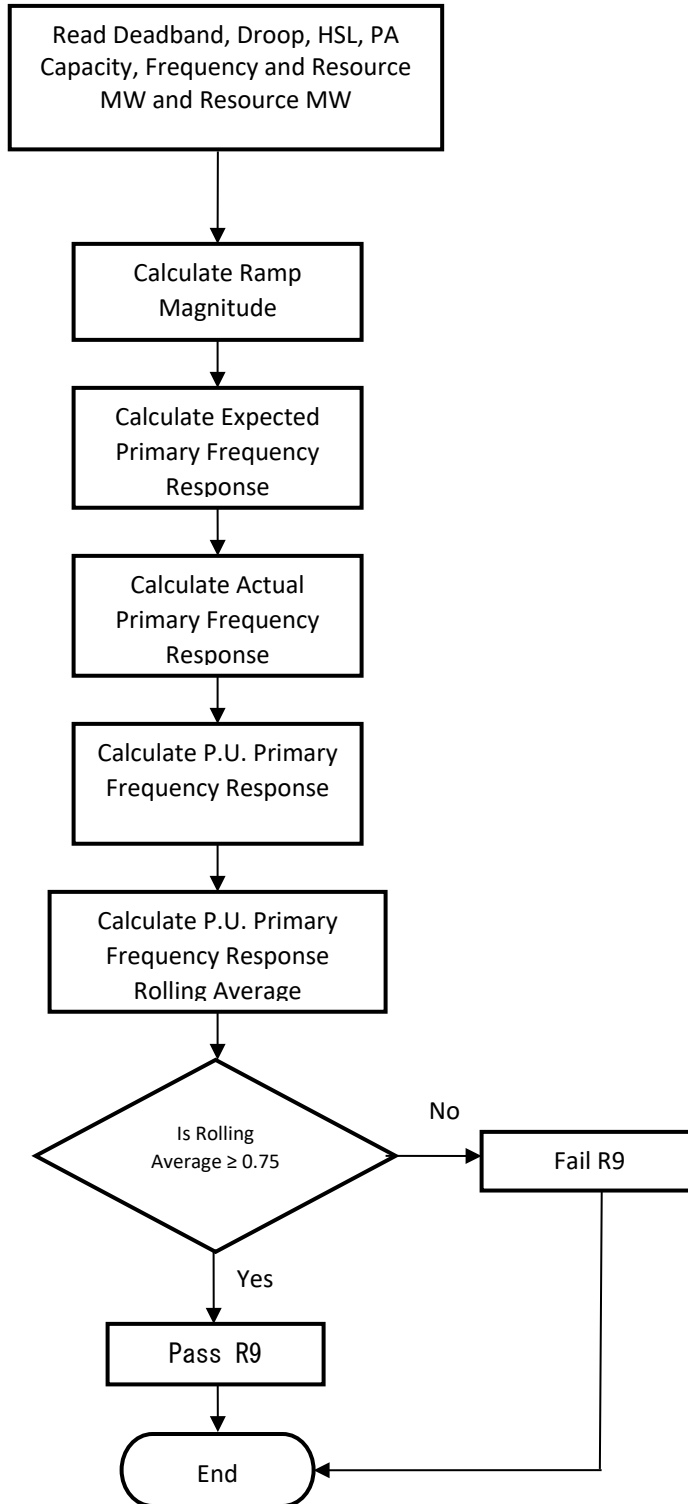
⁴ In this circumstance, when frequency is below 60 Hz, the EPFR_{final} is set to operating margin based on HSL (adjusted for any augmentation capacity) AND when frequency is above 60 Hz, the EPFR_{final} is set to operating margin based on LSL for the purpose of calculating PUPFR_{resource}.

**Attachment A to
Primary Frequency Response Reference Document**

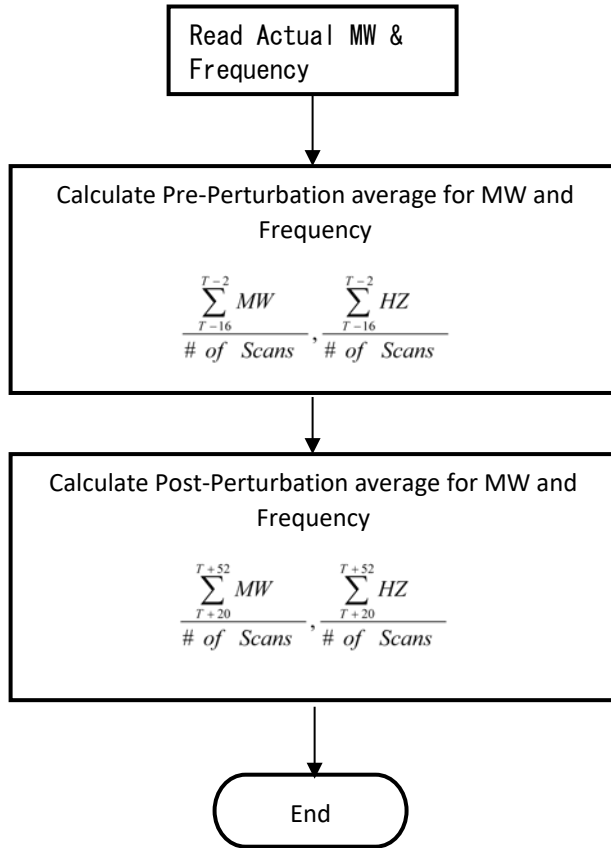
**Initial Primary Frequency Response Methodology for
BAL-001-TRE-2**

Primary Frequency Response Measurement and Rolling Average Calculation – Initial Response

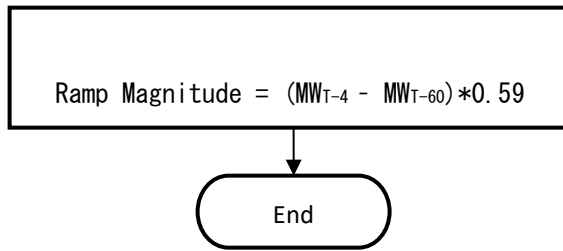
PA=Power Augmentation
HSL=High Sustained Limit



Pre/Post-Perturbation Average MW and Average Frequency Calculations

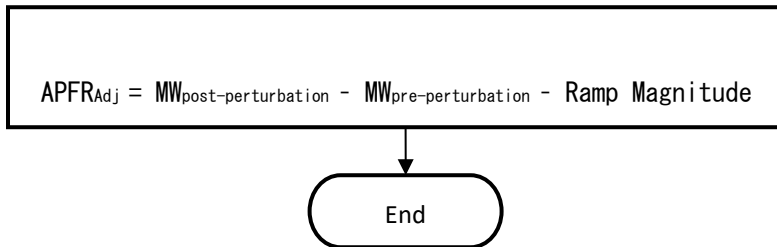


Ramp Magnitude Calculation



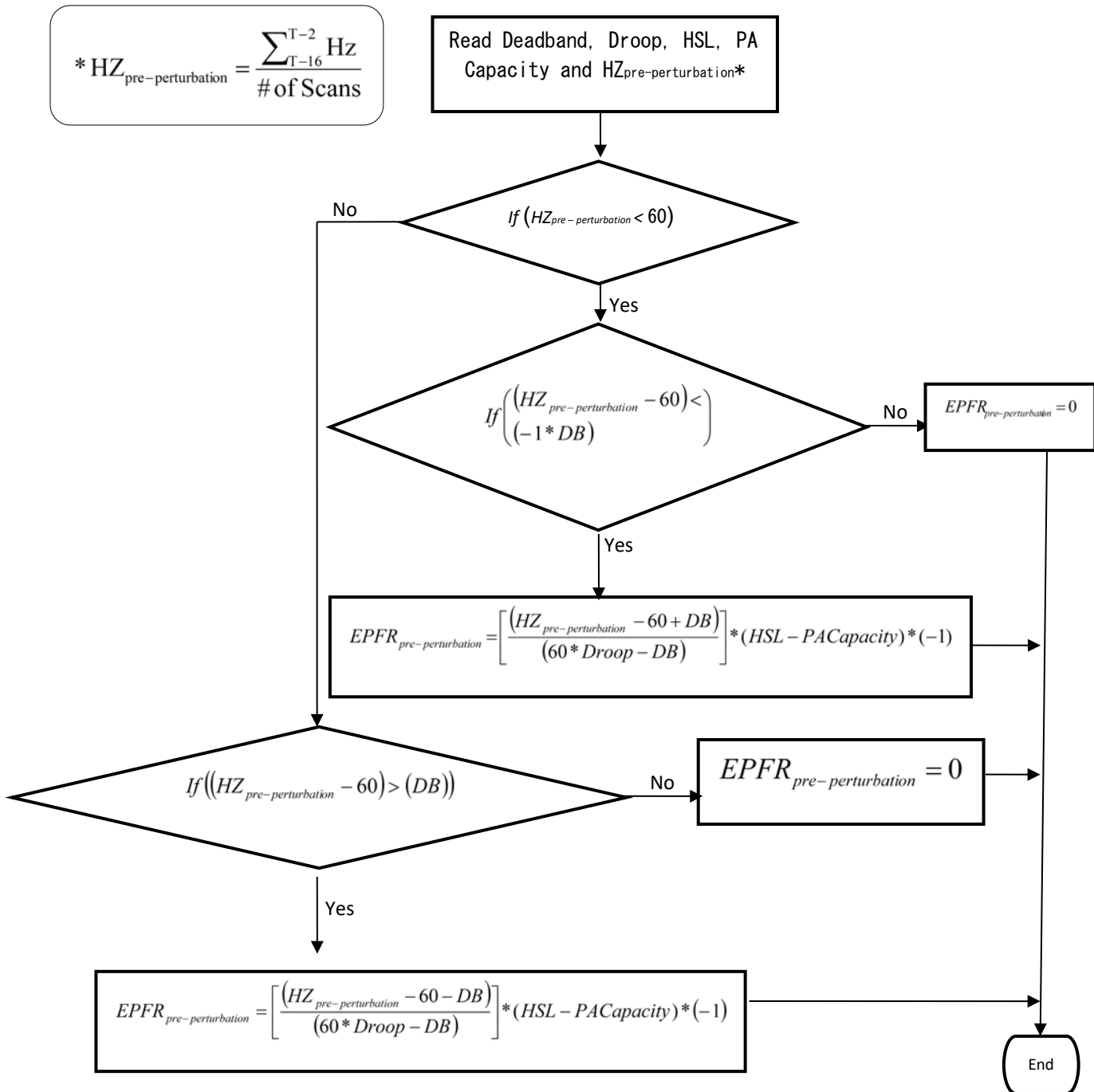
$(MW_{T-4} - MW_{T-60})$ represents the MW ramp of the generator resource/generator facility for a full minute prior to the event. The factor 0.59 adjusts this full minute ramp to represent the ramp that should have been achieved during the post-perturbation measurement period.

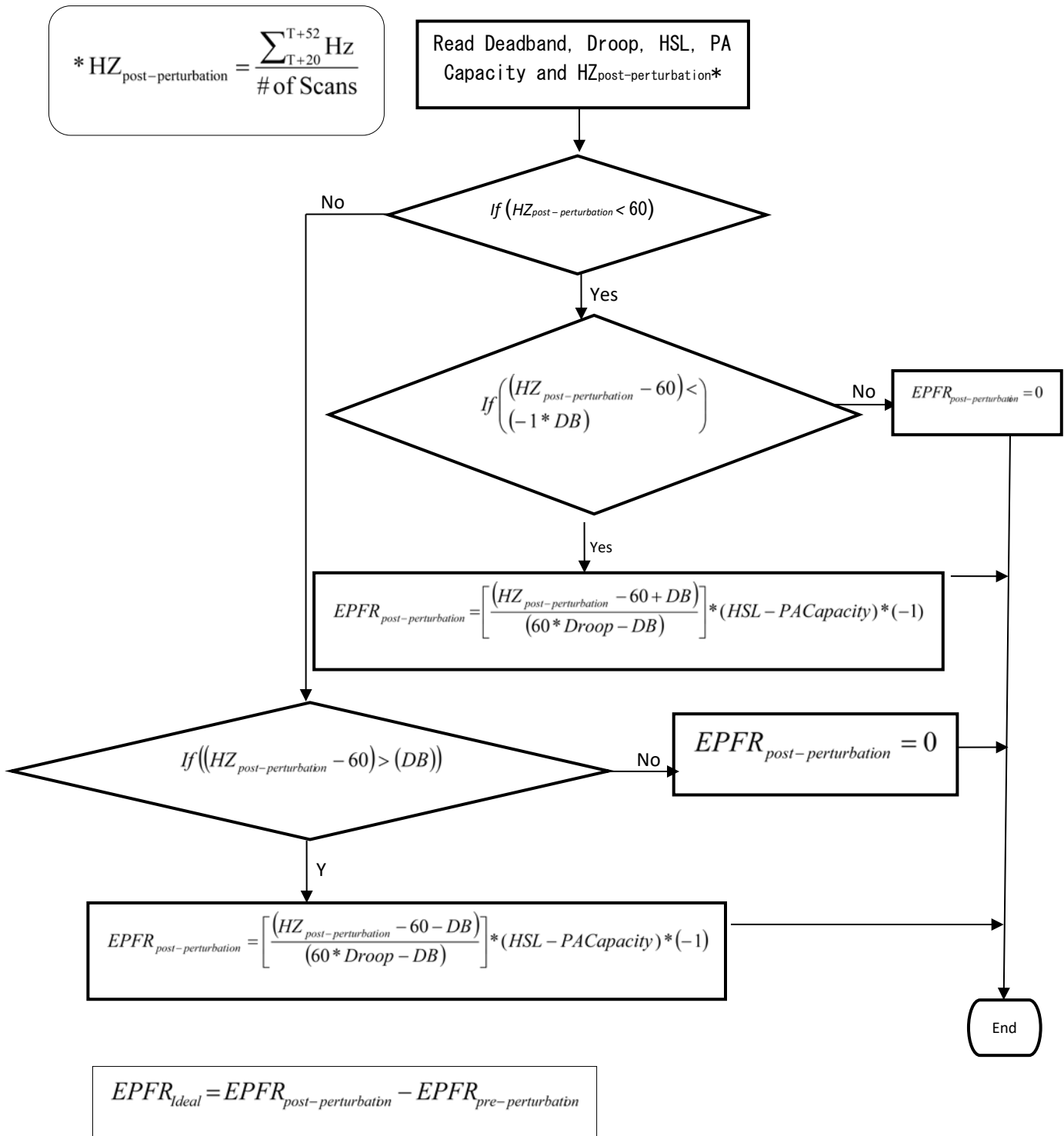
Actual Primary Frequency Response (APFR_{Adj})



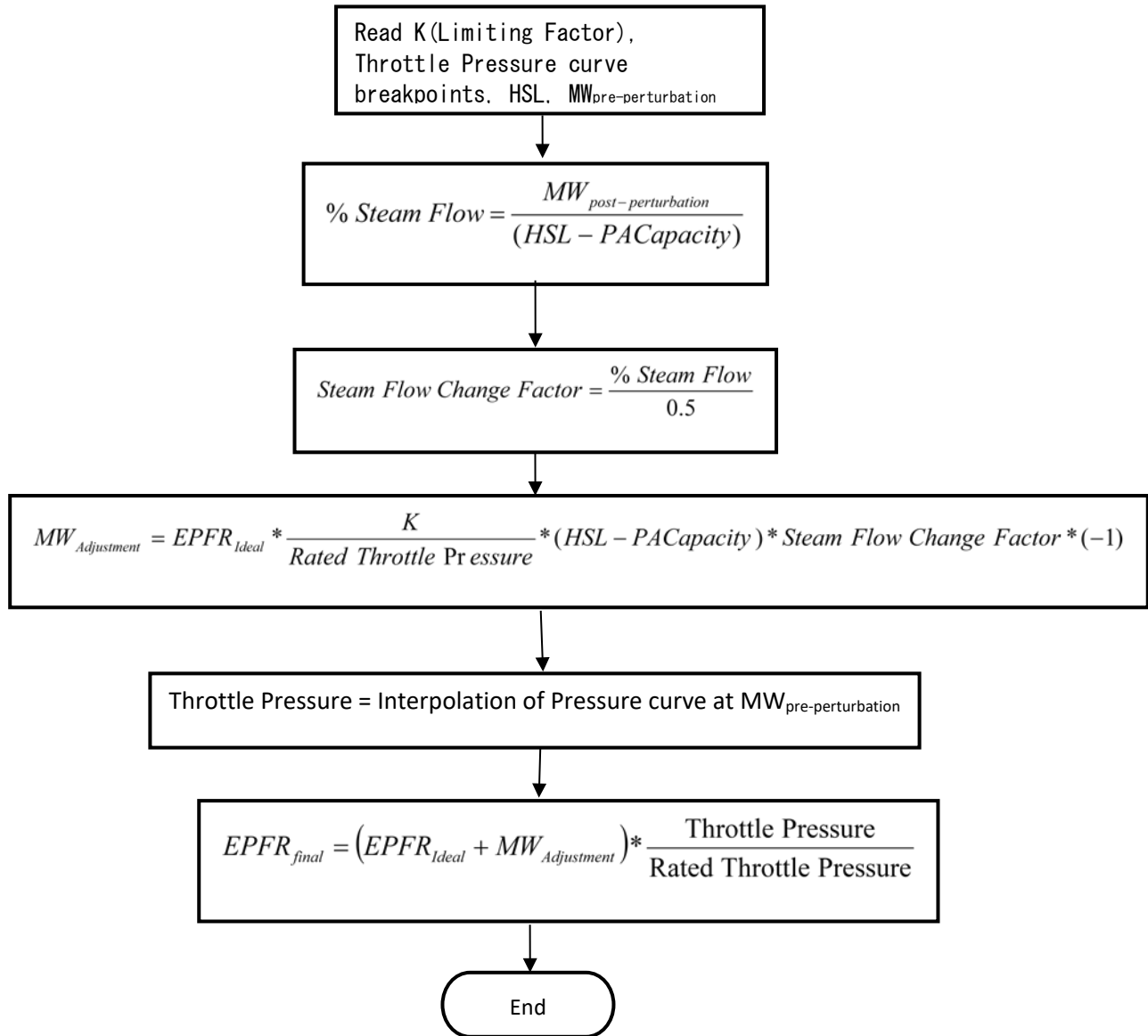
Expected Primary Frequency Response Calculation

Use the maximum droop and maximum deadband as required by R6. For Combined Cycle Facility evaluation as a single resource (includes MW production of the steam turbine generator), the EPFR will use 5.78% droop in all calculations.

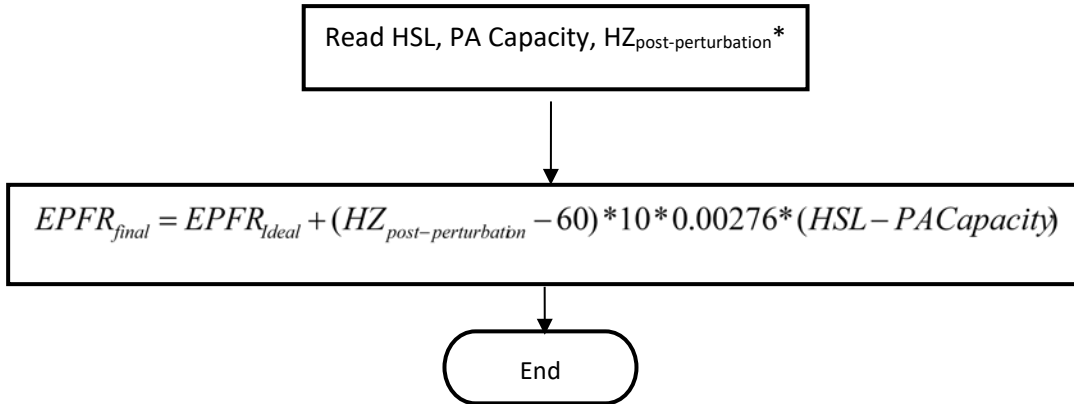




Adjustment for Steam Turbine

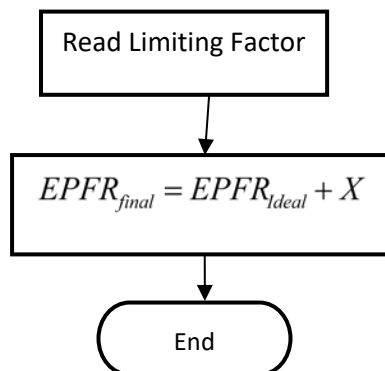


Adjustment for Combustion Turbines and Combined Cycle Facilities



0.00276 is the MW/0.1 Hz change per MW of 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.)

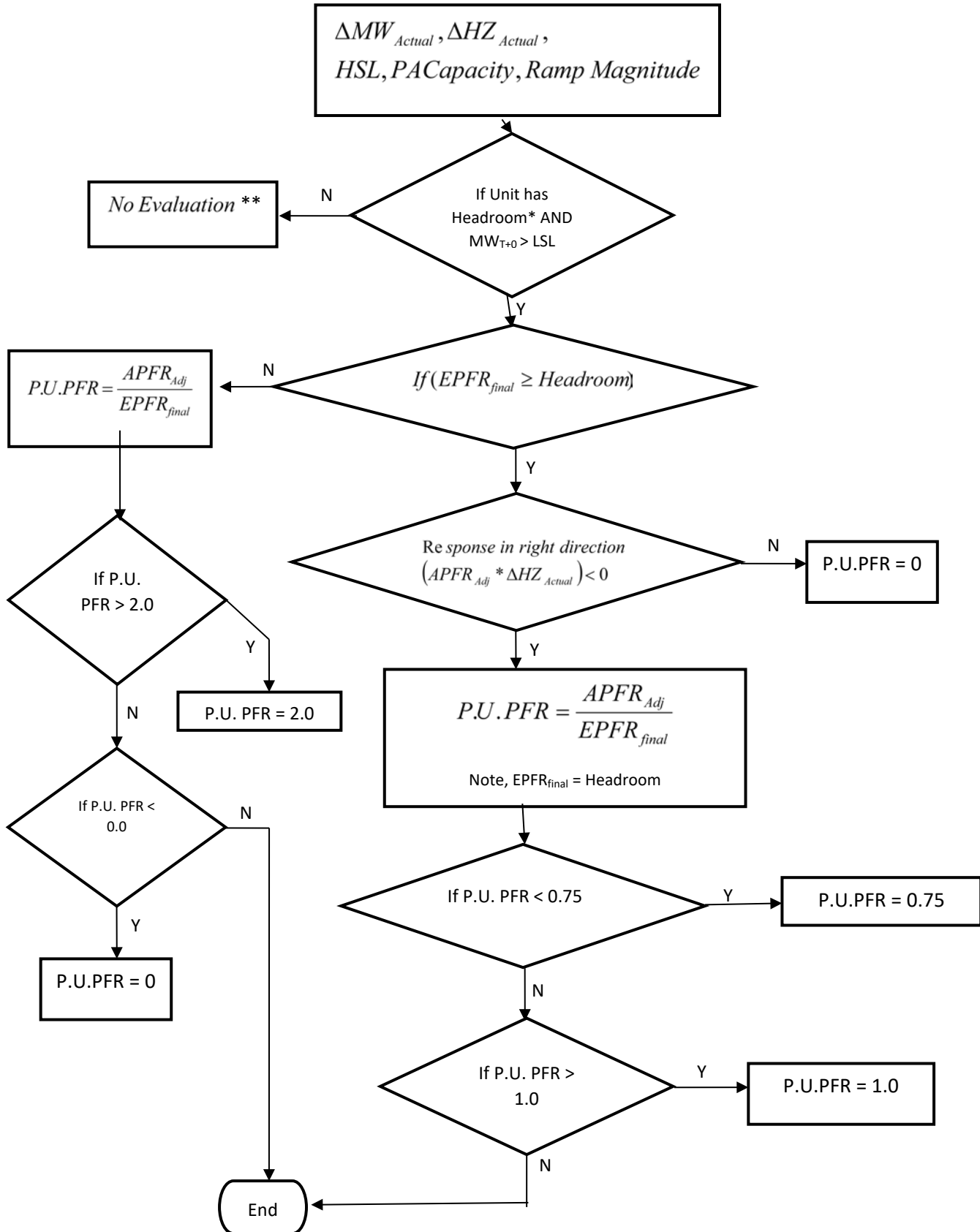
Adjustment for Other Units



$$* \text{HZ}_{\text{post-perturbation}} = \frac{\sum_{T+20}^{T+52} \text{HZ}_{\text{Actual}}}{\# \text{ of Scans}}$$

This adjustment Factor X will be developed to properly model the delivery of PFR due to known and approved technical limitations of the resource. X may be adjusted by the BA and may be variable across the operating range of a resource.

P.U. Initial Primary Frequency Response Calculation



*Check for adequate up headroom, low frequency events. Headroom must be greater than either 5MW or 2% of (HSL less PA Capacity), whichever is larger. If a unit does not have adequate up headroom, the unit is considered operating at full capacity and will not be evaluated for low frequency events.

Check for adequate down headroom, high frequency events. Headroom must be greater than either 5MW or 2% of (HSL less PA Capacity), whichever is larger. If a unit does not have adequate down headroom, the unit is considered operating at low capacity and will not be evaluated for high frequency events.

For low frequency events:

$$Headroom = HSL - PACapacity - MW_{T-2}$$

For high frequency events:

$$Headroom = MW_{T-2} - LSL$$

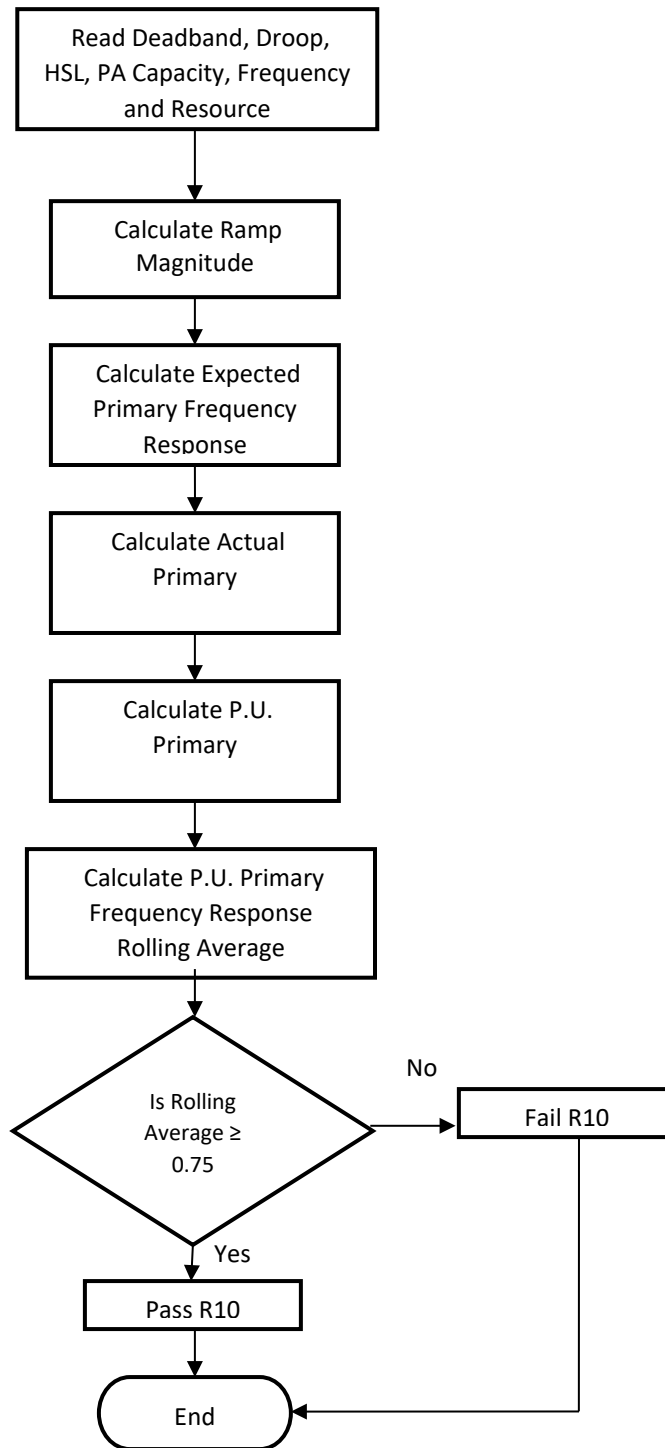
**No further evaluation is required for Sustained Primary Frequency Response. This event will not be included in the Rolling Average calculation of either Initial or Sustained Primary Frequency Response.

T = Time in Seconds

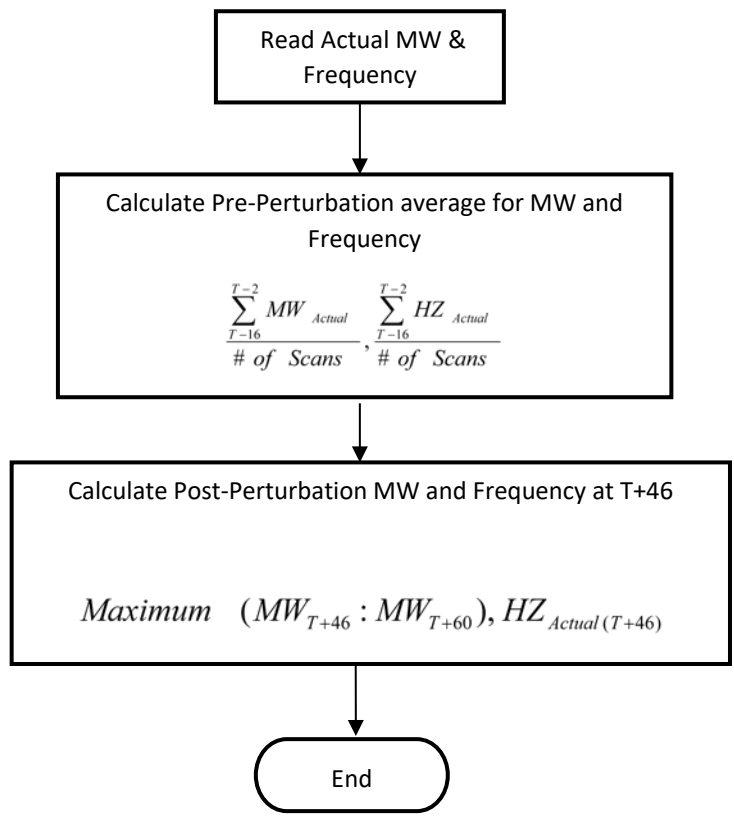
**Attachment B to
Primary Frequency Response Reference Document**

**Sustained Primary Frequency Response Methodology for
BAL-001-TRE-2**

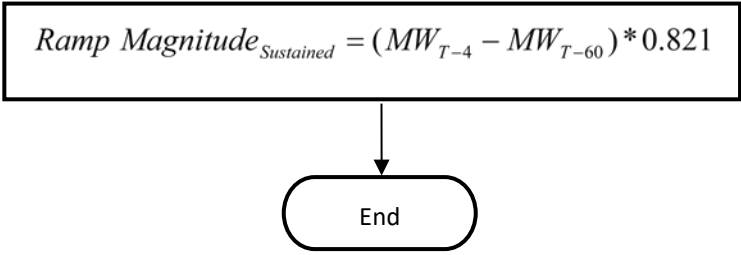
Primary Frequency Response Measurement and Rolling Average Calculation—Sustained Response



Pre/Post-Perturbation Average MW and Average Frequency Calculations



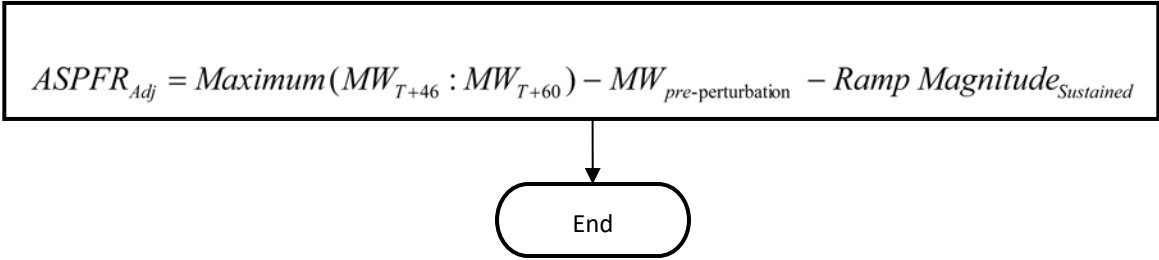
Ramp Magnitude Calculation - Sustained



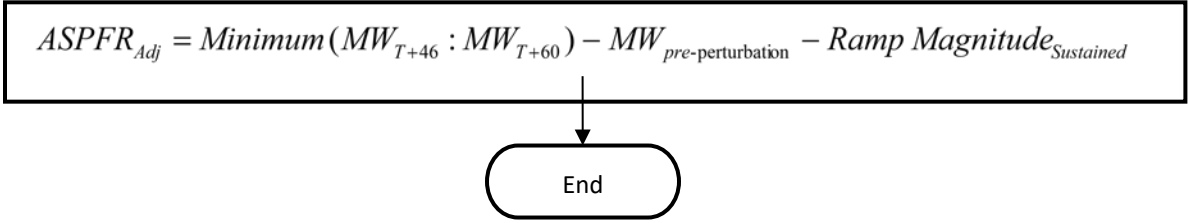
$(MW_{T-4} - MW_{T-60})$ represents the MW ramp of the generator resource/generator facility for a full minute prior to the event. The factor 0.821 adjusts this full minute ramp to represent the ramp the generator would have changed the system had it been allowed to continue on its ramp to T+46 unencumbered.

Actual Sustained Primary Frequency Response (ASPFR_{adj})

For low frequency events:

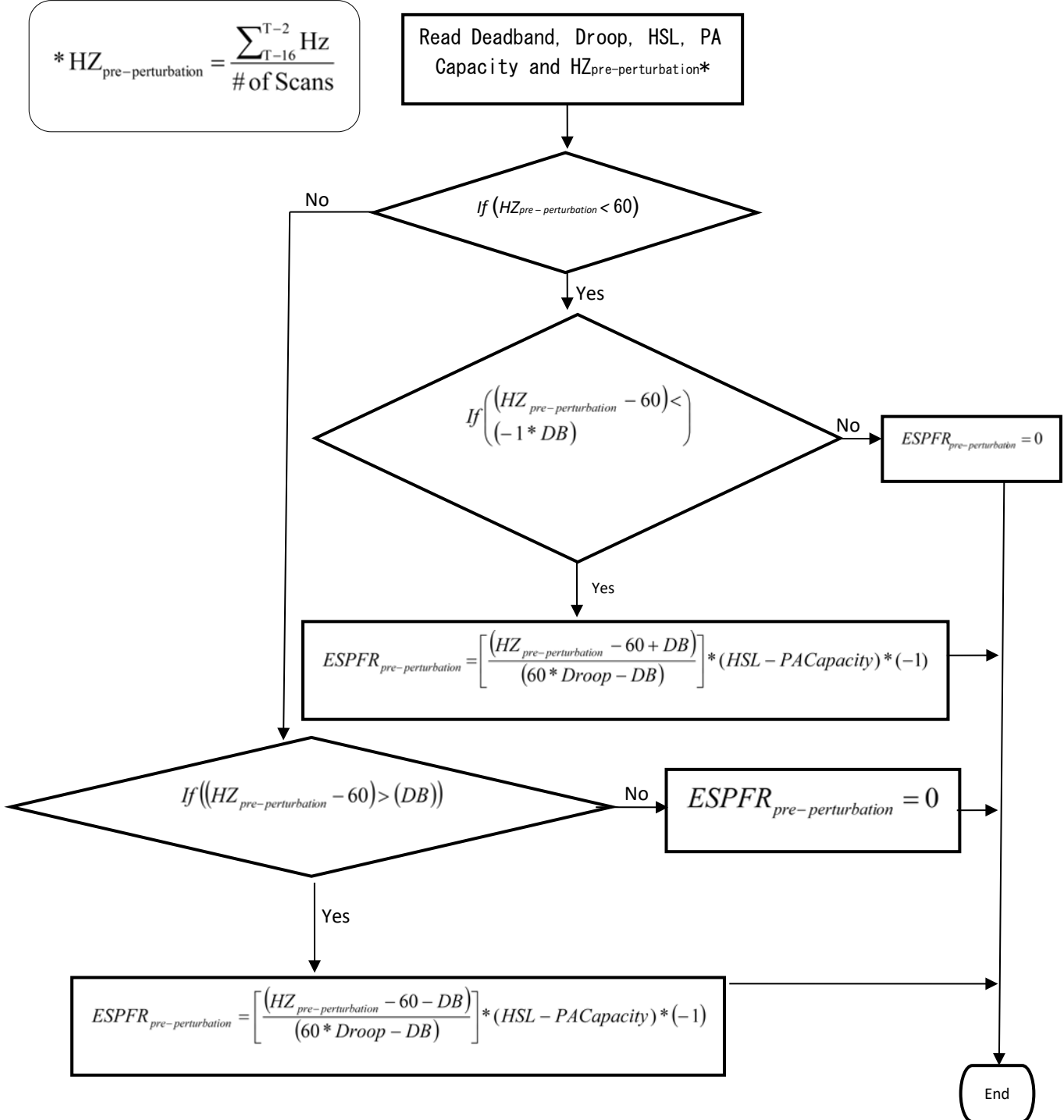


For high frequency events:



Expected Sustained Primary Frequency Response Calculation

Use the droop and deadband as required by R6. For Combined Cycle Facility evaluation as a single resource (includes MW production of the steam turbine generator), the EPFR will use 5.78% droop in all calculations.



* $HZ_{post-perturbation} = HZ_{(T + 46)}$

Read Deadband, Droop, HSL, PA Capacity and $HZ_{post-perturbation}$ *

If ($HZ_{post-perturbation} < 60$)

Yes

If ($\frac{(HZ_{post-perturbation} - 60)}{(-1 * DB)} <$)

$ESPFR_{post-perturbation} = 0$

$ESPFR_{post-perturbation} = \left[\frac{(HZ_{post-perturbation} - 60 + DB)}{(60 * Droop - DB)} \right] * (HSL - PACapacity) * (-1)$

If ($(HZ_{post-perturbation} - 60) > (DB)$)

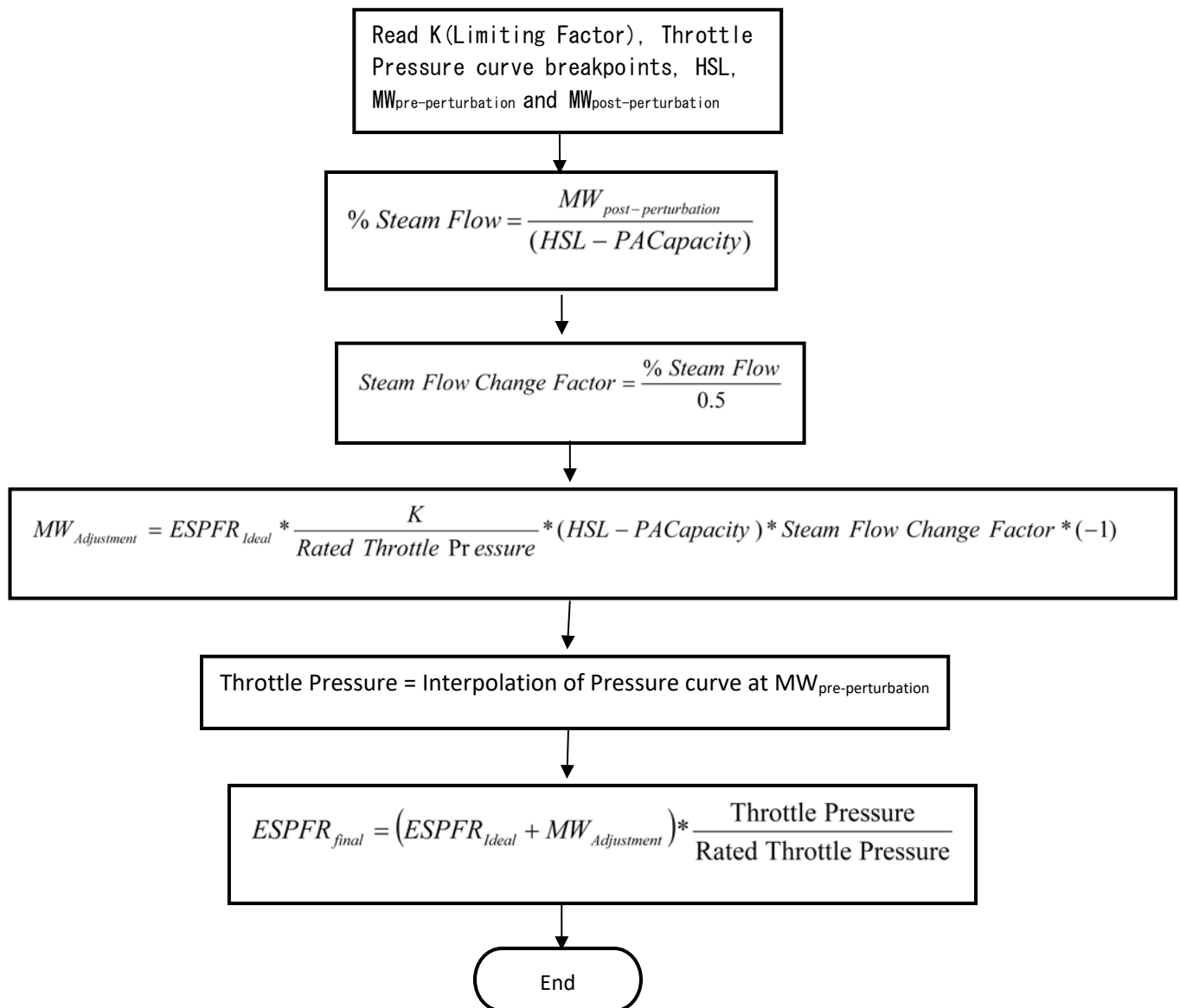
$ESPFR_{post-perturbation} = 0$

$ESPFR_{post-perturbation} = \left[\frac{(HZ_{post-perturbation} - 60 - DB)}{(60 * Droop - DB)} \right] * (HSL - PACapacity) * (-1)$

End

$ESPFR_{ideal} = ESPFR_{post-perturbation} - ESPFR_{pre-perturbation}$

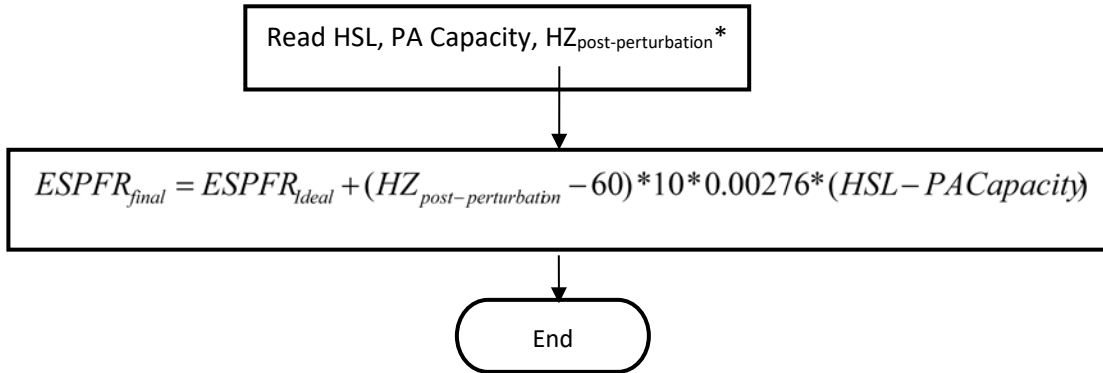
Adjustment for Steam Turbine



$MW_{\text{post-perturbation}}$ = Maximum ($MW_{T+46} : MW_{T+60}$) for low frequency events.

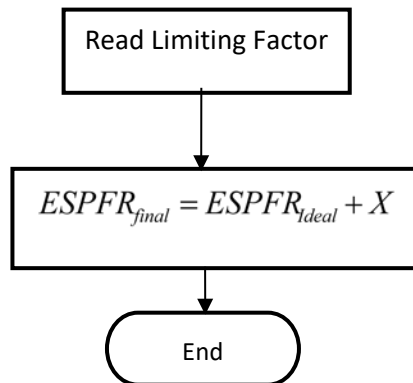
$MW_{\text{post-perturbation}}$ = Minimum ($MW_{T+46} : MW_{T+60}$) for high frequency events.

Adjustment for Combustion Turbines and Combined Cycle Facilities



0.00276 is the MW/0.1 Hz change per MW of 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.)

Adjustment for Other Units

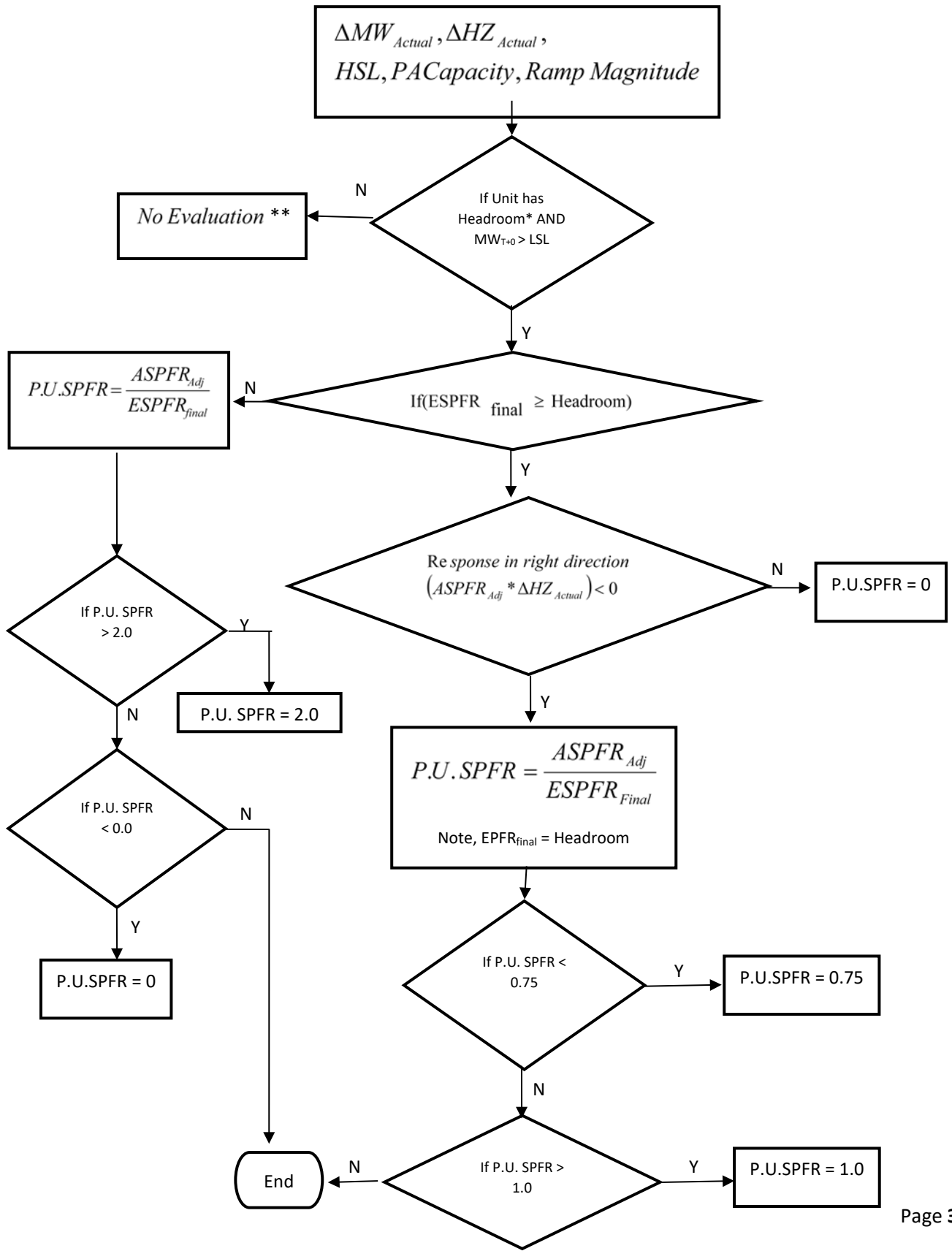


* $HZ_{Actual} = HZ_{(T + 46)}$

This adjustment Factor X will be developed to properly model the delivery of PFR due to known and approved technical limitations of the resource. X may be adjusted by the BA and may be variable across the operating range of a resource.

P.U. Sustained Primary Frequency Response Calculation

* $HZ_{Actual} = HZ_{(T + 46)}$



*Check for adequate up headroom, low frequency events. Headroom must be greater than either 5MW or 2% of (HSL less PA Capacity), whichever is larger. If a unit does not have adequate up headroom, the unit is considered operating at full capacity and will not be evaluated for low frequency events.

Check for adequate down headroom, high frequency events. Headroom must be greater than either 5MW or 2% of (HSL less PA Capacity), whichever is larger. If a unit does not have adequate down headroom, the unit is considered operating at low capacity and will not be evaluated for high frequency events.

For low frequency events:

$$Headroom = HSL - PACapacity - MW_{T-2}$$

For high frequency events:

$$Headroom = MW_{T-2} - LSL$$

**No further evaluation is required for Sustained Primary Frequency Response. This event will not be included in the Rolling Average calculation of either Initial or Sustained Primary Frequency Response.

T = Time in Seconds

Revision History

Version	Date	Action	Change Tracking
1	7/25/2011	Approved by SDT and submitted to Texas RE RSC for approval to post for regional ballot	
1.1	12/7/2012	Approved by SDT for submission to Texas RE RSC for approval to post for second regional ballot.	Changed sustained measure from average over event recovery period to point at 46 seconds after FME, and other changes to respond to field trial results, comments, and corrections.
1.1	3/6/2013	Texas RE RSC approves submittal to Texas RE Board	
1.1	4/23/2013	Texas RE Board approves submittal to NERC and FERC	
1.1	9/18/2013	NERC and Texas RE file Petition for approval to FERC	
1.1	1/16/2014	Approved by FERC	
1.2	5/21/2015	Texas RE Board approves revisions to Attachment 2 Primary Frequency Response Reference Document	<p>For clarification and consistency of the equations used in the Attachment, changes performed to:</p> <ul style="list-style-type: none"> - “T” in the equations refers to the start of the Frequency Measurable Event. - “T-2” nomenclature utilized for clarity rather than “t(-2)” (applicable to numerous equations) - Removed floating x in $EPFR_{final}$ for Steam Turbine equation - Corrected sign convention for Expected Sustained Primary Frequency Response to match the calculation for expected primary frequency response. Corrected Adjusted MW for $ESPFR_{final}$ for Steam Turbine by multiplying -1 to calculate proper value. - On Steam Flow Change Factor removed floating x and reinserted PA Capacity. - Clarified Footnote 5 for scenario of high frequency event for setting LSL as operating margin (similar to HSL for low frequency events). - Clarified in flowcharts for both P.U. Initial Primary & Sustained

BAL-001-TRE-2 — Primary Frequency Response in the ERCOT Region

			<p>Frequency Response Calculations:</p> <ul style="list-style-type: none"> ○ Unit needs to have Headroom and be above LSL to be scored. ○ Cap EPFR_{final} at value of Headroom on unit <ul style="list-style-type: none"> - Per RSC 5/11/2015, all references to “Final” were changed to “final”. - Per RSC 5/11/2015, P.U.PFR and P.U.S.PFR removed italics in flowcharts.
1.3	11/14/2016	RSC approves minor changes to Attachment 2 Primary Frequency Response Reference Document	Replaced Reliability Standards Committee with Members Representative Committee to conform with changes to the Texas RE bylaws and regional standards development process.
1.3	12/07/2016	Texas RE Board approves minor changes to Attachment 2 Primary Frequency Response Reference Document.	Replaced Reliability Standards Committee with Members Representative Committee to conform with changes to the Texas RE bylaws and regional standards development process.
2.0	12/11/2019	Texas RE Board approves changes to the Attachment.	<p>Removed the requirement for Governor droop and deadband settings for Steam turbines of combined cycle resources.</p> <p>Edited Requirements R9.3 and R10.3 to reflect the current process for submitting an exclusion request.</p> <p>Removed Attachment 1, which is the implementation plan for Regional Standard BAL-001-TRE-1. Changed numbering on Attachment 2 to Attachment 1</p>