BAL-001-TRE-1

Primary Frequency Response

Evaluation Model Version 1.9 - Manual

Eric Armke, LCRA

Table of Contents

Introduction

This manual provides information on the use of the new Excel Primary Frequency Response Evaluation Model which efficiently evaluates the frequency response of generating units (Resources) in preparation for the BAL-001-TRE NERC Regional Standard. The manual first provides a "quick setup" section which allows the user to quickly set up their Resources and perform a trip event evaluation without going into unnecessary detail. The results of an evaluation are then explained, again listing only the essentials. The remainder of this manual analyzes each worksheet within this model in detail and includes an explanation of all cells and their purposes.

This model checks compliance for 2 out of the 9 requirements listed in the Standard. The requirements the model checks are the following:

1) If a unit's initial $\frac{MW\ Actual}{MW\ Ideal}$ output is ≥ 0.75 P.U. (BAL-001-TRE requirement 8).

2) If a unit's sustained $\frac{MW\ Actual}{MW\ Ideal}$ output is ≥ 0.75 P.U. (BAL-001-TRE requirement 9).

A unit does not fail if the rolling average of at least 8 measurable events is ≥ 0.75 P.U. A unit can fail a single event ($P.U.^{Single} < 0.75$) but still pass the Standard ($P.U.^{Avg} \geq 0.75$). This model deals only with single-event trips. It does not perform a rolling average.

Model Worksheets

Your fleet performance is summarized in the 4 worksheets below:

1) Governor Parameters – Summarizes governor settings for each Resource.
2) Unit MW HSL – Raw data of units' MW output and HSL is input here.
3) Total Gen - Graphs the grid frequency and total generation of the fleet for a 1 hour period.
4) Report Summary – Summarizes the performance of each Resource for the trip event.

Each Resource is summarized in the 4 worksheets below:

1) FR Unit 'x' - Calculates frequency response for Unit 'x' based on unit HSL, droop setting, and governor deadband.
2) Unit 'x' Perf – Performance evaluation for Unit 'x'. Builds data around trip event for the unit and assembles the data for "Chart Unit 'x'". Calculates initial and sustained performance. The chart on this worksheet is a visual check of Requirement 9.
3) Chart Unit 'x' – Displays 2 minutes of data around the event with the unit's initial performance results. This is a visual check of Requirement 8.
4) Unit 'x' – Displays the full hour of data for frequency and Unit MW.

Fleet pass/fail results are most easily seen in the "Report Summary" worksheet after a trip event has been evaluated.

Quick Setup

This section gives a swift run-through on how to initially set up and use the spreadsheet for a trip event. Details and descriptions for specific items can be found in the later sections.

Most of these steps need only be done for the initial setup. After this first setup, only the steps under "Unit MW HSL", "Report Summary", and possibly "Throttle Pressure" need be completed for all trip evaluations afterwards.

"Unit MW HSL" Worksheet

1) Rename all units in row 4. These names will carry over to the rest of the worksheets. Do not delete any unit columns that are not used.
2) Put in the data start time and end time in cells B1 and B2 respectively.
    a. The start time should be approximately 10-20 minutes before the beginning of the event; it does not have to be exact. The end time is exactly one hour after the start time.
3) Put the data start time in cell B6 and copy it down that column, increasing it in 2-second intervals for one full hour.
    a. Also, right-click on cell B6 and select "format cells". Under the number tab, click on time and select the type that gives the full name e.g., 1:30:55 PM.
4) Obtain 2-second interval data for the frequency, net MW, and HSL for all units. Frequency data goes in column C. MW data begins in column D. HSL data begins in column BC.

"Governor Parameters" Worksheet

1) Fill out the three highlighted columns "Gross or Net MW", "Governor Type" (Choose between Electronic, Digital or Mechanical), and "Prime Mover Type" (Steam, Combined Cycle CT, Hydro, etc.).
    a. The difference between electronic and digital is electronic refers to an analog signal while digital refers to a digital signal of a software program.

"Report Summary" Worksheet

1) Identify the beginning time of the trip event. To acquire this time, find the first frequency value that deviates from the pre-event steady state frequency in column C of worksheet "Unit MW HSL". ***This identifies the beginning of the event t(0).*** Once acquired, replace the row number identified as t(0) in the formula in Cell E2 of the worksheet "Report Summary" with this row number (you would insert, for example, B420 if the cell B420 on the unit MW HSL sheet is the first frequency deviation of the event). All "Unit 'x' Perf" worksheet evaluations and "Chart Unit 'x'" graphs will now be centered and evaluated around the event at t(0).

2) Input the recovery time of the trip event. This recovery time is when frequency returns to the pre-event frequency or 59.984 Hz, *whichever is lower* for low-frequency events. For high frequency events, the recovery time is when frequency returns to pre-event frequency or 60.0166 Hz, *whichever is higher*. The pre-event frequency is located 2 seconds before t(0). The recovery time is the first frequency that surpasses this pre-event frequency. Once acquired, replace the cell number in the formula in Cell E6 of the worksheet "Report Summary" with this new cell number. This is virtually the same procedure as when finding the frequency at the beginning of the trip event.

"FR Unit 'x'" Worksheet

1) Fill out the following highlighted cells in column D
    a. Grid Nominal Frequency
    b. Turbine Capability
        i. This is the HSL of the unit at the time of the event.
    c. Droop Setting in %
    d. Deadband Setting (Hz)
2) Fill out the following highlighted cells in column K:
    a. Is this a Combustion Turbine? Type Y or N.
        i. If Y, then enter .00276 for cell K2.
        ii. If N and this is not a steam turbine (hydro, etc.), then enter a 1 in cell K2, a 1 in cell P12 on the "Unit x Perf" worksheet, and a 0 in cell K4.
    b. Rated Throttle Pressure.
        i. This is the throttle pressure that the unit operates at to reach HSL under normal conditions.
    c. PSIG Change/MW Change.
        i. This is the throttle pressure decay. This factor is only for steam turbines. If this is not a steam turbine, then enter a 0 in this cell.
        ii. If you don't know the pressure drop or if there is none, then just enter a 0 in this cell to eliminate the reduction in expected performance.

PSIG/MW Example	PSI	MW
Pre-Event	2000	220
Post-Event	1996	228
Difference	4	8
PSIG Change/MW Change	**0.5**	

"Unit 'x' Perf" Worksheet

1) Governor Minimum Load Performance (cell N14).
    a. This is the minimum MW load of the plant at which the unit cannot provide any more frequency response DOWN with respect to a high frequency event.
    b. This should be close if not exactly LSL.
2) Throttle Pressure Impact Curve (cell P12)
    a. Use the table provided to enter the typical throttle pressure curve of the unit.

    Cell P12 represents the throttle pressure at the time of the event.
3) Frequency Response Filter Constant
    a. This models the delay in delivery of primary frequency response. A 1.0 means the unit provides instantaneous MWs. The following settings are general guidelines:
        i. 0.08-0.20 hydro units.
        ii. 0.10-0.25 steam turbines coal fired and large gas fired steam turbines
        iii. 0.25-0.35 steam turbines gas fired less than 550 MW
        iv. 0.45 combustion turbines and wind turbines
    b. To fine-tune this constant, look at the graph on the "Perf Unit 'x'" worksheet. Change the filter constant to get the sensitivity of the target trend to match the actual gen MW. This can be achieved by adjusting the constant to get the slope of the target trend to have the same slope as the actual MW trend during the initial MW response.

Again, most of these steps need only be done for the initial setup. After this first setup, only the steps under "Unit MW HSL", "Report Summary", and possibly "TP" need be completed for all trip evaluations afterwards.

Evaluation Results

This section explains the results of a trip event evaluation.

Report Summary

The "Report Summary" worksheet provides a quick overview of each unit's performance. The user can quickly check if a unit passed or failed an event and by what degree. Various fleet totals are provided as well. A section at the bottom of the report is available to enter event data provided by ERCOT. This will be the official Pre and Post event frequencies, MW amount that contributed to the event and total LaaR tripped if any. From this data the Interconnection frequency response performance will be calculated and displayed.

Column C displays the HSL for each unit at the beginning of the trip event.

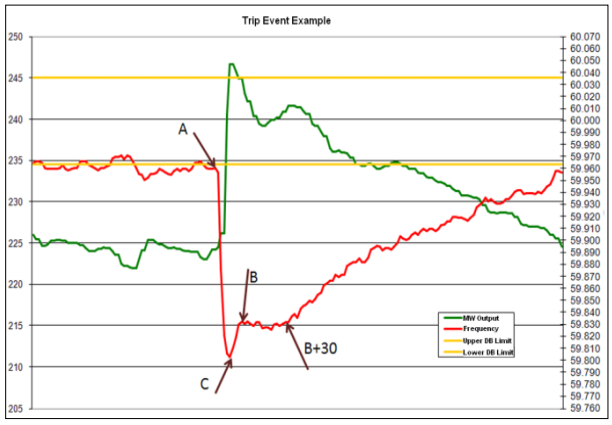
Column D displays the spinning reserve for each unit that is online.

Column E displays unit MW output just prior to the beginning of the trip event.

> Cells E3 and E4 display the frequency before and after the trip event respectively. Cell E5 displays the overall change in frequency due to the trip event.

Column F displays the initial MW change used in R8 evaluation for each unit due to the trip event.

Column G displays the initial performance of each unit as a per unit measurement. This column displays the $\frac{Actual\ MW}{Expected\ MW}$ output ratio from pre-perturbation to post-perturbation, which is shown in the graph below. If the rolling average of a unit's initial output ratio is ≥ 0.75 P.U., the unit passes Requirement 8 of the Standard. A rolling average consists of at least 8 measurable events.



Point A – Pre-perturbation average frequency

Point C – Lowest frequency level during the trip

Point B – Post-perturbation average frequency

Red Line – Frequency

Green Line – MW Output

Column H displays the droop for each unit.

Column I evaluates whether or not a unit's performance is acceptable with respect to its initial PU performance.

Column J displays the sustained performance of each unit as a per unit measurement. This column displays the same ratio as in column G except that the measurement period is during the recovery period of the frequency event. If the rolling average of a unit's sustain output ratio is ≥ 0.75 P.U., the unit passes Requirement 9 of the Standard. A rolling average consists of at least 8 measurable events.

Column K evaluates whether or not a unit's performance is acceptable with respect to its sustaining PU performance.

Row 58 displays fleet totals for the various parameters given above.

Total Gen

The "Total Gen" worksheet gives a graphical representation of grid frequency and fleet MW output for the entire hour. It also displays the fleet totals from row 58 in worksheet "Report Summary".

Chart Unit 'x'

The "Chart Unit 'x'" worksheet gives a detailed 2-minute graphical representation of an individual unit's initial performance. Aside from the grid frequency (pink) and specific unit MW output (dark blue), this chart also displays numerous other statistics that are described below.

Standard Minimum Performance MW Change – This is the purple line and indicates the minimum performance the specified unit can have and still pass compliance standards. This corresponds to a P.U. value of 0.75.

100% Performance – This is the dark red line and indicates the ideal performance of the unit based on droop setting, governor deadband, and unit limiting factor. This corresponds to a per unit value of 1.0.

Average MW – This is the light blue line and indicates the average MW performance of the unit during the initial performance measurement. This is the actual MW value of the generator.

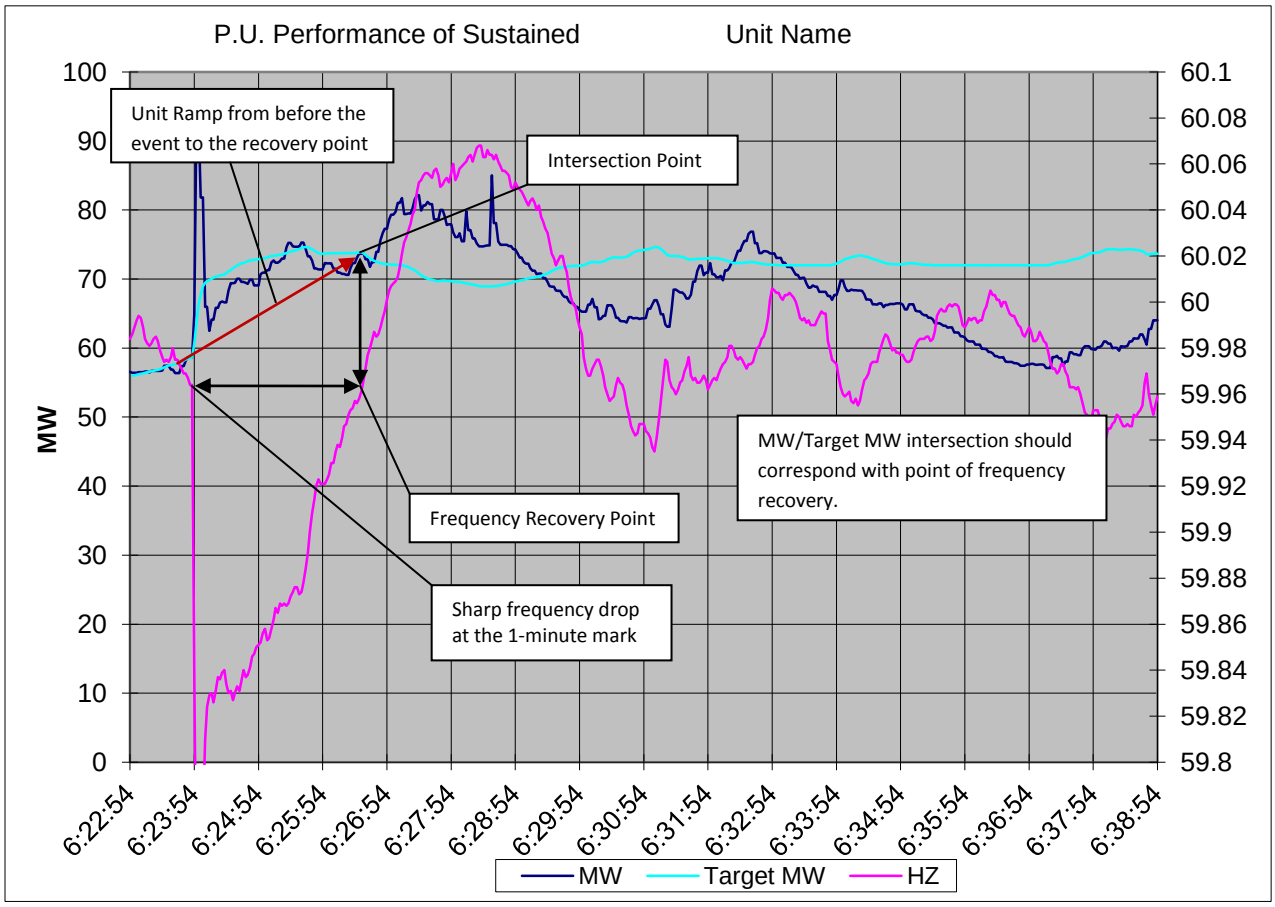
***The order of the three previously mentioned performance lines is important.* The minimum performance line will always be underneath the 100% performance line. If the average MW line is below the minimum performance line, then this visually shows the unit has failed for that event. If the average MW line is above the 100% performance line, then the unit has outperformed the model's ideal performance estimate (P.U. value > 1.0).

Average Frequency – This is the yellow line and shows the average frequency before and after the event.

Unit 'x' Perf

This worksheet provides a vast amount of information that is mainly used to calculate the initial and sustained results that are displayed in other worksheets and graphs for easy inspection. Key data in this worksheet is described below.

1) Builds the table for the sustain response and sustain response graph.
    a. This is the graph on the far right which displays 16-minute data showing the grid frequency, ideal (target) MW output of the unit, and actual MW output of the unit starting exactly 1 minute before t(0), and ending 15 minutes after t(0). The number in the top left of the graph is the sustained P.U. performance of the unit. It is the ratio of the actual MW response with respect to the ideal MW response during the frequency recovery period. A 1.0 represents a perfect MW response of that unit (follows target exactly).
    b. If t(0) is selected correctly, then the 'frequency drop' should sharply decrease at the one-minute mark. Also, the actual MW and target MW lines ***should intersect with each other exactly at the time of frequency recovery*.** This is required since the area under the curve is integrated as part of data calculations. However, if the Target reaches the HSL of the unit during the recovery period, the Target will diverge from Actual MW at the recovery point. In this scenario special tests are performed to select the correct measurement of performance. The point of frequency drop and the point of actual MW/target MW intersection are the boundaries of this integration. If these boundary points are correct, then this model has evaluated the trip correctly. The spreadsheet should inherently force this to happen. An example is shown below:



It should be noted that the actual MW/target MW may cross various times during the recovery period. This means the unit is on target and is withdrawing frequency response correctly as the frequency recovers.
This graph also gives a visual of the Resources' Unit Ramp (cell G4). The Unit Ramp can be seen with a line that starts at the actual MW/target MW intersection at the beginning of the event and ends at the actual MW/target MW intersection at the point of recovery.

2) Builds the table for initial response and initial response graph. This is the graph just described in the worksheet "Chart Unit 'X'".
3) Resource pre-event ramp adjustment (MW change). This is cell F4 and indicates if the Resource was ramping up (positive number) or ramping down (negative number) before the start of the trip event.

Unit 'x'

This worksheet visually displays the unit's frequency response for the entire 1-hour evaluation. Frequency is indicated in pink while MW output is indicated in blue. The chart also shows **Pre-Event HSL**, **Spinning Reserve**, and **P.U. Performance** at the top.

Detailed Worksheet Overview

The following sections give a detailed analysis of each worksheet.

Governor Parameters

This worksheet summarizes governor settings used in the evaluation tool for each Resource and provides the user the opportunity to add additional information about each Resource.

Column A – Provides buttons (macro) that navigates the user to each unit's specific "Chart Unit 'x'" worksheet. Pressing Ctrl+G will return the user to the "Governor Parameters" worksheet.

Column B – Labels each unit as "Unit 'x'".

Column C – Retrieves the actual name of each unit from worksheet "FR Unit 'x'".

Column D – Retrieves turbine HSL from worksheet "FR Unit 'x'".

Column E – User inputs whether turbine capacity is gross HSL or net HSL. Net HSL will normally be used except for facilities that have additional parasitic load.

Gross HSL – Power at the generator terminals.

Net HSL – Power delivered to transmission system.

$$Net\ HSL = Gross\ HSL - Auxilaries - Transmission\ losses$$

Column F – Retrieves droop setting from worksheet "FR Unit 'x'".

Column G – Retrieves deadband setting from worksheet "FR Unit 'x'".

Column H – User inputs governor type (mechanical, digital, or electronic).

The difference between electronic and digital is electronic refers to an analog signal while digital refers to a digital signal.

Column I – Indicates whether or not each unit is a combustion turbine.

Column J – User inputs unit type (Combined Cycle, Steam, etc.).

Column K – Limiting factor. This is the factor that models the limits that prevent the unit from operating at maximum performance during the initial measurement period of this standard. This will be based on throttle pressure decay and stored energy limitations for steam turbines. For combustion turbines, the limiting factor represents the mass flow change due to the change in speed of the turbine during the event. This column references the "Throttle Pressure Change" in cell G3 of the worksheet "FR Unit 'x'". Refer to the explanation of cell G3 of worksheet "FR Unit 'x'" for more information.

Column L – Indicates what creates the limiting factor. This will either be "Throttle Pressure Change" or "Mass Flow Change with Speed Change".

Column M – Governor Minimum Load Performance. Minimum load at which the governor primary frequency response can no longer be sustained during an event. This is the minimum MW load of the plant in which the unit cannot provide any more frequency response down with respect to a high frequency event. This should be close if not exactly LSL. At some minimum operating point, the controls of the generator must block the governor action in order to prevent the unit from tripping. If there is no blocking action required, then 0 MW will be displayed.

Column N – Frequency Response Filter Constant. This is a time filter that models the delay in a unit's MW response with respect to a grid frequency change. This filter is needed since it takes time to deliver the energy within a unit to produce a MW response. Typically, the larger the unit, the longer this time delay. This filter can model any type of unit. A 1.0 means the unit provides instantaneous MWs and turns the time filter off. The following settings are recommended and are changed in the "Unit 'X' Perf" worksheet:

i. 0.08-0.20 hydro units.
ii. 0.15-0.25 steam turbines coal fired and large gas fired steam turbines
iii. 0.25-0.35 steam turbines gas fired less than 550 MW
iv. 0.45 combustion turbines and wind turbines

To fine-tune this constant, look at the graph on the "Perf Unit 'x'" worksheet. Change the filter constant to get the sensitivity of the target trend to match the actual gen MW. They should have the same slope if the time constant is set close. Once set for that unit, it should stay the same for all future evaluations.

Unit MW HSL

This worksheet is where the user enters its fleet MW and HSL data during the trip event. Grid frequency, MW values, and HSL data is entered here. The spreadsheet is set up for 60 minutes of 2-second interval data. 4-second interval data will not be evaluated correctly unless serious changes are made to the "Unit 'X' Perf" sheets. If a 4-second scan rate is used, simply repeat each data point to mimic 2-second data. Data should be selected around the frequency event beginning approximately 10 to 20 minutes before the beginning of the event.

Column B – Excluding Cells B1-B2, Column B displays a time span of 60 minutes in 2-second intervals. The beginning time is arbitrarily selected 10 to 20 minutes before the beginning of the trip.

Cell B1 – User inputs unit trip evaluation start time.

Cell B2 – User inputs unit trip evaluation end time.

Column C – Grid frequency data for each 2-second interval.

Column D – Column BA– Net MW output of each unit during the selected time span. The name of each unit goes in row 4. The names inserted here will be appropriately distributed to all graphs and worksheets. Data entry begins in row 6.

Column BC – Column CZ – High sustainability limit (HSL) of each Resource in the given time span.

Total Gen

Graphs the grid frequency and total generation of the fleet for the time period selected. The graph includes data such as total MW change, total frequency response of the fleet, and droop performance of the fleet.

On-Line Capacity – The total online capacity at the time of the trip event. This is the sum of the HSLs of all online Resources.

Total Generation – Sum of each Resources' generation before the trip event. This summation occurs at the pre-perturbation point of the event.

Spinning Reserve – Sum of each unit's spinning reserve before the trip event.

$$Spinning\ Reserve = HSL - Online\ Capacity$$

Total MW Change – Sum of the total trip event MW change of all online units.

MW/0.1Hz – MW change per $1/10^{th}$ of a Hertz change of the fleet.

Report Summary

Summarizes the performance of each Resource for the trip event. Only the cells highlighted in yellow require user input. All other cells obtain their data from other areas of the spreadsheet.

Column A – Provides buttons (macros) that direct the user to each unit's specific "Chart Unit 'x'" worksheet. Pressing Ctrl+R will return the user to the "Report Summary" worksheet.

Column B – Unit name.

Column C – HSL for each unit at the start of the event. This is taken from Column S in worksheet "Unit 1 Perf" beginning in the row below the cell that contains the text "Pre-Event HSL" (beside column S).

Column D – Spinning Reserve for each unit. This is taken from worksheet "Unit 'X' Perf". However, if a unit's MW Pre-event output is insignificant (<1), then this cell is left blank. This usually means the unit is offline.

Column E – MW Pre-event output. Beginning in row 8, column E lists MW output of each generator before the trip event.

Cell E2: User inputs the beginning time of the trip event. To acquire this time, find the first frequency value that deviates from the pre-event steady state frequency in column C of worksheet "Unit MW HSL". *This identifies the beginning of the event t(0).* Once acquired, replace the row number identified as t(0) in the formula in Cell E2 of the worksheet "Report Summary" with this row number (you would insert, for example, B420 if the cell B420 on the unit MW HSL sheet is the first frequency deviation of the event). All "Unit 'x' Perf" worksheet evaluations and "Chart Unit 'x'" graphs will now be centered and evaluated around the event at t(0).

Cell E3: The average frequency before trip event. Taken from Cell E2 on worksheet "Unit '1' Perf".

Cell E4: The average frequency at the initial evaluation point of the event. Taken from Cell E3 on worksheet "Unit '1' Perf".

Cell E5: Difference between the frequencies taken before and after the trip event. Taken from Cell I2 on worksheet "Unit 'X' Perf".

Cell E6: User inputs the recovery time of the trip event. This recovery time is when frequency returns to the pre-event frequency or 59.984 Hz, whichever is lower *for low-frequency events*. *For high frequency events*, the recovery time is when frequency returns to pre-event frequency or 60.016 Hz, whichever is higher. The pre-event frequency is located 2 seconds before t(0). The recovery time is the first frequency that surpasses this pre-event frequency. Once acquired, replace the cell number in the formula in Cell E6 of the worksheet "Report Summary" with this new cell number. This is virtually the same procedure as when finding the frequency at the beginning of the trip event.

Column F – Difference in the average power output before and after the trip event. This is taken from Cell I3 on worksheet "Unit 'X' Perf".

Column G – The initial P.U. Performance of each unit during this event.

$$P.U.Performance = \frac{Actual\ Primary\ Frequency\ Response}{Expected\ Primary\ Frequency\ Response}$$

If the 12-month rolling average of a unit's initial performance is ≥ 0.75 P.U., the unit passes Requirement 8 of the Standard. A rolling average consists of at least 8 measurable events. This model evaluates 1 event at a time.

Column H – Droop performance of each unit. This is calculated on worksheet "Unit 'X' Perf". If a unit's MW Pre-event output from column E in worksheet "Report Summary" is insignificant (<1), then this cell is left blank and the Resource is labeled as offline.

Column E – Row 64 through Row 71. Enter ERCOT publically reported information about the event (R1 and R3 of the standard). This includes Generator MW lost, Total LaaR tripped if any and the official Pre and Post Perturbation frequencies.

Column I evaluates whether or not a unit's performance is acceptable with respect to its initial PU performance.

Evaluation responses are given below:

MW Pre-event Condition	P.U. Performance	Initial Evaluation
<1	Blank	Off Line
>1	Blank	No Evaluation
>1	<0.7	Low
>1	0.7<x<0.8	Marginal
>1	0.8<x<0.9	Good
>1	>0.9	Excellent

Column J displays the sustain performance of each unit as a per unit measurement. This column displays a similar ratio as column G except this time for the performance during the frequency recovery period. If the rolling average of a unit's sustained output ratio is ≥ 0.75 P.U., the unit passes Requirement 9 of the Standard. A rolling average consists of at least 8 measurable events.

Column K – Sustained response evaluation. Evaluates whether or not a unit's performance is acceptable with respect to its sustained PU performance.

Sustainment responses are given below:

Initial Evaluation Condition	P.U. Performance Sustain	Sustain Evaluation
Off Line	Blank	Blank
No Evaluation	Blank	No Evaluation
Online and any Initial Evaluation	<0.75	Withdrawn
Online and any Initial Evaluation	>0.75	Sustained

Column L – Comment column. Reasons that contributed to below-expected performance are written here.

Cell R2 – Minimum spinning reserve. This model and the Standard do not evaluate Resources operating greater than 98% of their HSL for low frequency events.

Column AF – Total Generation of the portfolio for the Total Gen graph.

FR Unit 'X'

Calculates the MW frequency response and droop values of Unit 'x'. Columns C – F calculate MW/droop values without limiting factors considered. These are ideal values. Columns H – K calculate MW/droop values with limiting factors considered. These are the values the unit should actually display.

Column A – Frequency deviation between nominal grid frequency and actual grid frequency.

Column B – Frequency span of a 5% droop Resource in incremental steps.

Column C – Unit's frequency response without limiting factors considered. If a particular grid frequency (Column B) is within the user-defined deadband range for that unit, then the corresponding frequency response will display 0 MW.

Column D -- Excluding first 5 rows, Column D calculates the proportional droop curve of the specified unit at each frequency increment.

Cell D1 – User inputs nominal grid frequency.

Cell D2 – User inputs turbine capacity for unit (the unit's HSL).

Cell D3 – User inputs governor droop setting.

Cell D4 – User inputs deadband setting (in Hz).

Cell D5 – Span of the proportional droop curve of the governor with the deadband taken into consideration (cell E3).

Column E – Excluding Cell E3, Column E calculates (for information only) the MW response performance that the Resource would attain if they perform at 75% of the stated droop curve and deadband.

Cell E3 – Span of frequency based on the droop setting of the Resource relative to the nominal frequency. This is calculated by multiplying the droop setting with the nominal grid frequency.

Column F – Column F calculates (for information only) the droop% performance that the Resource would attain if they perform at 75% of the stated droop curve and deadband.

Column G – Excluding Cell G3, Column G calculates the Resource limiting parameter factor. The Standard has identified limiting factors for different types of Resources that account for operational conditions that limit performance during the initial primary frequency response measure. For combustion turbines, this includes the effect of changes in mass flow through the turbine due to grid frequency. For steam turbines, it includes operation at less than rated steam pressure, steam expansion based on % steam flow, and loss of steam pressure due to the sudden change in steam demand.

Cell G3 – For steam turbines, the value represents the typical pressure change per MW change near mid-load of the Resource. For combustion turbines, the value represents the typical MW change in output caused by a $1/10^{th}$ Hz change in frequency due to mass flow change. In both cases this is a calculated value from other areas of the spreadsheet.

Column H – For combustion turbines, this is the Resources' expected MW frequency response adjusted for mass flow change. For steam turbines, this is the Resources expected MW frequency response adjusted for the loss of steam pressure due to sudden change in steam demand.

Column I – Calculates expected droop adjusted for limiting factors considered in column H.

Column J – Calculates minimum expected MW frequency response adjusted for limiting factors considered in column H.

Column K – Excluding Cells K1-K4, column K calculates minimum expected droop% adjusted for limiting factors considered in column H.

Cell K1 – User indicates if unit is a combustion turbine.

Cell K2 – User indicates rated throttle pressure if unit is a steam turbine. If specified unit is a combustion turbine, enter 0.00276. This value is used in calculating the limiting factor impact on the Resource. For a combustion turbine, the factor is multiplied by the capacity (HSL) of the Resource to calculate the value for cell G3, which the MW change per 1/10th Hz change in frequency. For steam turbines, rated throttle pressure is used to calculate the impact of operations at reduced pressure.

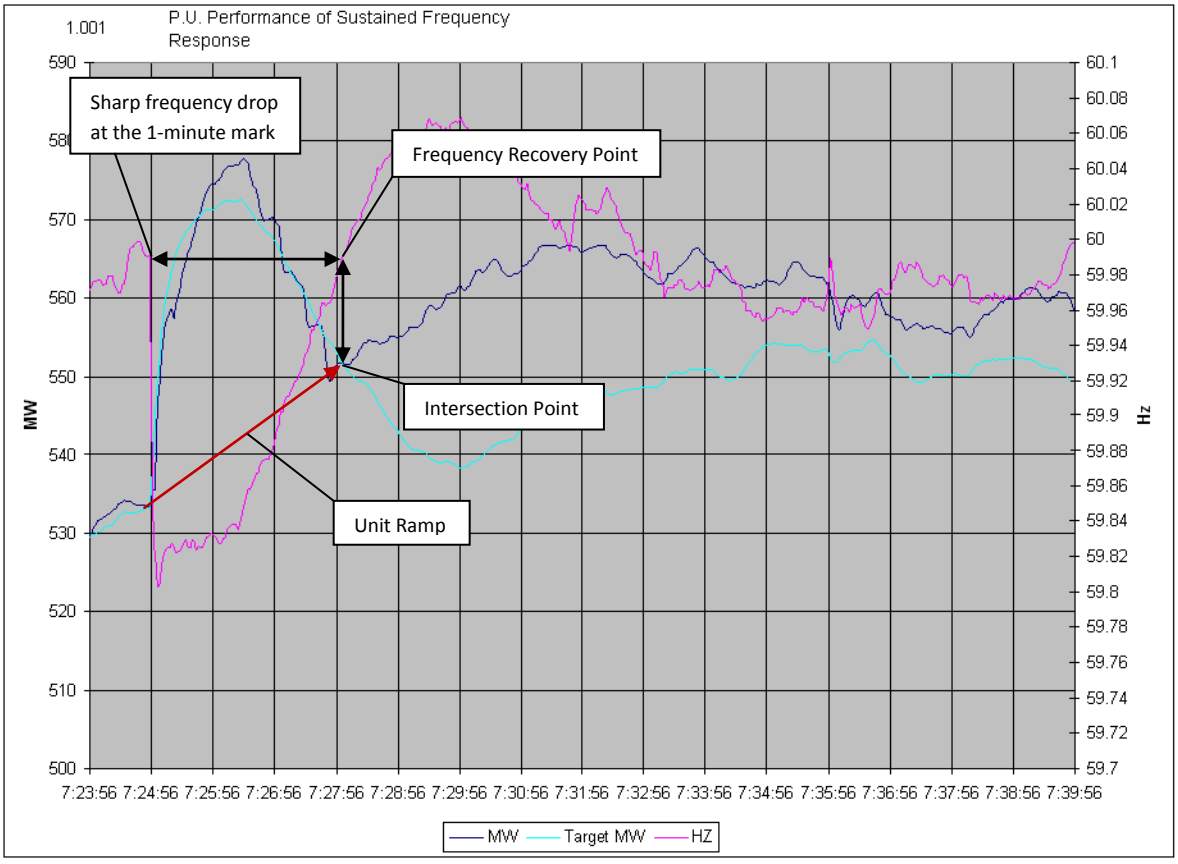
Cell K3 – Informational display of the Resources' initial P.U. performance.

Cell K4 – User enters expected PSIG Change/MW Change when the Resource is operating near 50% output. This value is used to calculate the impact of throttle pressure change due to the sudden change in steam flow. This factor is for steam turbines only.

Unit 'X' Perf

Performance evaluation for Unit 'x'. Builds data around trip event and assembles the data to be displayed in "Chart Unit 'x'". The graph on the far right displays 16-minute data showing the grid frequency, ideal (target) MW output of the unit, and actual MW output of the unit starting exactly 1 minute before t(0), and ending 15 minutes after t(0). The number in the top left of the graph is the sustained P.U. performance of the unit. It is the ratio of the actual MW response with respect to the ideal MW response during the frequency recovery period. A 1.0 represents a perfect MW response of that unit (follows target exactly).

The actual MW and target MW lines must intersect at the time of frequency recovery. This model should force this to happen automatically. An example is given below:



If the Target reaches the HSL of the unit during the recovery period, the Target will diverge from the Actual MW at the recovery point. Logical if statements are then used to properly calculate performance.

Column A through Column D is a table built automatically, based on t(0), to align the event data for performance evaluation and chart construction.

Column A – Time label reference (t(0)) for each 2-second interval during the event.

Column B – Displays the clock during the event covering 1 minute before and 15minutes after the beginning of the trip event in 2 second intervals. The beginning of the trip event begins in row 34 (t(0)).

Column C – Excluding Cells C1 and C2, Displays the grid frequency at each 2-second interval.

Cell C1 -- Beginning time of the trip event (t(0)) that is sourced from the "Report Summary" sheet.

Cell C2 – Scan rate of the data. Leave at 2 seconds for proper evaluation.

Column D – Displays the net MW output for each time interval.

Column E

Cell E2 – Average grid frequency before trip event. Averages the frequency in Cells C26-C33 to determine frequency for the "A" point.

Cell E3 – Average grid frequency after trip event. Averages the frequency in Cells C44-C60 to determine frequency for the "B" point.

Column F

Cell F2 – MW output of unit 'x' before trip event. Averages the MW output in Cells C26-C33. This value is used for the initial P.U. performance measure.

Cell F3 – MW output of unit 'x' after trip event. Averages the MW output in Cells C44-C60. This value is used for the initial P.U. performance measure.

Cell F4 – Resource Pre-event Ramp adjustment (MW change). The effect of the pre-event ramping of the Resource is added to the expected frequency response to account for controlled unit movement during the measurement periods of the initial performance measure.

MW Change (Cells F5-F8)

Cell F5 – Standard Minimum Performance MW change due to frequency response. Does not include pre-event ramp component.

Cell F6 – Ideal MW change adjusted for deadband and all limiting factors including mass flow for combustion turbine, steam pressure change due to sudden change in steam flow, reduced throttle pressure operation and steam expansion for steam turbines.

Cell F7 – Ideal MW change based on droop setting and deadband. This is for a Resource with infinite energy.

Cell F8 – Ideal MW change adjusted for droop, db, all limiting factors & pre-event ramp of the Resource.

Droop% Values (Cells F10-F14)

Cell F10 – Standard Minimum Performance droop. Does not include pre-event ramp component.

Cell F11 –Ideal droop adjusted for deadband and all limiting factors including mass flow for combustion turbine, steam pressure change due to sudden change in steam flow, reduced throttle pressure operation and steam expansion for steam turbines.

Cell F12 –Ideal droop based on droop setting and deadband. This is for a Resource with infinite energy.

Cell F13 – Ideal droop adjusted for droop, db, all limiting factors & pre-event ramp of the Resource.

Cell F14 – Actual droop of the Resource during the event.

Cell F16 – Actual MW change of the Resource divided by the expected MW change. The expected MW change includes adjustment for all limiting factors and pre-event ramp.

Cell F17 – The sustained P.U. performance of the Resource during the recovery period. This is calculated by dividing the Resources' average MW delivery during the frequency recovery period by the average expected MW delivery during the frequency recovery period. The expected MW delivery is based on droop and governor deadband settings that is time-filter adjusted and the net change in MW of the Resource from the beginning of the event to the frequency recovery point.

Cell F19 – Unit name.

Cell F20 – Displays date of event.

Cell F23 – Unit's spinning reserve.

Column I

Cell I2 – The difference between the average post-perturbation frequency and the average pre-perturbation frequency.

Cell I3 – The difference between the average post-perturbation MW of the Resource and the average pre-perturbation MW of the Resource.

Column K – Displays the average frequency for the event. This is for information only and is used for graphing. Shows same data as cells E2 & E3.

Column L – Displays the average MW output for the event. This is for information only and is used for graphing. Shows same data as cells F2 & F3.

Column N

Cell N2 – Pre-event MW change due to frequency with respect to ideal droop and the unit's deadband.

Cell N3 – Post-event MW change due to frequency with respect to ideal droop and the unit's deadband.

Cell N4 – Event total MW change with respect to ideal droop and deadband for the event frequency change. Displays the difference between the post-event and pre-event frequency responses.

Cell N5 – Limiting Factor MW Impact on expected primary frequency response.

Cell N6 – Percent Steam Flow $= \frac{\text{MW output after trip event.}}{\text{Unit HSL}}$. Used to determine the impact of steam expansion over the load range of the Resource.

Cell N7 – Calculates the sensitivity of throttle pressure change due to the sudden change of steam flow based on the % of steam flow.

Cell N14 – User Inputs minimum load for governor in service. This is the minimum MW load of the plant at which the unit cannot provide any more frequency response down with respect to a high frequency event. This should be close to if not exactly LSL.

Column O

Cell O2 – Pre-event expected MW change based on pre-perturbation average frequency with respect to ideal droop and deadband that is adjusted for all limiting factors.

Cell O3 – Post-event expected MW change based on post-perturbation average frequency with respect to ideal droop and deadband that is adjusted for all limiting factors.

Cell O4 – Event total expected MW change with respect to ideal droop and deadband that is adjusted for all limiting factors. This does not include the pre-event ramp adjustment.

Column P

Cell P2 –Pre-event expected MW change based on pre-perturbation average frequency with respect to ideal droop and deadband that is adjusted for all limiting factors multiplied by 0.75 to calculate the minimum pre-event MW change.

Cell P3 – Post-event expected MW change based on post-perturbation average frequency with respect to ideal droop and deadband that is adjusted for all limiting factors multiplied by 0.75 to calculate the minimum post-event MW change. This does not include the pre-event ramp adjustment.

Cell P4 – Event total expected MW change with respect to ideal droop and deadband that is adjusted for all limiting factors multiplied by 0.75 to calculate the minimum total event MW change. This does not include the event ramp adjustment.

Cell P12 – Calculates the throttle pressure of the Resource at the pre-perturbation MW output. A table is provided to estimate throttle pressure of the unit at the time of the event. This table is for units that reduce pressure when the operate at minimum load. If the unit does not reduce pressure, enter rated pressure in cells P18, P19, P20 and P21. If it does reduce pressure, enter the MW – Pressure breakpoints in the table provided. If not known or data is not available, the value can be set equal to the rated throttle pressure.

Column Q

Cell Q9 – Calculates the impact (in MW) due to the sudden change in steam flow caused by the event. The value represents the impact if the Resource was a 50% output.

Cell Q10 – Calculates the impact (in MW) due to the sudden change in steam flow caused by the event. The value represents the impact at the estimated % steam flow of the Resource.

Cell Q12 – Calculates the percent of rated throttle pressure at pre-perturbation time period.

Column S – High Sustainability Limit. Displays the HSL at each time interval.

Column T

Cell T33 – Indicates the last HSL before the trip event occurs.

Column U – Standard Minimum Performance MW used for graphing.

Column V – User inputs Frequency Response Filter Constant.

a. This models the delay in delivery of primary frequency response. A 1.0 means the unit provides instantaneous MWs. The following settings are general guidelines:
    i. 0.08-0.20 hydro units.
    ii. 0.15-0.25 steam turbines coal fired and large gas fired steam turbines
    iii. 0.25-0.35 steam turbines gas fired less than 550 MW
    iv. 0.45 combustion turbines and wind turbines
b. To fine-tune this constant, look at the graph on the "Perf Unit 'x'" worksheet. Change the filter constant to get the sensitivity of the target trend to match the actual gen MW. This can be achieved by adjusting the constant to get the slope of the target trend to have the same slope as the actual MW trend during the initial MW response.

Column W – Performance multiplier for sustained frequency response measure. This value is set to 1.0, removing its impact on the measure.

Column X – Expected frequency response based on droop and deadband settings that is time-filtered based on the frequency response filter constant.

Column Y – Expected initial primary frequency response based on droop, dead band setting, and all limiting factors. Used for graphing.

Column Z – Expected frequency response based on droop and deadband settings that are time-filtered based on the frequency response filter constant multiplied by 1. This is effectively the same as column X.

Column AA – The pre-event MW ramp, and the frequency recovery period MW ramp is calculated based on initial and ending MW output levels. From these ramp values, a linear MW change during the pre-event and frequency recovery period is calculated. The values in column AA represent the scan rate MW change based these two ramp periods.

Column AB – Calculates the expected MW change during the frequency recovery period based on expected frequency response in column Z and ramp MW in column AA.

Cell AB2 – Calculated total MW change of the Resource from the pre-perturbation point to the frequency recovery point.

Column AC – Calculates the Resource target MW by adding the expected MW change (column AB) to the pre-perturbation MW output level.

Cell AC2 – Evaluation Duration. This displays the time span of the trip event.

Column AD

Cell AD41 – Calculates the average target MWs during the frequency recovery period.

Cell AD42 – Calculates the average actual MWs during the frequency recovery period.

Column AE

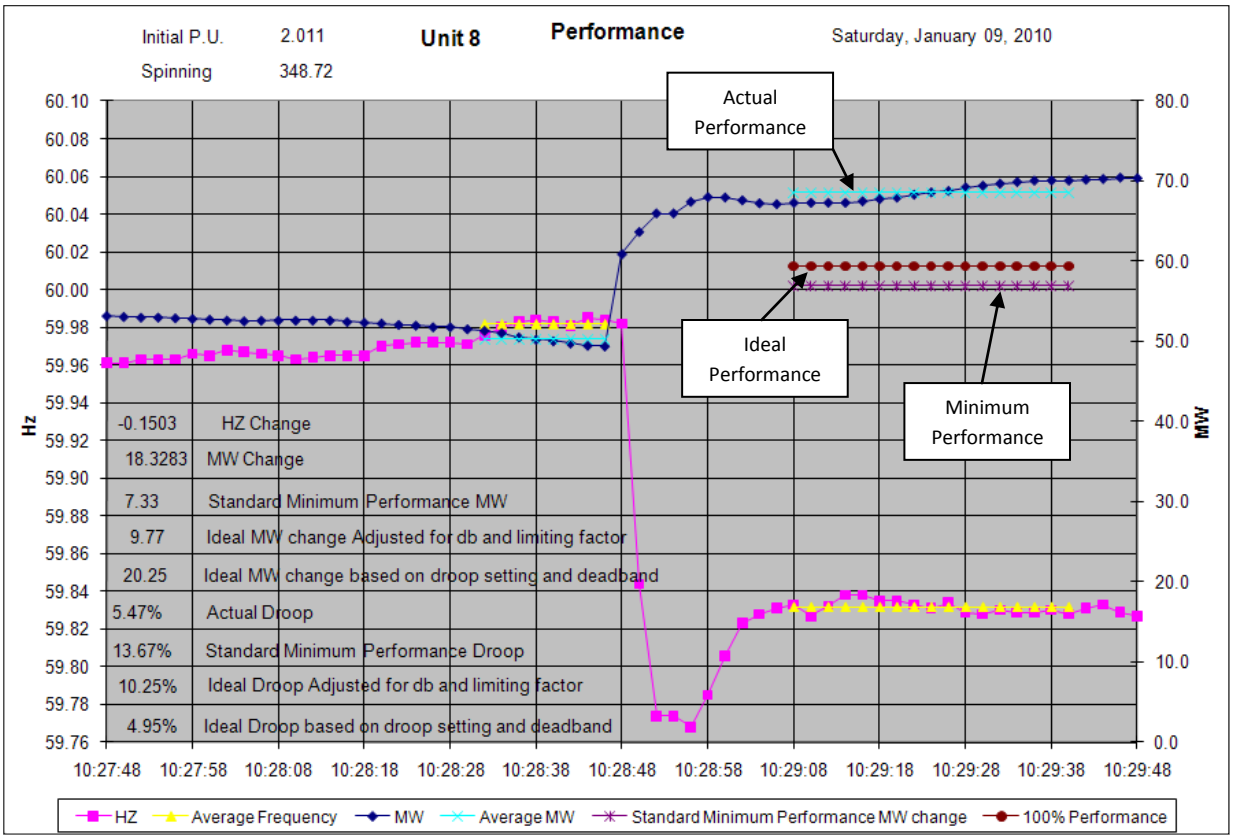
Cell AE62 – Sustained Response P.U. Performance Measure. This is the ratio of actual MW of frequency response divided by the target MW frequency response during the frequency recovery period. A 1.0 represents a perfect MW response of that unit. Tests are also performed to determine if the target reached the HSL of the unit during the recovery period.

Column AF – Average Actual MW.

Column AG – The average target MWs during the frequency recovery period.

Chart Unit 'x'

This chart displays various details of a unit's performance during the initial performance period. The chart is set up with a 2-minute time span to provide a close-up view of the trip event with t(0) being in the center of the graph. Along with showing the grid frequency and MW output, this chart also displays other parameters that are explained below along with an example graph for reference.



Unit 'x'

This worksheet visually displays the unit's frequency response for the entire 1-hour evaluation. Frequency is indicated in pink while MW output is indicated in blue. The chart also shows **Pre-Event HSL**, **Spinning Reserve**, and **P.U. Performance** at the top. This graph is for informational purposes only.