Introducing

Vestas - IEEE2800 Conformity Assessment

Inverter-Based Resource Working Group

Miguel Angel Cova Acosta

IEEE 2800-2022 - DISCLAIMER

Requirement Interpolation – PoI vs WTG

The following criteria are partially defined at this stage by IEEE:

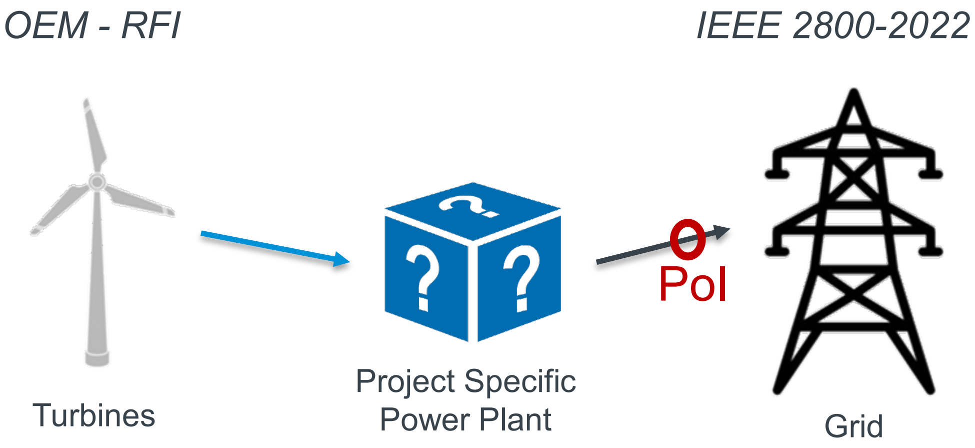
Evaluation Criteria

- Operational Points
- Loading Factor
- Project specific control tuning

Project Specific Conditions that will affect the compliance outcome:

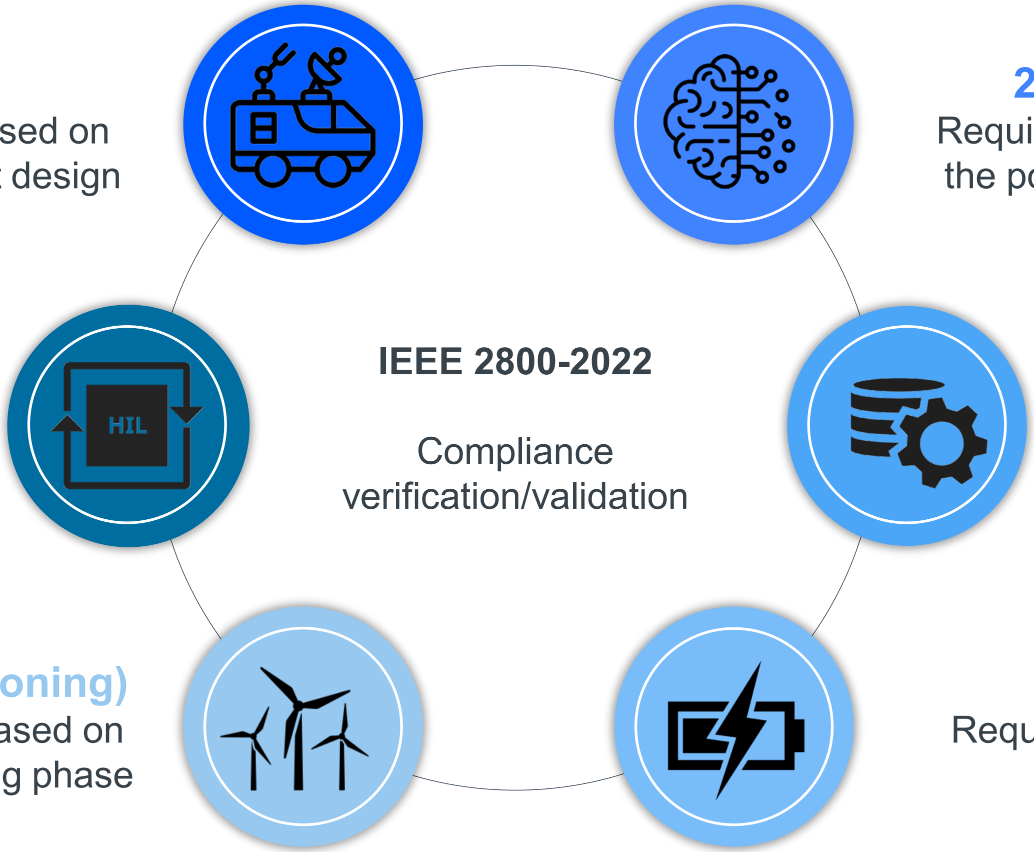
- Grid Stiffness
- Single Line Diagram/Reactive Compensation devices
- PPC Configuration (Control strategy)
- Nearby IBR plants
- Others

It is not straightforward to translate requirements from PoI to WTG



How to demonstrate IEEE 2800-2022 Compliance

Options



1. Field Test
Requirement compliance verification based on measurement campaigns during product design

2. EMT/RMS Model Simulation
Requirement compliance verification based on the power system tool simulation (RMS/EMT)

3. HiL Verification / Validation
Requirement compliance verification based on HiL Lab

4. OEM Confirmation/Attestation
Requirement compliance verification based on OEM model written confirmation

5. Park Performance (Commissioning)
Requirement compliance verification based on plant performance during commissioning phase

6. Exemption
Requirement Exemption based on Technology and/or Grid Stability

Vestas IEEE 2800 Overview

Conformity Assessment

5. Reactive power-voltage control requirements within the continuous operation region

Section	Conformity	Clarity
5.1 Reactive power capability	High	High
5.2 Voltage and reactive power control modes	High	High
5.2.1 General	High	High
5.2.2 Voltage control	High	Low
5.2.3 Power factor control mode	High	High
5.2.4 Reactive power control mode	High	High

6. Active-power—frequency response requirements

Section	Conformity	Clarity
6.1 Primary frequency response (PFR)	High	High
6.1.1 PFR capability	High	Low
6.1.2 PFR performance	High	Low
6.1.3 PFR utilization in operations	High	High
6.2 Fast frequency response (FFR)	High	Low
6.2.1 FFR capability	High	Low
6.2.2 FFR performance	High	Low
6.2.2.1 FFR1: FFR proportional to frequency deviation	High	High
6.2.2.2 Other variants of FFR	High	High
6.2.3 Fast frequency response from wind turbine generator	High	Low

7. Response to TS abnormal conditions

Section	Conformity	Clarity
7.2 Voltage	High	High
7.2.1 Voltage protection requirements	High	High
7.2.2 Voltage disturbance ride-through requirements	High	High
7.2.2.1 General requirements and exceptions	High	High
7.2.2.2 Voltage disturbances within continuous operation region	High	High
7.2.2.3 Low- and high-voltage ride-through within the mandatory operation	High	High
7.2.2.3.1 General	High	High
7.2.2.3.2 Low- and high-voltage ride-through capability	High	High
7.2.2.3.3 Low and high-voltage ride-through performance	Medium	Low
7.2.2.3.4 Current injection during ride-through mode	High	High
7.2.2.3.5 Performance specifications	High	High
7.2.2.4 Consecutive voltage deviations ride-through capability	Medium	High
7.2.2.5 Dynamic voltage support	High	High
7.2.2.6 Restore output after voltage ride-through	High	High
7.2.3 Transient overvoltage ride-through requirements	Medium	Low
7.3 Frequency	High	High
7.3.1 Mandatory frequency tripping requirements	High	High
7.3.2 Frequency disturbance ride-through requirements	High	High
7.3.2.1 General requirements and exceptions	High	High
7.3.2.2 Continuous operation region	High	High
7.3.2.3 Frequency disturbances within the mandatory operation region	High	High
7.3.2.3.1 Low-frequency ride-through capability	High	High
7.3.2.3.2 Low-frequency ride-through performance	High	High
7.3.2.3.3 High-frequency ride-through capability	High	High
7.3.2.3.4 High-frequency ride-through performance	High	High
7.3.2.3.5 Rate of change of frequency (ROCOF) ride-through	Medium	Low
7.3.2.4 Voltage phase angle changes ride-through	High	Low
7.4 Return to service after IBR plant trip	High	High

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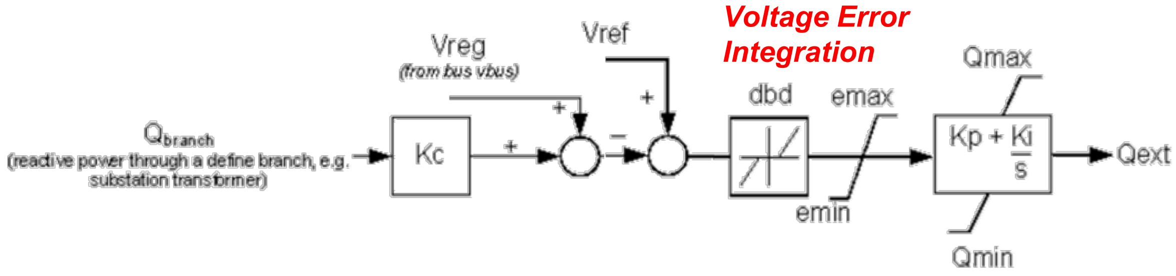
Reactive power-voltage control

Voltage and reactive power control modes

When in this mode, the *IBR plant* shall operate in closed-loop automatic voltage control mode to regulate the steady-state voltage at the RPA to the reference value, as adjusted by the droop function, to within 1% of the RPA voltage set point unless to do so requires reactive power exceeding the reactive power capability of the *IBR plant*. The RPA voltage set point shall be specified by the *TS operator*.
The voltage control system shall be capable of reactive power droop to provide a stable and coordinated response. The droop setting shall be settable and coordinated by the *TS operator* and *IBR operator*. The automatic voltage control shall have a range of available droop settings from 0 to 0.3 per unit voltage change
for 1.0 per unit reactive power on the ICR base. The RPA voltage control settings are allowed to be adjusted locally and/or remotely as specified by the *TS operator*. The dynamic reactive power response of the *IBR plant* to a step change in the RPA voltage within the *continuous operation region* and within *IBR plant*'s
reactive power capability shall be as specified in Table 5.62, 63 Dynamic performance requirements shall be based on, and only applicable to, a defined range of TS equivalent impedance at the POM, specified by the *TS operator*.



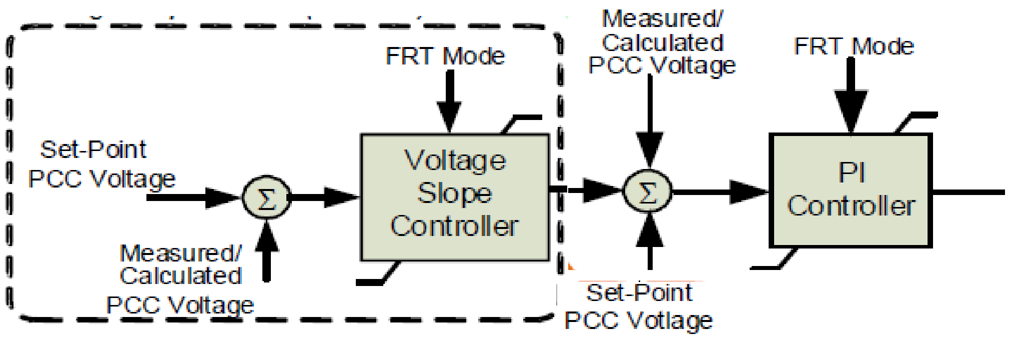
- ***If Kc is not properly tuned, plants will always saturate Q production causing instability during abnormal operation***
- **Q branch response depends on grid strength dQ/dV.**
- **Rise time will not remain constant with grid evolution.**

Parameter	Performance target	Notes
Reaction time	< 200 ms	
Maximum *step response time*	As required by the *TS operator*	The slowest response shall be tuned based on the *TS operator* requirements for response time and stability given the anticipated range of grid strength, other local voltage control devices, and *overshoot* requirements. The *step response time* may typically range between 1 s and 30 s. Any switched shunts or LTC transformer tap change operation needed to restore the dynamic reactive power capability in Figure 8 shall respond within 60 s.

Reactive power-voltage control

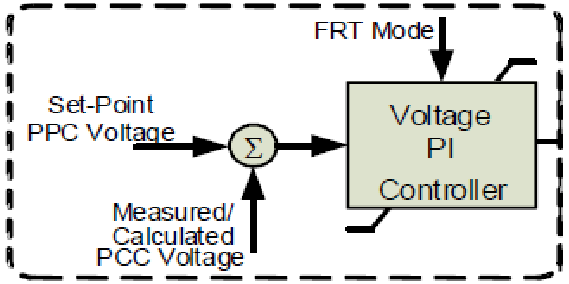
Voltage and reactive power control options

A



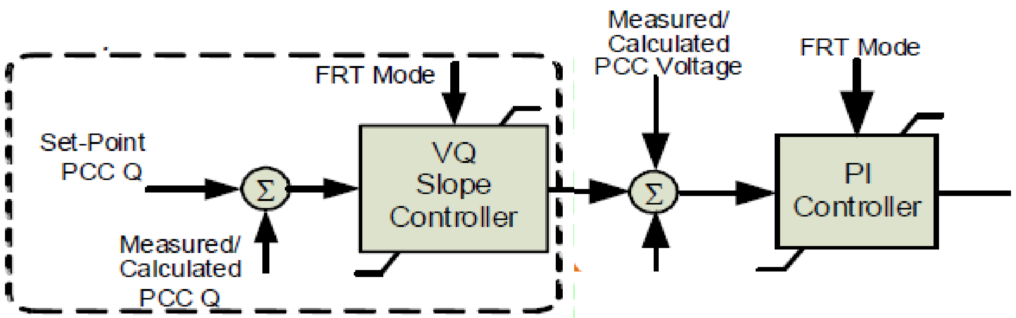
$$Qout_{VslopeType0(Upper)} = \frac{\frac{(V_{ref}[KV]-V_{meas}[KV])}{V_{base}[KV]} + V_{deadbandUpper}[pu]}{Slope_{upper}[pu]}$$

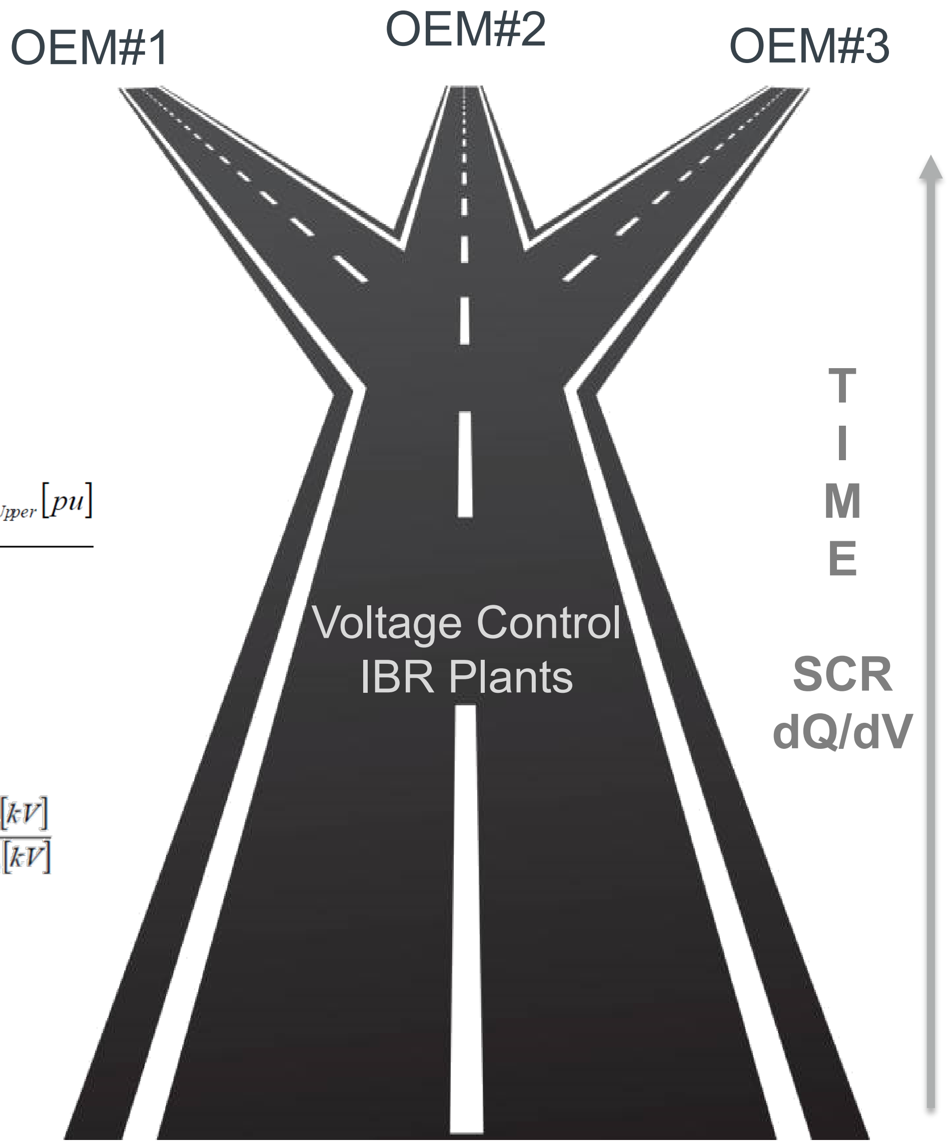
B



$$V_{out}[pu] = Lambda*\frac{Q_{ref}[kVar]-Q_{meas}[kVar]}{P_{nom}[kW]} + \frac{V_{ref}[kV]}{V_{nom}[kV]}$$

C





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Active-power—frequency response requirements

PFR capability

The default *reference point of applicability* (RPA) for the primary frequency response (PFR) capability requirements of an *IBR plant* shall be the *point of measurement* (POM).

The primary frequency response function and overall response capability of an *IBR plant* shall meet the specified performance requirements at the RPA as shown in Figure 9 and Table 6. The *IBR plant* shall have the capability to provide primary frequency response in *continuous operation region* as well as *mandatory operation region* as specified in 7.2 and 7.3.[65]

The primary frequency response shall include the capability to respond to under-frequency disturbances (by active power increase) and over-frequency disturbances (by active power decrease). The use of such capability shall be mutually agreed to between the *IBR owner* and *TS operator*.

The primary frequency response controller shall have fixed droop characteristics (k_{OF} and k_{UF}) with default values as specified in Table 7. It shall be possible to set different levels of droop for under-frequency and over-frequency conditions. The *IBR plant*'s frequency droop parameters shall be capable of adjustment at least to the *ranges of available settings* specified in Table 7. Frequency droop shall be based on the difference between *IBR continuous rating* (ICR) and zero output such that the slopes of the droop curves are always constant.

IBR plant response during under-frequency (UF) conditions shall be limited by the *available active power*.

Note that the *available active power* is limited by *IBR continuous rating* (ICR) or temporarily *IBR short-term rating* (ISR).

Low frequency	$p = \min\{p_{avl}, p_{pre} + p_{PFR}\} = \min\left\{p_{avl}, p_{pre} + \max\left(0, \frac{f_{nom} - f - db_{UF}}{f_{nom} \times k_{UF}}\right)\right\}$ e.g., ICR = 100 MW, k_{UF} = 0.03 Hz/MW (0.05 p.u. droop), db_{UF} = 0.036 Hz p_{pre} = 50 MW = 0.50 p.u., p_{avl} = 51 MW = 0.51 p.u., f_{nom} = 60 Hz; f = 59.9 Hz, then $p = \min\{0.51, 0.50 + (60 - 59.9 - 0.036)/60/0.05\} = \min\{0.51, 0.5213\} = 0.51$ p.u. = 51 MW
High frequency	$p = \max\{p_{min}, p_{pre} + p_{PFR}\} = \max\left\{p_{min}, p_{pre} + \min\left(0, \frac{f_{nom} - f + db_{OF}}{f_{nom} \times k_{OF}}\right)\right\}$ e.g., ICR = 100 MW, k_{OF} = 0.024 Hz/MW (0.04 p.u. droop), db_{OF} = 0.036 Hz, p_{min} = 10 MW = 0.10 p.u. f = 60.1 Hz, p_{pre} = 50 MW = 0.50 p.u., then $p = \max\{0.10, 0.50 + (60 - 60.1 + 0.036)/60/0.04\} = \max\{0.10, 0.4598\} = 0.4598$ p.u. = 45.98 MW

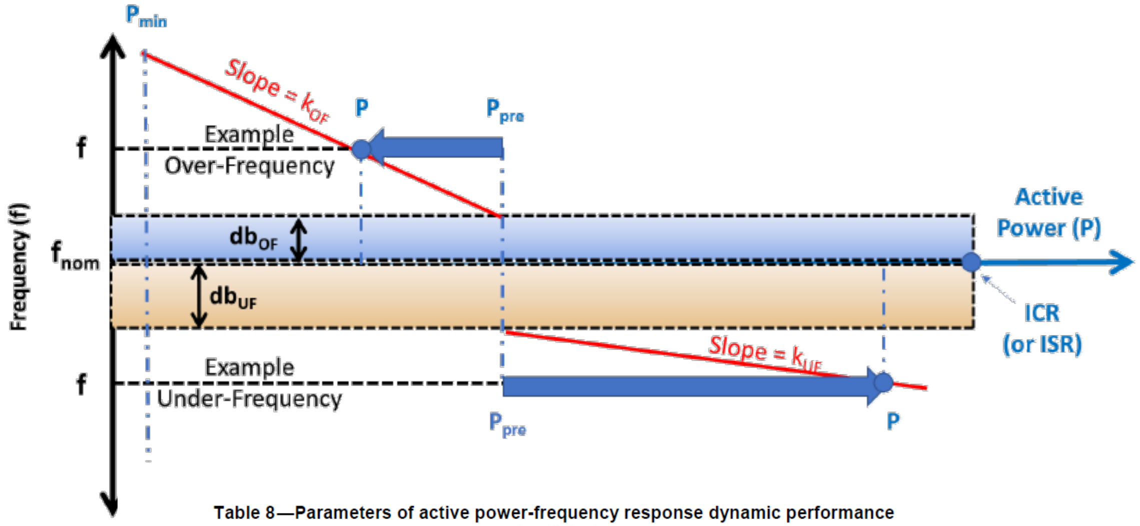


Table 8—Parameters of active power-frequency response dynamic performance for *IBR plant*

Parameter	Units	Default value	*Ranges of available settings*	
			Minimum	Maximum
Reaction time	Seconds	0.50	0.20 (0.5 for WTG)	1
Rise time	Seconds	4.0	2.0 (4.0 for WTG)	20
Settling time	Seconds	10.0	10	30
Damping ratio	Unitless	0.3	0.2	1.0
Settling band	% of change	Max (2.5% of change or 0.5% of ICR)	1	5

Texas (ERCOT) Primary Frequency Response Evaluation

BAL-001 TRE-2

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.

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.

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

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

Aligned IEEE 2800

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

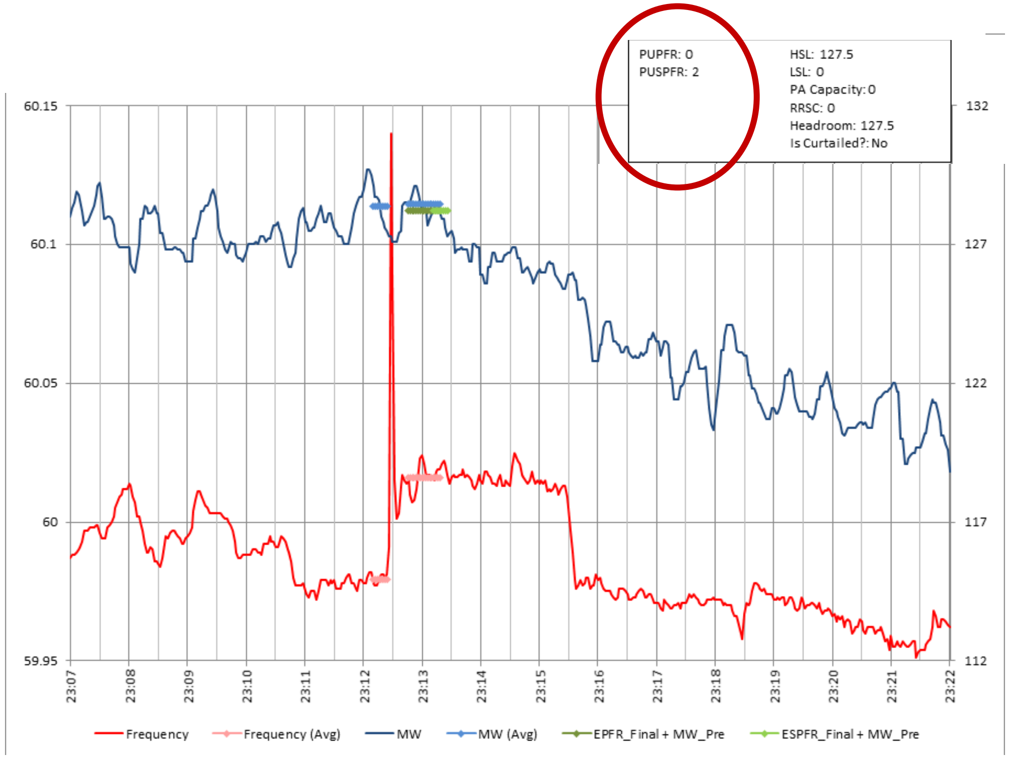
$$APFR_{adj} = MW_{post-perturbation} - MW_{pre-perturbation} - Ramp\ Magnitude$$

Inconsistency IEEE 2800

ERCOT Nodal Operating Guides
Section 8
Attachment J

Initial and Sustained Measurements for Primary Frequency Response

December 9, 2022



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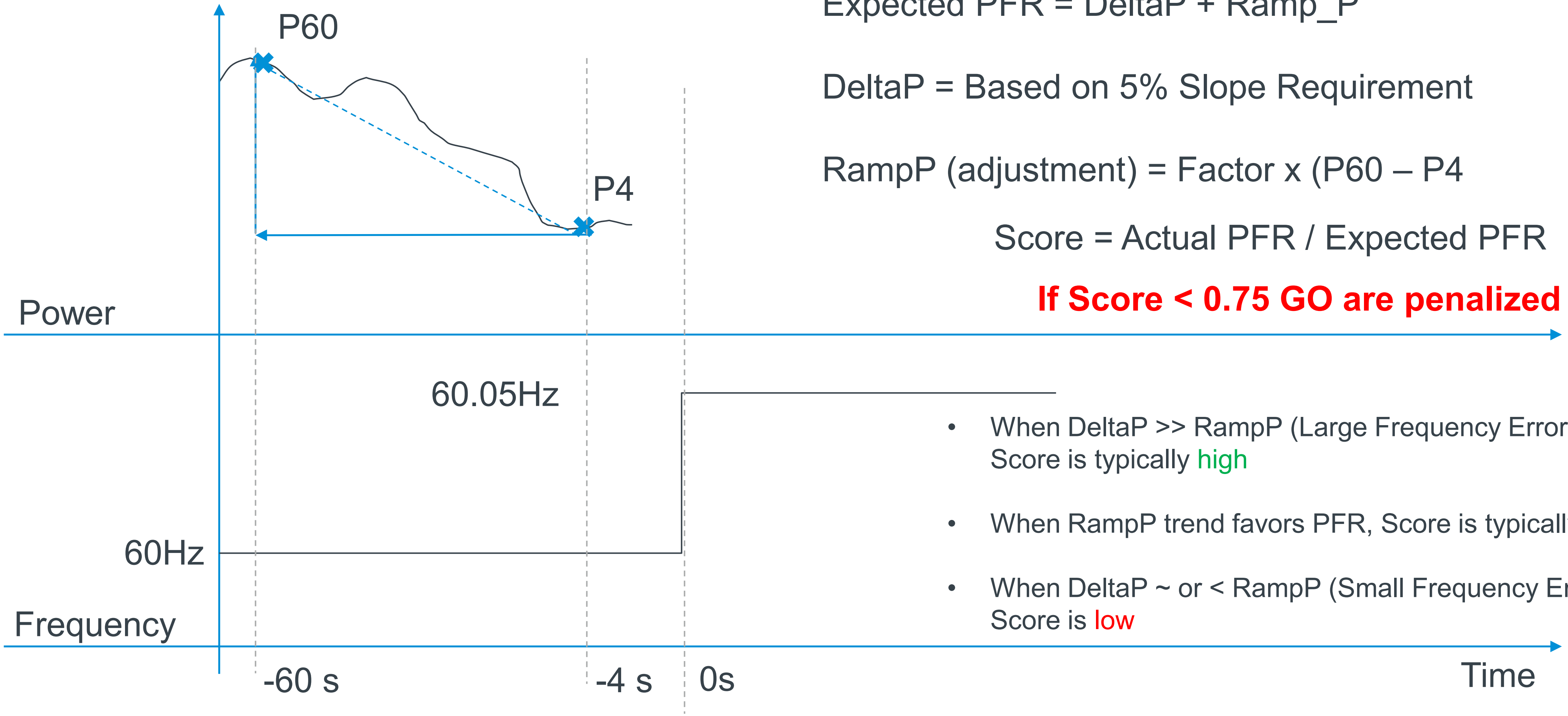
Texas (ERCOT) Primary Frequency Response Evaluation

BAL TRE 001



Expected PFR = DeltaP + Ramp_P

DeltaP = Based on 5% Slope Requirement

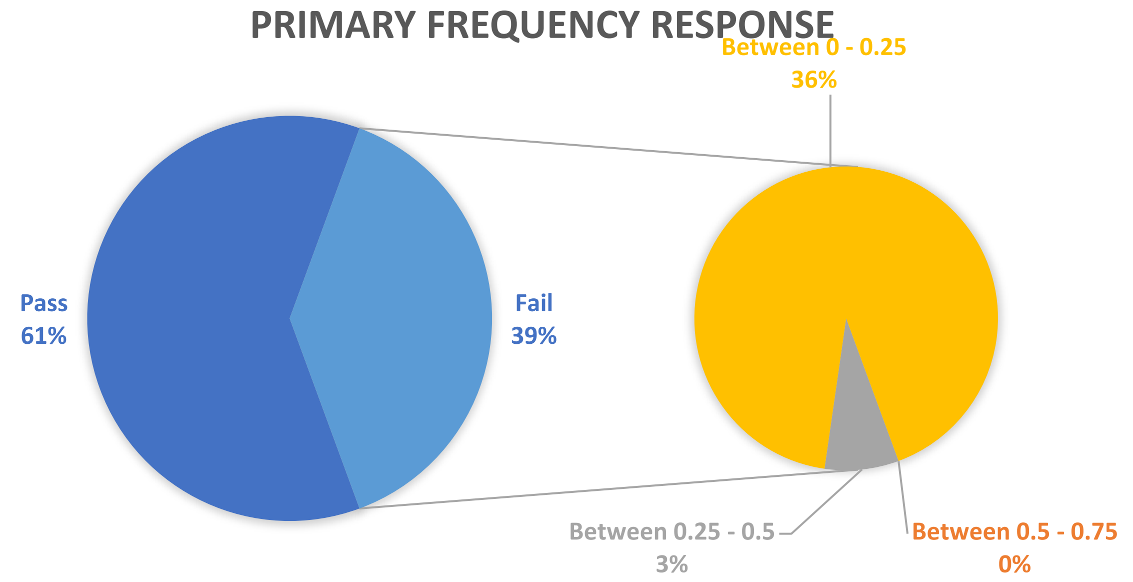
RampP (adjustment) = Factor x (P60 – P4

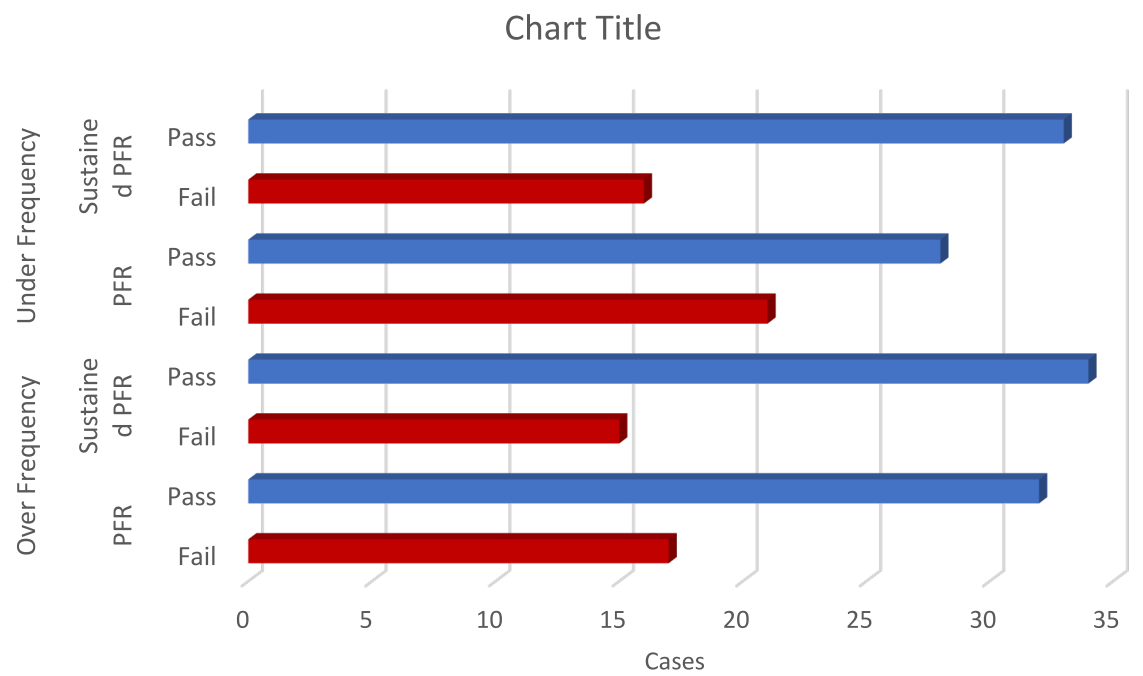
Score = Actual PFR / Expected PFR

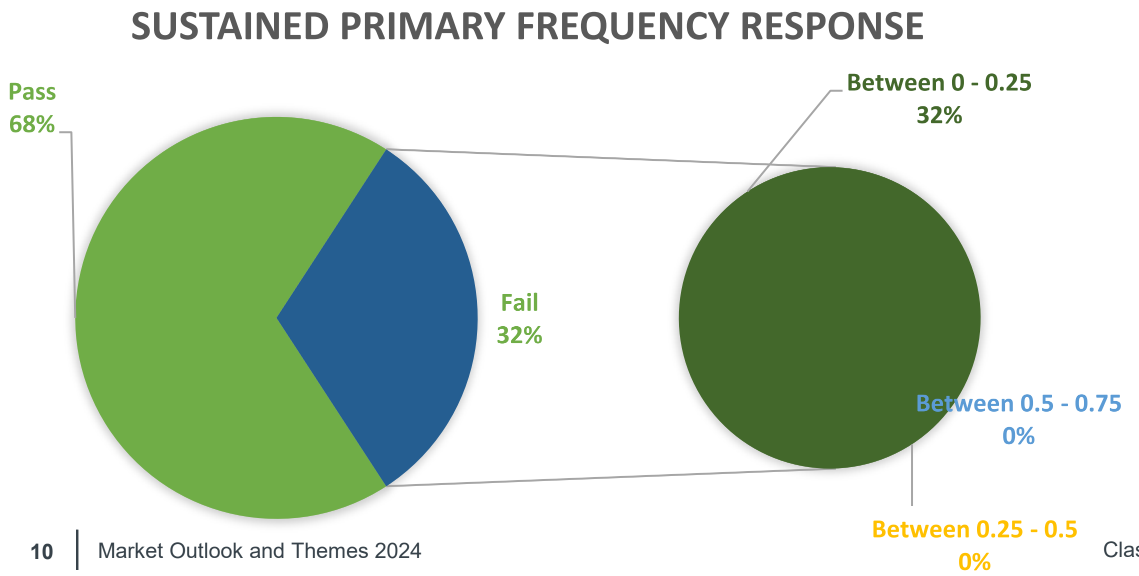
If Score < 0.75 GO are penalized

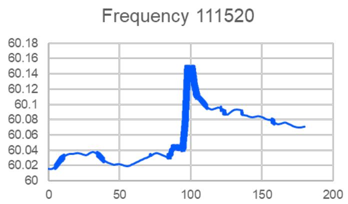
- When DeltaP >> RampP (Large Frequency Error), Score is typically high
- When RampP trend favors PFR, Score is typically high
- When DeltaP ~ or < RampP (Small Frequency Error), Score is low

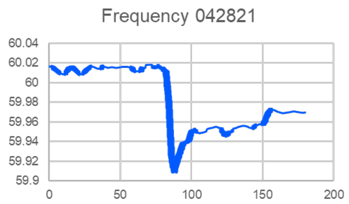
Texas (ERCOT) Primary Frequency Response Evaluation

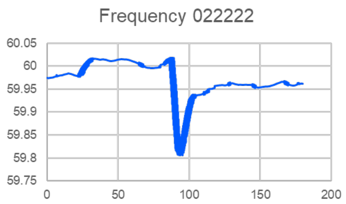


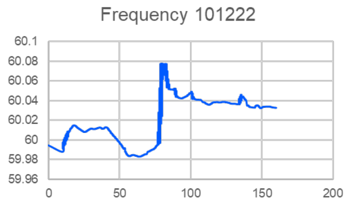


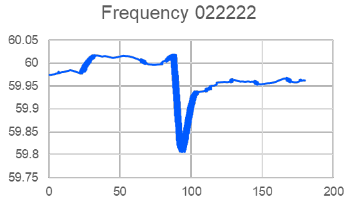


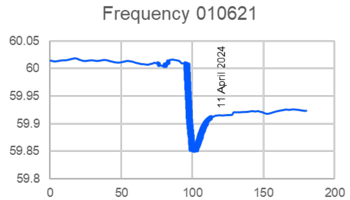












Rate of change of frequency (ROCOF) ride-through

Evaluation

Rate of change of frequency (RoCoF) is the time derivative of the power system frequency (df/dt): it is an important quantity that qualifies as the robustness of an electrical grid. The initial value of the df/dt is the instantaneous RoCoF just after an imbalance of power in the electrical power system (i.e. disconnection of a generator/load tripping), before the action of any control. RoCoF is calculated as follows:

$$RoCoF|_{t=0^+} = \frac{\Delta P_{imbalance}}{P_{LOAD}} \cdot \frac{f_0}{2 \cdot H}$$

Turbines have been tested to ride through 6.5Hz/s+ Hz/s. However, not all corner points have been tested to ensure +-5Hz/s

Important to note EMT or any other model will be useless for ROCOF verification, unless all Auxiliary equipment are modeled and included

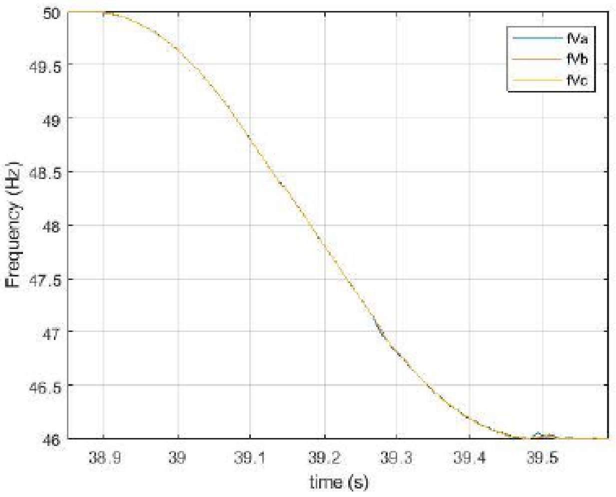


Figure 44 Test 21 Voltage frequency 1st step

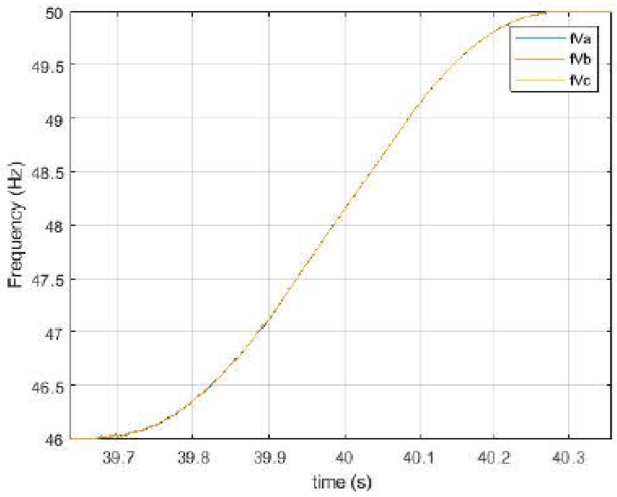


Figure 45 Test 21 Voltage frequency 2nd step

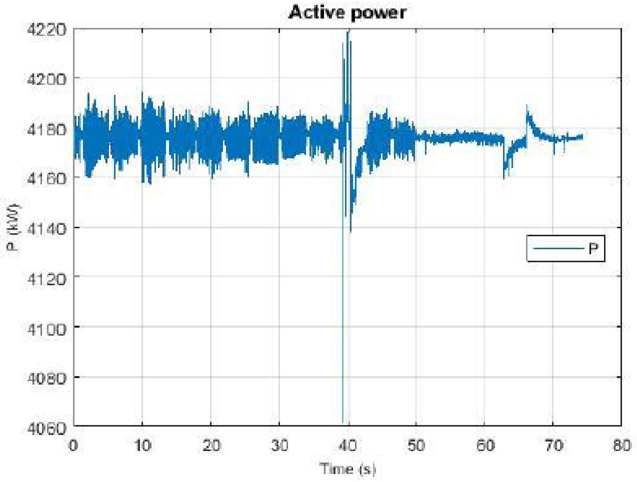
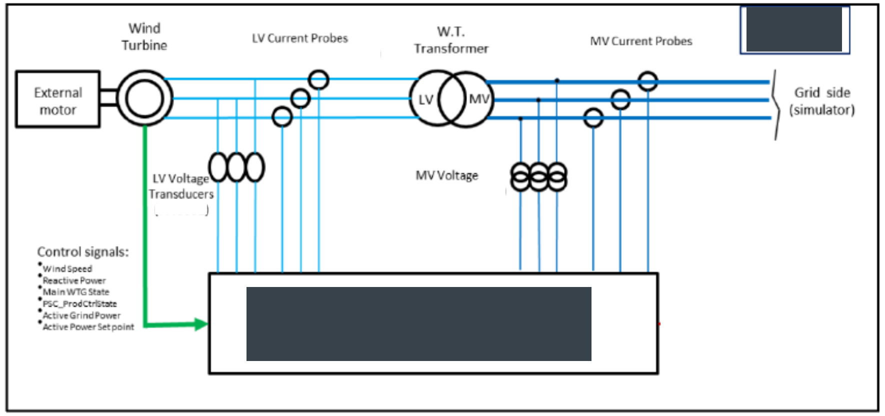


Figure 46 Test 21 Active power



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