POWER ELECTRONICS

# PE LVRT and P(f) Response

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August 2025

# LVRT Response

- Response based on P&Q at event T=0 i.e. $Is_{prev}$ + KDV
- Q Response based on V Threshold and K Value
- During LVRT, PPC setpoints are ignored
- Exit Response Based on LVRT Recovery Ramp Rates
- Inverter may trip if Voltage and Frequency protection trip settings are exceeded.

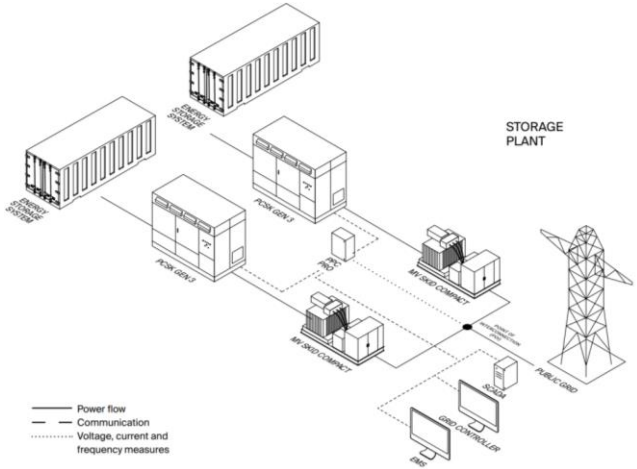
$$K = \frac{\Delta I_r / I_n}{\Delta U / \Delta U_n}$$

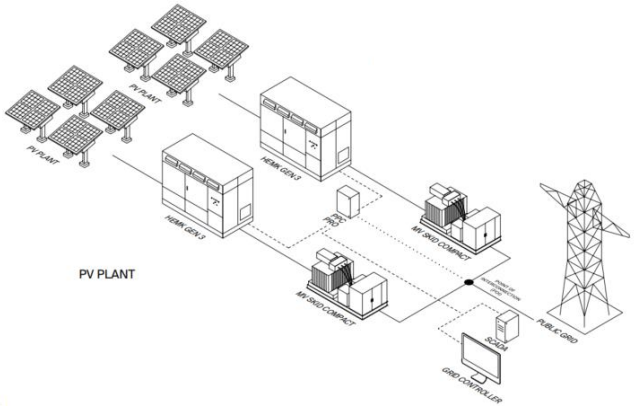
# Powerful, accurate and flexible

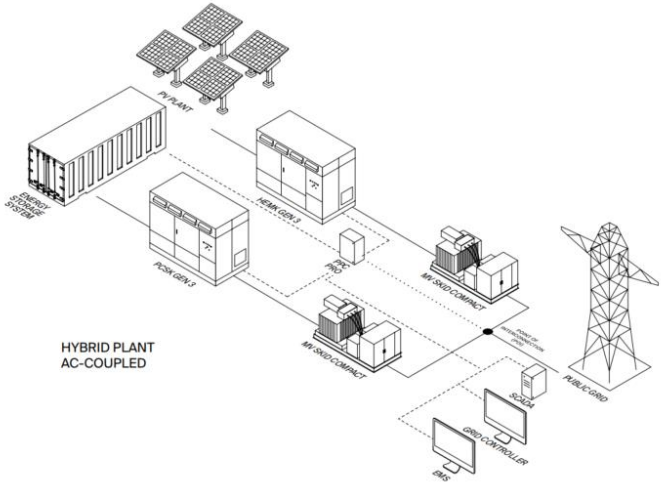
*Flexible PLC Technology*

Real-time control and monitoring for advanced utility-scale applications.

- Solar
- Standalone storage applications [1]
- Hybrid plants- AC coupled [1]
- Self-consumption
- Zero grid injection systems




*[1] BCI required*

- . ERCOT is seeing issues with IBR plants measuring and responding to frequency during VRT events, frequency spikes are being erroneously measured and then PPC responds to those once the event is over, which means it either sends the plant output in the wrong direction or doesn't let the plant's MW recover because it "thinks" there 's an over frequency event.
- ERCOT is looking for OEMs presentations about how they do things today in terms of hand over between VRT mode (which is at inverter level) and PFR response (which is usually at PPC level) as well as how frequency measured & filtered for PFR response. Also, of interest is to understand how an inverter enters and exists VRT mode, i.e. what is driving it, assuming it's voltage, is it instantaneous value, if not what is the measurement window, any time delays there

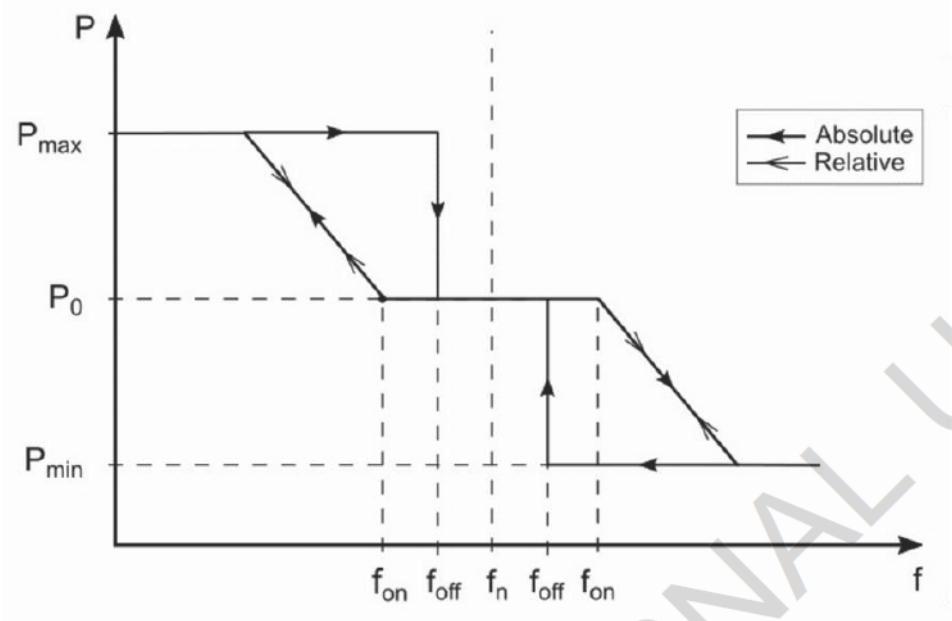
# Inverter parameters and Algorithms

- Voltage and Frequency Protection settings
- Inverter power output - P_limit (solar) and P_set (ESS)
- P and Q Ramp Rate limits
- LVRT and OVRT Algorithms
- Frequency Droop Curves

# Inverter Frequency Droop Curve

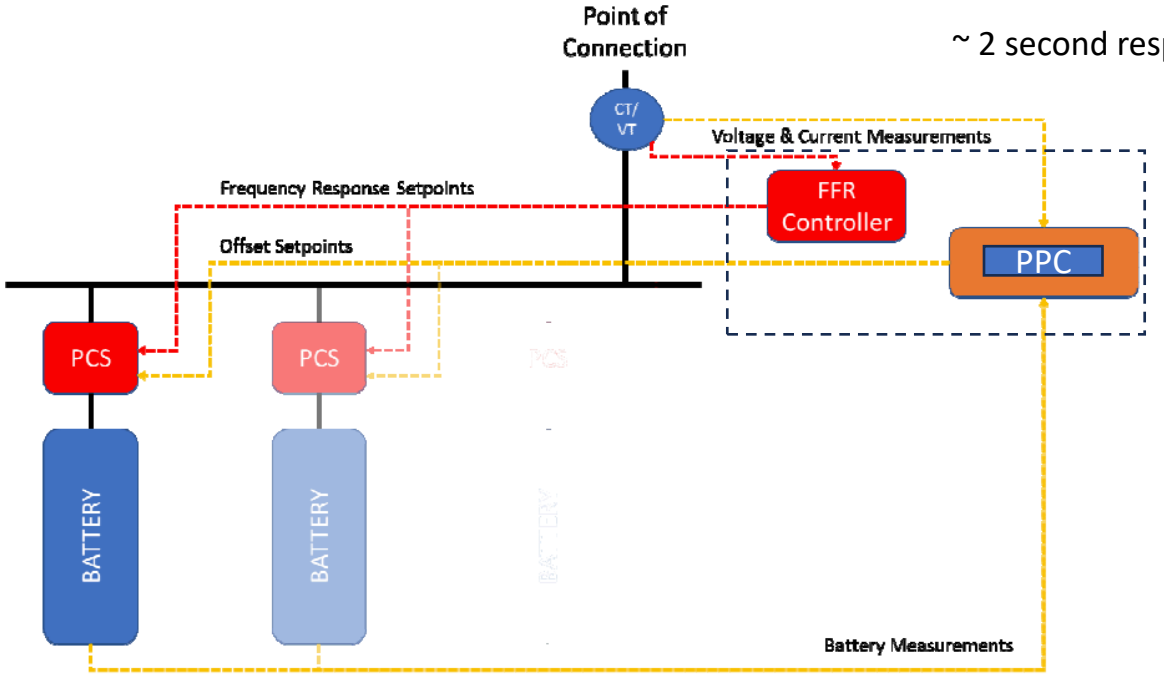
## Subgroup G4.7: P(f) Curve

This subgroup allows the configuration of the P(f) algorithm. The following graph represents the algorithm curve.



# FFR – Central Controller response

### 3.1 Central Controller Option




~ 2 second response

Figure 2 - Central FFR controller

# FFR – Central Controller response

*3.1 Central Controller Option*

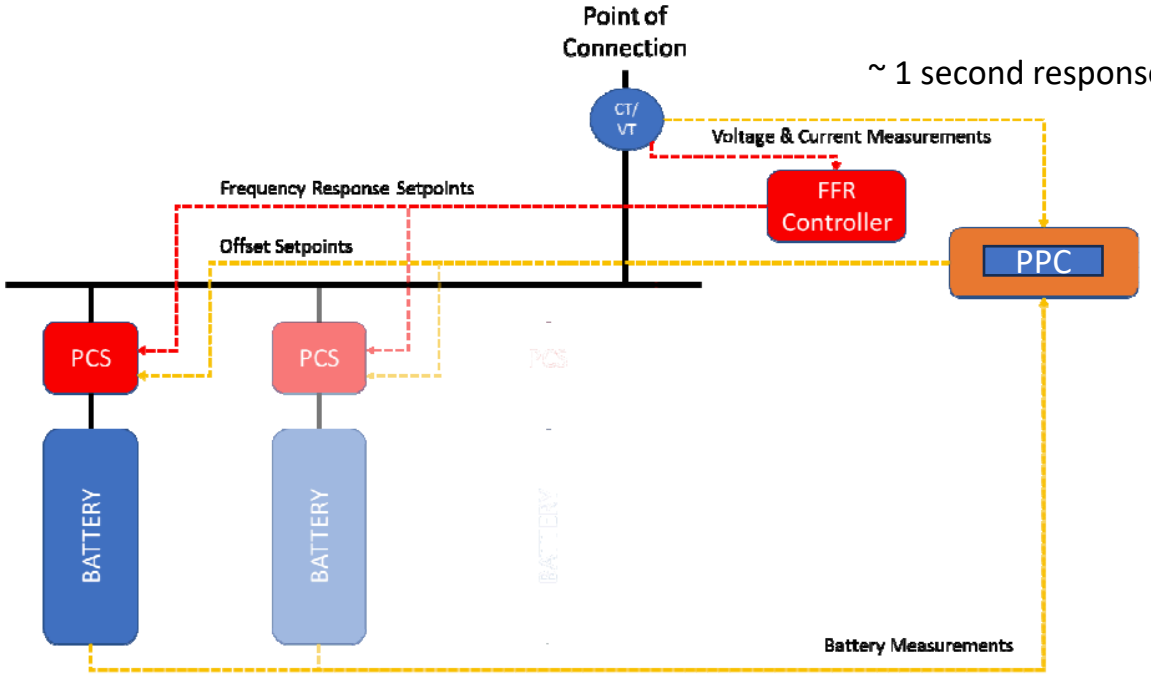



Figure 2 - Central FFR controller

# FFR – Independent inverter response

~ 100 mS second response

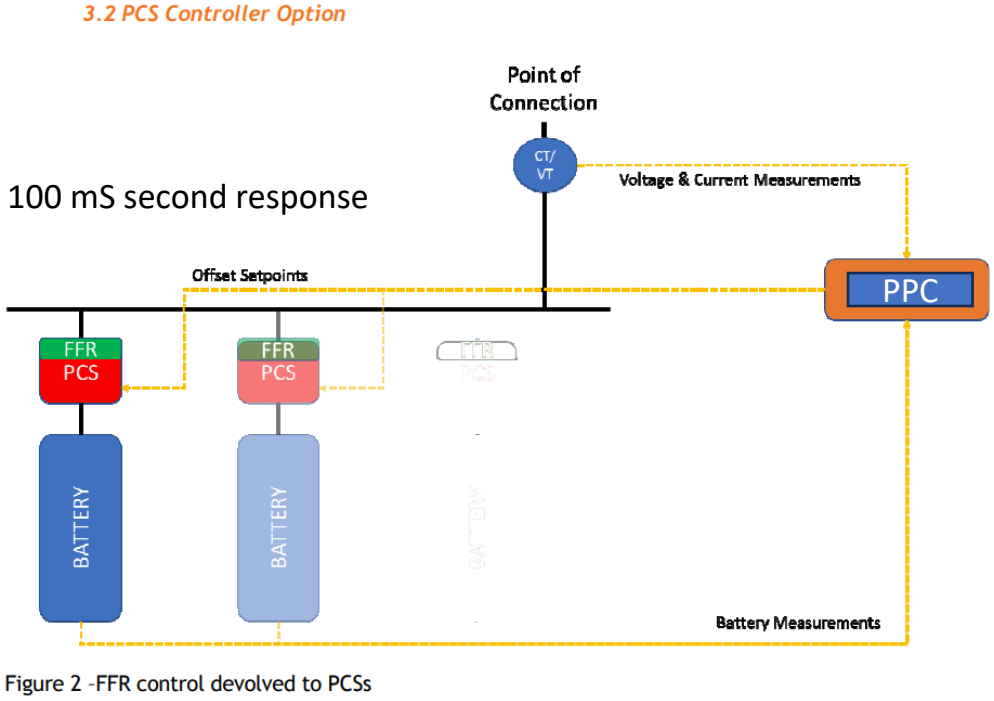
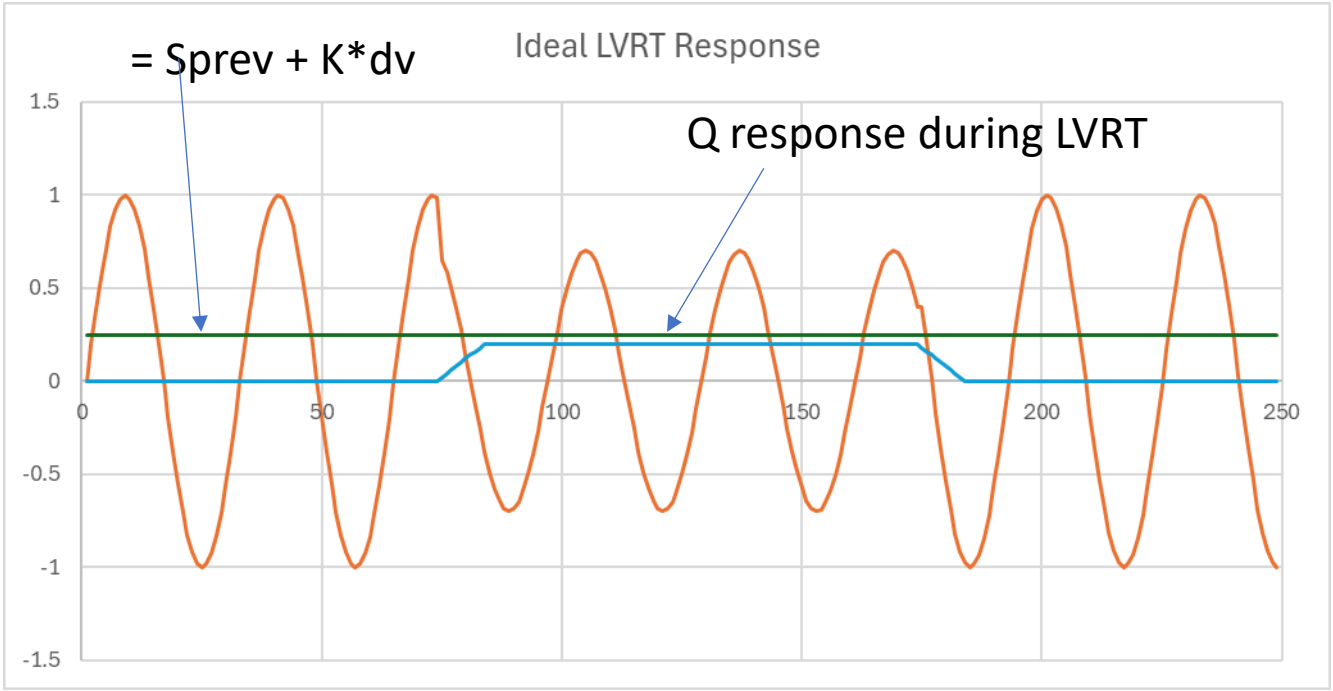


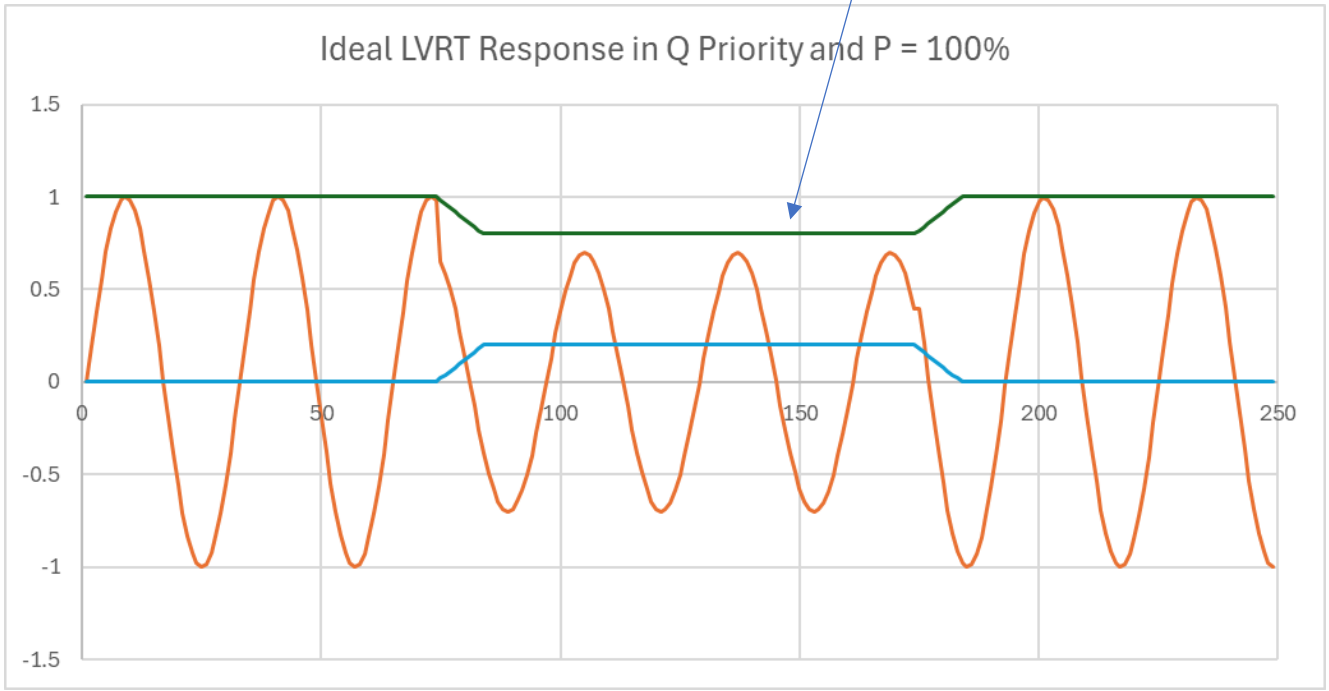

Figure 2 -FFR control devolved to PCSs

# Ideal LVRT Response

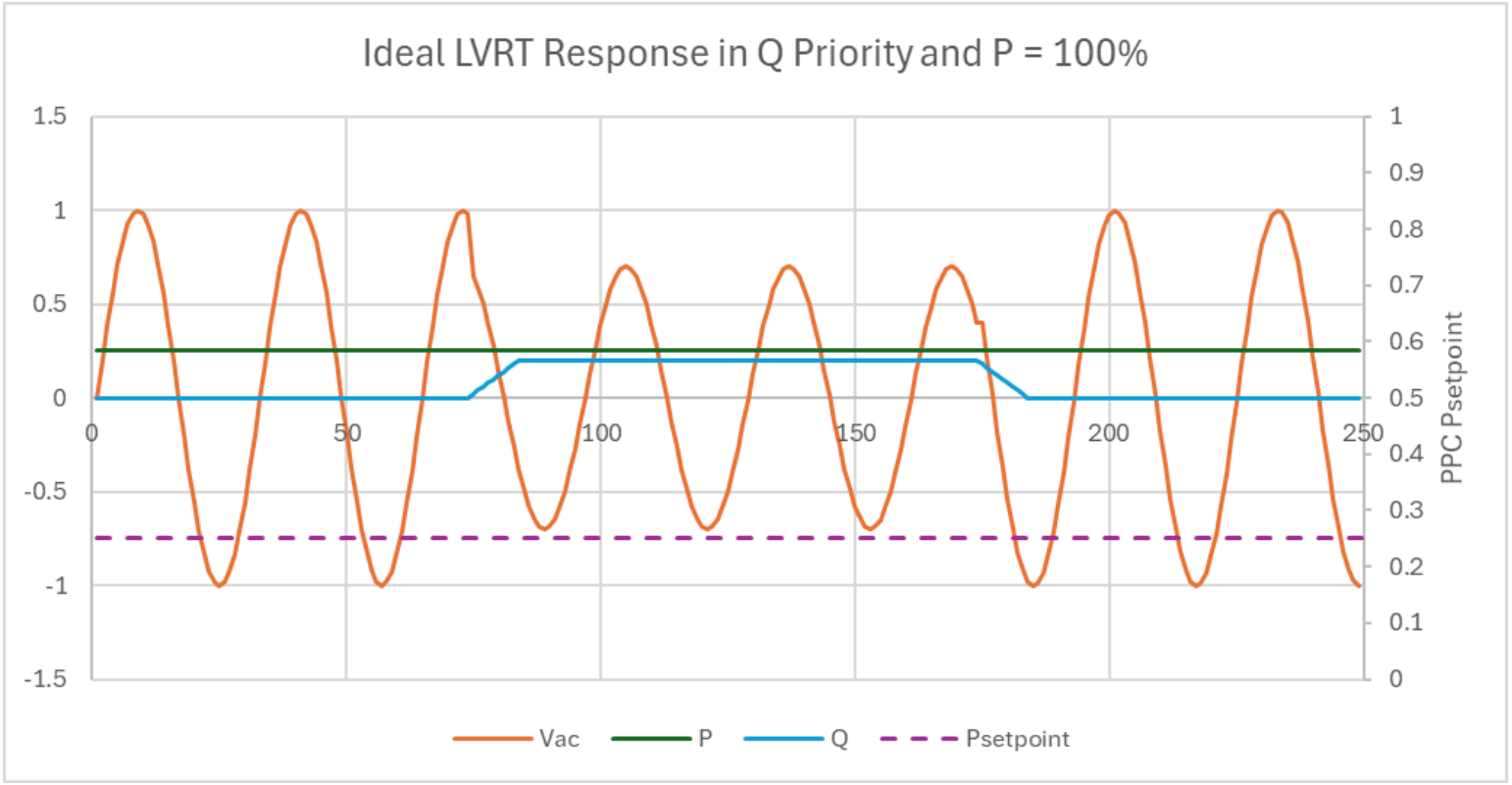


# LVRT Response with P = Pmax

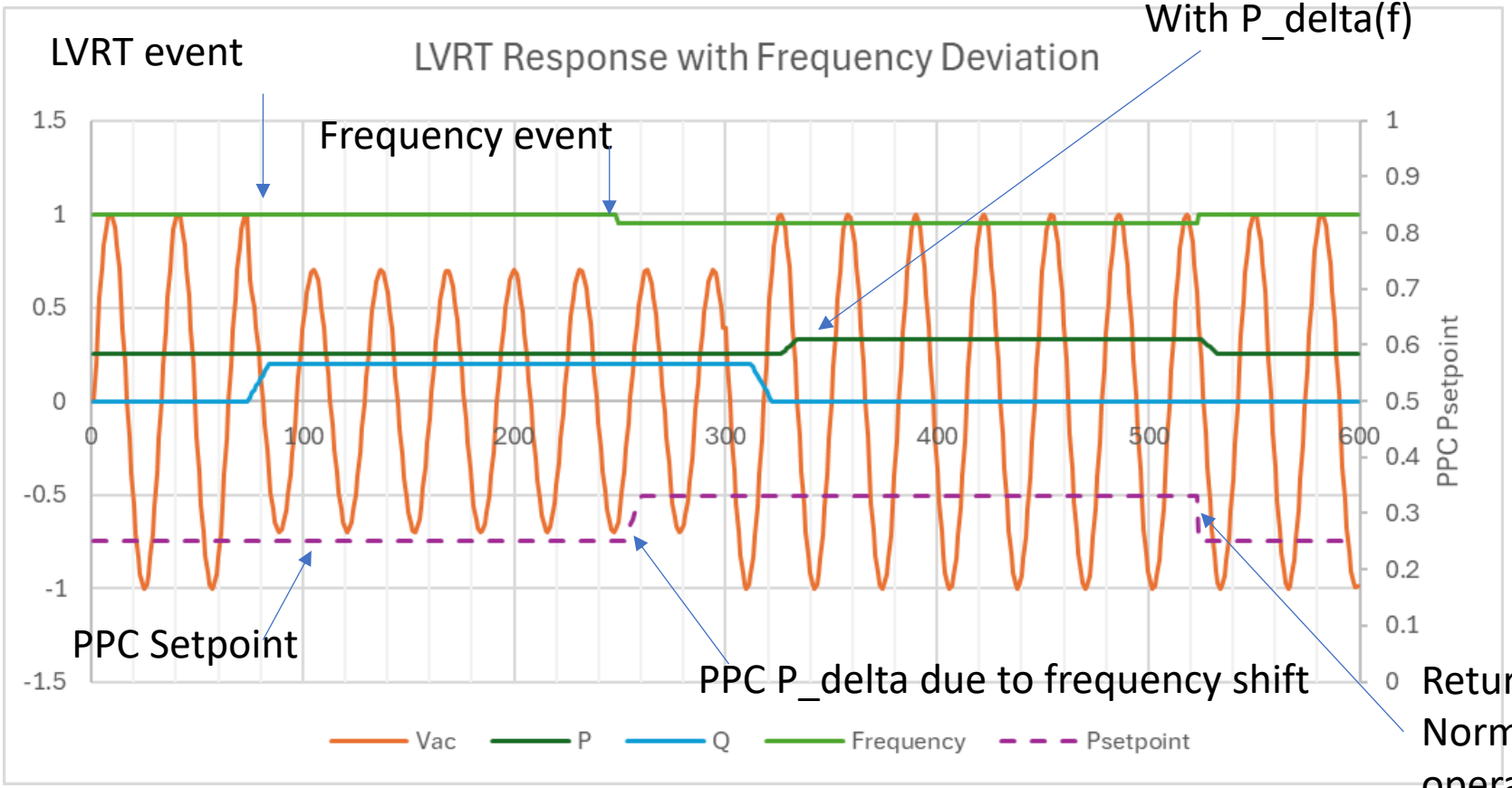
In Q priority P is reduced to satisfy Q



# LVRT Response and PPC Pset response



# LVRT Response with Frequency Deviation



# Exiting LVRT Mode

- Configurable Parameters
  - Maximum LVRT Duration
  - Delay time
  - Hysteresis
  - P & Q Recovery setpoints
  - Recovery ramps for P & Q

- Appendix

# Voltage Protections

LVRT protections

| Screen | Range | Recommended Value | Function | Set on run |
|---|---|---|---|---|
| **G5.1.1.1-Enable** | Slow: Y / N<br>Fast: Y / N<br>Fast 2: Y / N<br>Very fast: Y / N<br>Very fast 2: Y / N | YYYYN | There are five low voltage protection levels:<br>- Slow protection<br>- Fast protection<br>- Fast 2 protection<br>- Very fast protection<br>- Very fast 2 protection<br>To enable each protection, set the corresponding bit to Yes and adjust the voltage values and delay as desired (parameters G5.1.1.2 to G5.1.1.11). | Yes |
| **G5.1.1.2-Slow protection** | 0.0 to 100.0 % | 85.0% | Protection levels can be set from 0.0% up to 100.0%. 100.0% corresponds with the rated voltage.<br><br>The slow protection delay can be set from 0.0 s up to 6550.0 s. Fast protections delay can be set from 0.00 s up to 655.00 s.<br><br>Very fast protections delay range varies between 0.000 s and 65.500 s. | Yes |
| **G5.1.1.3-Delay slow protection** | 0.0 to 6550.0 s | 10.0 | | Yes |
| **G5.1.1.4-Fast protection** | 0.0 to 100.0% | 65.0% | | Yes |
| **G5.1.1.5-Delay fast protection** | 0.0 to 655.00 s | 5.00 | | Yes |
| **G5.1.1.6-Fast 2 protection** | 0.0 to 100.0 % | 45.0% | | Yes |
| **G5.1.1.7-Delay fast 2 protection** | 0.00 to 655.00 s | 2.00 | | Yes |
| **G5.1.1.8-Very fast protection** | 0.0 to 100.0% | 20.0% | It is possible to enable/disable each protection level individually in G5.1.1.1. Default values, on the other hand, depend on the selected normative. | Yes |
| **G5.1.1.9-Delay very fast prot** | 0.000 to 65.500 s | 1.00 | | Yes |
| **G5.1.1.10-Very fast 2 protection** | 0.0 to 100.0% | Disabled | | Yes |
| **G5.1.1.11-Delay very fast 2 prot** | 0.000 to 65.500 s | Disabled | | Yes |

OVRT protections

| Screen | Range | Recommended Value | Function | Set on run |
|---|---|---|---|---|
| **G5.1.2.1-Enable** | Slow: Y / N<br>Fast: Y / N<br>Fast 2: Y / N<br>Very fast: Y / N<br>Very fast 2: Y / N | YYNYN | There are five low voltage protection levels:<br>- Slow protection<br>- Fast protection<br>- Fast 2 protection<br>- Very fast protection<br>- Very fast 2 protection<br>To enable each protection, set the corresponding bit to Yes and adjust the voltage values and delay as desired (parameters G5.1.2.1 to G5.1.2.11). | Yes |
| **G5.1.2.2-Slow protection** | 100.0 to 150.0 % | 115.0% | Protection levels can be set from 0.0% up to 150.0%. 100.0% corresponds with the rated voltage.<br><br>The slow protection delay can be set from 0.0 s up to 6550.0 s. Fast protections delay can be set from 0.00 s up to 655.00 s.<br><br>Very fast protections delay range varies between 0.000 s and 65.500 s.<br><br>It is possible to enable/disable each protection level individually in G5.1.2.1. Default values, on the other hand, depend on the selected normative. | Yes |
| **G5.1.2.3-Delay slow prot** | 0.0 to 6550.0 s | 2.0 | | Yes |
| **G5.1.2.4-Fast protection** | 100.0 to 150.0 % | 125.0% | | Yes |
| **G5.1.2.5-Delay fast protection** | 0.00 to 655.00 s | 0.10 | | Yes |
| **G5.1.2.6-Fast 2 protection** | 100.0 to 150.0 % | Disabled | | Yes |
| **G5.1.2.7-Delay fast 2 protection** | 0.00 to 655.00 s | Disabled | | Yes |
| **G5.1.2.8-Very fast protection** | 100.0 to 150.0% | 140.0% | | Yes |
| **G5.1.2.9-Delay very fast prot** | 0.000 to 65.500 s | 0.003 | | Yes |
| **G5.1.2.10-Very fast 2 protection** | 100.0 to 150.0% | Disabled | | Yes |
| **G5.1.2.11-Delay very fast 2 prot** | 0.000 to 65.500 s | Disabled | | Yes |

# Frequency Protections

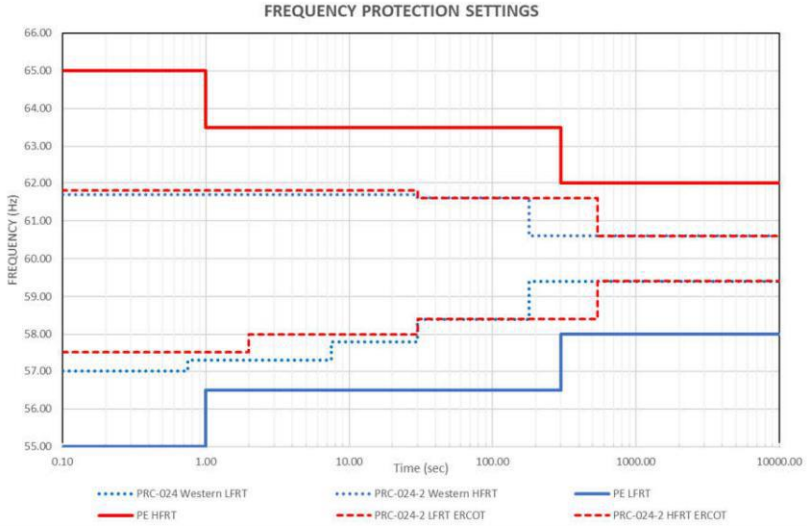
LFRT protections

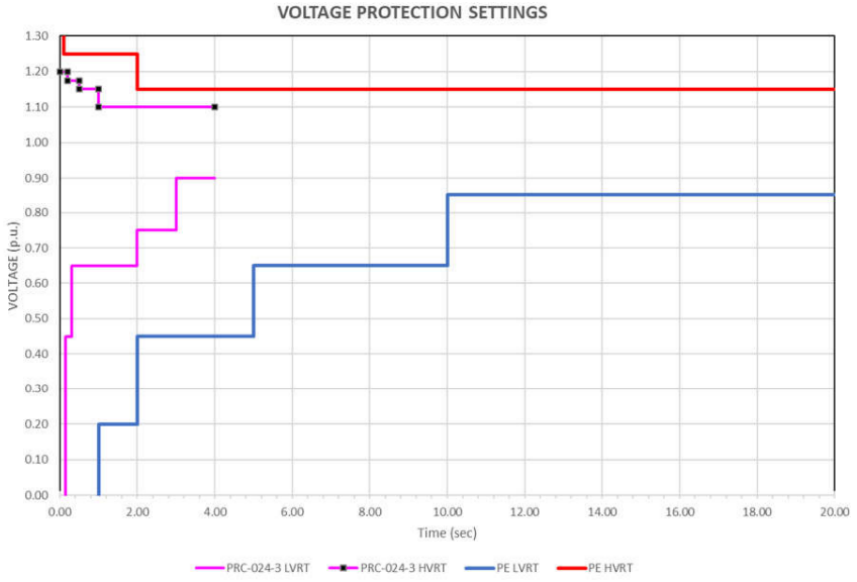
| Screen | Range | Recommended Value | Function | Set on run |
|---|---|---|---|---|
| **G5.1.3.1-Enable** | Slow: Y / N<br>Slow 2: Y / N<br>Fast: Y / N<br>Very fast: Y / N<br>Very fast 2: Y / N | YYYNN | There are five low frequency protection levels:<br>- Slow protection<br>- Slow 2 protection<br>- Fast protection<br>- Very fast protection<br>- Very fast 2 protection<br>To enable each protection, set the corresponding bit to Yes.<br><br>Protection levels can be set from 45.0 Hz up to 60.0 Hz.<br><br>The slow protection delay can be set from 0.0 s up to 6550.0 s. Fast protections delay can be set from 0.00 s up to 655.00 s.<br><br>Very fast protections delay range varies between 0.000 s and 65.500 s.<br><br>It is possible to enable/disable each protection level individually in G5.1.3.1. Default values, on the other hand, depend on the selected normative. | Yes |
| **G5.1.3.2-Slow protection** | 45.0 to 60.0 Hz | 58.0 | | Yes |
| **G5.1.3.3-Delay slow protection** | 0.0 to 6550.0 s | 300.0 | | Yes |
| **G5.1.3.4-Slow 2 protection** | 45.0 to 60.0 Hz | 56.5 | | Yes |
| **G5.1.3.5-Delay slow 2 protection** | 0. to 6550.0 s | 1.0 | | Yes |
| **G5.1.3.6-Fast protection** | 45.0 to 60.0 Hz | 55.0 | | Yes |
| **G5.1.3.7-Delay fast protection** | 0.00 to 655.00 s | 0.10 | | Yes |
| **G5.1.3.8-Very fast protection** | 45.0 to 60.0 Hz | disabled | | Yes |
| **G5.1.3.9-Delay very fast prot** | 0.000 to 65.500 s | disabled | | Yes |
| **G5.1.3.10-Very fast 2 protection** | 45.0 to 60.0 Hz | disabled | | Yes |
| **G5.1.3.11-Delay very fast 2 prot** | 0.000 to 65.500 s | disabled | | Yes |

OFRT protections

| Screen | Range | Recommended value | Function | Set on run |
|---|---|---|---|---|
| **G5.1.4.1-Enable** | Slow: Y / N<br>Slow 2: Y / N<br>Fast: Y / N<br>Very fast: Y / N<br>Very fast 2: Y / N | YYYNN | There are five low frequency protection levels:<br>- Slow protection<br>- Slow 2 protection<br>- Fast protection<br>- Very fast protection<br>- Very fast 2 protection<br>To enable each protection, set the corresponding bit to Yes.<br><br>Protection levels can be set from 50.0 Hz up to 65.0 Hz. | Yes |
| **G5.1.4.2-Slow protection** | 50.0 to 65.0 Hz | 62.0 | | Yes |
| **G5.1.4.3-Delay slow protection** | 0.0 to 6550.0 s | 300.0 | | Yes |
| **G5.1.4.4-Slow protection** | 50.0 to 65.0 Hz | 63.5 | | Yes |
| **G5.1.4.5-Delay slow protection** | 0.0 to 6550.0 s | 1.0 | | Yes |
| **G5.1.4.6-Fast protection** | 50.0 to 65.0 Hz | 65.0 | | Yes |
| **G5.1.4.7-Delay fast protection** | 0.00 to 655.00 s | 0.10 | Slow protection delays can be set from 0.0 s up to 6550.0 s. The fast protection delay can be set from 0.00 s up to 655.00 s.<br><br>Very fast protections delay range varies between 0.000 and 65.500 s.<br><br>It is possible to enable/disable each protection level individually in G5.1.4.1. Default values, on the other hand, depend on the selected normative. | Yes |
| **G5.1.4.8-Very fast protection** | 50.0 to 65.0 Hz | disabled | | Yes |
| **G5.1.4.9-Delay very fast prot** | 0.000 to 65.500 s | disabled | | Yes |
| **G5.1.4.10-Very fast 2 protection** | 50.0 to 65.0 Hz | disabled | | Yes |
| **G5.1.4.11-Delay very fast 2 prot** | 0.000 to 65.500 s | disabled | | Yes |

# PE Voltage and Frequency Protections



# LVRT Algorithm Options

<table>
<tr><th>Screen</th><th>Range</th><th>Recommended value</th><th>Function</th><th>Set on run</th></tr>
<tr><td>G4.3.1.1-Enable</td><td>Disabled<br>Mode 1<br>Mode 2<br>Mode 3</td><td>Mode 1</td><td>This parameter allows enabling the algorithm to define the behavior of the inverter during a voltage dip event.<br><br><table><tr><th>OPTION</th><th>DESCRIPTION</th></tr><tr><td>Disabled</td><td>LVRT algorithm is disabled.</td></tr><tr><td>Mode 1</td><td>Enable low voltage ride-through. The reference voltage corresponds with the direct sequence voltage.</td></tr><tr><td>Mode 2</td><td>Enable low voltage ride-through. The reference voltage corresponds with the lowest value of phase-to-phase voltages.</td></tr><tr><td>Mode 3</td><td>Enable the algorithm. The LVRT algorithm considers the estimated voltage in the POI to access or not to LVRT.</td></tr></table><br>Note: If this parameter is set to Disabled, the rest of parameters within this group will not be shown.</td><td>Yes</td></tr>
<tr><td>G4.3.1.2-Threshold</td><td>0.0 to 95.0%</td><td>85.0%</td><td>Sets the threshold for the LVRT algorithm. If the voltage goes under this value, the algorithm will be executed.</td><td>Yes</td></tr>
<tr><td>G4.3.1.3-Moment. cessation</td><td>0.0 to 100.0%<br>Off = 1001</td><td>Off</td><td>It configures a nominal voltage threshold below which the inverter does not inject power to the grid anymore (P=0 ; Q=0)</td><td>Yes</td></tr>
</table>

LVRT Mode Select
(Mode 1 is most popular)

LVRT threshold

Momentary cessation typically Disabled

# LVRT Configuration Continued

<table>
<tr><th>Screen</th><th>Range</th><th>Recommended value</th><th>Function</th><th>Set on run</th></tr>
<tr><td>G4.3.1.4-Configuration</td><td>kdV<br>Iq prev + kdVdir<br>Is prev + kdVdir<br>Proportional<br>Advanced</td><td>Is prev + kdV</td><td>Selects the behavior in case of a dip event:<br><table><tr><th>OPTION</th><th>DESCRIPTION</th></tr><tr><td>kdV</td><td>Response is proportional to voltage variation.</td></tr><tr><td>Iq prev + kdVdir</td><td>Response is proportional to the direct sequence voltage variation + previous reactive power.</td></tr><tr><td>Is prev + kdVdir</td><td>Response is proportional to the direct sequence voltage variation + previous apparent power.</td></tr><tr><td>Proportional</td><td>The response tries to maintain the pre-event direct sequence active and reactive power and adds reactive current in direct and reverse sequence proportional to the voltage variation, limiting both currents equally (proportional). Prioritizes the injection of Q over P.</td></tr><tr><td>Advanced</td><td>Allows configuring a customized behavior. Once this option is selected, parameters [Injection mode Id] and [-Injection mode Iq] will be shown.</td></tr></table></td><td>Yes</td></tr>
<tr><td>G4.3.1.5- P Control mode</td><td>Current<br>Power</td><td>Current</td><td>Allow selecting the P control mode:<br><table><tr><th>OPTION</th><th>DESCRIPTION</th></tr><tr><td>Current</td><td>Control by current.</td></tr><tr><td>Power</td><td>Control by power.</td></tr></table></td><td>Yes</td></tr>
<tr><td>G4.3.1.6-Q Control mode</td><td>Current<br>Power</td><td>Current</td><td>Allow selecting the Q control mode:<br><table><tr><th>OPTION</th><th>DESCRIPTION</th></tr><tr><td>Current</td><td>Control by current.</td></tr><tr><td>Power</td><td>Control by power.</td></tr></table></td><td>Yes</td></tr>
<tr><td>G4.3.1.7-P/Q priority</td><td>P<br>Q</td><td>Q</td><td>This parameter allows deciding which magnitude P or Q will take priority to keep S constant at a maximum value. P selects active power priority and Q selects reactive power priority.</td><td>Yes</td></tr>
<tr><td>G4.3.2.7-K dir</td><td>0.0 to 10.0</td><td>2.0</td><td>Adjusts the K multiplying factor for direct sequence during operation in LVRT.</td><td>Yes</td></tr>
</table>

Define starting P&Q starting point
For LVRT event

# LVRT Exit Parameters

| SCREEN | RANGE | DESCRIPTION | SET ON RUN |
|---|---|---|---|
| G4.3.3.1-Threshold Delay = Infinite | 0.005 to 60.000 s<br>Infinite = 60.001; | Sets a delay in seconds at the output of the LVRT algorithm. When set to 60001 the time is infinite. | Yes |
| G4.3.3.2-Hysteresis Delay = 0.005 s | 0.005 to 60.000 s | Sets a delay, in seconds, to the output of the LVRT algorithm if the hysteresis condition of parameter [G4.3.3.3-Hysteresis] is reached. | Yes |
| G4.3.3.3-Hysteresis = 2 % | 1 to 15 % | Defines the hysteresis to obtain the output voltage value (voltage at which there is no dip). If the voltage is below the threshold, it will be considered as a voltage dip and will end when the voltage is "threshold" + "hysteresis". | Yes |
| G4.3.3.4-P Recover = 100.0 % | 0.0 to 100.0 % | Sets the active power output of LVRT recovery. This is the P power value that the algorithm will apply on dip recovery before normal control starts acting again. | Yes |
| G4.3.3.5-Q Recover = 100.0 % | 0.0 to 100.0 % | Sets the reactive power output of LVRT recovery. This is, the Q power value that the algorithm will apply on dip recovery before normal control starts acting again. | Yes |
| G4.3.3.6a-P Recover Time = Disabled | Disabled = 0.0;<br>0.1 to 60.0 s | Time during which, after an LVRT event, active power references remain frozen. | Yes |
| G4.3.3.6b-Q Recover Time = Disabled | Disabled = 0.0;<br>0.1 to 60.0 s | Time during which, after an LVRT event, reactive power references remain frozen. | Yes |
| G4.3.3.7-ID Recover Ramp = Disabled | Disabled = 19;<br>20 to 3000 %/s | Recovery ramp at the LVRT exit. If the parameter is configured as "Disabled" the ramp will be disabled. Otherwise, the set value will determine the slope (percentage per second) of P. | Yes |
| G4.3.3.8-IQ Recover Ramp = Disabled | Disabled = 19;<br>20 to 3000 %/s | Recovery ramp at the LVRT exit. If the parameter is configured as "Disabled" the ramp will be disabled. Otherwise, the set value will determine the slope (percentage per second) of Q. | Yes |

## LVRT in PE UMD/PSCAD models - highlighted

| Mode | Priority | Active Power | Reactive Power |
|---|---|---|---|
| 0 | - | Id = 0 | Iq = k · dV |
| 1 | P | Id = Id_prev | Iq = Iq_prev + k · dV |
| 2 | Q | Id = Id_prev | Iq = Iq_prev + k · dV |
| 3 | P | Id = Id_prev | Iq = k · dV |
| 4 | Q | Id = Id_prev | Iq = k · dV |
| 5 | P | P = P_prev | Iq = Iq_prev + k · dV |
| 6 | Q | P = P_prev | Iq = Iq_prev + k · dV |

## Equivalent LVRT in inverter

| Mode | G4.2.1.3 Config | G4.2.1.4 P mode | G4.2.1.5 Q mode | G4.2.1.6 PQ Prior | G4.2.2.1 Id injection | G4.2.2.2 Iq injection |
|---|---|---|---|---|---|---|
| 0 | kdV | current | current | P/Q | - | - |
| 1 | Sprev + kdV | current | current | P | - | - |
| 2 | Sprev + kdV | current | current | Q | - | - |
| 3 | Advanced | current | current | P | X prev | kdV |
| 4 | Advanced | current | current | Q | X prev | kdV |
| 5 | Sprev + kdV | Power | current | P | - | - |
| 6 | Sprev + kdV | Power | current | Q | - | - |

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