Power Electronics

IEEE-1547 Review

Stephen Giguere | Engineering Director – US Solar Division | February 2020

Power Electronics España S.L. © reserves the right to modify the content without prior notice

IEEE-1547 Recent History

- IEEE-1547-2003
  - – shall not actively regulate voltage
  - - shall disconnect from the grid on voltage/frequency abnormalities
- IEEE-1547 – 2008
  - May regulate voltage
  - May Ride through abnormal Voltage/Frequency events
  - May Provide frequency Response (frequency Droop)
- IEEE-1547-2018
  - Shall be capable of actively regulating voltage
  - Shall ride through abnormal voltage/frequency
  - Shall be capable of frequency response
  - May provide inertial response

Power Electronics España S.L. © reserves the right to modify the content without prior notice

PV Inverter Timeline – 600 Vac

NEC 2005 - NEC 2011

- 600 Vac grounded arrays (PV panels $4.50 to $2.00 /watt)
  - Central Inverters 30 KW – 500 KW
  - 208 Vac or 480 Vac output
  - 1,000 Vdc Arrays allowed for Utility
  - 1,000 Vdc Arrays in Europe

Source: eBay

Power Electronics España S.L. © reserves the right to modify the content without prior notice

PV Inverter Timeline – 1,000 Vdc

NEC 2005 - NEC 2011

- 1,000 Vdc Gen. 1
- NEC 2014 widespread introduction of 1,000 Vdc systems
- Central inverters 500 KW to 1.5 MW
- 330 Vac to 390 Vac
- Matched to MVT transformer
- Introduction of String inverters 10 KW to 30 KW

- 1,000 Vdc Gen. 2
- 1,000 Vdc grounded arrays
- Central inverters 1.0 MW to 2.0 MW
- 400 Vac to 440 Vac
- String inverters up to ~80 KW

Power Electronics España S.L. © reserves the right to modify the content without prior notice

PV Inverter Timeline – 1,500 Vdc systems

- NEC 2017 Adoption of 1,500 Vdc systems
  - 1,500 Vdc grounded arrays
  - Central inverters 2.0 MW to 3.5 MW
  - 600 Vac to 690 Vac
  - Matched to MVT transformer

Power Electronics España S.L. © reserves the right to modify the content without prior notice

PV Cost Trends

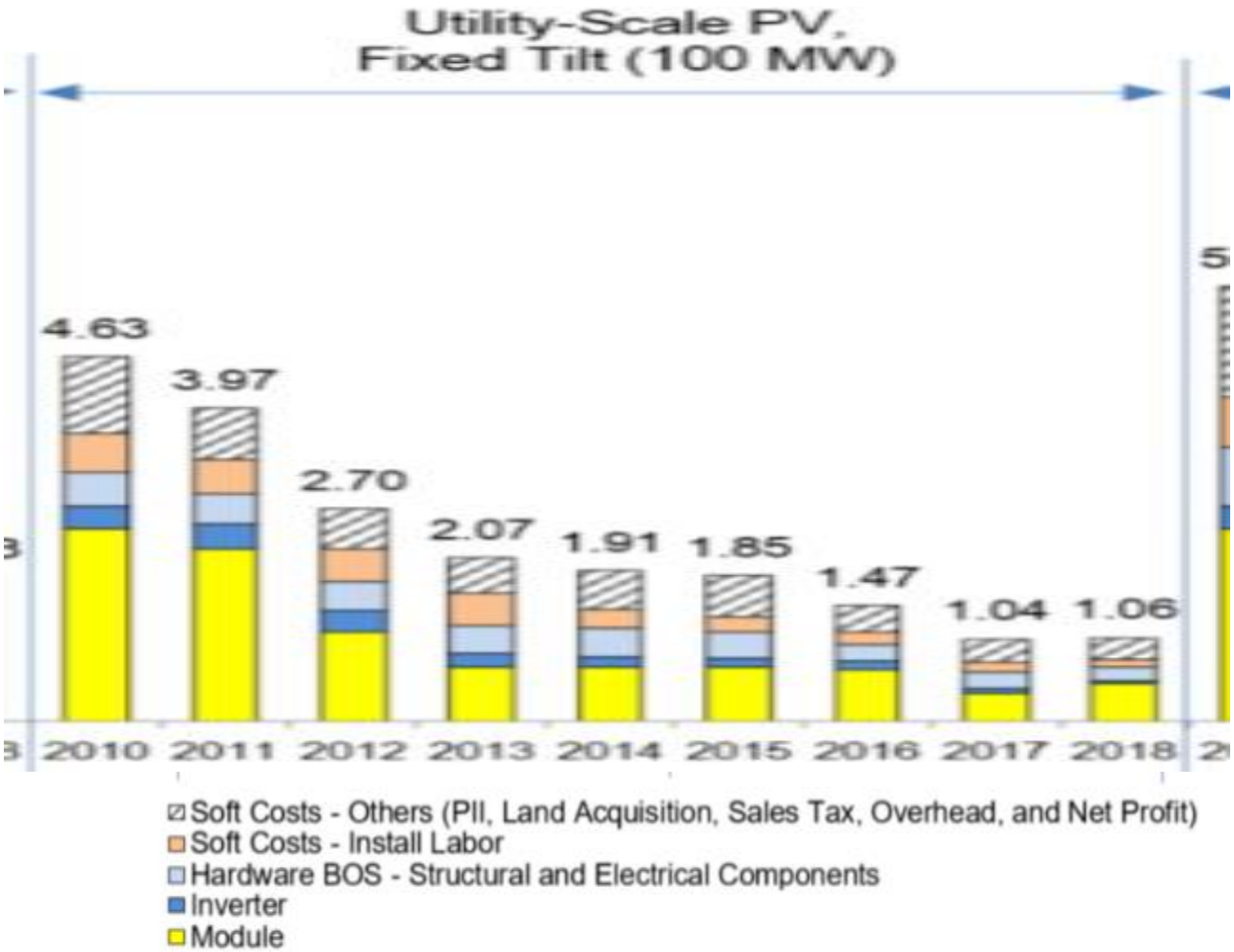


Figure ES-1. NREL PV system cost benchmark summary (inflation adjusted), 2010–2018

Power Electronics España S.L. © reserves the right to modify the content without prior notice

Smart Inverter Functions

	Inverter Feature	Function		Comments
Volt/VAR	Yes	Help Regulate Vac. Inject or absorb Reactive power based on AC incoming voltage		
Volt/Watt	Yes	Adjust real power based on AC incoming voltage		
Frequency/Watt	Yes	Stabilize Frequency adjust output Power based on measured input frequency		
Voltage-Ride Through	Yes	Disconnect from grid after voltage anomaly based on time and over/under voltage		Default per IEEE-1547
Frequency-Ride Through	Yes	Disconnect from grid after frequency anomaly based on time and over/under frequency		Default per IEEE-1547

Power Electronics España S.L. © reserves the right to modify the content without prior notice

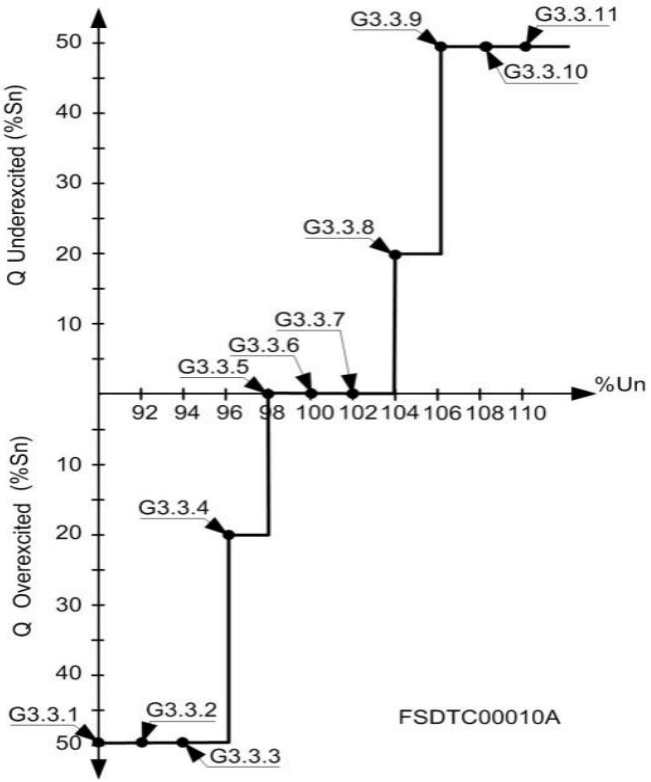
REACTIVE POWER CONTROL

- Reactive power provision to:
  - Regulate power factor at a remote location
  - Fix reactive power (VAr) constant at a remote location
  - Act as a function of voltage at a remote location, Q(V)
    - With voltage droop capability
- Power factor as a function of active power output
- Partial grid support (only remaining connected during grid disturbance)
- Full grid support (providing active/reactive current injection during grid disturbance)

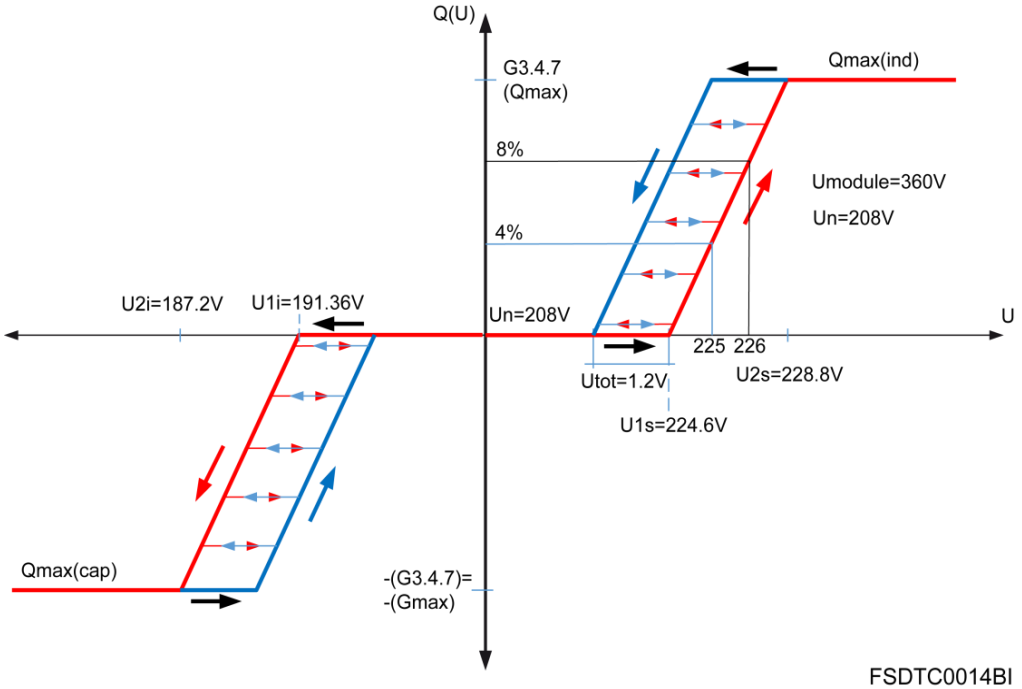
Power Electronics España S.L. © reserves the right to modify the content without prior notice

REACTIVE POWER CONTROL

Step Curve Q (U) - VRS



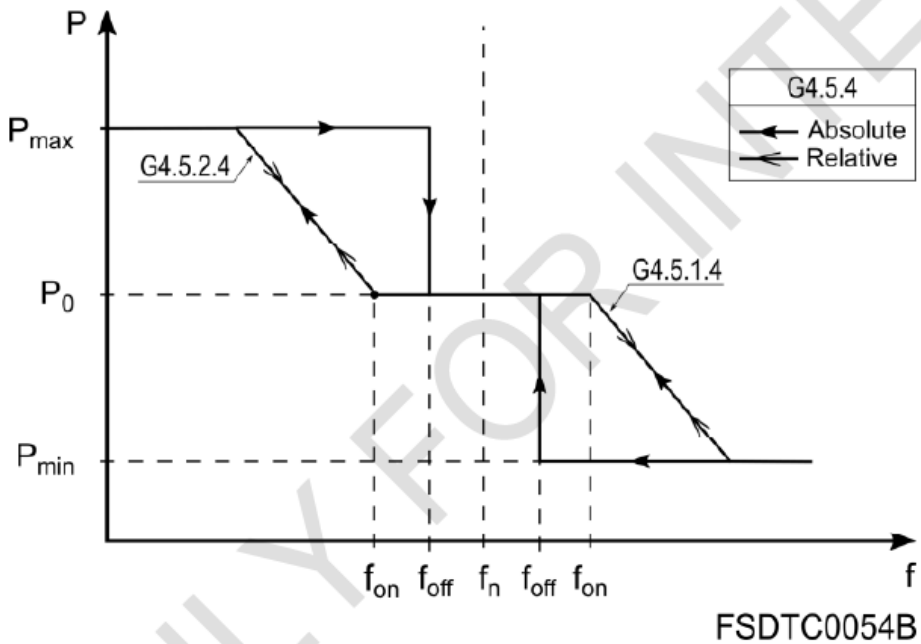
Continuous Curve Q(U)h - VRS



G3.4.8 / Activation power	0.00 to 1.00*Pn	This parameter allows setting the active power value for the activation of the curve.
G3.4.9 / Deactivation power	0.00 to (G3.4.8)*Pn	This parameter allows setting the active power value for the deactivation of the curve.

Power Electronics España S.L. © reserves the right to modify the content without prior notice

Power vs Frequency (Frequency Droop)



Power – Frequency Curve

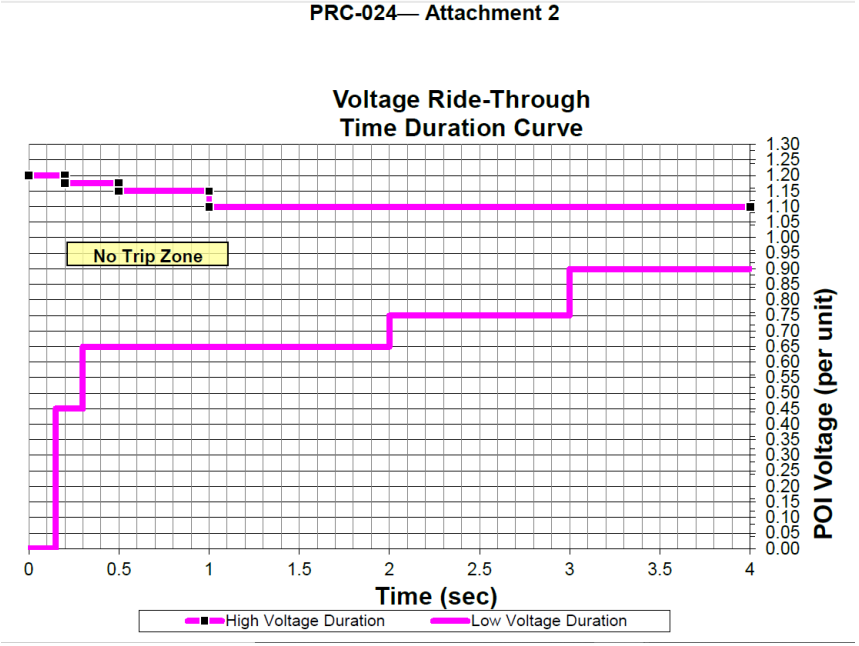
Overfrequency	Underfrequency
$f_{on} = G4.5.1.2$	$f_{on} = G4.5.2.2$
$f_{off} = f_{on} - G4.5.1.3$	$f_{off} = f_{on} + G4.5.2.3$

NLY FOR INTER

Power Electronics España S.L. © reserves the right to modify the content without prior notice

G5.1 and G5.2 Voltage Ride Through

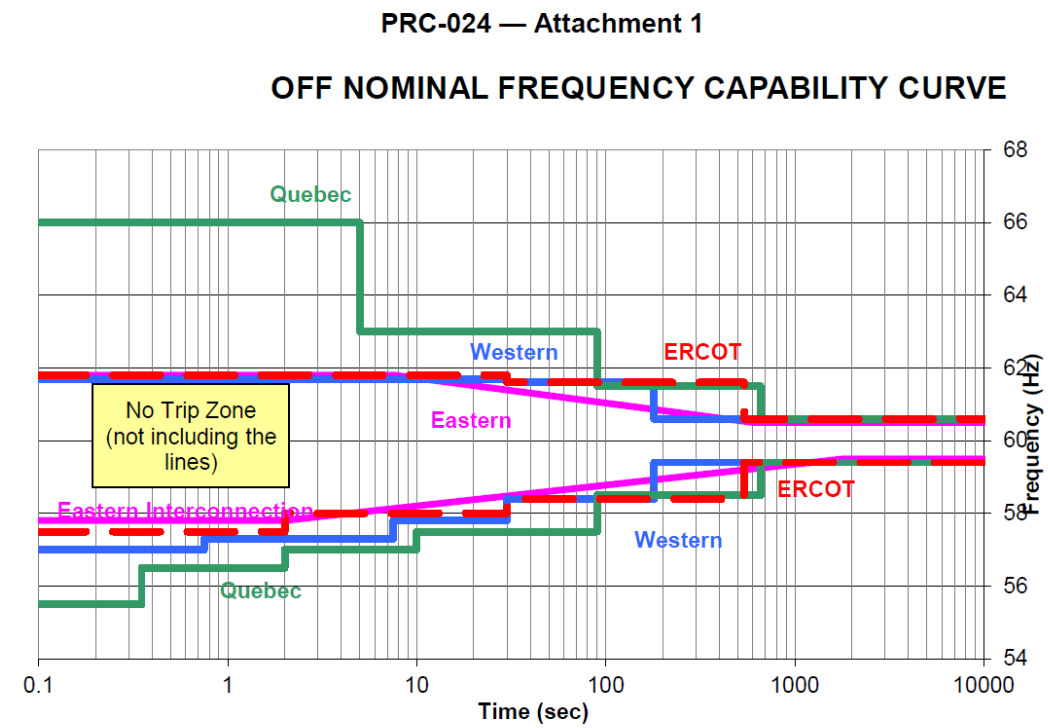
- G5.1 Low Voltage Ride Through
  - Up to 5 different time/ magnitude steps can be enabled.
- G5.2 Over Voltage Ride Through
  - Up to 5 different time/ magnitude steps can be enabled.
- IEEE-1547 defines a default set of OVRT and LVRT parameters but many utilities require voltage protection set points independent of the IEEE-1547 standard



Power Electronics España S.L. © reserves the right to modify the content without prior notice

G5.3 and G5.4 Frequency Ride Through

- G5.3 Low Frequency Ride Through
  - Up to 5 different time/ magnitude steps can be enabled.
- G5.4 Over Frequency Ride Through
  - Up to 5 different time/ magnitude steps can be enabled.



Power Electronics España S.L. © reserves the right to modify the content without prior notice

G4.2 LVRT Algorithm operation

- Now, here is where things get interesting.
- How should the energy source react to LVRT or OVRT events.
- Options:
  - Disconnect from the Grid and wait 5 minutes to reconnect
  - Continue to provide Real Power until OVRT threshold exceeded
  - Set P = Q = 0 but stay on-line until Vac = OK
  - Set P = 0 but Qset(Vac)
  - Keep Punchanged but vary Qout(Vac)

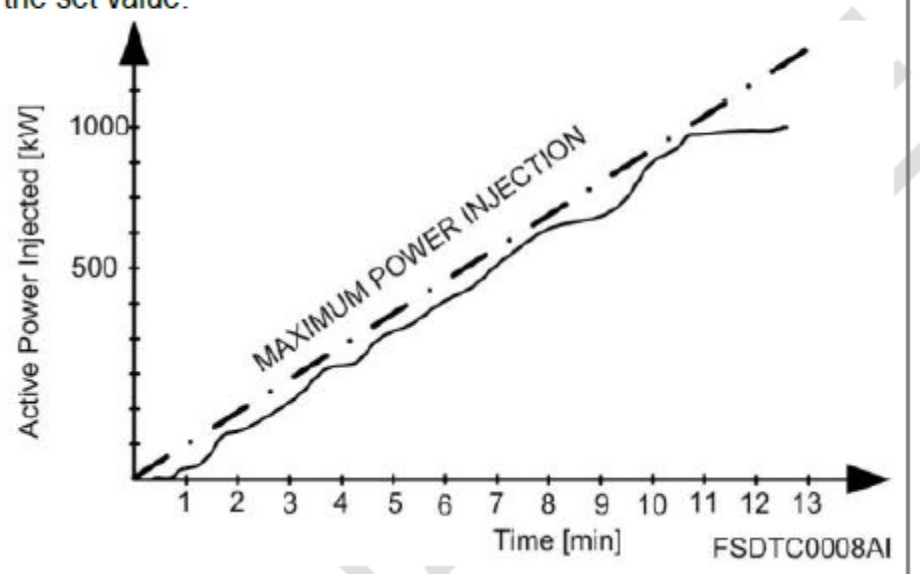
OPTION	DESCRIPTION
kdV	Response is proportional to voltage variation.
Q prev + kdV	Response is proportional to voltage variation + previous reactive power.
S prev + kdV	Response is proportional to voltage variation + previous apparent power.
P max + Q prev + kdV	Response is proportional to voltage variation + maximum active power and previous reactive power.
Constant	Injected current is a constant value that is set internally. It can only be modified by Power Electronics personnel.

Power Electronics España S.L. © reserves the right to modify the content without prior notice

G4.8 Gradient Control

- Configurable Ramp rates for both P & Q
- Programmable ramps for 4 different conditions
  - Start
  - Rise
  - Drop
  - Stop

When this option is enabled, power is injected gradually. The converter will increase its output power per minute depending on the set value.



Power Electronics España S.L. © reserves the right to modify the content without prior notice

Pros and Cons of Autonomous Inverter operation

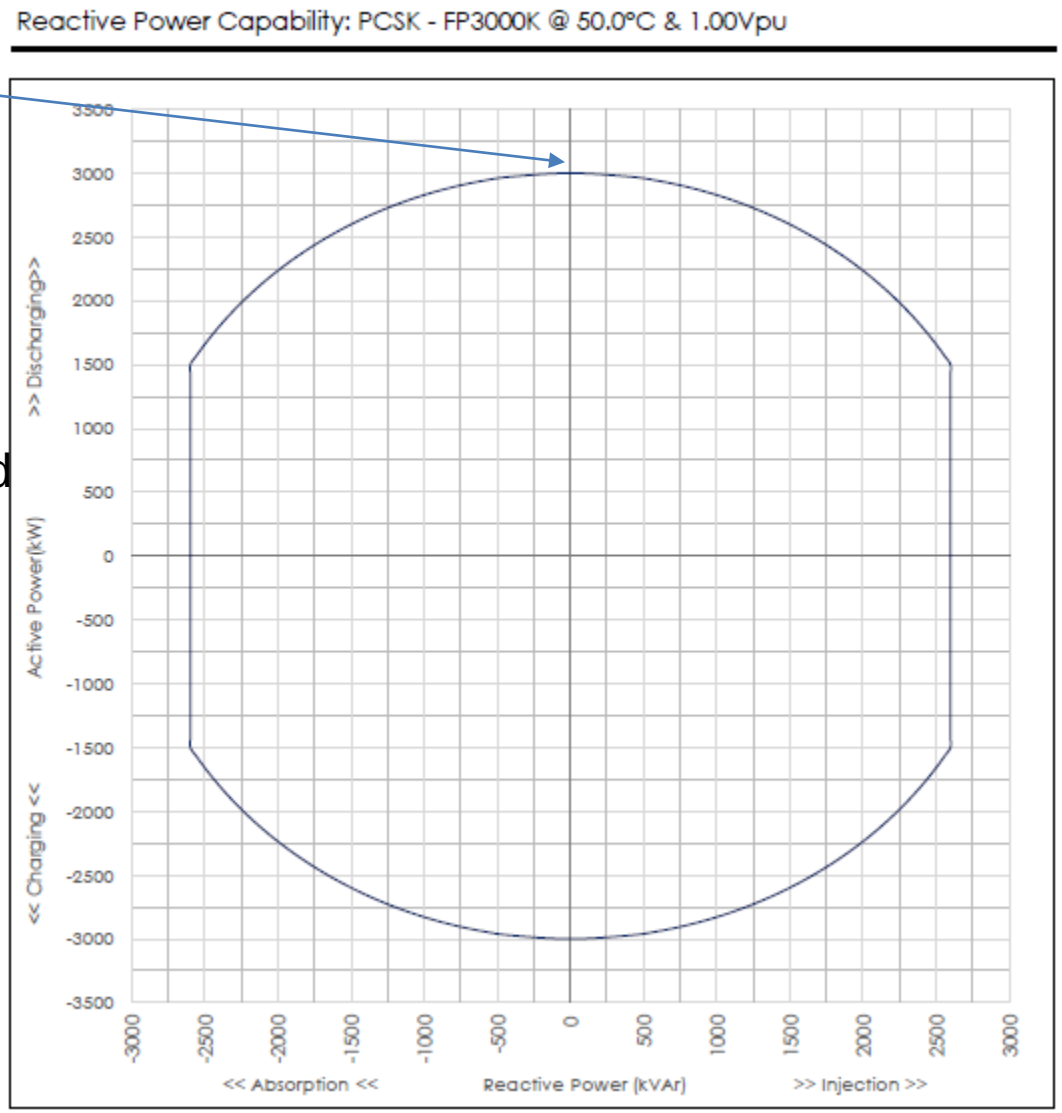
- Advantages to Autonomous operation
  - Inverter responds to voltage/frequency events at inverter terminals allowing for faster response without MODbus network delays.
  - Voltage and frequency protection settings are password protected limits based on the measurements at the inverter terminals.
  - Inverter has pre-programmed configurable algorithms to customize inverter response
- Advantages of coordinated response using SCADA controller
  - Inverter response can be coordinated using information collected from a Revenue Grade Meter at the Point of Interconnection.
  - Site response can be coordinated. (i.e. response can be adjusted if 1 unit is offline for maintenance).
  - Multiple inverters may interact in unpredictable ways. (i.e. in a frequency event, the first inverter to response may bring the incoming voltage within range but the other inverters may also react for a disproportional response).

Power Electronics España S.L. © reserves the right to modify the content without prior notice

How are inverter settings affected by Low output

Inverter limited
By Pac_output rating

If the DC source is limited
To less than the inverter
Nameplate then the
Real Power (y axis) is
Limited to the DC source
Available.



Power Electronics España S.L. © reserves the right to modify the content without prior notice

What Smart Inverter Functions can be utilized together and how would they be prioritized

- Voltage and Frequency protection settings are always in place based on the measurements at the inverter terminals.
- Volt / Var response provides reactive power based on Voltage
- Frequency droop (Frequency/KW) adjusts the Real power based on Frequency.

- Adding a Watt-Var response would create some interesting dynamics between Volt/Var and Frequency / KW.

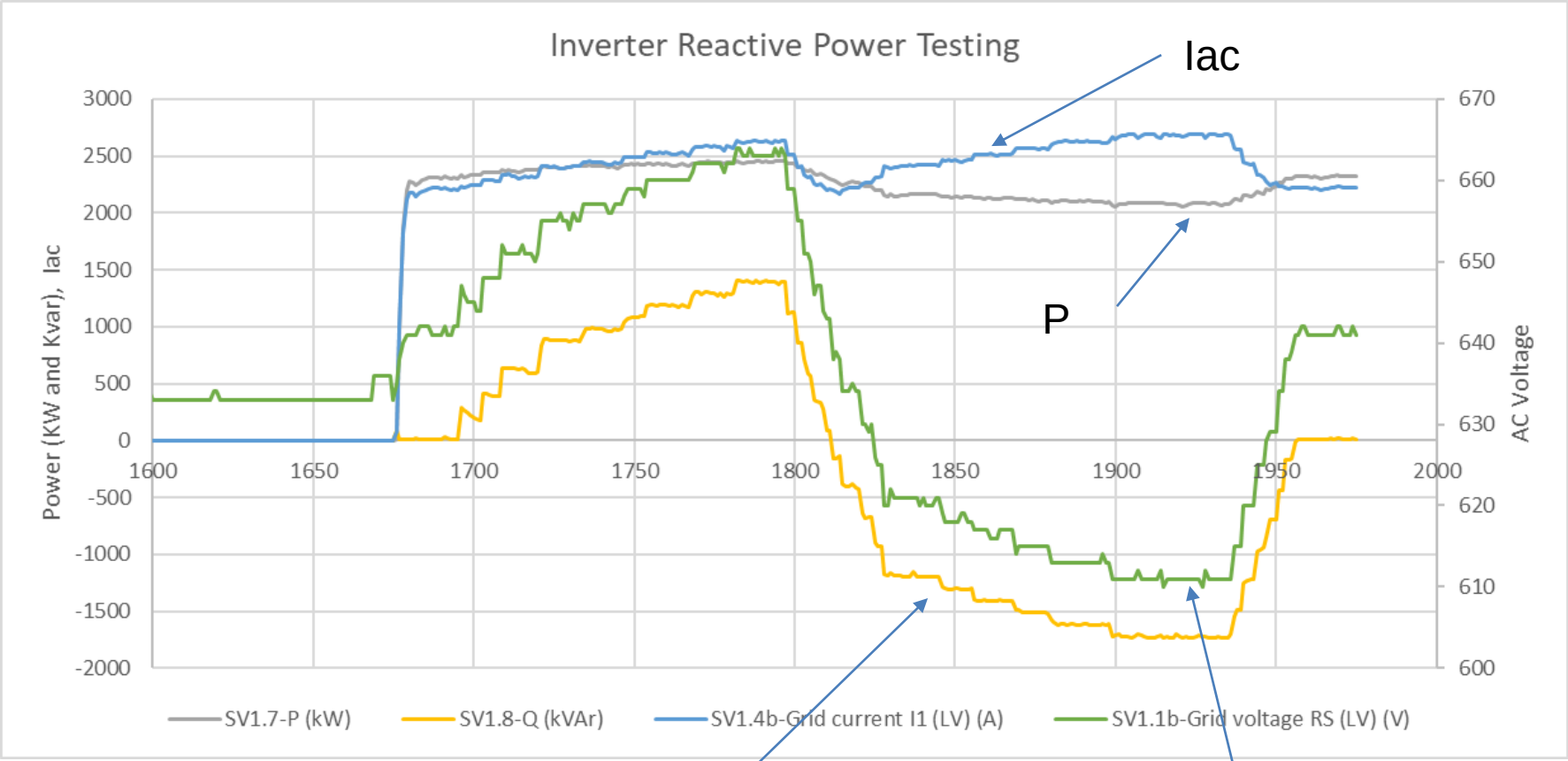
Power Electronics España S.L. © reserves the right to modify the content without prior notice

How do Smart inverter functions affect other inverter operations

- Anti-islanding – The anti-islanding detection is independent of the Smart inverter functions. Per IEEE-1547, the inverter has 2 seconds to disconnect when islanded conditions are detected. This could get tricky if the inverter needs to stay on-line during ZVRT.
- Self-Protecitive Overvoltage – Inverter OVRT protective limits will disconnect the inverter from the grid when an overvoltage condition is detected. Typically a limit like disconnect immediately > 1.4 pu.
- Voltage Ride-Through – A Volt-Var programmed response may keep an inverter on-line rather than disconnect from the grid due to a low voltage.

Power Electronics España S.L. © reserves the right to modify the content without prior notice

Reactive Power Testing (Adjust Q + and – 1.5 MVar)



Iac

P

Q

Vac

Power Electronics España S.L. © reserves the right to modify the content without prior notice

Thank you for your Attendance

For further information

Contact:
Power-Electronics, Inc.
1510 N. Hobson St.
Gilbert, AZ

Sales: Darren Bronen
DBronen@power-electronics.com

Technical: Stephen Giguere
SGiguere@power-electronics.com

Power Electronics España S.L. © reserves the right to modify the content without prior notice