Referenced Documentation

- CEI016 (Italian standard): Technical regulation for connection of producers and consumers to High Voltage and Medium Voltage grids of electrical utilities.

Definitions and acronyms

- POI: Point of Interconnection
- LVFRT: Low Voltage Fault Ride Through
- RTU: Real Time Unit
- SPI: protection interface device
- PSxxx: SIEL Soleil Power Delivery and Generation station, from 660kVA up to 2500kVA.

1. Introduction

This document aims to summarizing the features of the Siel Soleil DSPX PV inverters and PSxxx Station (xxx being the power capability, ranging from 660kVA up to 2500kVA) (both power delivery and conversion) , to directly interface it to a Medium Voltage grid.
As default, the Siel Soleil DSPX inverter and PSxxx conversion station are supplied as products compliant with the Italian grid code specified in the domestic regulation **CEI016**.
The CEI016 specifies all the requirements for the following items:

- Protection Interface (SPI) and tolerance bands for voltage and frequency.
- Grid support functions and services, divided in:
  - Low Voltage Failure Ride Through (LVFRT capability).
  - Active and Reactive power generation capability (P/Q diagram).
  - Active and Reactive power remote control (Pref, Qref set-points).
  - Primary frequency control through active power self-limitation, as a function of the measured frequency [P(f) function].
  - Voltage control through reactive power self-control, as a function of the measured voltage [Q(V) function].
  - Remote On/Off command for the inverter.

The Soleil inverter plays an active role to support the proper operation of the whole grid (at a distribution or transmission level), requiring for this task, to acquire some information (measures, power set-points, commands) from a plant control system (RTU), to carry out all the required controls and regulations at the Point of Interconnection.

1.1. The concept of 'Point of Interconnection' (POI)

In a power generation plant, it is very important to figure out where is located the so called 'point of interconnection' between the PV plant and the rest of the power plant.
Actually a power plant could include, beside PV generators, also other types of generators (like steam-generators, hydro, wind and so on), each of them contributing to generate power at some voltage level in the power plant.
Therefore, a power plant controller has to manage and control all the generation sources connected to the plant, by sending to every single source, an appropriate set of commands and power (active/reactive) set-points, in order to achieve two main tasks, both dealing with the stability of the grid at the POI:

- Voltage regulation.
- Primary Frequency regulation.

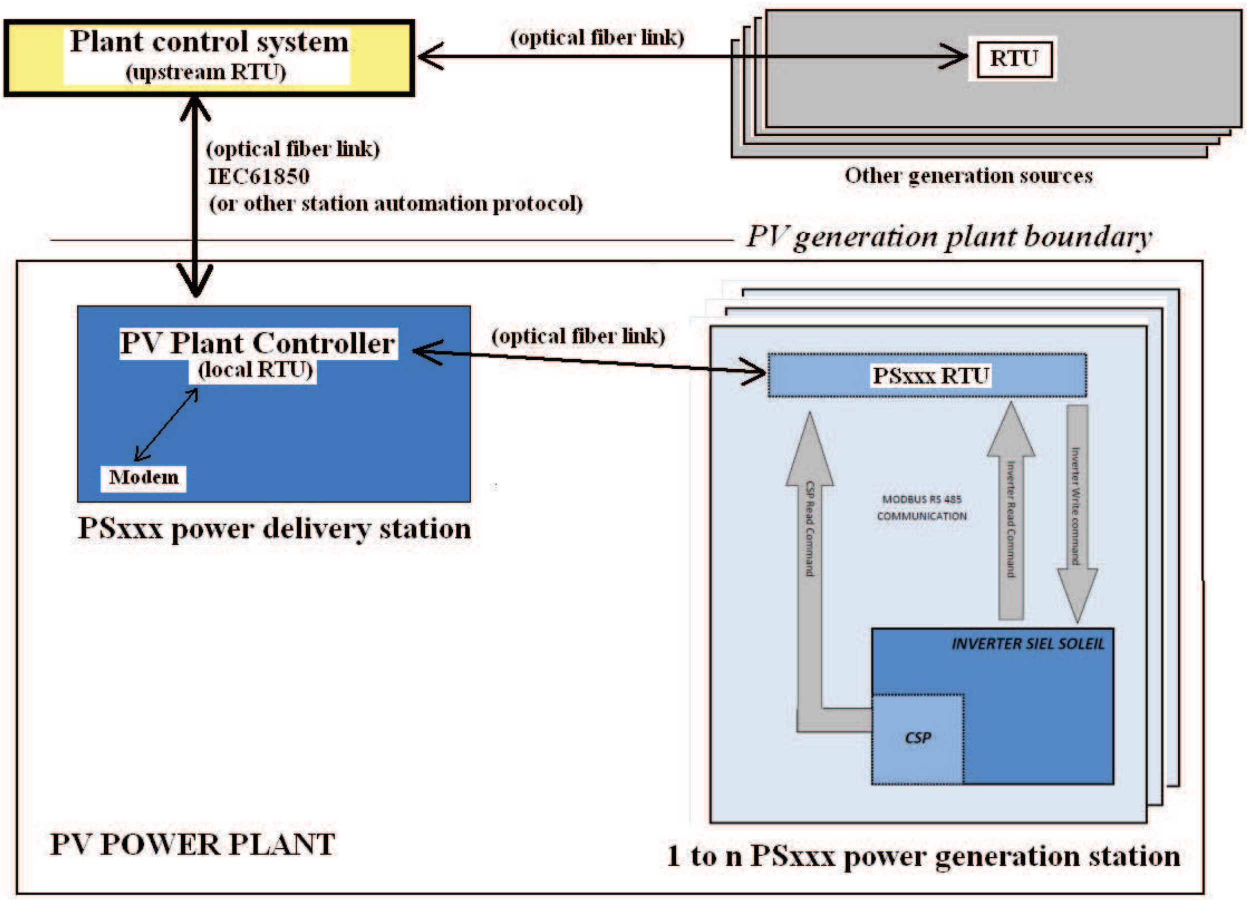
So basically, the POI is the point where the aforementioned regulations have to take place. Usually, this is also the point where the generated energy is measured.
Assuming that a plant control system is already present at some point of the plant (for example in a substation at a Distribution level), all the PV generators present into the plant, have to interface with this plant control system (through their own RTUs), in order to properly participate to the voltage and frequency regulations, just like any other generation source, as explained.

1.2. Hierarchical control of the plant through the PSxxx delivery station and PSxxx generation stations

The SIEL PSxxx generation and delivery units, embed an RTU (local plant controller) gathering all the information pertaining the Point of Interconnection and coming from the plant control system (upstream RTU), such as:

- Medium Voltage (line to line) measures at the POI.
- Active power set-point (or limit) Pref, for Primary frequency regulation at the POI.
- Reactive power set-point Qrefì, for voltage regulation at the POI.
- Remote Start/Stop command.

These information is dispatched from the PV plant controller (local to every PSxxx power delivery station) to every single PSxxx generation station (through optical fiber). Each PSxxx generation station has its own RTU, dispatching the received information to every single Soleil inverter (RS485 Modbus RTU).
The inverter, eventually, executes the commands and actuate the set-points, delivering the demanded active and reactive power to the plant, to perform the required regulation at the POI.
The schematic block diagram and communication flow is as follows:



The communication data stream between the RTUs (arrow links into the schematic), is always bi-directional, because the communication must be carried out through a Command-Acknowledge-Execution approach.
Furthermore, the PV plant controller, acts as a collector of all the information coming from the PV plant, such as:

- Statuses and alarms of each inverter.
- Electrical measures from each inverter (voltage, current, P, Q, etc.)
- Electrical measures from each PV junction box (CSP)

This information coming from the PV plant, is transmitted on a dedicated channel through a Modem device (ADSL, wireless GPRS or satellite), located into the Delivery Station, to a server, located into a dedicated server room, running a SCADA for remote control and monitoring.
Chapter 8 will provide further clarification about the task and operating modes of the plant controller.
It is very important understanding how the regulation functions as implemented into the inverter control logic, may be similar (or identical) or differ from those required by the NTSCS standard. The purpose of this document is right to highlight the differences (where present) between NTSCS requirement and the inverter implementation.

1.3. Purpose of this document

This document provides an insight about the grid support features implemented in the Soleil inverters, which are the generation units of the PSxxx generation stations.
Even though these features are required by the CEI016 (Italian standard) and may slightly differ from those recommended by other national code standards (such as the German BDEW), they constitute the backbone of the regulation set of functions for whichever kind of MV and HV grids.
Full compatibility with other country-specific grid codes, can be achieved either by modifying some user-adjustable parameters of the inverters and SPI (such as voltage and frequency thresholds, ramp slopes, trip delay and so on) or through a specific FW change for the inverter (please contact closest Siel distributor or Area Manager for further information).

2. SPI device: frequency out of range and voltage out of range protections

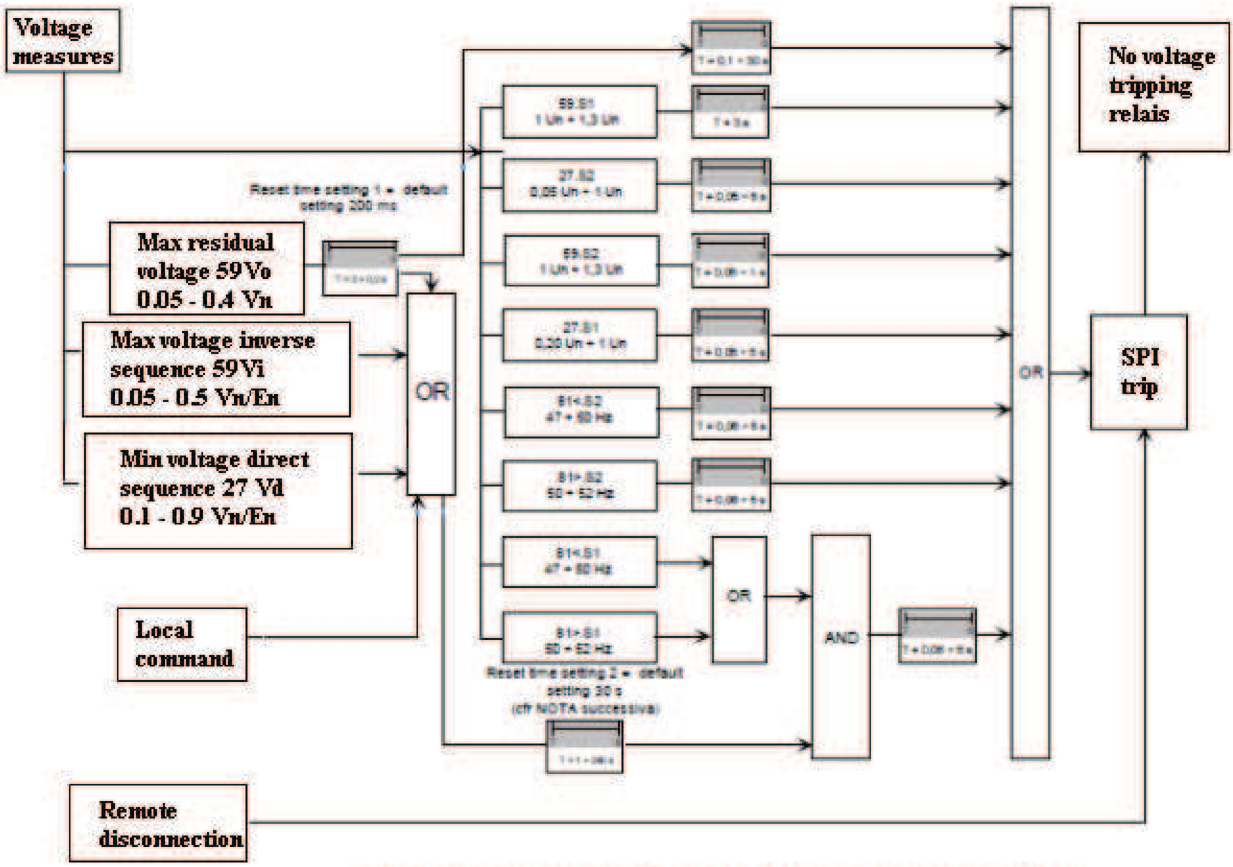
The SPI device is a protection relais (with its own CPU and display), installed into the PSxxx power delivery station and acting on the main switchgear, by disconnecting the PV plant from the grid when the frequency of the voltage of the grid are out of their tolerance bands.
The protections implemented by the SPI, are compliant with CEI016 standard and are summarized in the following table:

Protection	Trip intervention threshold	Tripping time	Opening time of interface disconnection device
Max voltage (59.S1, based upon rms calculation)	1.10Vn	Max 603s	Total opening time is obtained by summing up the Tripping time (previous column) plus 70ms
Max voltage (59.S2)	1.20Vn	0.6s	
Min voltage (27.S1)	0.85Vn	1.5s	
Min voltage (27.S2)	0.3Vn	0.2s	
Max frequency (81>.S1) (restrictive threshold)	50.2Hz	0.15s	
Min frequency (81<.S1) (restrictive threshold)	49.6Hz	0.15s	
Max frequency (81>.S2)	51.5Hz	1.0s	
Min frequency (81<.S2)	47.5Hz	4.0s	
Max residual voltage (59Vo)	5%Vrn	25s	
Max voltage inverse sequence (59Vi)	15%Vn/En		
Min voltage direct sequence (27Vd)	70Vn/En		

There are two thresholds (so called 'restrictive' and 'permissive') for 'minimum frequency' protection and another two thresholds for 'maximum frequency' protection.
The same goes for the 'minimum voltage' and 'maximum voltage' protections.

The residual operating time after the relevant frequency threshold has been crossed, before tripping, can be adjusted (within some limits) by properly setting up the CEI016-compliant SPI device.

The logic that the SPI operates according with, is specified by the normative CEI016, as follows:



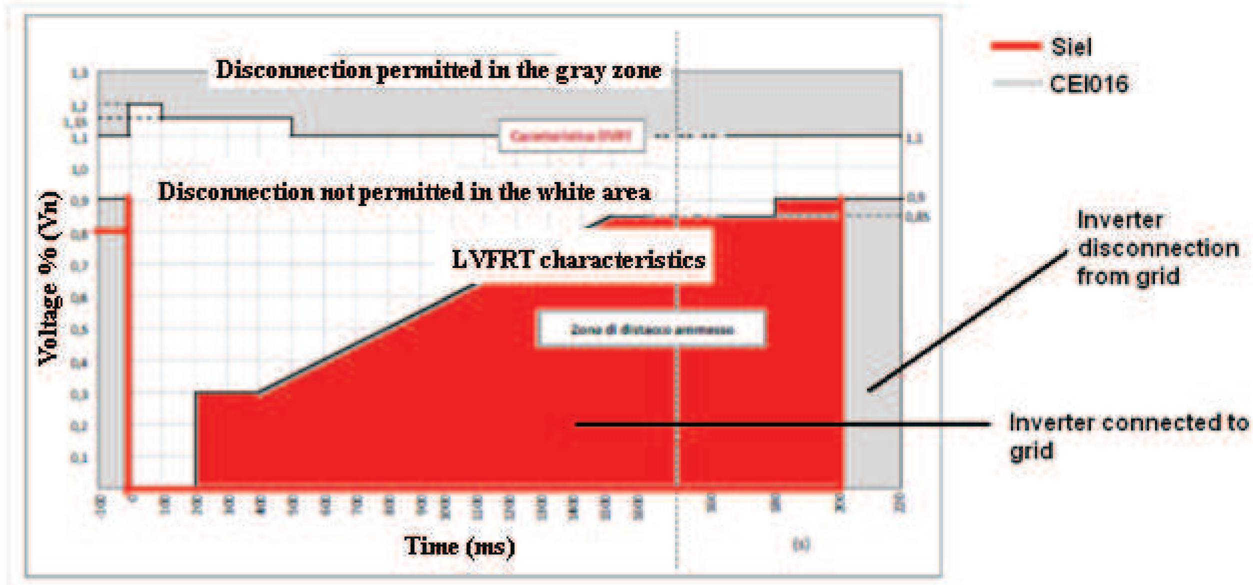
Functional schematic diagram about SPI logic

If a different operation scheme of the protection relais is required for the country-specific reasons, please contact closest Siel distributor or Area Manager for further information.
For instance, some country (like Chile) requires a protection interface relais with more than 3 thresholds for frequency undervoltage and 3 thresholds for frequency overvoltage protection.
It is important to remark that the Soleil inverter can be operated with whichever protection relais, pending a proper SW parameter adjustment on both the protection relais and the inverter (e.g., the acceptance range for the frequency and voltage on the inverter, must be such to not interfere with the setting of the relais). These adjustments can be done either by an expert user or by Siel Technical Staff.

3. LVFRT capability

This feature is related to the capability of each inverter composing the PV installation, to stay connected to the grid whenever a voltage dip occurs, within some limits of time.
It is aimed to keep a certain degree of 'responsiveness' by the generators, whenever a failure occurs at some point of the grid (e.g. a phase-to-ground short circuit).

Soleil inverters match and exceed the requested features of the CEI016, in terms of capability to withstand a low voltage ride through, as shown in the graph herein reported:



Behavior of the inverter face to a voltage dip, is like follows:

Inverter manufactured before January 2014:

- As soon as the voltage drops below 80% (FW programmable threshold), the inverter stops generating power (switching commands to power bridge turned OFF).
- The inverter stays online (connected to the grid with its output contactor closed) until the voltage is rising above 80%, for a maximum time of 2secs (programmable).
- Outside the highlighted area of the V-t diagram, the inverter is physically disconnected (its output contactor is open) from the grid.

During the whole duration of the LVFRT, NO REACTIVE CURRENT can be provided by the inverter, being it in a OFF status (according to point a).

Inverter manufactured after January 2014:

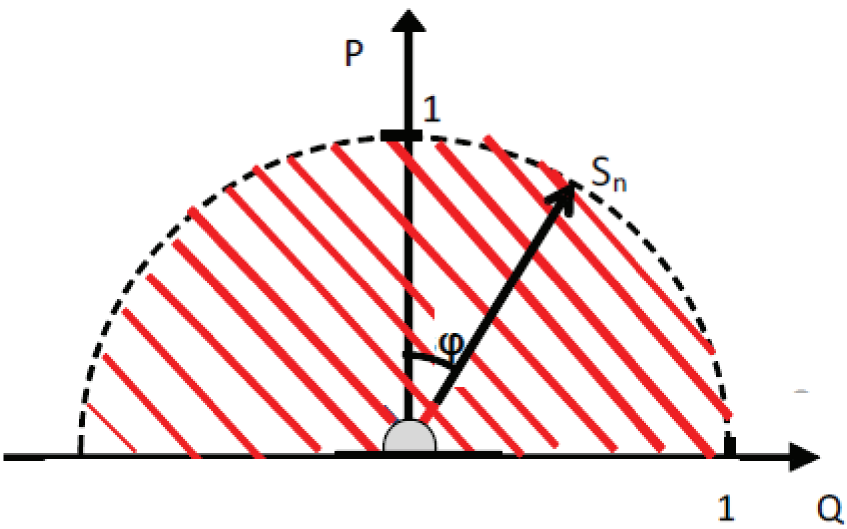
- As soon as the voltage drops below 80% (FW programmable threshold), the inverter enters a special operating condition called ‘voltage ride through’, where the generated power is managed as follows:
  - The active power is immediately cut down to zero.
  - Some amount of reactive power is generated, as a linear function (percentage ‘perc%’ of the nominal current of the inverter ‘In’) of the difference between the actual voltage (‘U’) and the rated voltage (‘Un’):
    - **Ireact = perc% x In x (U-Un)**

If the coefficient 'perc% is set to 100%, the inverter always generates the maximum reative current ('In') during the voltage ride through.

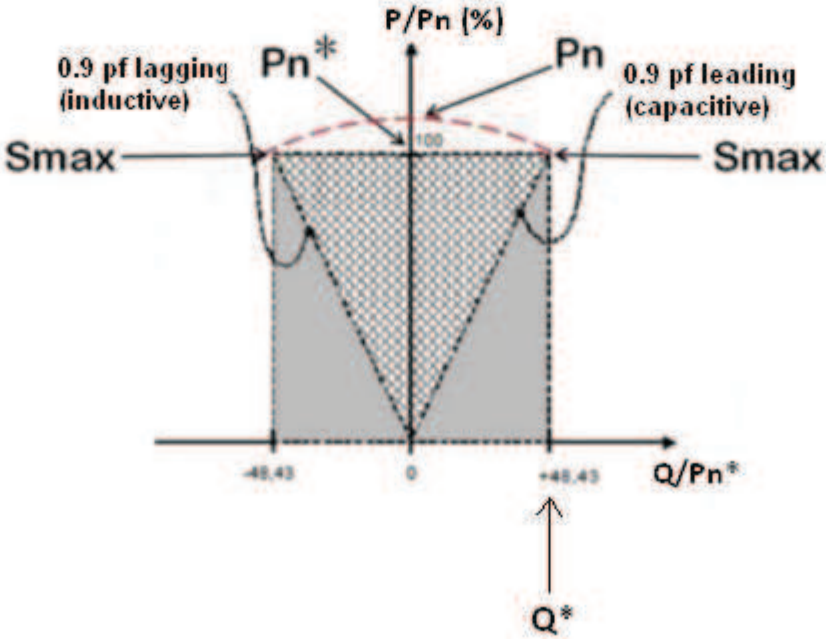
- The inverter stays online (connected to the grid with its output contactor closed) until the voltage is rising above 80%, for a maximum time of 2secs (programmable).
  Inverter models manufactured after December 2013, can stay online with no restriction of time (as long as there's enough power from the DC side to keep the logic powered on).
- Outside the highlighted area of the V-t diagram, the inverter stops generating current and is physically disconnected (its output contactor is open) from the grid.

4. Active and reactive power generation capability

This is a property of the PV plant involving being able of generating, upon request, a certain amount of active and reactive power, in order to act as a buffer, encountering the needs of the grid when it comes to regulating the voltage at the POI.
It is therefore a property involving the sizing of the inverter and its ability to be operated in whatever point of the P,Q (active/reactive) working space.



As per previous graphs (dashed red-line area), Siel inverters can work in whichever point of the P,Q space delimited by the semi-circular diagram (red line).



Previous figure can help understanding a quite common condition where a power factor of 0.9 (leading and lagging) is required by the specific grid code.

Acronyms

Pn = Maximum active power continuously produced by the inverter if no reactive power is demanded.
Smax = Maximum apparent power continuously produced by the inverter.
Pn*= Maximum active power continuously produced by the inverter, if operation at 0.9 power factor is required.
Q*= Reactive power continuously produced by the inverter, if operation at 0.9 power factor is required.
Qmax = Maximum reactive power continuously produced by the inverter if no active power is demanded.

As an example, the Soleil DSPX 660 TLH is considered:

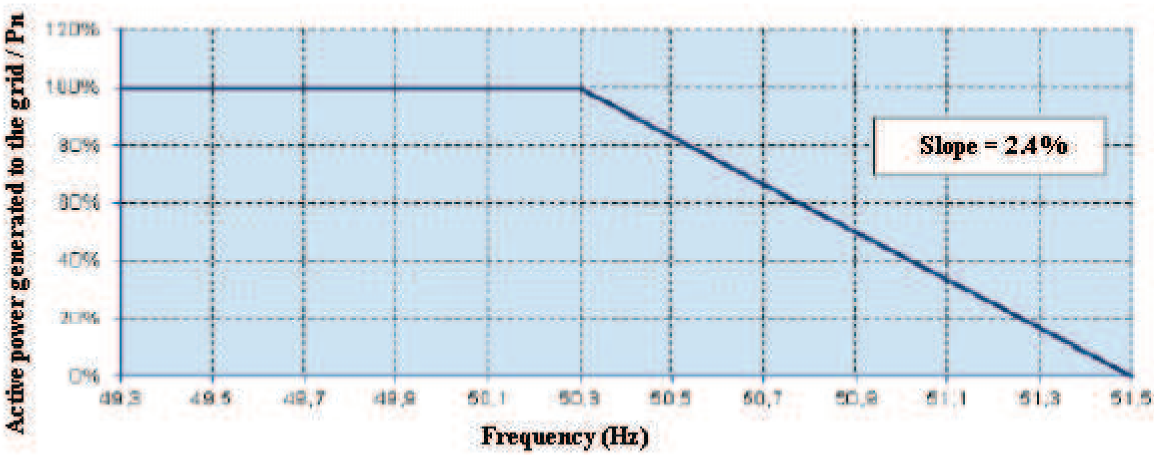
Acronym	SIEL Soleil DSPX
Pn	660kW
Smax	660kVA
Pn*	0,9 x 660 = 594kW
Q*	0,4843 x Pn* = 287,6kAr
Qmax	660kVAr

5. Participation to Primary Frequency regulation at the POI

The primary frequency control can be performed at two different levels:

- At a Plant control system level, by issuing an active power limitation set-point **Pref** to each inverter (trough the communication link with each Power Delivery Station, as explained in the Introduction).
  In this case, the system plant controller is the 'master' of the regulation, because, out of the frequency and power measures taken at the POI, it closes the loop of the frequency regulation, by generating the **Pref** set-point for each generator.
  When this working mode is enabled, the inverter only acts as a 'slave' of the plant control system, just delivering as much active power as required by the **Pref** set-point, regardless of the available PV radiation.
  Please notice that Pref is always less than the nominal power Pn of the inverter (i.e. it is a power limitation). By setting Pref at zero, the inverter stops generating power.

- At the generator-level, directly performed by each inverter. In this case, the inverter, by constantly monitoring the value of the instantaneous frequency, can self-limit the active power being generated, according to a static function, depicted in the following diagram:



The static function limiting the active power upon the frequency, is flexible and can be configured at a user-level, as follows:

- The starting frequency of the active power derating (standard: 50.3 Hz), is adjustable from 50.1Hz up to 50.5Hz, with a 10mHz resolution step.
- The ending frequency of the active power derating (where the power becomes zero) is as default 51.5Hz, but it can be adjusted from 50.2 up to 53Hz, with a 10mHz resolution step.
- The power ramp after a power derating has taken place, is applied in order to restart full power generation with a default rate of 20%/of the pre-fail power per minute. This rate is adjustable by

simply specifying the desired time (in minutes) in order to reach the 100% of the pre-fail power. By setting it at 10 (minutes), a ramp with a 10% of the pre-fail power per minute will be applied.

6. Participation to the Voltage Regulation at the POI

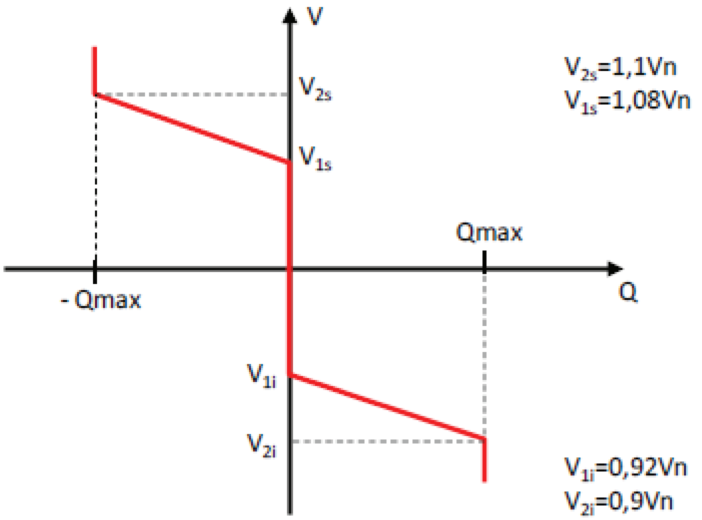
Grid voltage regulation function is carried out by appropriate generation of reactive power by the PV power plant. This feature is performed by both the plant control system and the inverters.

The power factor can be regulated according to the capability of the inverter as summarized in chapter 6.2, i.e. any couple of value of P and Q within the circular diagram are achievable.
Therefore, all the values of the power factor requested by the NTSCS can be obtained.
The ways the voltage regulation can be performed by the system are basically 2, herein summarized:

- In a Closed-loop fashion, by the Plant Control System.
  The inverter, upon receiving the reactive power set-point(Qref) from an uppermost RTU (e.g. a substation at the distribution-level), thanks to its power capability (P,Q circular diagram), acts as the actuator (slave) of the control loop, by simply generating the reactive power as requested by the Plant Control System.
  The 'control loop' on the power factor (active and reactive power control) at the POI, pretty much as for the Primary frequency control (see Chapter 6), is closed by the Plant Control System, by measuring the power, calculating the cosphi and generating a new set-point of Qref.
  The Plant Control System, must implement a lumped model of the whole system (all the generators, cable lengths, transformers and so on) and keep the status of the model updated by continuously measuring the electrical parameters (voltage, active and reactive power) at the POI.

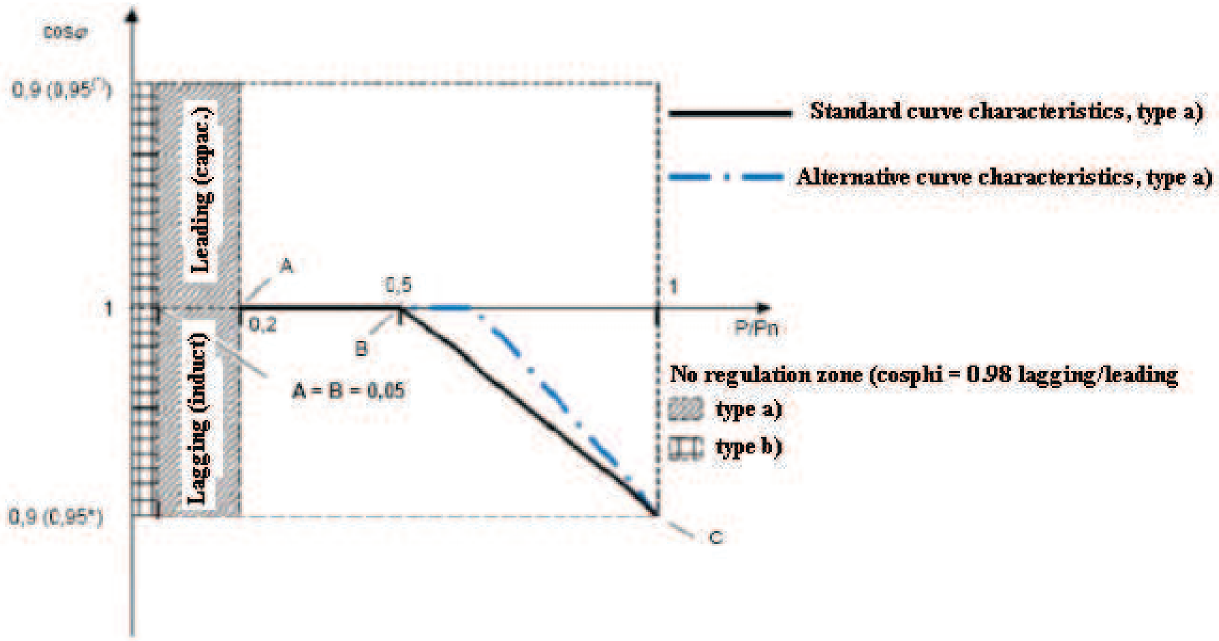
- In an Closed-loop fashion, by the PSxxx plant controller.
  In this case, the PSxxx plant controller, by receiving the measures of the voltage and the reactive power at the POI (from an uppermost RTU, e.g. the Plant Control System) and by knowing the lumped parameters model of the whole plant, can generate by itself the reactive power reference Qref for the inverters.

- In an Open-Loop (or feedforward) fashion, by the inverters.
  The inverters, thanks to their automatic regulation functions [Q=f(V)] or cosphi=f(P)], can generated the correct amount of reactive power to ensure the voltage regulation at the POI :
  - Q=f(V) approach: the reactive power is generated as a function of the voltage at the POI (whose measures are received by the Plant Control System). In this case, the inverter is the units which controls the voltage in 'feedforward'.



- Voltage thresholds V1s, V2s and V1i, V2i are adjustable by user.
- Qmax is 43.6% of the rated value of apparent power Sn (see diagram chapter 4)

- Cosphi = f(P) approach: the inverter can regulate the power factor at the POI as a function of the active power (whose measures are received by the Plant Control System). In this case, the inverter is the units which controls the power factor in 'feedforward'.



These last two operating modes work well, when the PV sources are the only generators present on the plant at the POI, so that, no other generator being present, there's no need to keep into account any lumped parameter model of the system.