Document #: 12020
Status: DRAFT
Version 1.5

SunSpec Inverter Models

SunSpec Alliance Interoperability Specification

SunSpec Alliance Inverter Workgroup

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Version 14

ABSTRACT

The SunSpec Alliance Interoperability Specification suite consists of the following documents:

- SunSpec Technology Overview
- SunSpec Information Model Specification
- SunSpec Information Model Reference Spreadsheet
- Collection of SunSpec Device Category Model Specifications
- SunSpec Plant Extract Document

This document describes the inverter model of the SunSpec Alliance interoperability specification.

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Change History, Inverter Control & Monitoring Models

Version	Date	Description
Version 0.0b	11-01-2011	Initial draft proposal.
Version 0.0c	01-06-2012	Change var setting in Volt-VAr array from %Wmax to %avail vars. Add MPPT block. Change Dynamic VAr to Dynamic Reactive Current. Add description for control mode enumerations. Add new appendix A for additional basic monitoring points; rename existing appendix A to appendix B.
Version 0.0f	01-16-2012	Move Modbus maps to separate spreadsheet document. Add figures and descriptive text for various control modes.
Version 0.1	01-18-2012	Update associated map spreadsheet based on Jan 18 meeting.
Version 0.2	01-25-2012	Minor updates based on Jan 25 meeting.
Version 0.2a	01-27-2012	Add new figure showing example chained control blocks. Remove text mentioning a corresponding floating point map. Remove additional DC measurements from Appendix A.

Version 0.3	02-07-2012	Add text regarding lifetime energy accumulations. Update figures 1, 3 and 7. Add DC measurements back into Appendix A. New SunSpec logo. Add meaning for VAR setting in volt-var arrays. Change "VarXXX" to "VArXXX" and Pref to WRef to match IEC nomenclature. New figures for dynamic reactive current support.
Version 0.4	02-13-2012	Remove appendices. Add Security section.
Version 0.5	02-17-2012	Reword parts of the Dynamic Reactive Current support section to match the figures (11 & 12). Add text to Nameplate Ratings and Basic Settings blocks for positive and negative VARs and leading and lagging power factor. Add text to Measurements block for new status limit bit mask. Add Acknowledgements section.
Version 0.8	04-27-2012	Replace figure 7 and add table 1 with info from latest IEC 61850-90-7 draft 21. Use short names when referring to data elements. Add statement of representation of percentages.
Version 0.9	06-26-2012	Update figures 3, 7, 8 and 18 with info from IEC 61850-90-7 draft 27a. Delete original figure 4. Clarify text for low pass filter on independent variable in curves. Recommend four curves of 10 points each for Watt-PF array for consistency and scheduling. Increase recommended number of points for LVRT/HVRT curves from 10 to 16. Change function name of "Static Volt-VAR" to "Volt-VAR".
DRAFT 10	08-29-2012	Writeable clarification. Supported modes and options clarification
DRAFT 11	06-02-2013	Standardization on EEI sign convention for Power Factor notation. • Replace two quadrant VAr and PF settings with four quadrant values. • Add new LFRT/HFRT models. • Increase minimum array size to 20 points for all curves. • Add recommendations for handling of errors and unsupported values/enumerations.
DRAFT 12	06-19-2013	Clarify behavior of Enable registers. Cleanup up terminology ("function" and "block" now "model" in most cases).
DRAFT 13	01-10-2014	Clarify definition of Power Factor.
DRAFT 14	03-25-2015	Combine Inverter Monitoring Spec into this Monitoring and Control specification, and include references to the Comprehensive Data Model and Modbus Map.
Version 1.5	04-06-2015	Updated descriptions. Underlying model definitions are unchanged.

Change History, Monitoring Specification

Change history for the Inverter Monitoring Specification.

Revision	Date	Reason
Approved 1.1	04-01-2013	Published "Inverter Models v1.1" on website
Approved 1.2	06-01-2013	Updating logo, replace point names

		Adding MPPT Model to collection
Approved 1.3	09-18-2014	Change to new SunSpec document format, change name from “Inverter Models” to “Inverter Monitoring Model ”

Contents

Introduction

The SunSpec Alliance Interoperability Specifications describe the data models and Modbus register mappings for devices used in Renewable Energy systems. This document describes models for read-only inverter data (monitoring) as well as support of programmed, scheduled, and autonomous inverter control operations.

Device models can be chained together per the SunSpec Information Model Specification, to create a specific implementation. This built-in flexibility removes any fixed constraint on the number and types of controls that can be incorporated with minimal overhead.

To allow inverter control modes to be optional on a feature basis, unique SunSpec Models are defined for each of these new features. This allows the inverter to offer a set of capabilities to clients and for those clients to discover the capabilities of the inverter and allow a client to skip models it does not recognize or implement. See Figure 1 for an example of inverter models chained together to create an inverter implementation.

This specification applies to single-phase, split-phase and three-phase inverters.

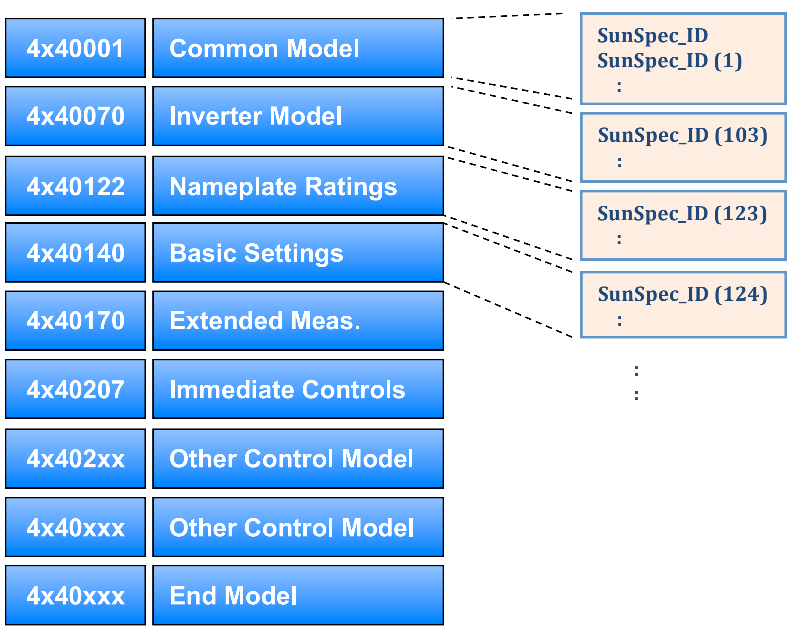

Figure 1: Chained Inverter Control Models

Note that the SunSpec Interoperability Specifications and the definition of data models are open to revision. We strongly suggest that you visit www.sunspec.org and download the latest information before you actually begin implementing inverter devices. An overview of SunSpec Technology and the SunSpec Information Model Specification are included in the download.

Model Headers

The following top-level data elements are provided to describe each inverter model.

- **ID** – A well-known value –1xx that uniquely identifies this model as an inverter model.
- **Length** – The length of the inverter model in registers, not including the ID or Length registers.

Inverter Data Models and Modbus Maps

Refer to the SunSpec Information Model Reference spreadsheet (http://sunspec.org/download) for a complete definition of all specific environmental device models and all included data elements. This spreadsheet is part of the comprehensive download of all SunSpec Specifications**.**

All inverter data models are defined in the 100 series of models (100-199). Look in the Index tab of the spreadsheet to locate the model(s).

Each specific inverter data model goes through a separate approval process. The SunSpec Information Model Reference spreadsheet includes data models that are of Approved, Test, or Draft status. Status for each Model is indicated on the SunSpec website. Be sure to check the status of any model before you implement. Only approved models can be certified by SunSpec.

The SunSpec Information Model Reference spreadsheet is generated programmatically from the model definitions contained in the SunSpec model repository. The SMDX files in the model repository are the definitive representations of SunSpec models.

Monitoring Data Element Types

The following data element types are defined for Monitoring:

- Inverter AC values
- Inverter DC values
- Inverter Operating Temperature
- Inverter Operating Status
- Inverter Event Flags

Models for monitoring data can be found between 100 and 119 in the Information Model Reference spreadsheet.

Inverter Control Models

The various models are described in detail in the subsequent sections.. Implementations should leave unused or unsupported data points within a control model set to the "not implemented" value.

Control settings are marked in the SunSpec Information Model Reference spreadsheet with access RW. It is not required to support writeable for all settings. Settings may be read-only if the setting is fixed or not settable via the communication interface. Such limitations must be noted in the PICS document.

Some settings specify various modes are options. It is not required for implementations to support all modes and options. Any limitations should be noted in the PICS document. Any application writing an unsupported mode or optional value shall receive a Modbus "Illegal data value, exception 3" response.

Many control points are specified in terms of percent of a fundamental setting or nameplate rating (e.g., percent of WMax or percent of VRef). Unless otherwise stated, data elements with units of percent are integer values from 0 to 100 and a scale factor of 0. In many instances, a scale factor register is provided to allow higher resolution (e.g., a value of 124 with a scale factor of -1 represents 12.4%).

For the purposes of this document, any references to power factor or PF means cos(ϕ) (defined as cosine of the phase angle between the fundamental voltage and a current), using the EEI power factor sign convention (Figure 6).

Most of the control models include a time window, reversion timeout value and ramp time. The time window is a period of time within which the inverter randomly delays before beginning execution of the command. This helps prevent a groups of inverters from changing state or operating level at the exact same time. The reversion timeout value (if non-zero) specifies a time for the requested change to revert to its default state. A timeout value of zero means the change persists until another change is made. If a reversion timer expires and control reverts to its default state, any bits in the StActCtl register and/or associated enable register, if supported, must be updated to reflect the new state. The ramp time is a fixed time in seconds, over which the inverter settings are to transition from their pre-setting level to their post-setting level. The purpose of this parameter is to prevent sudden changes in output as a result of the receipt of a new command (Figure 2).

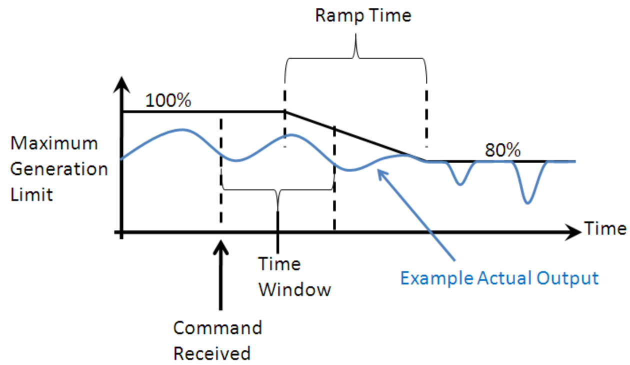

Figure 2: Example Time Window and Ramp Time

Many curve based controls also provide settings for a low pass filter and/or maximum increment and decrement gradients. The low pass filter is applied to the independent variable of the curve while the gradients are applied to the dependent variable (Figure 3). The low pass filter is specified by RmpPT1ms, the time, in seconds to achieve a change of 3τ (95%) . RmpDecTmm and RmpIncTmm (in percent of output change per minute) provide the limiting linear gradients to avoid sharp shifts at the breakpoints of the piecewise linear curve.

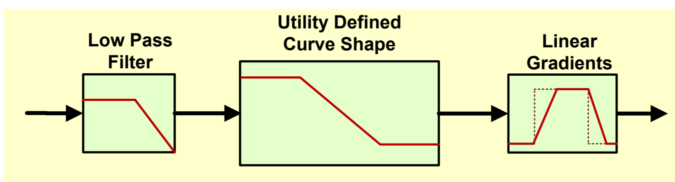

Figure 3: Transfer Function for Curve-Based Controls

Nameplate Ratings (Model 120)

The nameplate ratings are read-only values set by the inverter manufacturer by design or manufactured configuration. They specify such values as the continuous power output rating (WRtg), continuous VAR capability in each quadrant (VArRtgQ1, VArRtgQ2, VArRtgQ3 and VArRtgQ4) and scale factors for these values. The nameplate ratings are used as the default values for the corresponding basic settings, such as WMax and VArMaxQn used in the other inverter control models (Figure 4). Some inverter architectures may have different VAR capability for positive (leading/inductive) VARs versus negative (lagging/capacitive) VARs, so the nameplate rating model includes four values each for maximum VAR and minimum PF ratings – one for each quadrant - instead of a single rating for each.

Basic Settings (Model 121)

The Basic Settings model provides a means to modify the operating limits of an inverter as originally set by the nameplate ratings. For example, the operating level may be reduced or increased as a function of the number of attached PV panels or condition of the equipment or even season of the year or intended use. The Basic Settings section also includes settings related to a specific installation, such as VRef, the voltage at the point of common coupling, VRefOfs, the voltage difference from the point of common coupling to the electrical connection point of the inverter, and the set point for the nominal frequency (Figure 5). Similar to the Nameplate Ratings model, four values each are provided for the maximum VAR values..

While a watt-power factor array is provided for fine control of power factor versus active power, some installations may want a simpler way to control PF limits, for example to allow the PF to autonomously decrease down to a prescribed minimum, after which power or other inverter setting(s) would be limited to keep the PF pinned to that minimum value. To accommodate this, the PFMinQ1 through PFMinQ4 registers are available to set an operating limit (greater than or equal to the respective PF ratings) for power factor.

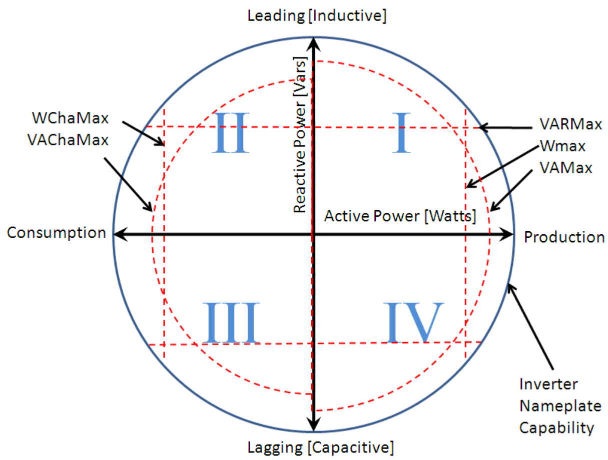

Figure 4: Nameplate and Operational Settings (producer frame of reference)

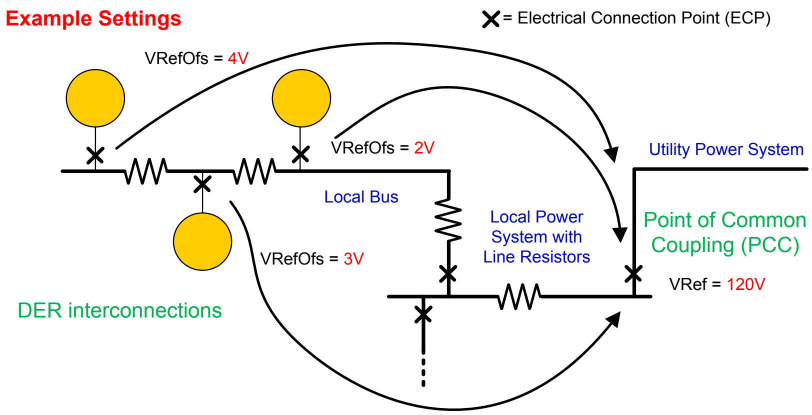

Figure 5: Connection Points

Measurements and Extended Status Reporting (Model 122)

Basic status reporting is defined in the base Inverter Models document. With interactive inverter controls, additional status reporting is required. This includes primary information, including ECP/grid connection status, PV connection/availability, storage connection/availability and lifetime accumulated real, apparent and reactive energy values. While the base inverter model includes scaled lifetime real energy, the energy values in this model are all 64-bit quantities. Reactive energy by quadrant is included for multi-quadrant inverters. The quadrant nomenclature is per Figure 4.

In some installations, a customer, user or energy provider/supplier may want to know if an inverter is operating at one of its defined limits. This can be achieved by reading the current values for the parameters of interest and comparing to the prescribed limits. However, to make the task easier, an optional status bit mask is introduced to indicate when one of the defined limits is reached (maximum real, apparent or reactive power, available VARs or minimum power factor). These status bits are cleared by the device when the register is read and on powerup.

The optional StActCtl register provides feedback to the controller on which controls are active. The bits in this register should indicate actual current operating status of a given control, not just the enabled state. For example, a given control may be enabled but not active due to randomization window, ramp time or a higher priority control. In this case, its status bit would indicate not active (0).

Time settings are included to support the use of schedules and time stamping of events. Time source, TmSrc, is a string that defines the source of the inverter time reference. Possible strings could include “RTC”, “SNTP”, GPS”, “DNP3”, ”Modbus”, etc. The current time, Tms, is read/write register that can be used to read the current inverter time, as well as set the time if the time source is Modbus or the inverter requires an initial time setting for its internal real time clock (RTC). Since there is no practical use for representing time in the past, Tms is define as an unsigned 32-bit integer with an epoch of 01 Jan 2000 00:00:00 UTC.

Immediate Controls (Model 123)

The immediate controls model includes the following: connect/disconnect from the grid, adjust maximum generation level up/down, adjust power factor and adjust fixed VAR delivery. Note that setting power factor and VARs are mutually exclusive, but otherwise one or more of these controls may be active at the same time. The sign convention for power factor is the EEI convention (Figure 6).

Each of the immediate control functions, except connect/disconnect, has an associated enable (Ena) register. Each time a control value is changed, the associated enable register must be written with the ENABLED value (1). If a reversion timer is set for a given control, the associated enable register must be cleared by the device when the timer expires. Due to random window and ramp times, the enable register may not indicate the actual operational status of a control. Use the StActCtl register of the Measurements and Extended Status model, if available, to determine the current state of the inverter controls.

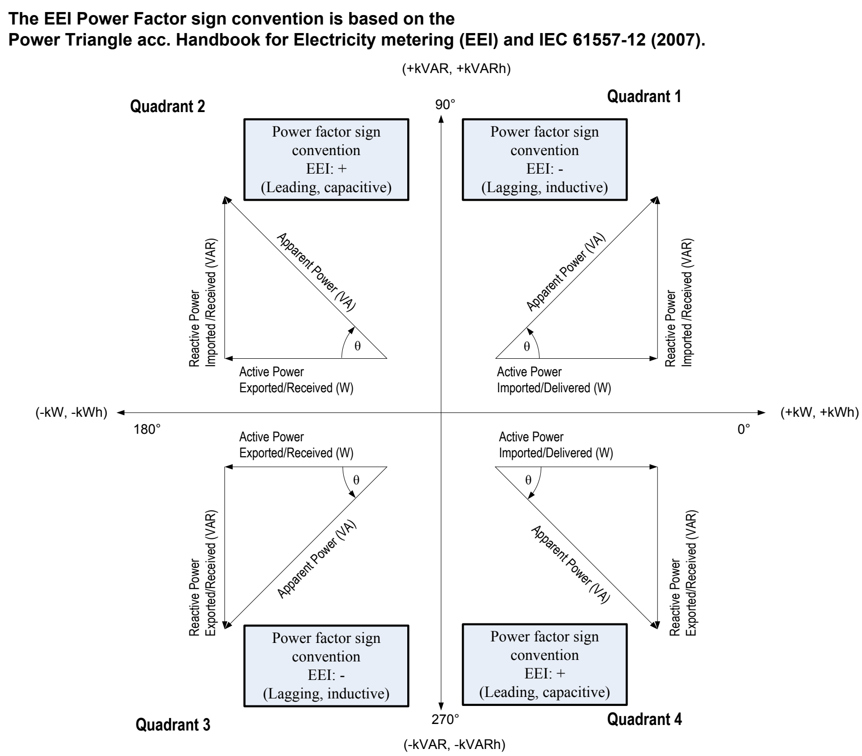

Figure 6: EEI Power Factor sign convention

Basic Storage Control (Model 124)

The Storage Controls model includes settings, status and controls for battery-based storage subsystems. The settings include maximum charge and discharge rates, minimum reserve and their respective scale factors. Status includes the current available energy, available storage, internal battery voltage and the charge status. Controls include requesting real power (charge or discharge storage), setting the charge or discharge rate and an indication if charge is allowed from the grid or PV only.

Pricing Signal (Model 125)

The pricing signal is used to adjust the power output or with storage systems to allowing the storage system to manage its charging and discharging based on an abstract pricing signal indicating the price (or value) of energy. The actual pricing signal value is utility or ESP defined, but could be absolute price in local currency, price difference (positive or negative) in local currency or a price multiplier. Or, it could be an abstract value, such as high/medium/low.

When the pricing signal is used in conjunction with Basic Scheduling to modify the inverter operating conditions based on the pricing signal value, the actual meaning of the price signal, must match the control or range (x) values in the corresponding schedule array so a meaningful comparison/match can be made.

Volt-VAR Arrays (Model 126)

The Volt-VAR model provides one or more Volt-VAR arrays, each of which consists of Volt-VAR pairs: a set of voltage levels and their corresponding VAR levels that will be treated as a piecewise linear function with hysteresis (Figure 7). Hysteresis is not required and if not present, the falling voltage curve follows the rising curve. Hysteresis can be simulated with a deadband (Figure 8). The voltage is in percent of VRef, the voltage at the point of common coupling. The VAR setting meaning depends on the DeptRef which selects percent of available VARs (VArAval), percent of maximum available VARs (VArMax) or percent of maximum watts (WMax). In addition to the array points, an increment and decrement ramp rate and ramp time are included. A minimum of four curves of 20 points each are recommended to allow a controller to select a pre-defined profile or for scheduling.

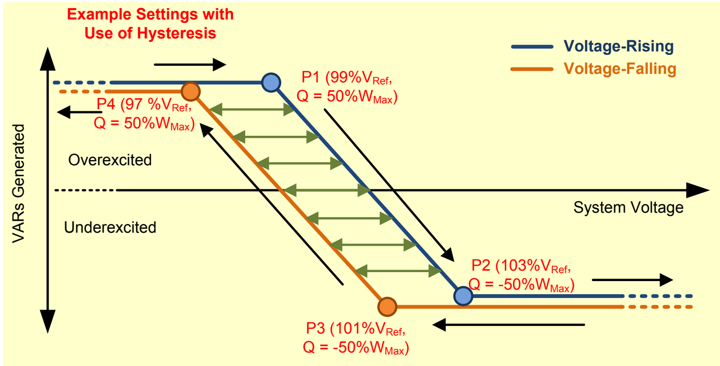

Figure 7: Volt-VAR Array Setting with Hysteresis

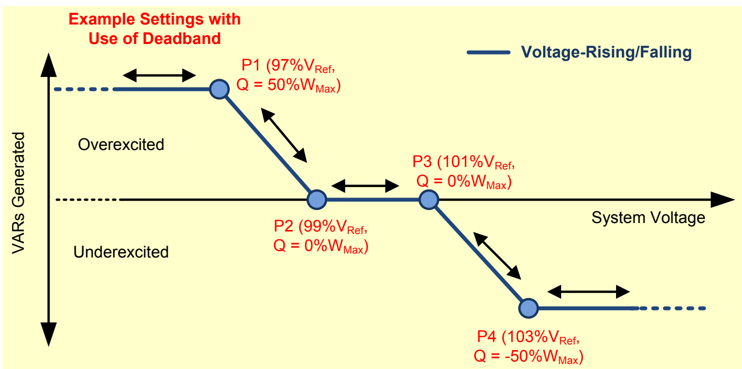

Figure 8: Volt-VAR Array Setting with Deadband

Frequency-Watt Control (Model 127, Model 134)

Frequency-watt control is used to limit active power generation or consumption when the line frequency deviates from nominal by a specified amount. There are two approaches available for frequency-watt control: the parameter approach and the curve approach.

In the parameter-based approach (Model 127), the active power output is reduced (curtailed) when the measured frequency exceeds the nominal frequency by a specified amount (HzStr) and removes the power restriction when the frequency deviation drops below the specified stop frequency (HzStop). Hysteresis is available, as is a gradient for the rate of power curtailment and restoration (

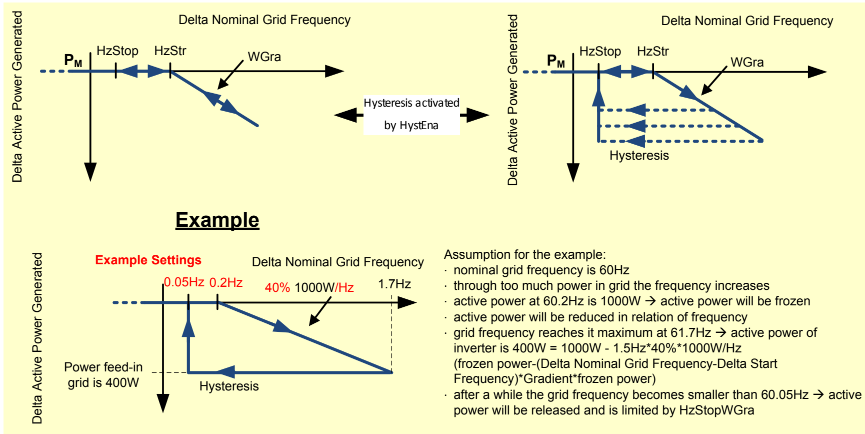

Figure 9).

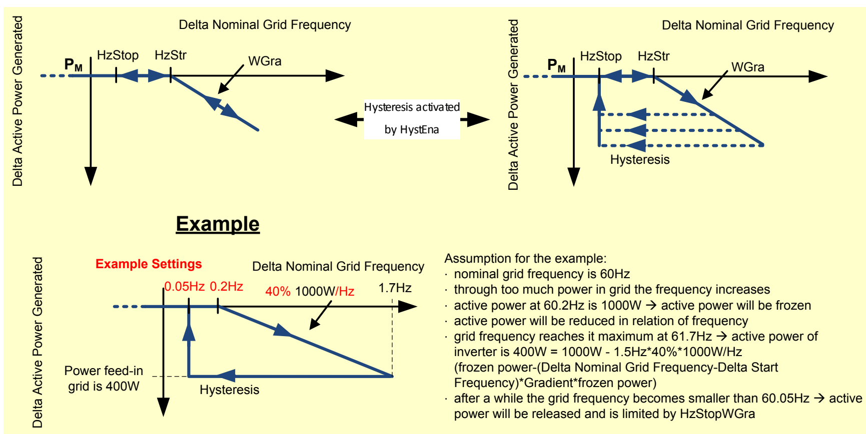

Figure 9: Parameter-Based Frequency-Watt Control

The curve-based approach (Model 134) consists of one or more frequency-watt arrays, each of which consists of frequency-watt pairs: a set of frequencies and their corresponding Watt levels that will be treated as a piecewise linear function with hysteresis (Figure 10). The frequency setting is the actual frequency in Hertz. The watt setting is 0% to 100% of the maximum available watts (WMax). In a storage system, the watt setting may be negative to indicate the system should absorb power from the grid to try and reduce the frequency even further. Hysteresis is supported, as well as an optional snapshot mode. A minimum of four curves with 20 points each is recommended.

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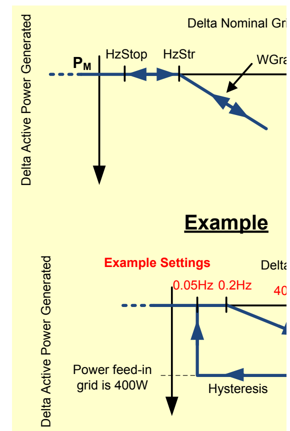

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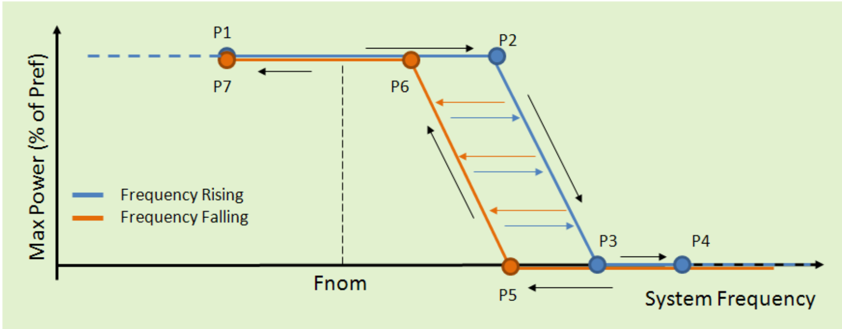

Figure 10: Curve-Based Frequency-Watt Control with Hysteresis

In some cases, it may be desirable to limit and reduce power output relative to the instantaneous output power at the moment when frequency deviates to a certain point (snapshot). To enable this capability, each frequency-watt mode configuration may optionally include the following parameters, in addition to the array: SnptW, WRefStrHz and WRefStopHz.

Dynamic Reactive Current (Model 128)

This control provides a mechanism for inverters to provide reactive current support in response to dynamic variations in service voltage. This is distinct from the Volt-VAR function in that the controlling parameter is the change in voltage from a moving average, rather than the instantaneous voltage level itself. The FilTms setting is used to specify the time window used to calculate the moving average of VRef. ArGraSag and ArGraSwell identify the additional reactive current as a percent of the rated current (ARtg), based on the delta voltage from the moving average of voltage. A deadband, defined by DbVMin and DbVMax, can be used to limit this function to be activated only when the delta voltage exceeds some limit (Figure 11).

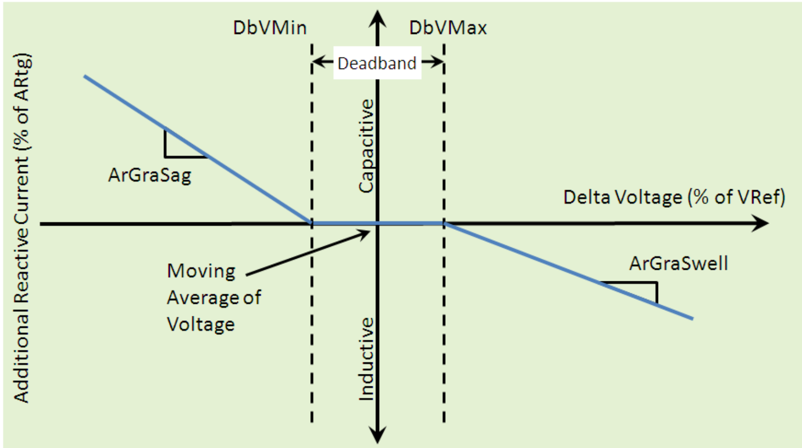

Figure 11: Dynamic Reactive Current Support

The settings identify the boundaries of the reactive current feed-in zones identified by the yellow shaded areas (Figure 12). The use of the deadband between DbVMax and DbVMin allows the activation of this behavior for a voltage sag or swell to be thought of as an "event". The event begins when the present measured voltage moves above the moving average voltage by DbVMax or below by DbVMin, as shown by the blue line in Figure 12 and labeled as t0.

In the example shown, reactive current support continues until a time HoldTmms after the voltage returns above DbVMin as shown. In this example, this occurs at time t1, and this event continues to be considered active until time t2 (which is t1 + HoldTmms). An optional blocking zone, inside which additional reactive current support is not provided can be defined by the three parameters BlkZnTmms, BlkZnV, and HysBlkZnV.

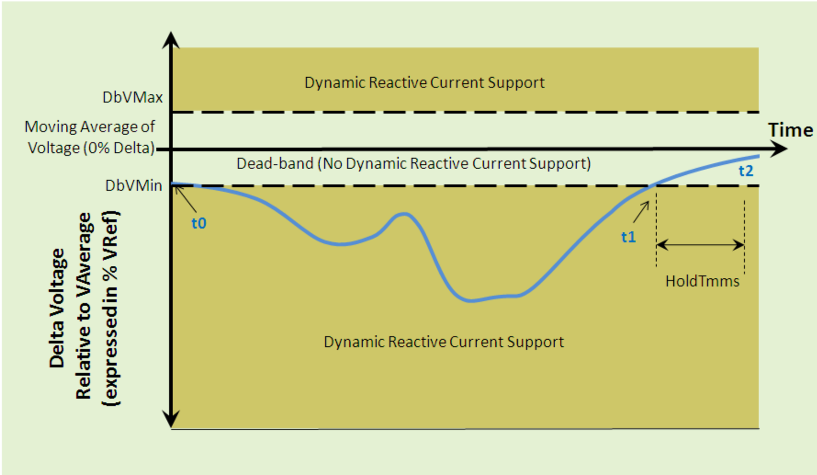

Figure 12: Activation Zones for Reactive Current Support

LVRT Arrays (Model 129, Model 137)

Two duration-volt arrays for low voltage conditions, each of which consists of duration-volt pairs: a set of durations (time at a given voltage) and voltage levels that will be treated as a piecewise linear function. One model (129) represents the "must disconnect" region and the second model (137) represents the "must remain connected" array (Figure 13). If the "must remain connected" array is not defined, it is assumed to be the same as the "must disconnect" array. The voltage is in percent of VRef, the voltage at the point of common coupling. In addition to the disconnect arrays, additional registers are used to define the reconnect behavior.

LVRT curves are assumed to extend horizontally to the left to zero seconds below the first point in the array and to the right horizontally above the right-most point in the array.

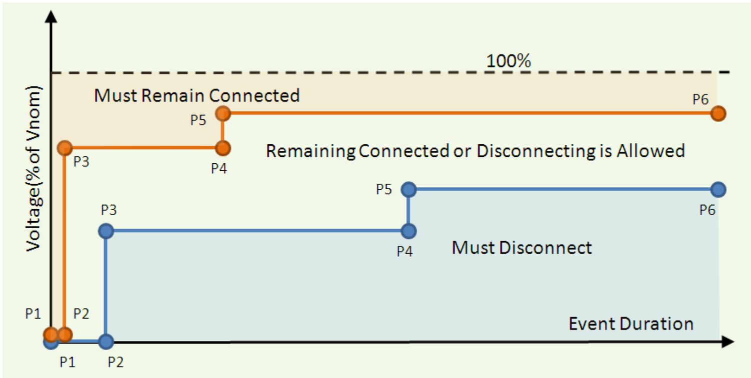

Figure 13: Use of Curves to Define LVRT Area

HVRT Arrays (Model 130, Model 138)

Similar to the LVRT, two duration-volt models with arrays for high voltage conditions, each of which consists of duration-volt pairs: a set of durations (time at a given voltage) and voltage levels that will be treated as a piecewise linear function. The first model (130) represents the "must disconnect" region and the second model (138) represents the "must remain connected" array (Figure 14). If the "must remain connected" array is not defined, it is assumed to be the same as the "must disconnect" array. The voltage is in percent of VRef, the voltage at the point of common coupling. In addition to the disconnect arrays, additional registers are used to define the reconnect behavior.

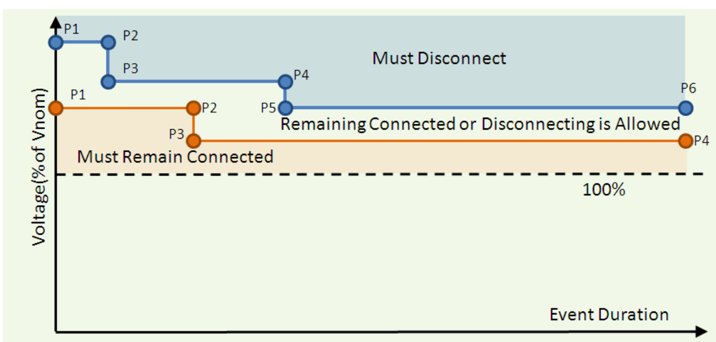

Figure 14: Use of Curves to Define HVRT Area

Watt-Power Factor Array (Model 131)

The watt-power factor (PF) control is curve-based with a watt-PF array, consisting of watt-PF pairs: a set of power levels and their corresponding PF setting that will be treated as a piecewise linear function with hysteresis (Figure 15). The watt setting is 0% to ±100% of the maximum available watts (WMax). The PF setting is the cosine of the power factor angle, using the EEI power factor sign convention. By using signed power and power factor, this curve can operate in all four quadrants. A minimum of four arrays with 20 points each is recommended.

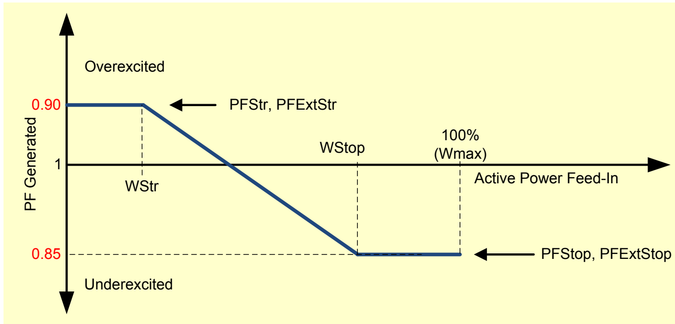

Figure 15: Example Watt-PF Curve

Voltage-Watt Arrays (Model 132)

This model provides a mechanism to control output power based on the local voltage (Figure 16). One or more voltage-watt arrays are defined, each of which consists of volt-watt pairs: a set of voltage levels and their corresponding watt levels that will be treated as a piecewise linear function with hysteresis. The voltage is in percent of VRef, the voltage at the point of common coupling. The watt setting is 0% to 100% of the maximum available watts (WMax). A minimum of four arrays with 20 points each is recommended.

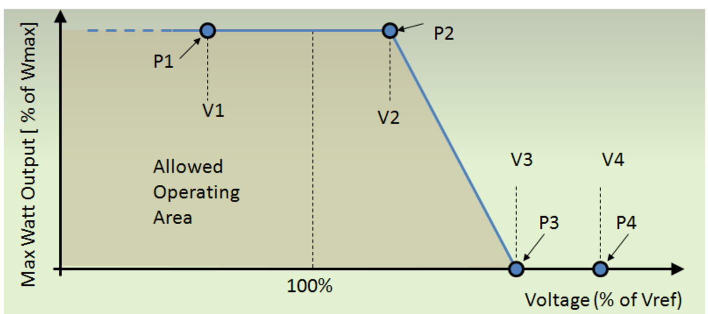

Figure 16: Example Voltage-Watt Curve

Basic Scheduling (Model 133)

Most of the control functions described previously can be performed according to a schedule (typically, but not necessarily, time-based). Schedules provide for additional autonomous operation and consist of the schedule x-value meaning, y-value meaning and an array of control or range (x) variables and the controlled or target (y) values. Multiple non-conflicting schedules may be active simultaneously. Inactive schedules must have their ActPoints entry set to zero.

Two types of pricing schedules are defined: one where pricing is the control variable and another where pricing is the controlled variable. In the first type, the schedule is an array of pricing values and their corresponding dependent operation (set power output level, charge/discharge gradients, VAR output, etc. In the other case, the control variable is time and the dependent variable the actual pricing value for real or reactive power. This allows a controller to preprogram a day-ahead pricing schedule. This schedule could run in parallel with the first type of pricing schedule or could run on its own with the actual inverter/storage operation determined by manufacturer determined controls.

A minimum of four schedules with 10 entries each is recommended.

LFRT Array (Model 135)

The LFRT model is a duration-frequency array for low frequency conditions, which consists of duration-frequency pairs: a set of durations (time at a given frequency) and frequency values (in Hertz) that will be treated as a piecewise linear function. A single LFRT model is provided with a “must disconnect” curve. Unlike LVRT, no corresponding “must remain connected” curve or model is provided.

HFRT Array (Model 136)

The HFRT model is a duration-frequency array for high frequency conditions, which consists of duration-frequency pairs: a set of durations (time at a given frequency) and frequency values (in Hertz) that will be treated as a piecewise linear function. A single HFRT model is provided with a “must disconnect” curve. Unlike HVRT, no corresponding “must remain connected” curve or model is provided.

SunSpec Inverter Control Procedural Requirements

Refer to the SunSpec Procedural Requirements section in the SunSpec Information Model Specification.

Modbus Security

It is recognized that where direct control of an inverter’s power generation capability is concerned, there is a concern that only authorized personnel or entities are allowed to make changes to the operating settings.

The Modbus standard does not include any mechanism to login or authenticate a master to a slave, or a slave to a master and has historically relied on physical security. SunSpec does not plan to create proprietary extensions to the Modbus standard for authentication.

However, there are common, commercial-off-the-shelf technologies and methods which can be used with Modbus/TCP connections:

- The device can implement 'Permitted Host' lists, preventing control actions from unauthorized IP peers.
- The device can limit control actions to Modbus/TCP clients connecting with SSL/TLS, which can include certificate-based authentication.
- Many cellular and broadband gateways include VPN end-point functionality, which allows remote hosts to securely tunnel standard Modbus/TCP via a bank-quality VPN link to remote sites.

Certification

If you would like to have your product SunSpec Certified, please read the information available at http://sunspec.org/sunspec-certified-program/

References

The work in this document is based on past and on-going work in various industry and standards bodies, including IEC TC57/WG17, DNP3 User's Group and EPRI.

[1] *Specification for Smart Inverter Interactions with the Electric Grid Using International Electrotechnical Commission 61850,* EPRI, Palo Alto, CA: 2010. 1021674.

[2] *DNP3 Profile for Basic Photovoltaic Generation and Storage*, DNP3 AN2011-001, Version 2011-03-21.

[3] *IEC 61850 Object Models for Photovoltaic, Storage and Other DER Inverters*, IEC 61850-90-7, draft ver 27a

[4] *Common Functions for Smart Inverters.* EPRI, Palo Alto, CA: 2011. Product ID Number 1023059

Acknowledgements

Figures 2, 4, 5, 9, 10, 11, 13, 14, 16 courtesy of EPRI 1023059 (reference 4).

Figures 3, 6, 7, 8, 12, 15 and Table 1 courtesy of IEC 61850-90-7 (reference 3).