Smart Inverters and FIDVR Events

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DOE / NERC Workshop, Alexandria, VA, Oct 2016

Presentation Overview

- **Inverter capabilities**
  - Old Inverters
  - Smart Inverters
- **Smart inverter functions defined today**
- **Defining the needed FIDVR response**
  - Normal operation (steady state) versus FIDVR (transient)
- **Conclusions**

The Old Days (2000 - 2003)

- **Grid tied PV systems were rare**
- **General philosophy was:**
  - Produce unity power factor
  - Get out of the way quickly if anything bad happened
  - Tight trip limits
  - No requirements for ride through
- **Relevant Standards**
  - UL 1741, IEEE 1547, 1547.1

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Today (2014 - 2016)

- **CA rule 21 approves smart inverter functionality. Phase 1 autonomous behaviors (Dec 2015)**
  - Voltage and frequency ride through
  - Real and reactive power control
  - Return to service behaviors / ramp rate control
- **Hawaiian Electric Inc. implements mandatory ride through requirements (Jan 2015)**
- **CA rule 21 Phase 2 in development.**
  - IEC 61850 data model, IEEE 2030.5 / SEP 2.0 Protocol
  - Updates to interconnection handbooks under development
- **Relevant Standards**
  - UL 1741, UL 1741 Supplement A, IEEE 1547, 1547.a,1547.1
  - IEC 61850, IEEE 2030.5
  - UL 1998 (firmware certification)

New Regulatory Concepts (in the US)

- **Voltage and frequency ride through**
  - ***<u>Must not trip</u>*** requirements during abnormal excursions
- **Real and reactive power control**
  - Provides frequency stability and voltage regulation
- **Operating regions with differing behaviors**
  - Multiple areas are bounded by pair points of Voltage/time or frequency/time
- **Cease to energize (momentary cessation)**
  - A mode where the DER must cease to energize the area EPS but ***<u>must not trip</u>***.
- **Return to service**
  - The criteria and behaviors required as the DER re-energizes the area EPS following an excursion

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UL 1741 Supplement A Functions

- **Voltage and frequency ride through**
- **Reactive power control (voltage regulation)**
  - Fixed Power Factor
  - Volt/VAr (voltage droop)
  - Commanded VAr
- **Active power control**
  - Ramp rate control
  - Volt/Watt
  - Frequency/Watt (frequency droop)
  - Commanded maximum power

➔ FIDVR response is NOT currently addressed

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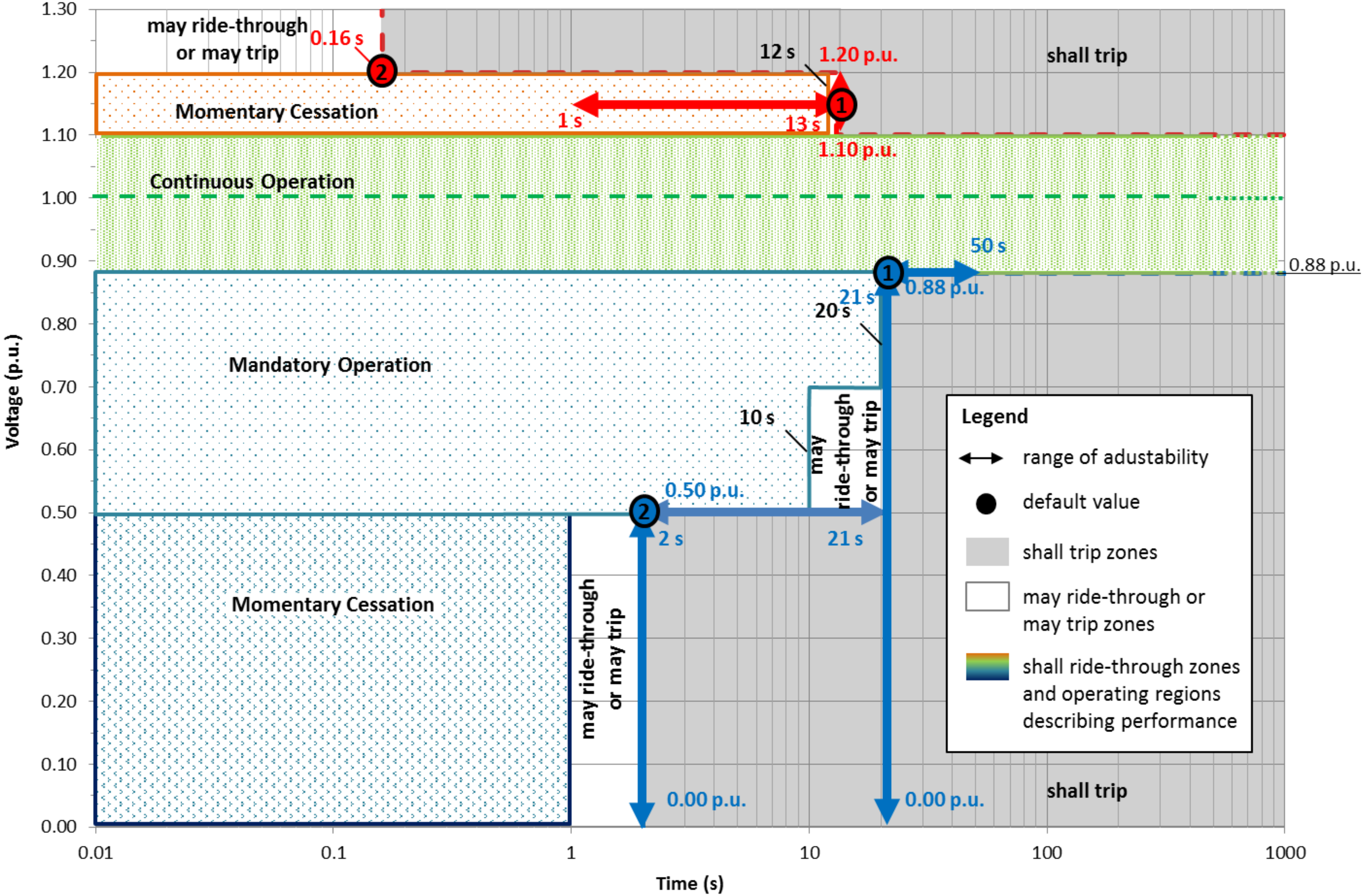
Category III Voltage Ride Through

(based on CA Rule 21 and Hawaii)



The Four Quadrants (IEEE sign convention)

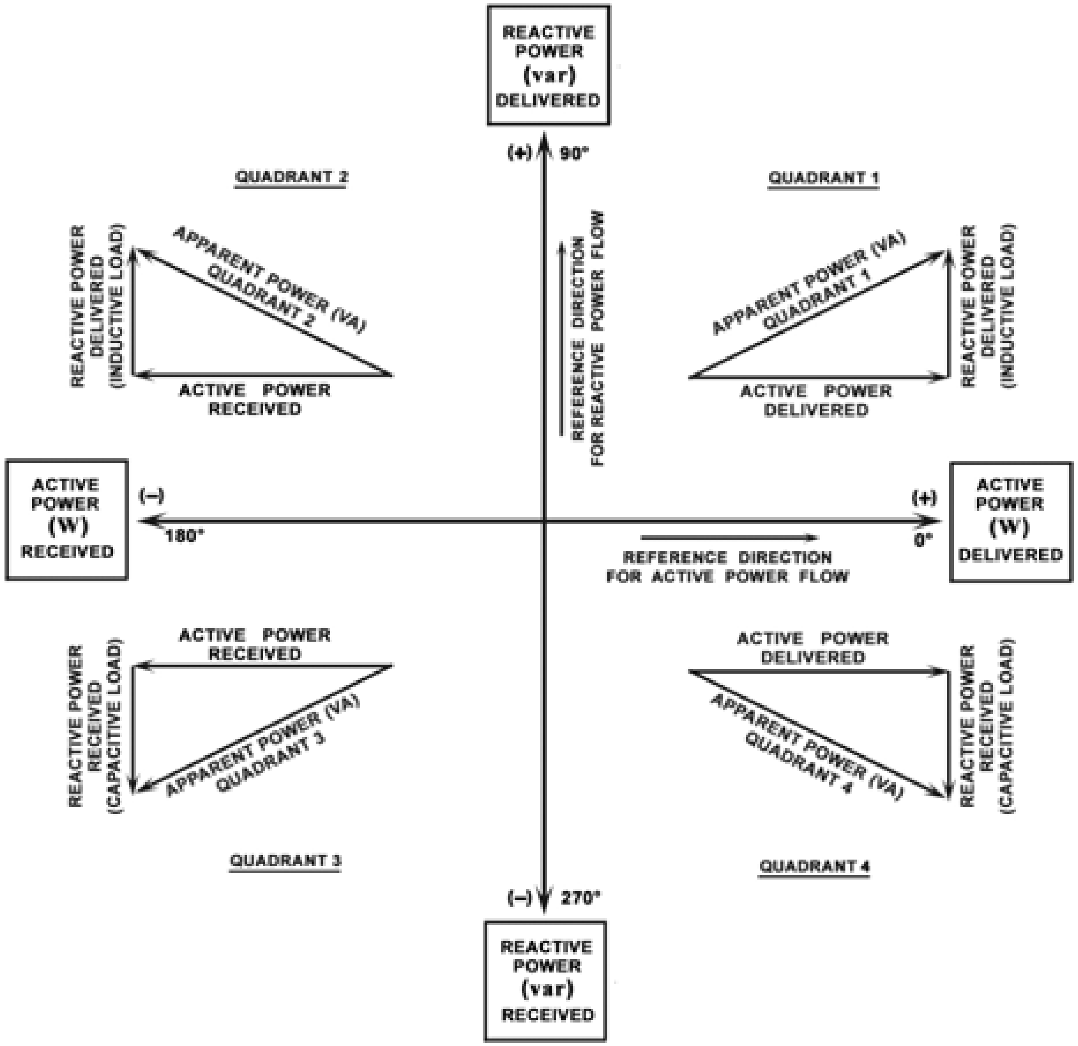
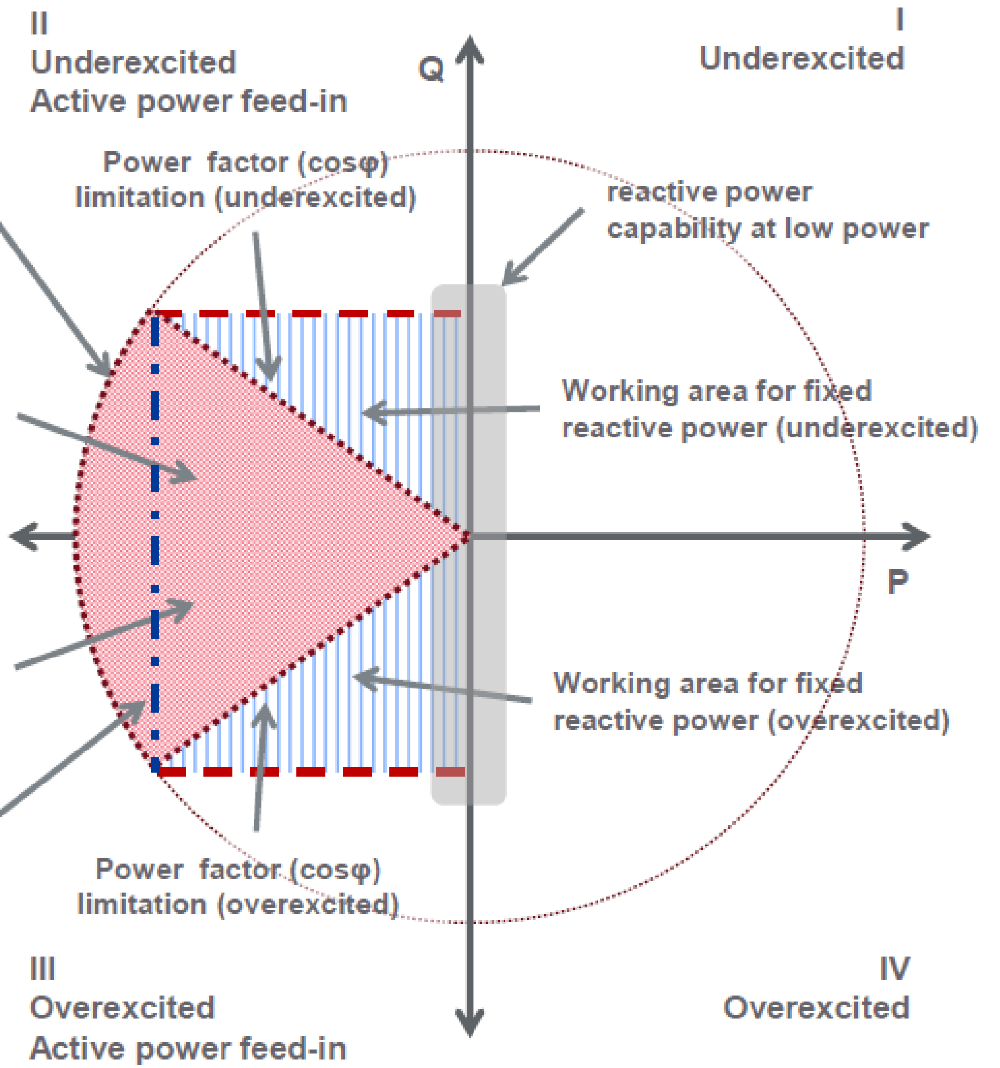


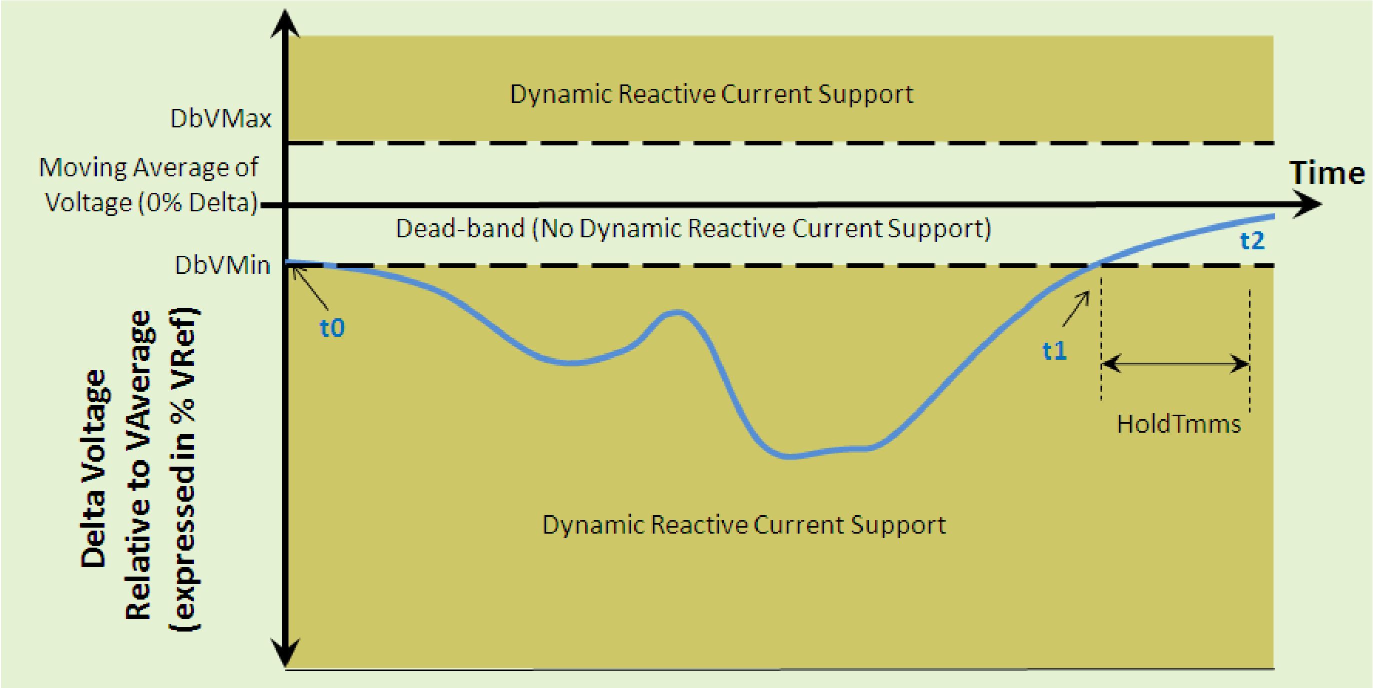
Figure 1 - Four-quadrant power flow directions
(© 1983 IEEE. Reprinted, with permission from the IEEE and R.H. Stevens [B19])
(redrawn by McEachern for clarity, 2012)

PV Inverter Operating Areas



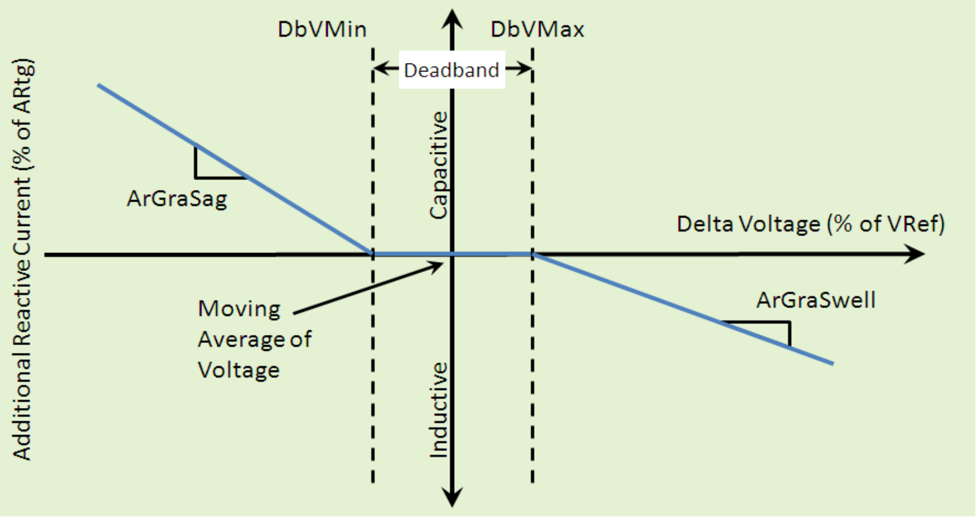
Terminology of FIDVR Response

- **“Event based dynamic reactive current support” (EPRI)**
  - Provide capacitive reactive current in response to low voltage
  - Similar to EPRI VV12 but transient in nature
  - Reduce active power to supply reactive power (VAR Priority)



Courtesy of EPRI, *Common functions of smart inverters*, Version 3, Feb, 2014, Brain Seal

Dynamic Reactive Current Support (EPRI)



- **Dead band default values and ROA's**
  - Default – ANSI Range B (88% to 110% PU) ?
  - ROA's – TBD
- **Gradient default values are TBD**
- **Time domain values are TBD**
- **Detailed modeling needed to establish baselines**

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Dynamic Reactive Current Support Variables

Name	Description
Enable/Disable Dynamic Reactive Current Support Function	This is a Boolean that makes the dynamic reactive current support function active or inactive.
DbVMin	This is a voltage deviation relative to Vaverage, expressed in terms of % of Vref (for example -10%Vref). For negative voltage deviations (voltage below the moving average) that are smaller in amplitude than this amount, no additional dynamic reactive current is produced.
DbVMax	This is a voltage deviation relative to Vaverage, expressed in terms of % of Vref (for example +10%Vref). For positive voltage deviations (voltage above the moving average) that are smaller in amplitude than this amount, no additional dynamic reactive current is produced. Together, DbVMin and DbVMax allow for the creation of a dead-band, inside of which the system does not generate additional reactive current support.
ArGraSag	This is a gradient, expressed in unit-less terms of %/%, to establish the ratio by which Capacitive % VAR production is increased as %Delta-Voltage decreases below DbVMin. Note that the % Delta-Voltage may be calculated relative to Moving Average of Voltage + DbVMin (as shown in Figure 16-1) or relative to Moving Average of Voltage (as shown in Figure 16-4), according to the ArGraMod setting.
ArGraSwell	This is a gradient, expressed in unit-less terms of %/%, to establish the ratio by which Inductive % Var production is increased as %Delta-Voltage increases above DbVMax. Note that the % Delta-Voltage may be calculated relative to Moving Average of Voltage +DbVMax (as shown in Figure 16-1) or relative to Moving Average of Voltage (as shown in Figure 16-4), according to the ArGraMod setting.
FilterTms	This is the time, expressed in seconds, over which the moving linear average of voltage is calculated to determine the Delta-Voltage.

Courtesy of EPRI, *Common functions of smart inverters*, Version 3, Feb, 2014, Brain Seal

Optional Variables of DRCS

Additional Settings (Optional)	
ArGraMod	This is a select setting that identifies whether the dynamic reactive current support acts as shown in Figure 16-1 or Figure 16-4. (0 = Undefined, 1 = Basic Behavior (Figure 16-1), 2 = Alternative Behavior (Figure 16-4).
BlkZnV	This setting is a voltage limit, expressed in terms of % of Vref, used to define a lower voltage boundary, below which dynamic reactive current support is not active.
HysBlkZnV	This setting defines a hysteresis added to BlkZnV in order to create a hysteresis range, as shown in Figure 16-5, and is expressed in terms of % of VRef.
BlkZnTmms	This setting defines a time (in milliseconds), before which reactive current support remains active regardless of how deep the voltage sag. As shown in Figure 16-5.
Enable/Disable Event-Based Behavior	This is a Boolean that selects whether or not the event-based behavior is enabled.
Dynamic Reactive Current Mode	This is a Boolean that selects whether or not Watts should be curtailed in order to produce the reactive current required by this function.
HoldTmms	This setting defines a time (in milliseconds) that the delta-voltage must return into or across the dead-band (defined by DbVMin and DbVMax) before the dynamic reactive current support ends, frozen parameters are unfrozen, and a new event can begin.

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Priority of Smart Inverter Functions

- **Multiple functions can be running simultaneously**
- **Can lead to conflicting requirements**
  - Example: active power needed during under frequency versus reactive power needed for voltage regulation / FIDVR
- **What is priority of functions during FIDVR event ?**
  - 1) Frequency support of bulk system
    - May cause limitations of reactive power capabilities (W priority)
  - **2) FIDVR response ? (New concept needs discussion)**
  - 3) Steady state voltage regulation (FPF, V/VAr)
  - 4) Commanded active / reactive power
  - 5) Scheduled responses

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Conclusions

- **Smart Inverters can provide dynamic reactive power in response to FIDVR events**
  - Capability exists today but functional requirements are TBD
- **Regulatory standards are under development now and FIDVR response is "on the agenda"**
  - IEEE 1547 (2016), IEEE 1547.1 (2016/170
  - UL 1741 Supplement A (2015), Full revision (2016)
- **Definition of the desired functionality is needed in order to implement and certify**
  - Inverters are very flexible and behaviors can be complex
  - Inverter models are very complex but will be critical in determining best guesses for initial functionality
- **Remote upgradability of inverters will likely be needed as PV proliferates and understanding evolves**

Thank you for your attention!

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“Smart System” Operating Areas