APPLICATION NOTE

ADVANCED ENERGY®

AE 500NX-1kV Utility-Interactive Inverter Control

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Introduction

Photovoltaic (PV) inverters are becoming significant contributors to overall power management on the electrical distribution network. Historically, grid-connected inverters have been treated as negative loads, and the focus was entirely on energy harvest and active power production of a given PV power plant; where in the case of a grid disturbance, the inverter was required to disconnect per the IEEE 1547 and UL 1741 standards. As the PV industry continues to grow, and transmission and distribution networks see higher penetration of PV generation, however, grid operators are forced to think differently about how they manage these growing distributed energy resources (DER).

While obtaining maximum energy harvest is still a priority, utilities are seeing the value of the ancillary services inverters can provide to support grid stability. For example, the electric system suffers when there is significant VAR content in a transmission network segment, resulting in lowered capacity and voltage. Inverters can provide Power Factor and VAR support during this common occurrence to help maintain grid voltage, similar to what conventional thermal plants do, and offset the need for installation of expensive voltage management devices (e.g. static VAR compensators). Similar voltage and load dynamics exist within the distribution network, as well, but there may not be a system operator managing the distributed PV resources. In such a case, the grid operator would benefit from coordinated and autonomous control by the inverters to provide ancillary services where inverters can provide nearly instantaneous setpoint changes based on VAR requests, again offsetting the need for capacitor banks or excessive cycling of voltage regulating devices. This requires the inverter to be quite flexible in its grid integration controls capabilities.

To help meet this industry need, Advanced Energy is contributing to many of the policy and standards development activities in North America that are bringing consistency to grid interactive controls. In particular, IEEE 1547.a and 1547.8 are being informed currently with enhancements for voltage management and frequency/voltage ride through. Advanced Energy is also participating in the Solar Energy Grid Integration System (SEGIS) program funded by the U.S. Department of Energy, which is exploring a wide variety of advanced inverter functions for anti-islanding and autonomous control leveraging a common communication platform outlined by EPRI and proposed in the IEC 61850-90-7. Through industry collaboration and ongoing technology innovation, Advanced Energy's inverters are being equipped to enable the next level of grid integration for power system operators.

Utility-Interactive Inverter Control Capabilities

The AE 500NX-1kV inverter currently provides Advanced Energy's most comprehensive suite of utility interactive controls to enable grid support functions and ancillary services. These capabilities include controls for active power (kW) with associated ramp rates during transitions, reactive power (kVAR), power factor (PF), and configurable voltage and frequency trip points. To access these control functions, operators have the choice of configuring the inverter directly, or integrating the inverter's grid support functions on existing SCADA and Distribution Management Systems using published communications specifications.

The AE 500NX-1kV inverter currently supports the following grid support controls, all of which are flexible in their configuration.

Active Power Curtailment specifies an upper limit for inverter active power (kW or P) output. When the output of the PV array at its maximum power point exceeds the power set point, the Active Power Curtailment control increases the PV voltage to reduce the power output of the array.

Active Power Ramp Rate defines the rate at which the active power production by the inverter ramps up or down, limited by the available DC power output of the array.

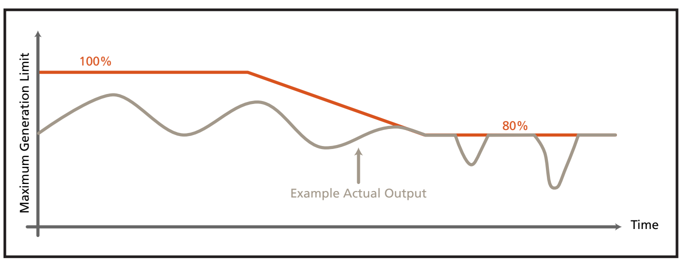

Figure 1 - Shown here is the transition between maximum active power set points and the associated ramp rate.

Reactive Power Control sets the level of reactive power (kVAR or Q) generation or consumption, and operates within the constraints of the inverter's power envelope and current irradiance conditions. The AE 500NX-1kV has a total capacity of ±165kVAR (subject to array and grid conditions).

Reactive Power Ramp Rate defines the rate at which the reactive power production by the inverter transitions between set-points.

Power Factor (PF) Control sets the ratio of real power to apparent power, allowing for sourcing or sinking of VARs to maintaining voltage and increase efficiency in the power system. The AE 500NX-1kV is capable of ±0.90 PF (subject to array and grid conditions).

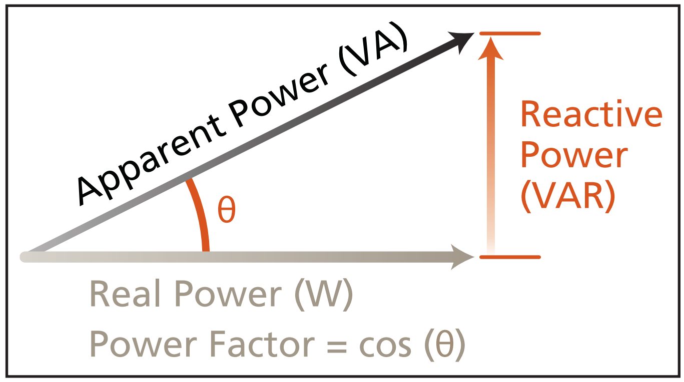

Figure 2 - The power triangle above represents the relationship between apparent power, real power, and the resulting reactive power.

Power Factor Ramp Rate defines the rate at which the inverter transitions between different power factor set-points.

Voltage Ride Through – The AE 500NX-1kV has the capability to ride through a wide range of voltage excursions. This control enables configuration of the desired window of operation under zero, low, and high voltage ride through conditions. The graph below shows the range of the AE 500NX-1kV (red line), as well as a few of the prominent regulatory trip curves mandated throughout the US.

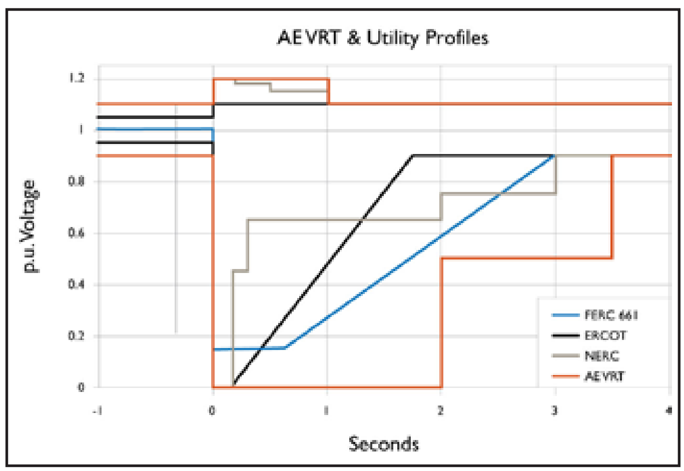

Figure 3 - The VRT window for the AE 500NX-1kV inverter supports multiple regional profiles.

Frequency Ride Through – The AE 500NX-1kV also has the capability to ride through both high and low variations in frequency, supporting a range from 63 Hz to 57 Hz with configurable trip limits to meet various regulatory requirements.

The AE 500NX-1kV Successfully Rides Through PG&E Low Voltage Events

Thirty AE 500NX-1kV inverters at PG&E's 15 MW Westside Solar Station endured four separate low voltage events caused by momentary phase-to-phase faults on a 12 kV circuit fed from the same substation that serves as the interconnect for the solar station near Fresno, California. The oscillography traces from a relay showed a nearly 50 percent voltage depression at the 12 kV bus for approximately 7 cycles. During these events, the inverters were operating at between 20 percent and 80 percent of full power, and all remained online, confirming the successful functioning of the low-voltage ride through capability.

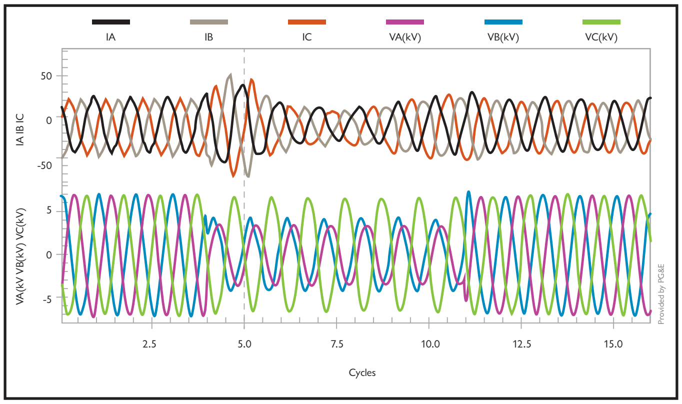

Figure 4 - Voltage and current plot from the SEL relay at Westside Solar Station. This plot confirms that the AE 500NX-1kV inverters on the site successfully rode through the low voltage event.

Monitoring and Control Capabilities

Inverters are typically required to be controlled by a SCADA-type solution in utility applications. This enables plant operators to control inverters based on the requirements of their interconnection agreement, while managing their asset similar to other forms of generation. SCADA systems support a number of different communications protocols, and are comprised of several layers, making them fairly complex to navigate. To easily manage system integration, Advanced Energy provides several options for operators to efficiently interface with the inverter(s).

In addition, the Advanced Energy NX line of inverters provides a robust monitoring and controls interface that enables plant operators and O&M contractors to access performance data and the inverter control functions.

As a standard feature, all Advanced Energy inverters support Modbus as a native communications protocol, accessible through either Modbus TCP over an Ethernet network or Modbus RTU utilizing an RS-485 serial connection. Modbus is a time-tested, widely adopted industrial communications protocol that enables supervisory monitoring and control systems to communicate with inverters, and other devices. The Modbus maps are published in the inverter's manual, providing the SCADA engineer everything needed to configure the system to monitor and control the inverter.

To optimize inverter communications and monitoring within the plant, an Inverter Master Controller (IMC) may be utilized to provide the SCADA system a single point of access to multiple inverters. The IMC enables the operator to issue a single command to a fleet of inverters for repeatable and reliable operation of the plant. In addition to inverter control, the IMC can serve as a data concentrator for various stakeholders of the plant to enable secure data transfer using a variety and industry-standard communications protocols, such as Modbus, DNP, and/or IEC 61850.

Some of the specific group commands and functions that the IMC could provide are:

- PF/VAR control
- Active power limit
- Ramp rate
- Enable/disable
- Inverter operating data aggregation
- Single point of access for SCADA and 3RD party Data Acquisition Systems (DAS)

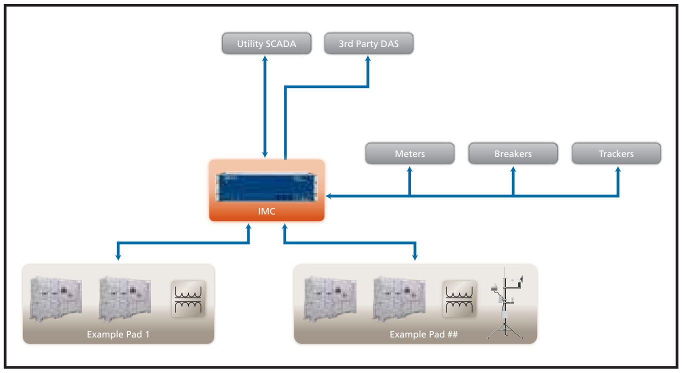

Figure 5 - The IMC simplifies the integration process by providing a single point of connectivity to monitor and control multiple inverters.

Conclusion

As noted in the Introduction, the integration challenges involved are neither inherent to DER, in general, nor to PV in particular. Rather, in the case of PV, the challenge is being exacerbated by regulations that prevent inverters from providing support functions that could help stabilize the grid. Organizations across the industry are endeavoring to address the issue and bring consistency to grid interactive controls. One such organization, the California Public Utility Commission (CPUC), summarized the issue well in its 2013 *Advanced Inverter Technologies Report**: "Despite proof of concept by national electric power systems in Europe, implementation of these functionalities is not presently supported by the standards which govern inverters in the United States, preventing both widespread adoption of these functions and realization of the corresponding benefits to the distribution network."

Fortunately, progress is being made and this self-imposed limitation is coming to an end. The CPUC's Advanced Inverter Technologies Report reaches this conclusion about the promising future of DER: "Advanced inverter functionalities may lend significant improvement to the stability, reliability, and efficiency, of the electric power distribution system in the US. Distribution automation systems implemented by utilities will be central to the integration of these functionalities, which require protection, control, and communication to reach full efficacy. Implementation of reactive power support functions can permit DER to respond to loading conditions to minimize losses and improve the quality of supplied power. By the same token, ride-through of adverse voltage and frequency conditions may enable inverter response to mitigate the impact of unexpected conditions, maintain interconnection, and thereby lend resiliency to these resources. At present, US compliance-based standards for interoperability and performance tend to inhibit the implementation of these functionalities, but they are being revised to consider safe and reliable augmentation of inverter functionality to support increased penetration of DER."

To help meet the grid support needs of transmission and distribution utilities, Advanced Energy provides a comprehensive suite of utility-interactive inverter controls, and recommends an optional Inverter Master Controller to simplify integration in large-scale PV plants. To ensure that these advanced control capabilities meet the evolving needs of operators, Advanced Energy will continue to participate in the industry collaboration activities that are shaping the integration of grid support functionality into inverters.

*http://www.miniurl.com/sa/Advanced_Inverter_Technologies_Report_CPUC_2013

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