

Electrical Power System Support-Function Capabilities of Residential and Small Commercial Inverters

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Abstract

Presently, approximately 20 GW or 2% of the nation's generating capacity comes from solar, and solar penetration is increasing. However, for this trend to continue without adversely affecting electrical power system (EPS) performance, the photovoltaic inverters must participate in voltage- and frequency-regulation requirements. EPS support capabilities under development are the low-/high-voltage and low-/high-frequency ride through, volt-Var, frequency-watt, watt-power factor, commanded power factor, commanded power functions, and others. Each of the functions have parameter set points, and most have ramp rates for implementation of the functions as defined in the International Electrotechnical Commission Technical Report 61850-90-7. This paper focuses on methods to quantify EPS support functions for DER certification. Sandia National Laboratories and Underwriters Laboratories, in collaboration with industry stakeholders, have developed a draft test protocol that efficiently and effectively evaluates support-function capabilities. This paper describes the functions, their intended use, and results of EPS support functions in a controlled laboratory environment.

Introduction

The nation's solar generating capacity continues to grow, and a DOE vision study suggests 14% of the total electricity demand could be met by solar by 2030. This displaces traditional electricity generation coming from centralized, dispatchable generators with an increasing amount of electricity production from distributed, variable generation resources. To minimize the adverse impacts from this shift, power converters have implemented functions that also provide electrical power system (EPS) support capabilities.

EPS SUPPORT FUNCTION PERFORMANCE EVALUATION

Sandia National Laboratories has been working with inverter manufacturers to quantify the performance of area EPS support functions in a controlled laboratory setting. For these evaluations, the functions were programmed through a manufacturer-provided graphical user interface which communicated to the equipment under test (EUT) over TCP/IP, and all of the assessments are implemented with the default ramp rates.

Low-/High-Voltage Ride Through

The low-voltage ride-through laboratory assessment is shown in Figures 1–2. The ac simulator was programmed to provide a step change in voltage below 50% of nominal. At this voltage level the EUT is required to temporarily cease to energize the simulated grid within 0.16 seconds until 1 second after the event. For this test, when voltage returns above 50% of nominal and the inverter ramps up the power and reaches pre-disturbance levels, see Figure 1. A multi-inverter evaluation was conducted to capture a condition of five residential PV systems feeding a distribution transformer.

Dynamic Volt-Var Operation/Fixed Power Factor

The Volt-Var function provides dynamic voltage-regulation response based on local or area EPS voltage. Either real or reactive power-prioritization behavior determines if real power is reduced when the inverter reaches its kVA limits. The volt-Var characteristic four-point curve showing the voltage and reactive parameter settings is shown in Figure 3.

The Volt-Var function characteristic curve shown in Figure 3 provides nondimensionalized reactive power values characteristic, the inverter will produce more reactive power as the voltage sags/surges beyond Vnom. A deadband between 98% and 102% of 240 Vac was programmed into the volt-Var curve. Figure 4 shows the volt-Var evaluation on five inverters configured as a typical residential system. All of the inverters respond within 1 volt of each other and maintain the same slope as ac voltage decreases and increases. The inverters started to inject reactive power in support of the voltage at roughly +3%, which is within the 2% deadband plus 2% manufacturers stated accuracy.

Fixed Power Factor

The fixed PF function sets the displacement angle as a response from a supervisory controller, local conditions, schedule, or other factors. It operates independently of voltage and frequency conditions at the point of common coupling (PCC) and may include a ramp rate and delay time. Electric Rule 21 requires an operating range of ± 0.9 PF for <15 kW systems and ± 0.85 PF for >15 kW systems. The figure below shows the results of commanded PF of 5 inverters operating under dynamic irradiance conditions.

Frequency-Watt Evaluation Results

Grid frequency deviations can be mitigated by triggering a frequency regulating function that manages the DER real power generation and will increase the real power generation when a low-frequency event is detected and reduce real power generation when real power generation a high-frequency event is detected.

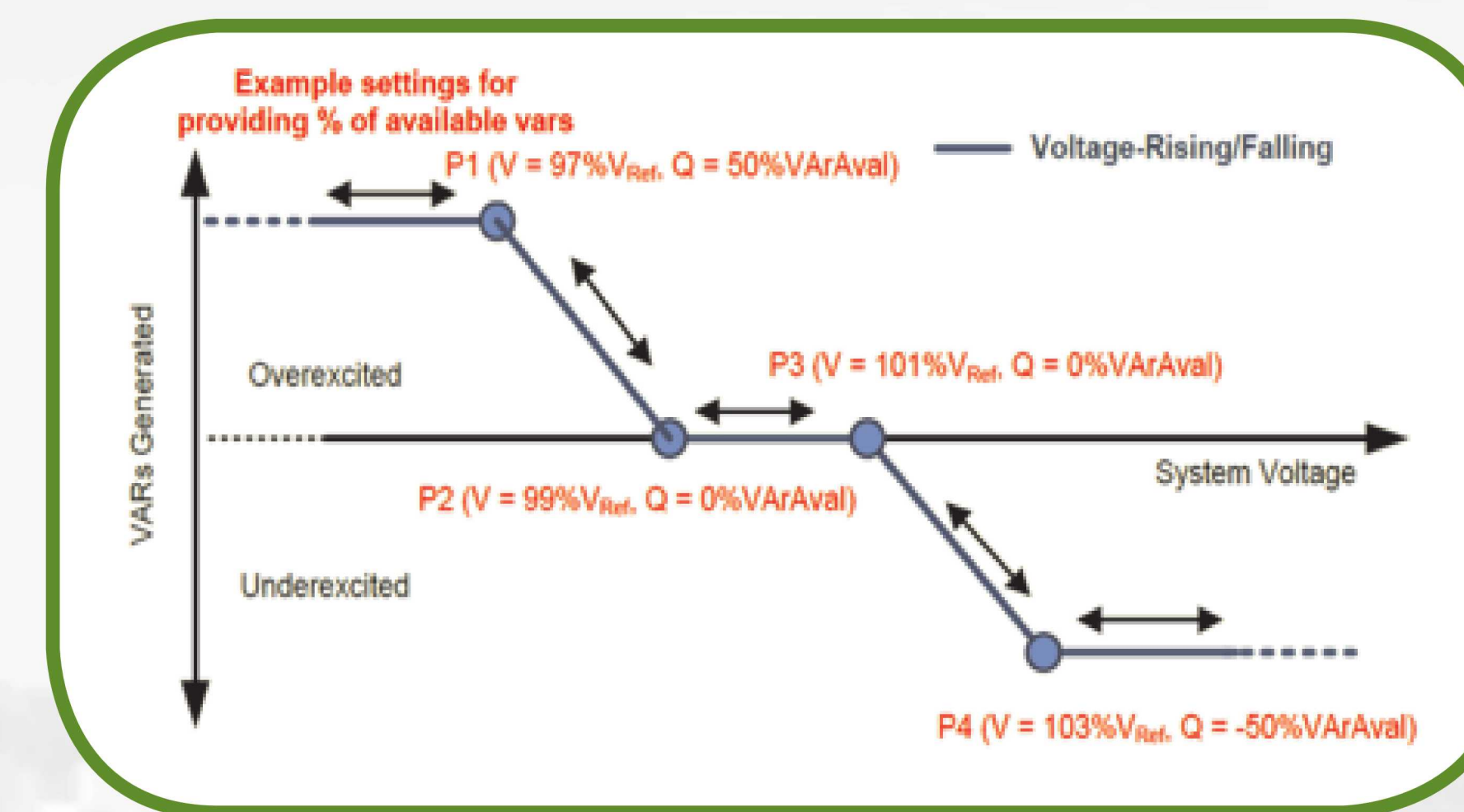


Fig. 3. Typical volt-Var curve

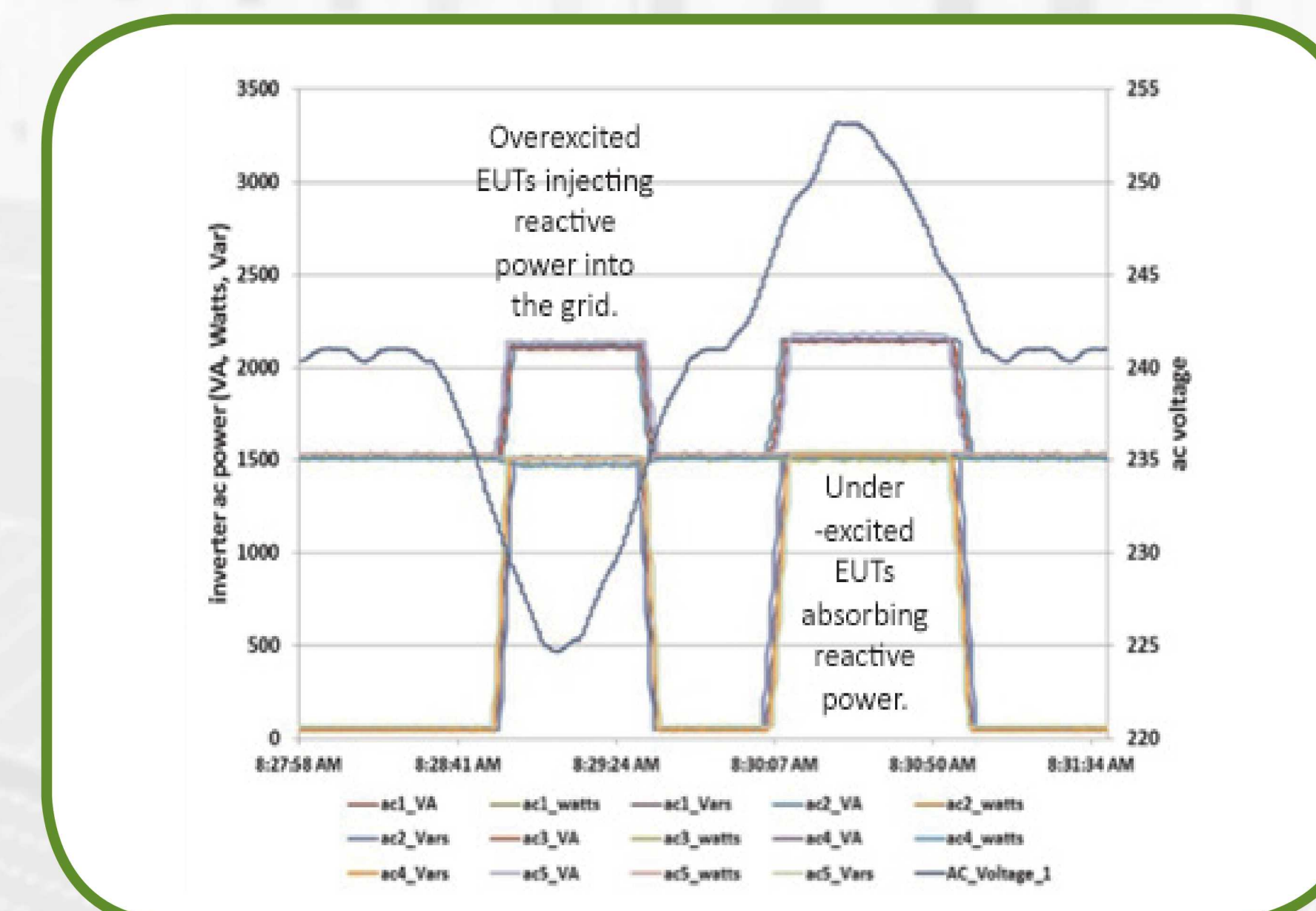


Fig. 4. Volt-Var evaluations conducted on five inverters.

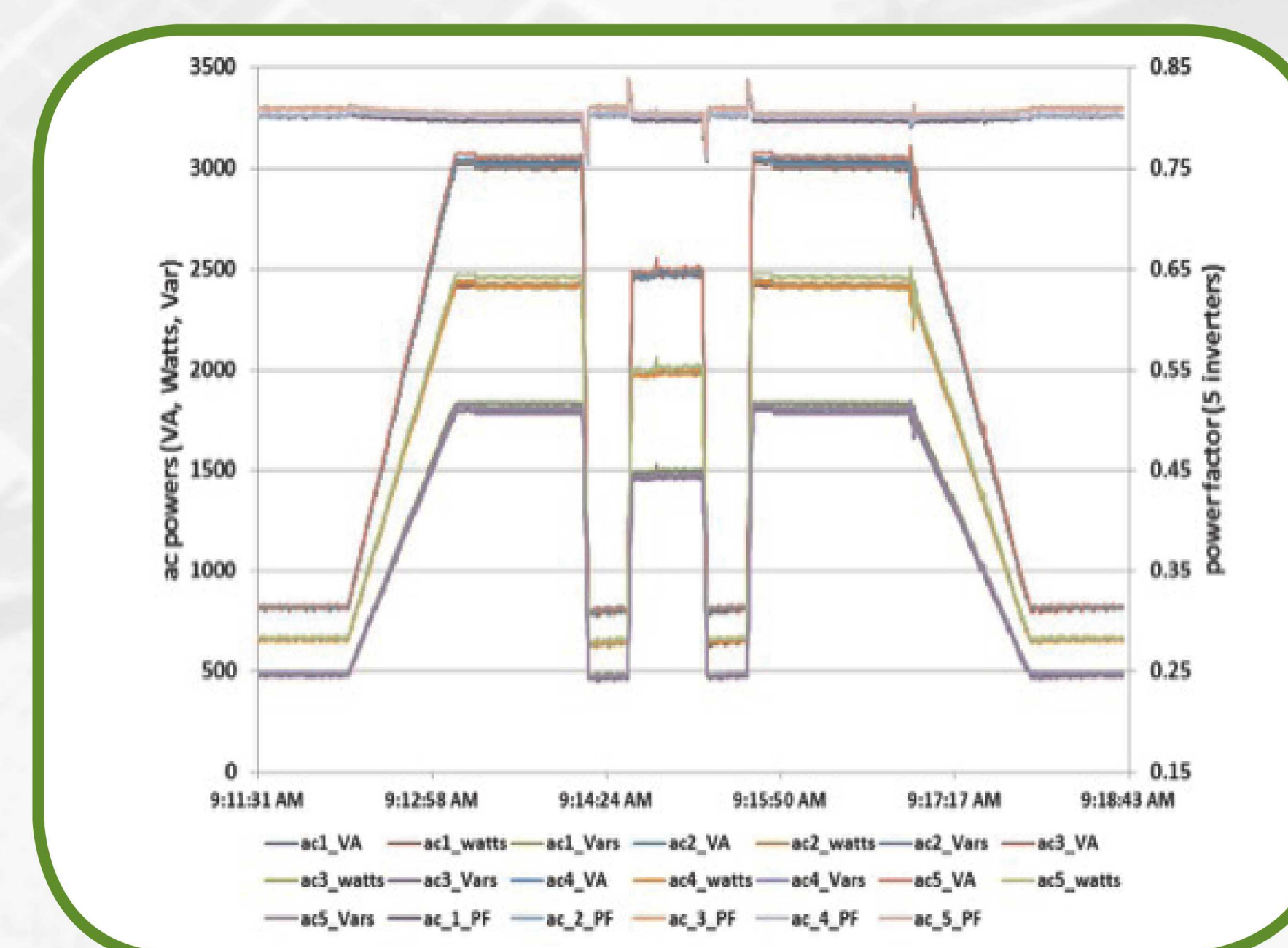


Fig. 5. PF evaluation with varying dclac power.

With the frequency-watt curve implemented into all five inverters, the inverter responses were analyzed during multiple frequency deviations. As shown in Figure 6, an over-frequency variation was programmed into the ac simulator and the real power generation from each inverter decreased depending on the severity of the deviation. As the frequency returned to nominal, the real power generation for each inverter returned to rated power levels, indicating high precision for inverter frequency-watt functions.

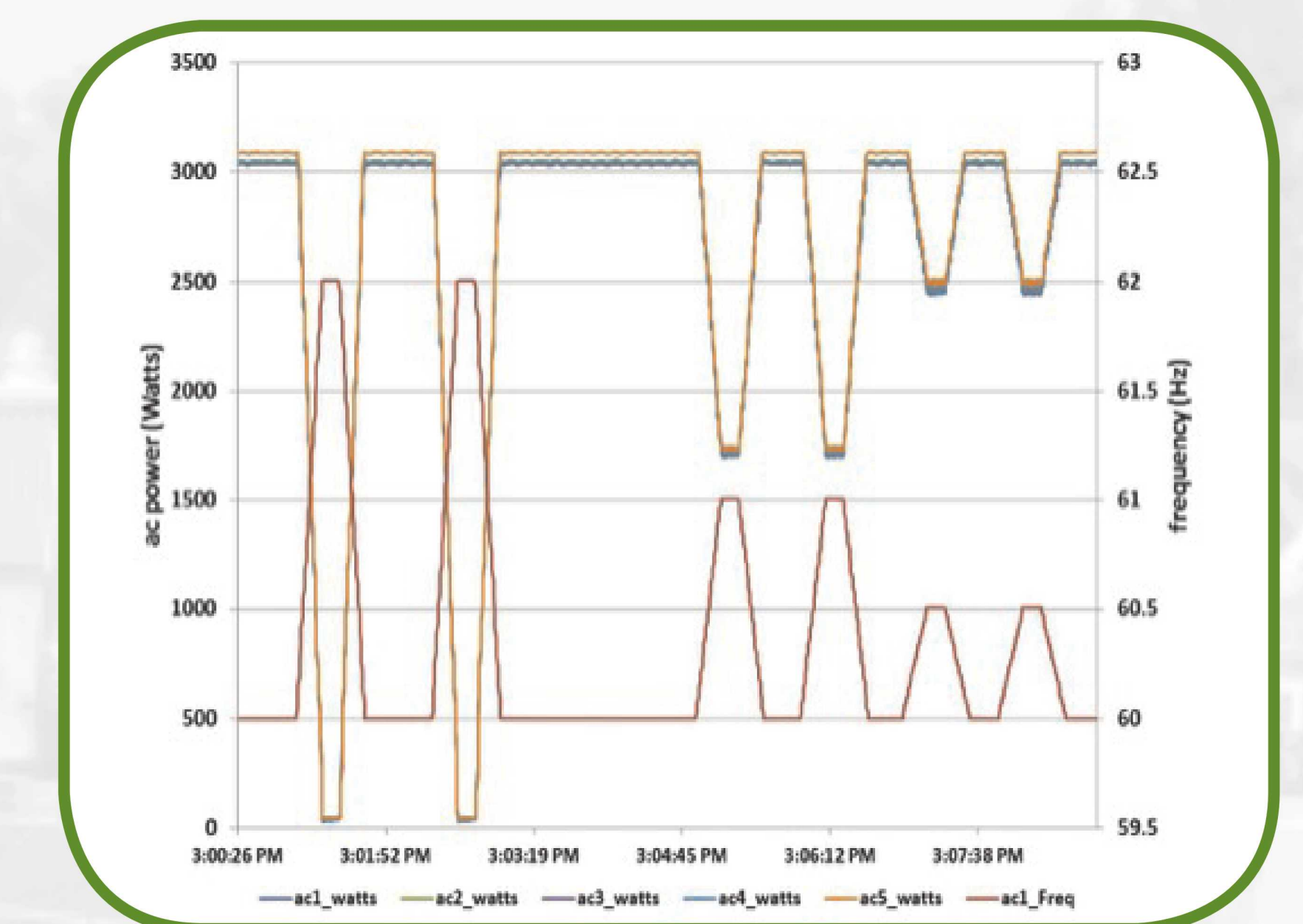


Fig. 6. Frequency-watt results with high-frequency deviation.

Unintentional Islanding Preliminary Results

Utility interconnected PV inverters must adhere to utility interconnection standards that require the inverter to recognize when the utility has experienced an interruption in service and cease energizing within 2 seconds.

The EPS support functions require the DER devices to ride-through voltage and frequency deviations that used to cause the devices to shutdown. The dynamic-voltage and frequency-regulating functions complicate the situation even further. Unintentional islanding algorithms, like Sandia's voltage and frequency shift, will either have to become more aggressive or an alternative method must be developed to become compliant with the loss-of-utility detection requirements.

Figure 7 shows the results of an extensive islanding test with the L/HVRT, L/HFRT, volt-Var, and frequency-watt functions enabled and set to their most aggressive settings.

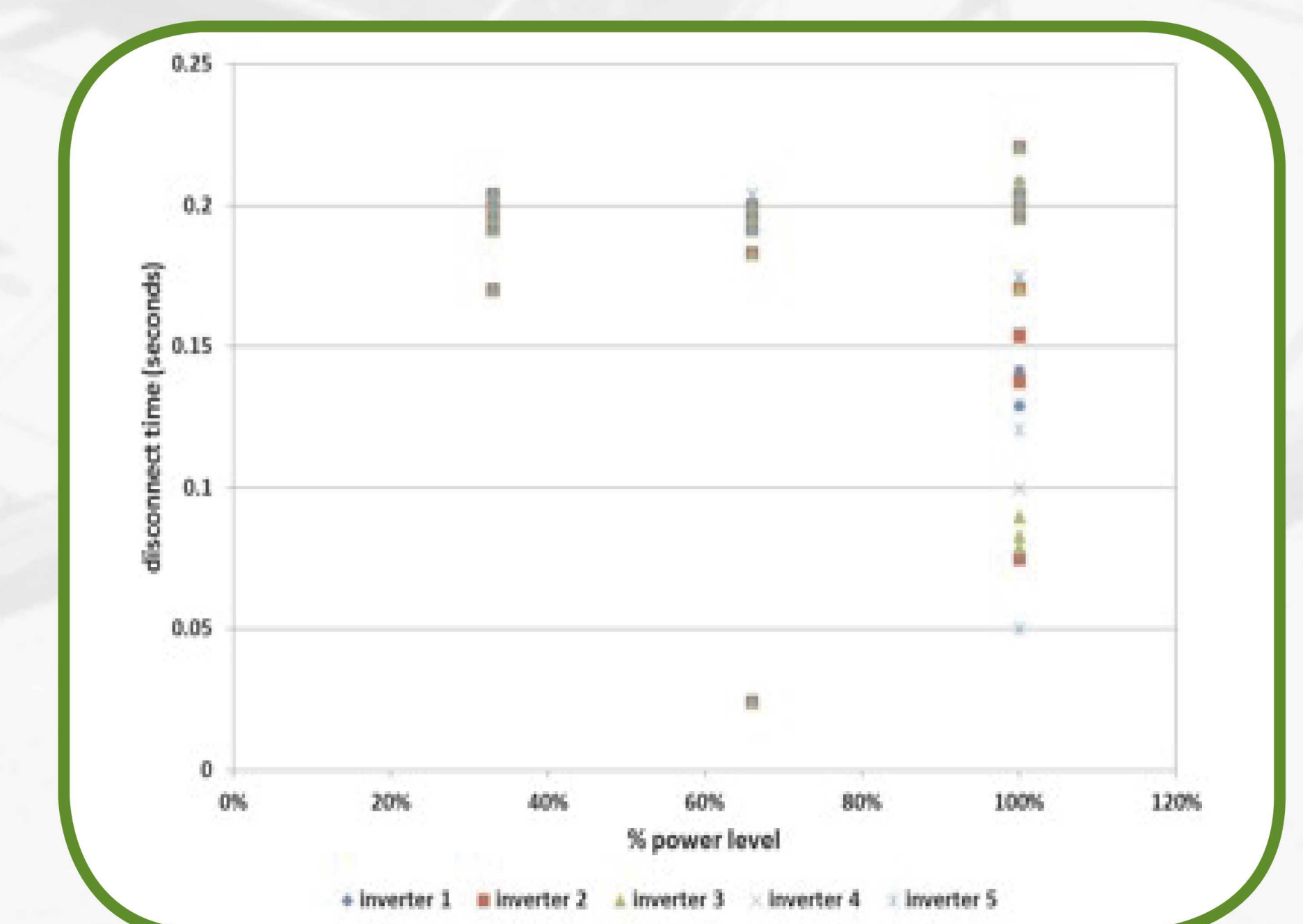


Fig. 7. Unintentional islanding test results with five inverters.

Conclusions

Inverters with EPS support functions will need to be implemented in large numbers in order to realize DOE's targeted levels of solar penetration. Thoroughly documenting the capabilities and finalizing draft UL 1741 Supplemental A test standards for utility interconnection requirements and safety listing are needed to correctly set EPS support-function parameters. This paper reports on the capabilities of EPS support functions and follow-up work will investigate the interactions of multiple-inverter configurations.

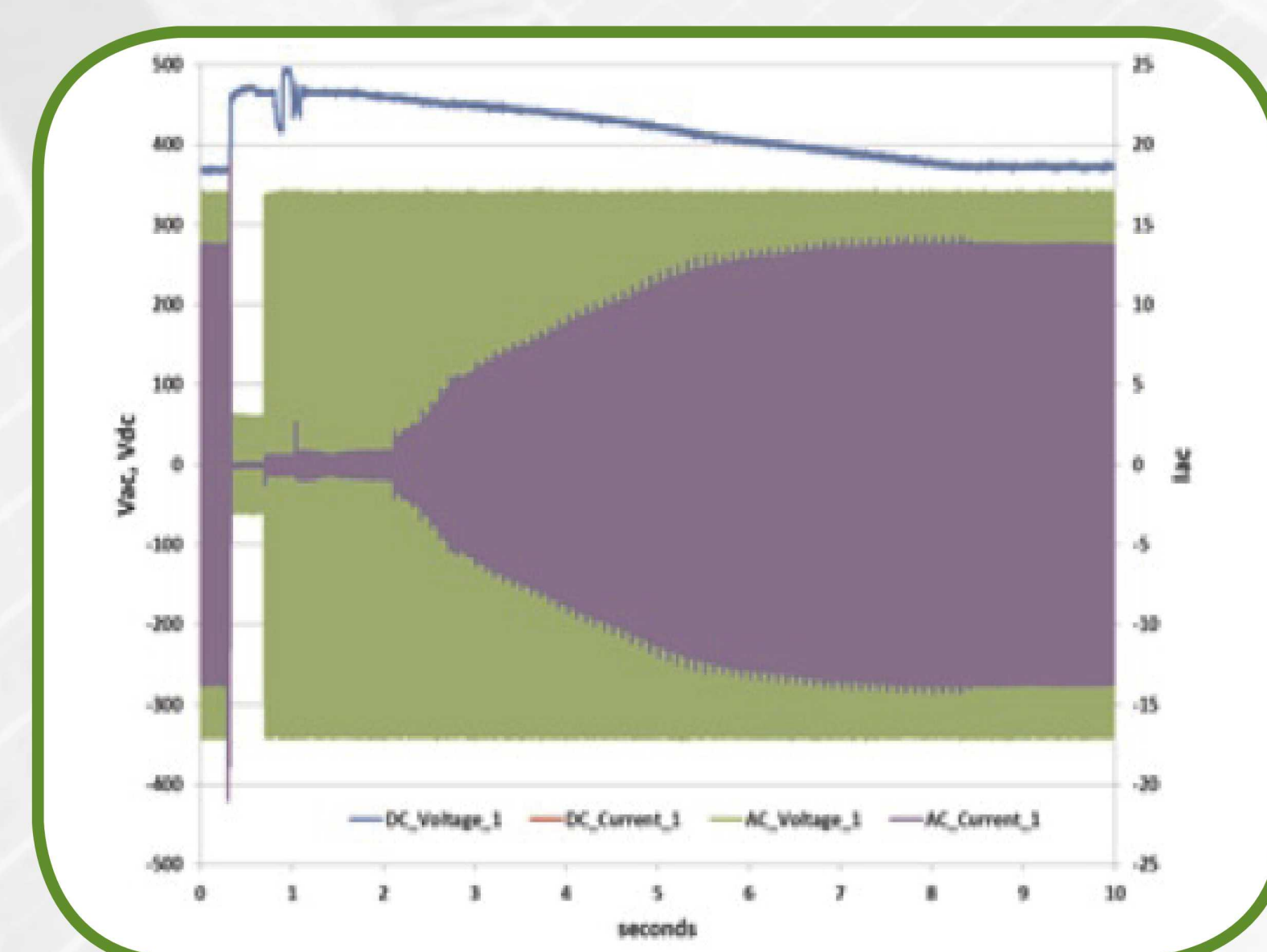


Fig. 1. Voltage < 50% of nominal ride through

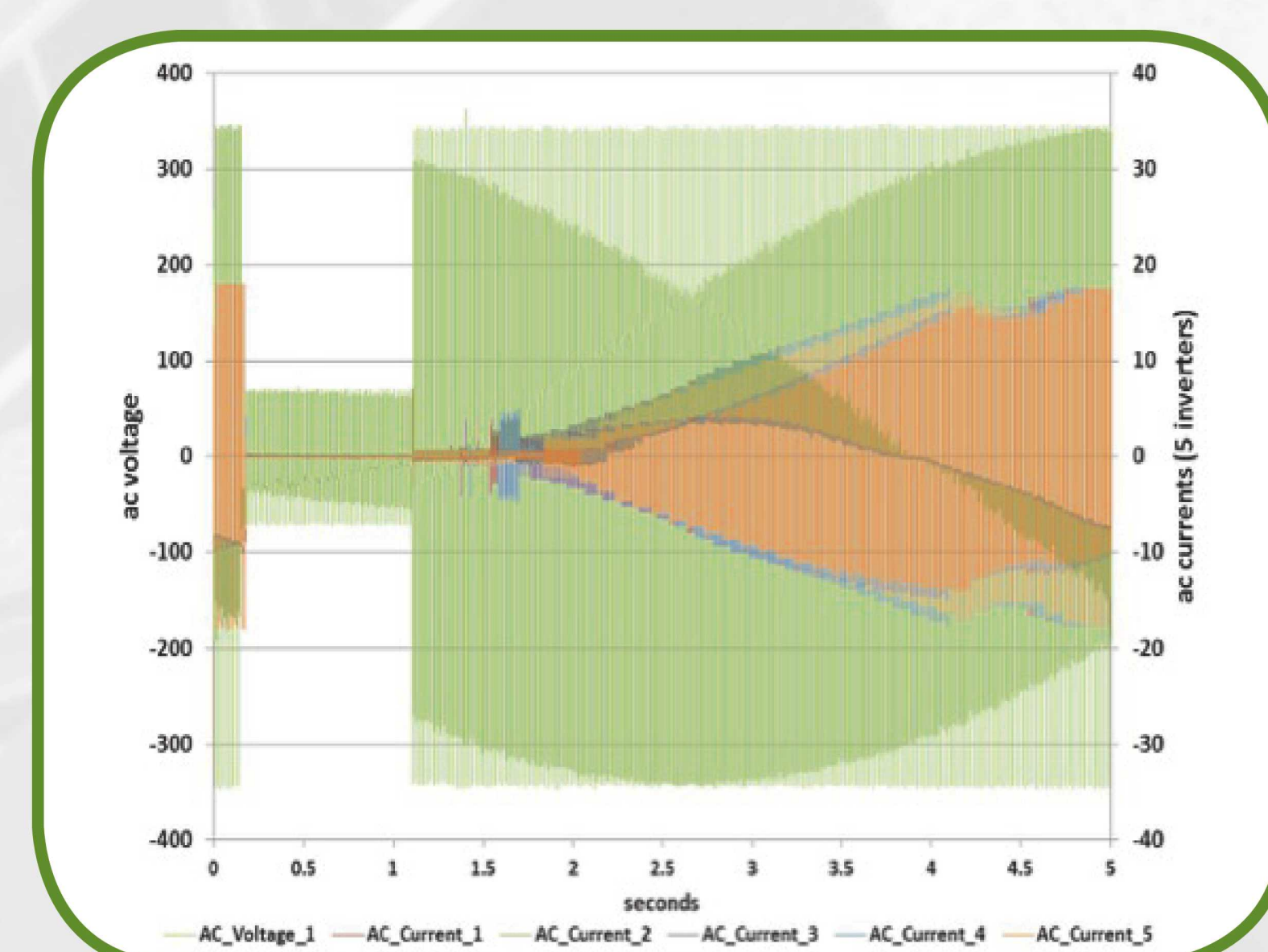


Fig. 2. Voltage < 50% of nominal ride through (5-inverter configuration).