SMART GRID
Smart Inverters

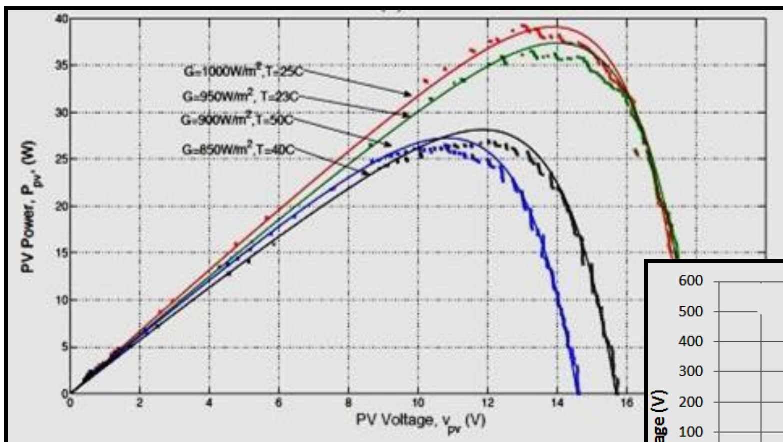
ECG 743

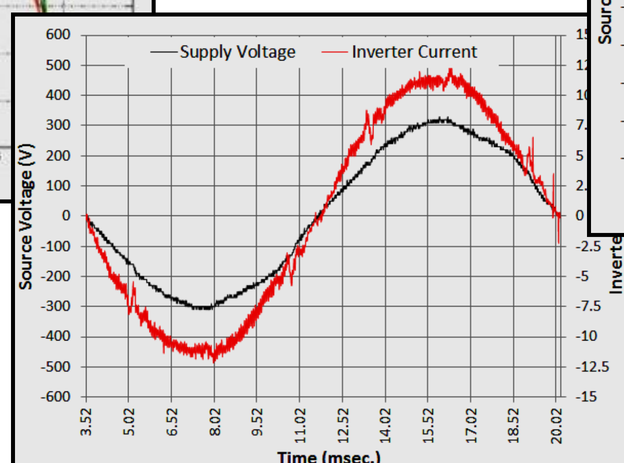
Conventional PV Inverters

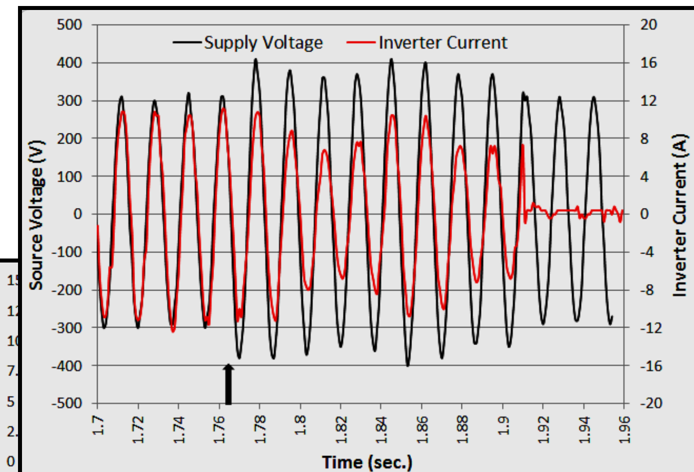
- Grid-tied photovoltaic (PV) inverters were initially designed for low PV penetration levels.
- They performed the basic functions of
  - extracting the maximum DC power from the PV array,
  - converting it to AC power that is compatible with the local grid, and injecting the generated power into the grid at unity power factor.
  - In addition, these devices monitor the grid and disconnect immediately after sensing utility voltage or frequency disturbances – as specified by interconnection standards such as IEEE 1547 (2003), and UL 1741.

Conventional PV Inverters (IEEE 1547 & UL 1741)

- Monitor the PV array and track its maximum power.
- Sense the presence of the grid, synchronize and inject a current in phase with the utility voltage.
- Monitor the grid and disconnect immediately in case of abnormalities in voltage or frequency.







Advanced Inverters (IEEE 1547a & UL 1741 SA)

- Due to high PV penetration, IEEE updated the connection Standard (1547a) in 2014, and UL 1741 was also updated to UL 1741 SA (Supplement A) - standards which identify inverter functions required for optimal grid stability.
- Advanced inverters are controlled by software applications; hence, many of their electrical characteristics can be modified through software settings and commands remotely.
- The smart-inverter technology will allow the utility to operate the solar installations as they would a power plant, ramping up or curtailing power and other control features based on the real-time needs of the grid. APS and California utilities are the first in the nation to deploy and control this advanced technology remotely.

Some Advanced Inverter Functions

1. Support anti-islanding to trip off under extended anomalous conditions.
2. Provide ride-through of low/high voltage excursions beyond normal limits.
3. Provide ride-through of low/high frequency excursions beyond normal limits.
4. Provide volt/var control through dynamic reactive power injection through autonomous responses to local voltage measurements.
5. Define default and emergency ramp rates as well as high and low limits.
6. Provide reactive power by a fixed power factor.
7. Reconnect by "soft-start" methods.

The references below review the common functions of advanced inverters, and how they can be applied to address area power system operational challenges.

1. *Advanced Inverter Technology for High Penetration Levels of PV Generation in Distribution Systems*, Subcontract Report NREL/SR- 5D00-60737, March, 2014.
2. *Common Functions for Smart Inverters - Version 2*, EPRI Report 1026809, November, 2012.

Response to Abnormal voltage and frequency (EEE Std. 1547a)

Table 1—Interconnection system default response to abnormal voltages

Default settings[a]		
Voltage range (% of base voltage[b])	Clearing time (s)	Clearing time: adjustable up to and including (s)
V < 45	0.16	0.16
45 ≤ V < 60	1	11
60 ≤ V < 88	2	21
110 < V < 120	1	13
V ≥ 120	0.16	0.16

[a] Under mutual agreement between the EPS and DR operators, other static or dynamic voltage and clearing time trip settings shall be permitted

[b] Base voltages are the nominal system voltages stated in ANSI C84.1-2011, Table 1.

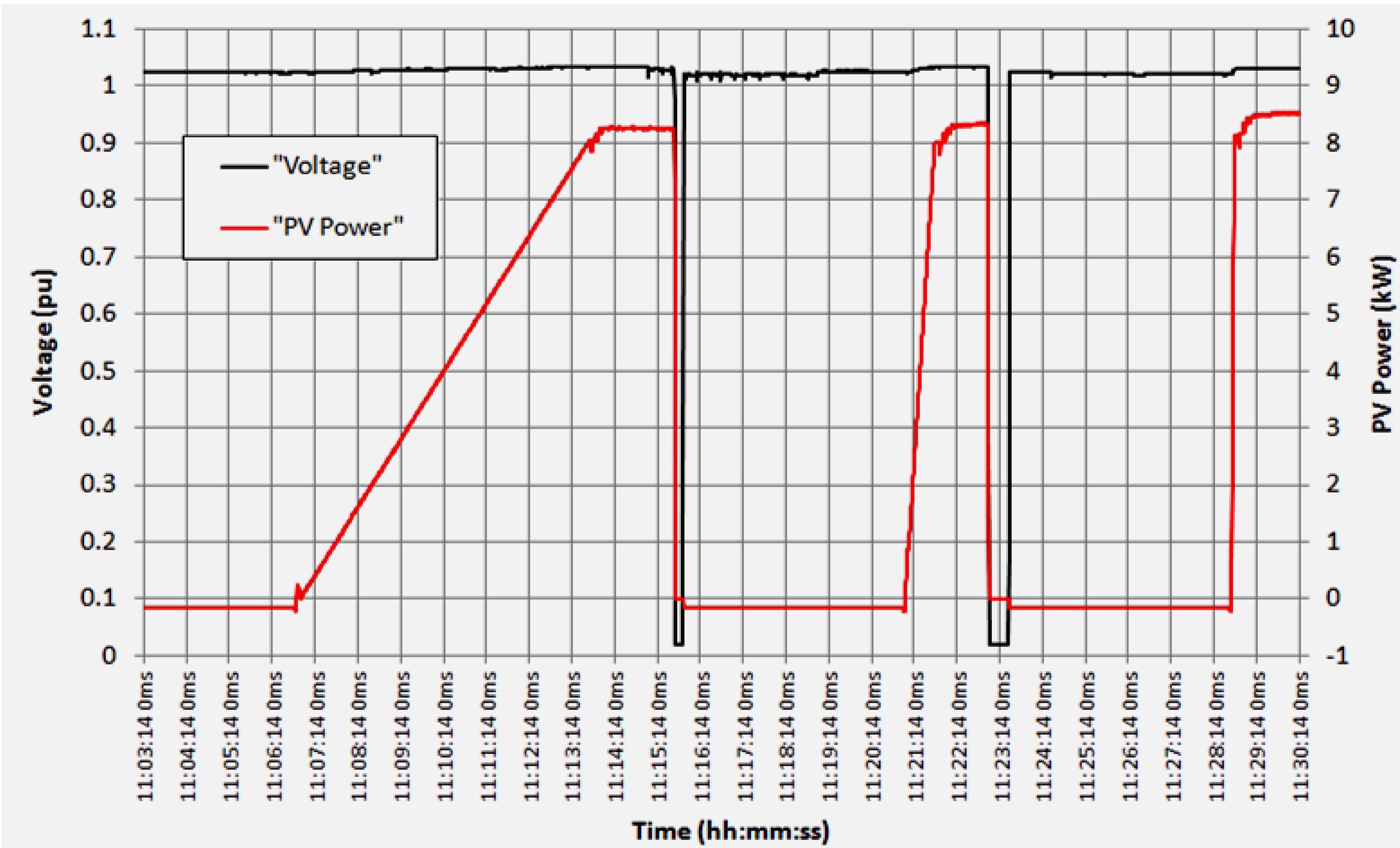
Table 2—Interconnection system default response to abnormal frequencies

	Default settings		Ranges of adjustability	
Function	Frequency (Hz)	Clearing time (s)	Frequency (Hz)	Clearing time (s) adjustable up to and including
UF1	< 57	0.16	56 – 60	10
UF2	< 59.5	2	56 – 60	300
OF1	> 60.5	2	60 – 64	300
OF2	> 62	0.16	60 – 64	10

Advanced Inverter Test Set-Up

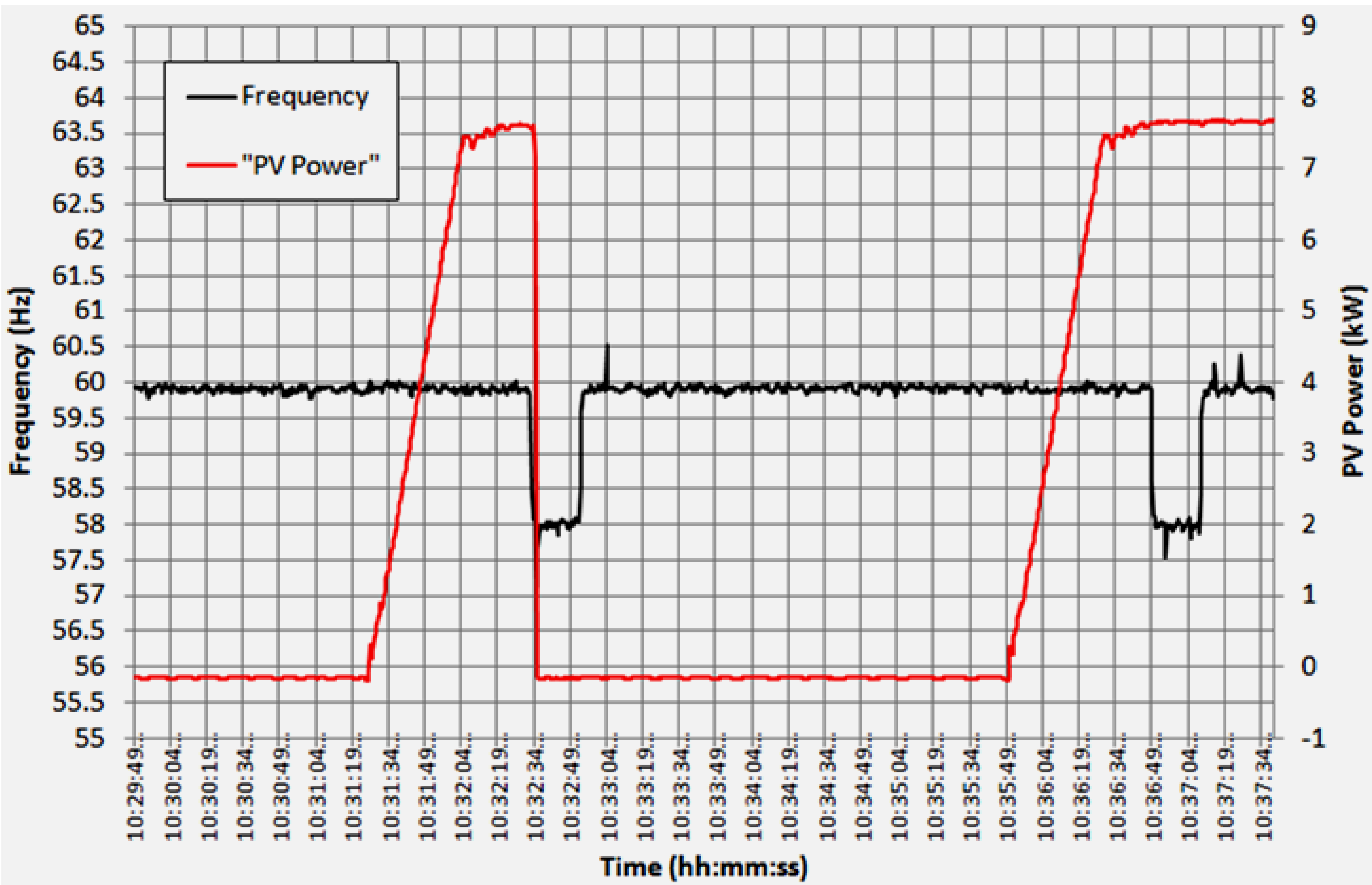
Sample Test - Soft Reconnect

Advanced PV inverters can help avoid “follow-up” voltage problems once PV systems reconnects after an outage.



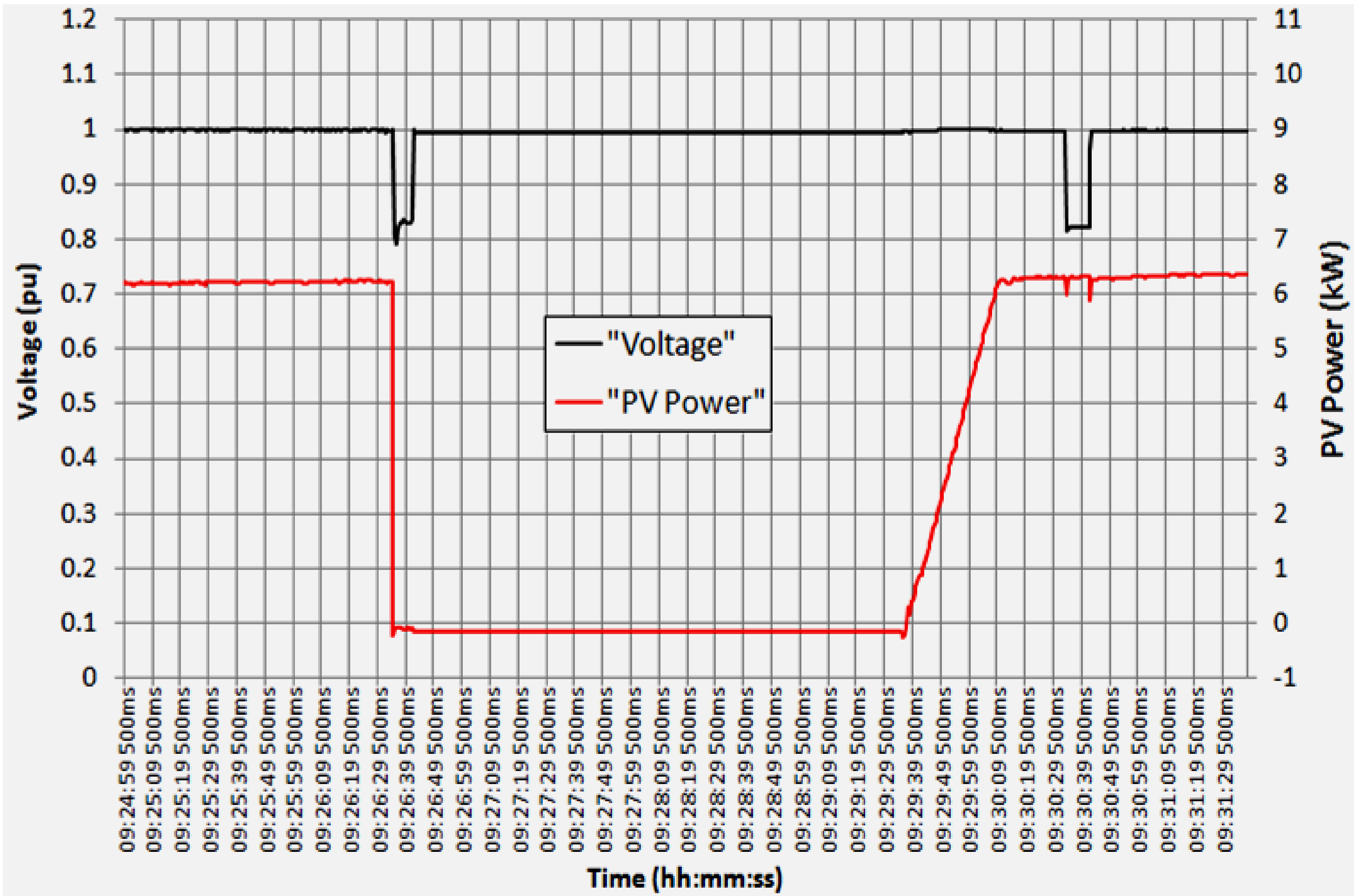
Sample Test: Under-Frequency Ride Through

Advanced PV inverters can assist the grid with frequency regulation during load-generation mismatch.



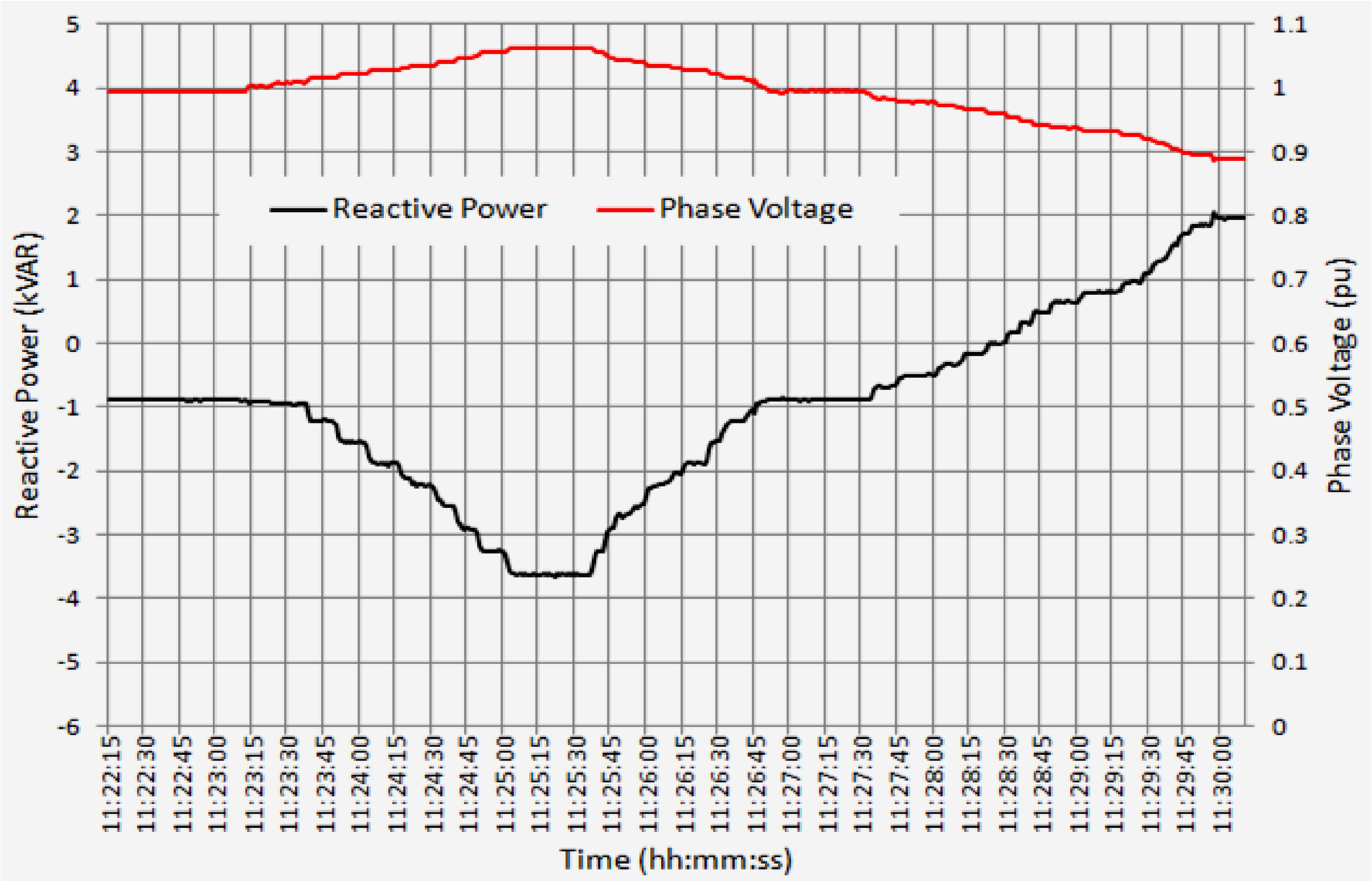
Sample Test: Under-Voltage Ride Through

Advanced PV inverters can improve power quality by remaining connected to the grid during temporary faults .



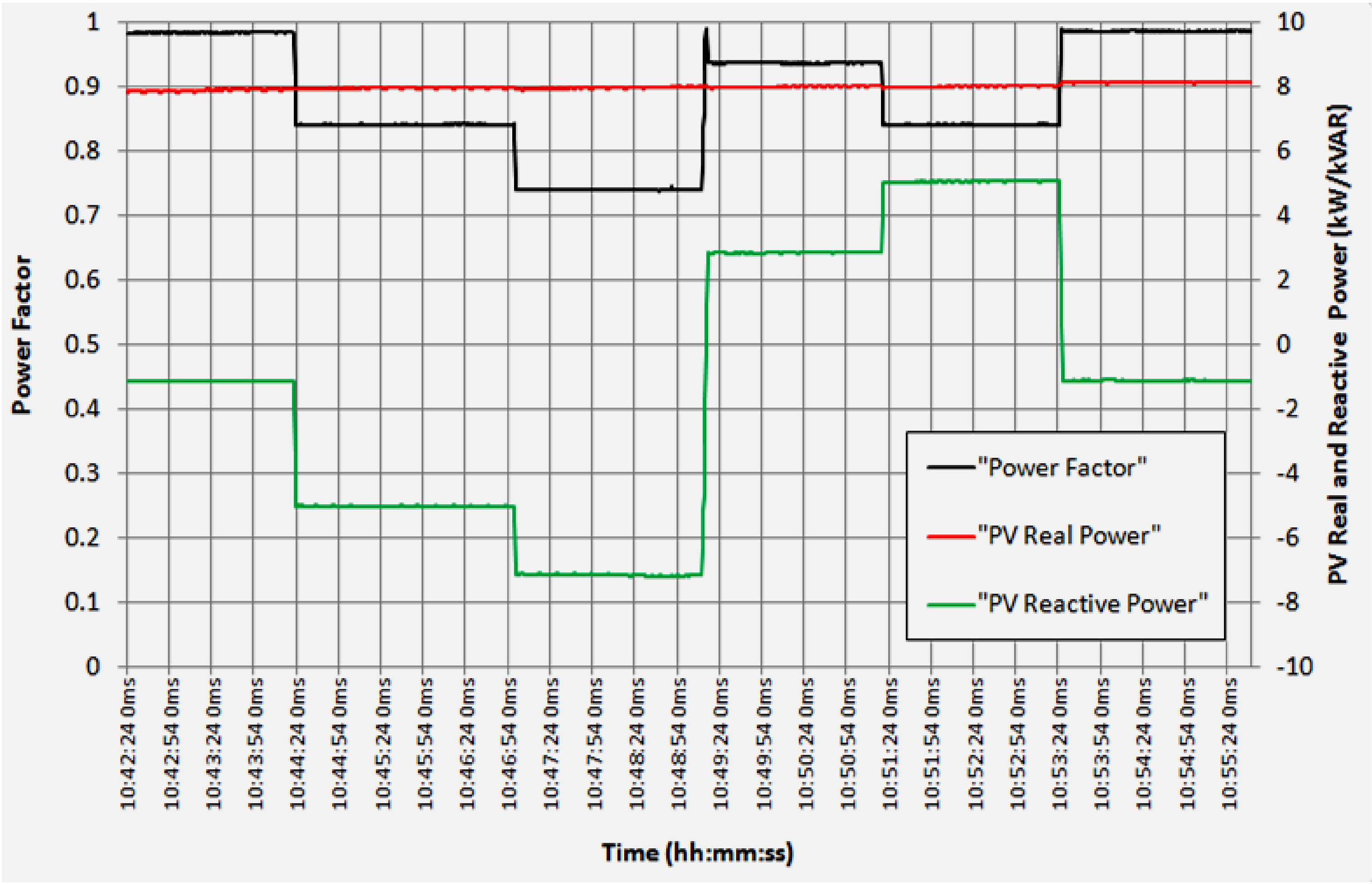
Sample Test: Dynamic Volt/Var Control

Advanced PV inverters can assist the grid with localized voltage regulation by absorbing or generating reactive power.



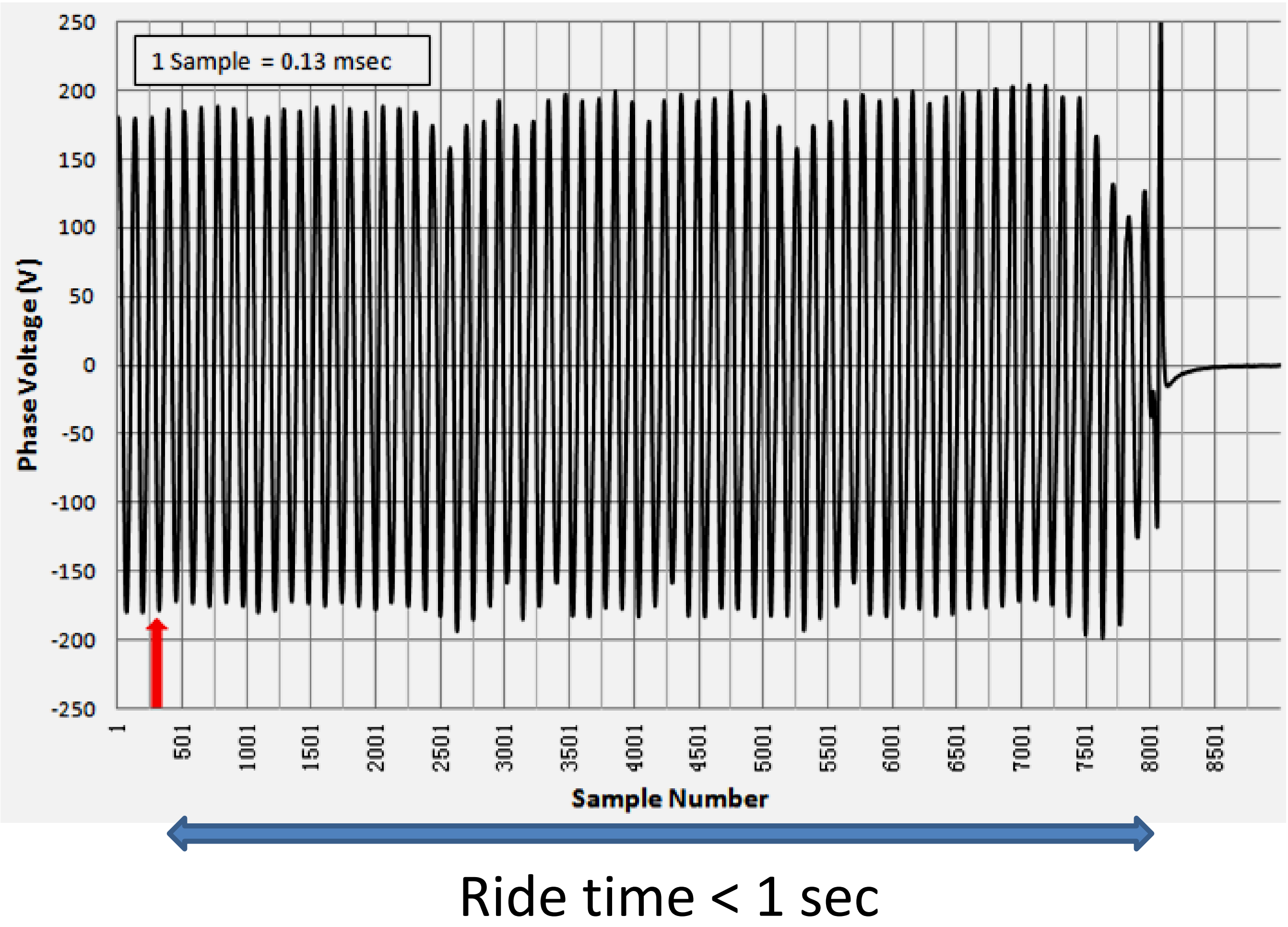
Sample Test: Non-Unity Power Factor Operation

Advanced PV inverters can assist the grid by generating or absorbing reactive power as needed (non-unity power factor)



Sample Test: Islanding Test

Advanced PV inverter functionalities do not appear to interfere with their anti-islanding schemes.



Other Smart Inverter Functions

- Refer to Appendix A of "*Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources*" California PUC, 2014.

Sample of Recent Technical Articles

1. Smart Inverter Impacts on California Distribution Feeders with Increasing PV Penetration: A Case Study
2. Voltage Regulation with Autonomous Distributed Smart Inverters in a Low Voltage Network
3. Investigation of Oscillations Caused by Voltage Control from Smart PV on a Secondary System
4. Control and Derating of a PV Inverter for Harmonic Compensation in a Smart Distribution System
5. **Optimal Settings for Multiple Groups of Smart Inverters on Secondary Systems Using Autonomous Control**
6. **Smart inverter settings for improving distribution feeder performance**
7. **Improving distribution network PV hosting capacity via smart inverterreactive power support**
8. **Smart Inverters for Utility and Industry Applications**
9. **Impact of smart inverter control with PV systems on voltage regulators in active distribution networks**
10. **Smart inverter capabilities for mitigating over-voltage on distribution systems with high penetrations of PV**
11. **Smart inverter volt/var control functions for high penetration of PV on distribution systems**
12. **A Dynamic Operational Scheme for Residential PV Smart Inverters**