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Utility Interconnection Standard Revisions and Electric Power System Support Function Development

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Introduction

The situation.

- 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. [1]

The problem.

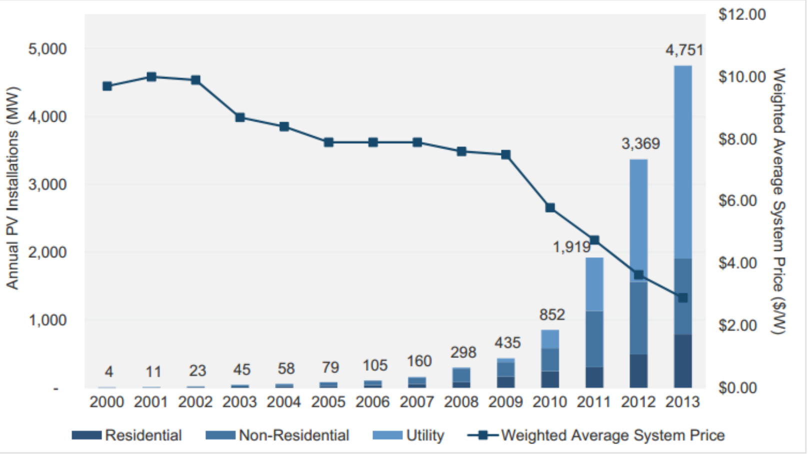
- Displacement of conventional generation will reduce grid inertia and increase power fluctuations, resulting in greater frequency variation [2-3].
- Variability of PV and other renewable sources can cause voltage fluctuations and frequency fluctuations, that can require upgrades to the substation (e.g., supervised reclosing, extended and enhanced line protection, etc.) [4].

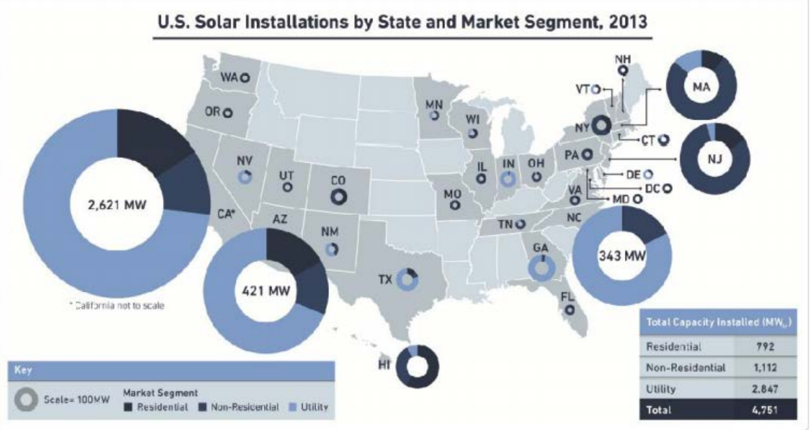
The solution.

- *Change utility interconnection standards* – IEEE 1547a allows voltage and frequency regulation [5] and full revision implements voltage/frequency ride-through
- *Advanced Inverters* – grid-connected power conversion systems that enact specialized controls or capabilities to mitigate impacts of DER on power quality by providing voltage and frequency support [6-8].

PV capacity is growing fast in the US!

- 4.7 GW in 2013, 12.1 GW total
  - Installed capacity is projected to triple by 2016!
  - Highest growth rate expected in distribution-connected PV
- High-Pen PV Areas
  - California
    - ~2 GW of distribution-connected PV
    - Aiming for 12 GW of DG (mostly PV) by 2020! [9-10]
  - Hawaii
    - Highest penetration at the balancing area level (island grids)
    - Half of distribution circuits are at 100% of daytime minimum load





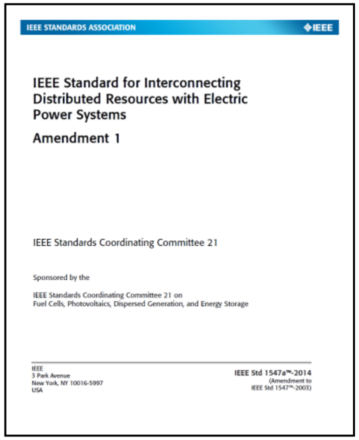
Source: SEIA/GTM Research, US Solar Market Insight 2013 Year in Review

Utility Interconnection Standard Changes

- IEEE Std. 1547 is the US-wide Distributed Resource (DR) technical standard

IEEE 1547-2008	IEEE 1547a-2014
Shall not regulate voltage [no volt/var allowed]	shall participate in voltage regulation [no specification]
Shall not regulate frequency [no freq/watt allowed]	shall participate in frequency regulation [no specification]
Restrictive voltage and frequency must-trip range [opposite of V/FRT]	More widely adjustable voltage and frequency must-trip range [No V/FRT requirement]

- Opens the door for jurisdictions to create different interconnection requirements
  - CPUC Electric Rule 21, PJM, HECO, others starting to develop standards addressing advanced functions


IEEE STANDARDS ASSOCIATION

IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems

Amendment 1

IEEE Standards Coordinating Committee 21

Sponsored by the

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IEEE Std 1547a™-2014
(Amendment to
IEEE Std 1547™-2003)

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Utility Interconnection Standard Full Revision

IEEE 1547 Draft includes the following

- Extended voltage and frequency operating ranges
- High/Low Voltage Ride-Through Requirements*
- High/Low Frequency Ride-Through Requirements*
- Voltage Regulation Operating Mode Requirements*
  - Power Factor Mode
  - Volt-VAr Mode
  - Active Power-Power Factor Mode
  - Reactive Power Mode
- Frequency Regulation Operating Mode Requirements*
  - Frequency-Watt
  - Power curtailment
  - Watt-power factor

*new requirements

Sandia Develops Advanced Inverter Test Protocol

Test protocols for Advanced Inverters [11] was developed as a evaluation tool for new functions and these evaluation methods are necessary to independently verify that the inverters are properly executing the advanced functions.

The advanced inverter test procedure includes a description of the functions and default values on adjustable parameters as well as maximum adjustable ranges. the following function are included in the test protocol:

- Low/High Voltage ride-through
- Low/High Frequency ride-through
- Fixed power factor
- Volt-VAr
- Frequency-Watt
- Normal ramp rate
- Soft start ramp rate

Sandia Develops Anti-Islanding Test Protocol

Sandia collaborated with NREL, testing laboratories, and industry stakeholders to develop anti-islanding test procedure requirements. For this test, the functions are set to the most aggressive state:

- minimal deadbband,
- steepest slope,
- maximum available reactive power

Test circuit remains the same and method of conducting the test are the same to previous version of IEEE 1547 but the following combinations are required.

Test	L/HVRT	L/HFRT	Power Factor	Volt-VAr	Ramp Rate	Freq-Watt
1	X	X				
2	X	X	X			X
3	X	X		X		X
4	X	X			X	X
5	X	X		X	X	X

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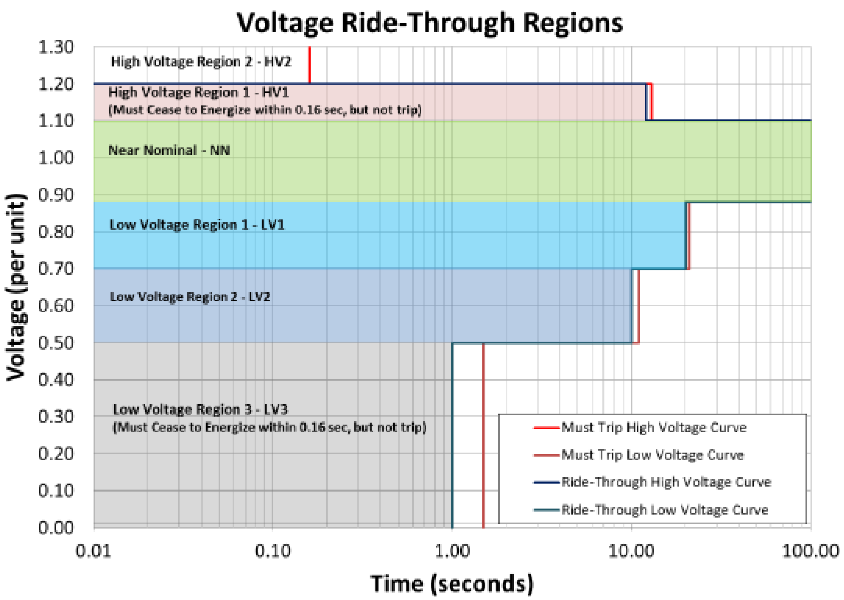
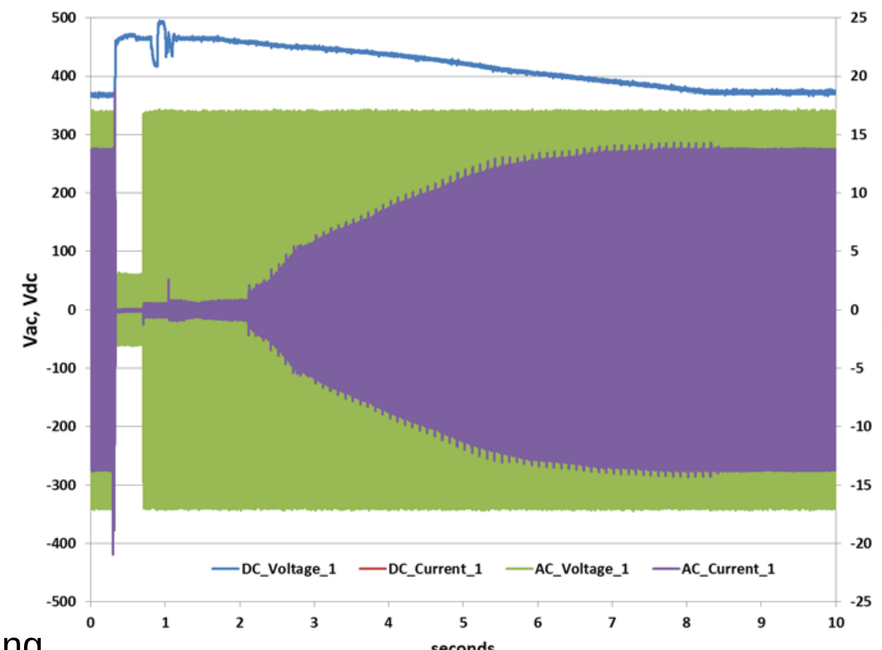
Low and High Voltage Ride-Through Requirements

Region	Voltage at PCC (% Nominal Voltage)	Ride-Through Until	Ride-Through Operating Mode	Maximum Trip Time
High Voltage 2 (HV2)	V ≥ 120	N/A	N/A	0.16 sec.
High Voltage 1 (HV1)	110 < V < 120	12 sec.	Momentary Cessation	13 sec.
Near Nominal (NN)	88 ≤ V ≤ 110	Indefinite	Continuous Operation	Not Applicable
Low Voltage 1 (LV1)	70 ≤ V < 88	20 sec.	Mandatory Operation	21 sec.
Low Voltage 2 (LV2)	50 ≤ V < 70	10 sec.	Mandatory Operation	11 sec.
Low Voltage 3 (LV3)	V < 50	1 sec.	Momentary Cessation	1.5 sec.

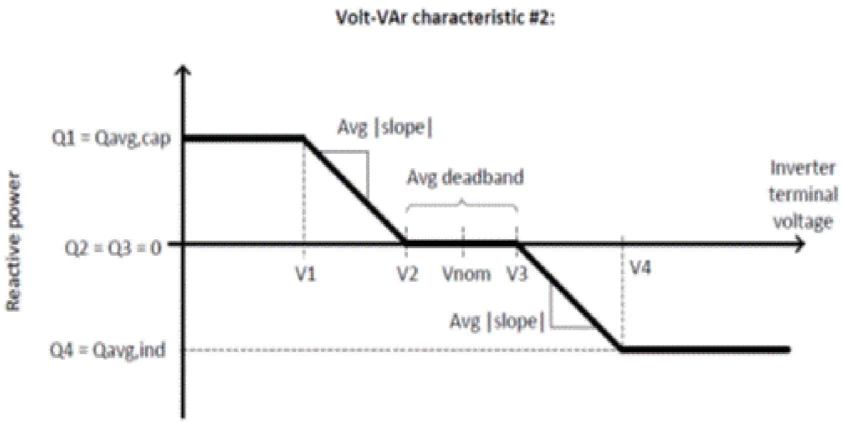


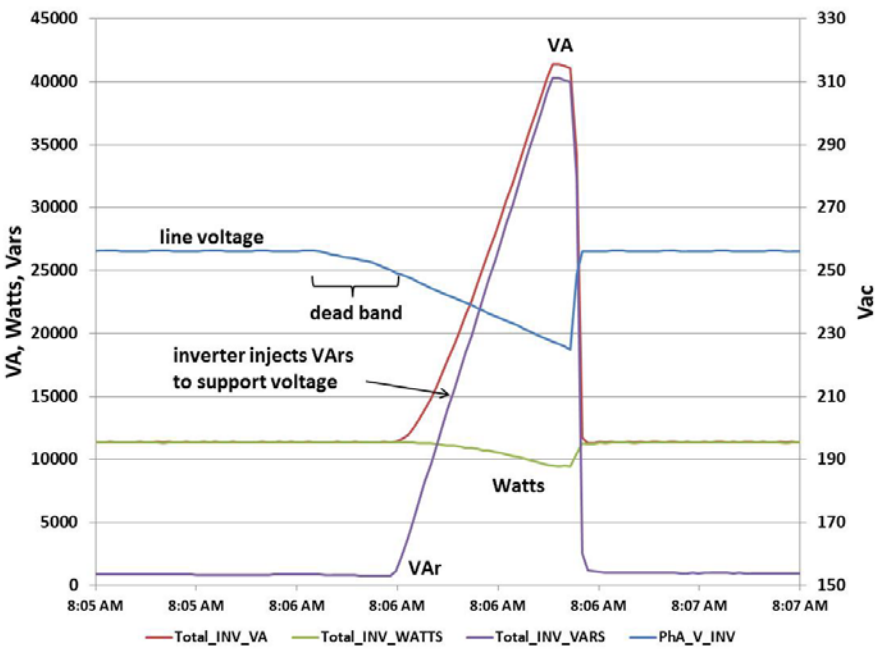


Momentary cessation: EUT stops exporting power to the utility but does not trip

Voltage Regulation Function (Volt-Var)

Using a programmable utility simulator at Sandia's distributed energy technologies Laboratory (DETL), the volt-VAr function was implemented by changing the voltage at the terminals of the inverter and monitoring the ac voltage and the apparent, real and reactive power.





Volt-VAr Modes

VV11-- available VAr support with on Impact on watts (watt priority)
VV12-- maximum VAr support without Exceeding maximum watts (var priority)
VV13– static VAr setting
VV14– Default setting (no VArs)

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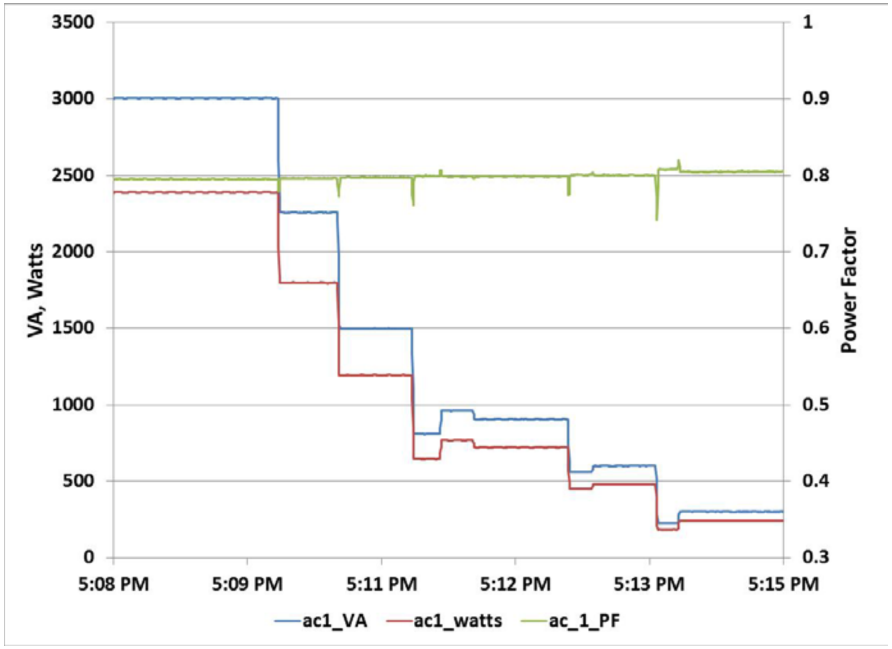
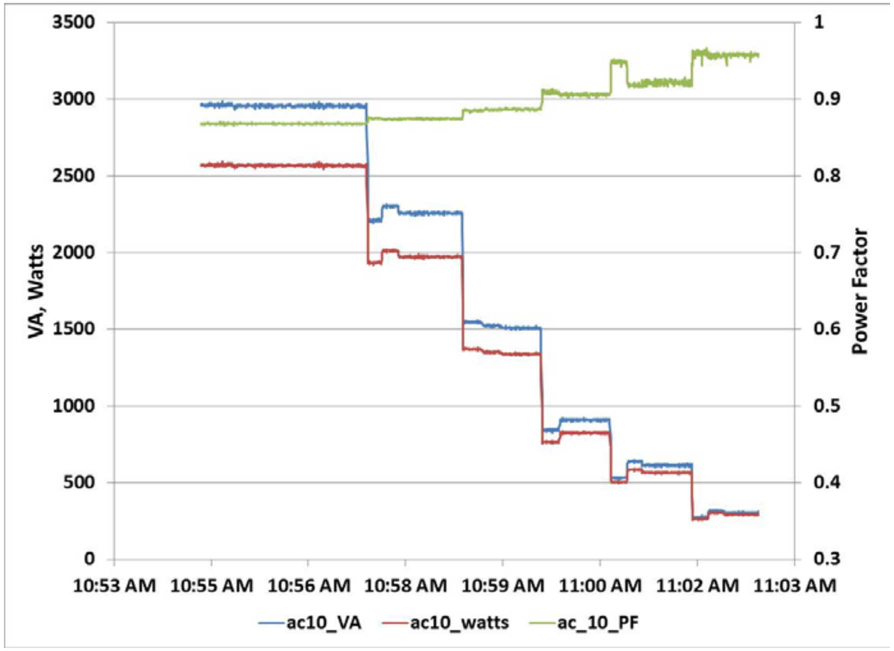
Voltage Regulation Function -- Constant Power Factor

This function was exercised at Sandia's DETL and for this test, the power factor was selected through the inverter GUI. The results are quite different between inverter manufacturers.



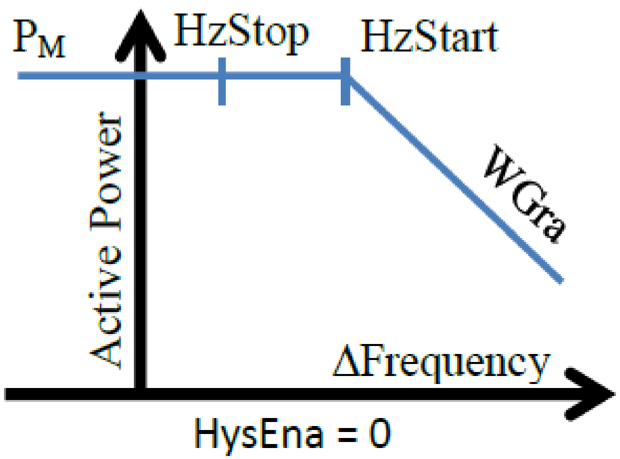


Target PF=.8
Inverter delivers PF at 6 power levels
100%, 75%, 50%, 30%, 20%,
10% of rated power

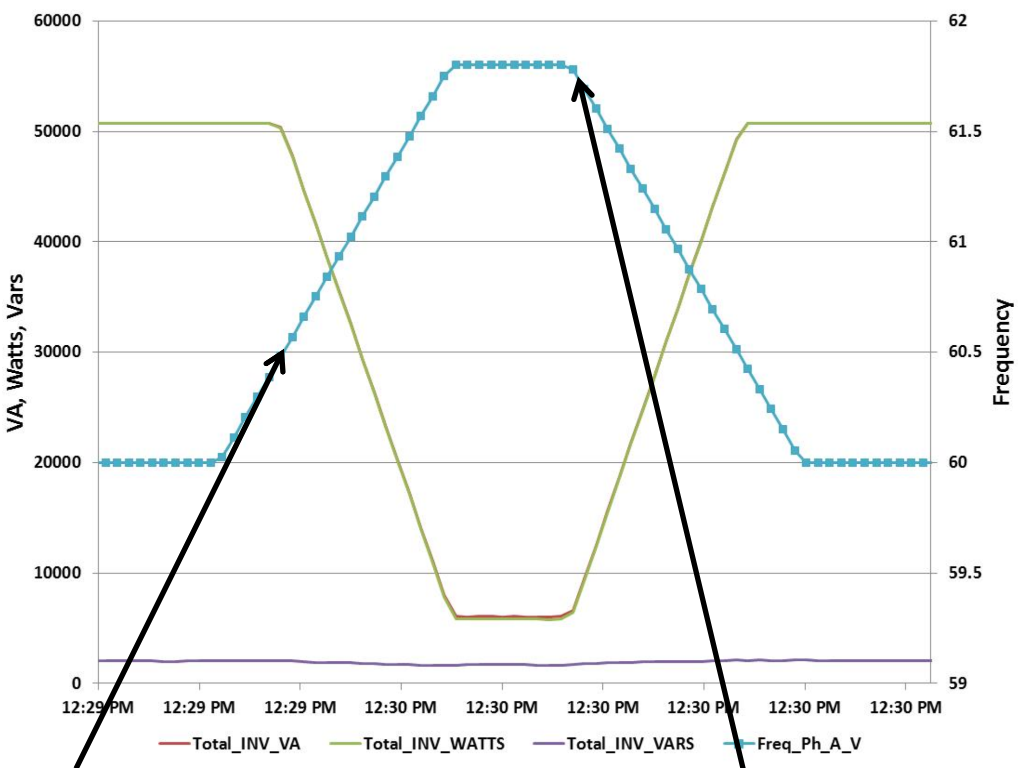
Target PF=.85
Inverter delivers PF at 6 power levels
100%, 75%, 50%, 30%, 20%,
10% of rated power

Frequency Regulation Function Frequency-Watt

Using a programmable AC source simulator at Sandia's DETL, the freq-watt function was implemented by changing the frequency at the terminals of the EUT.



W_{Gra}- The slope of the reduction of allowed watt output as a function of frequency (% max power/Hz)



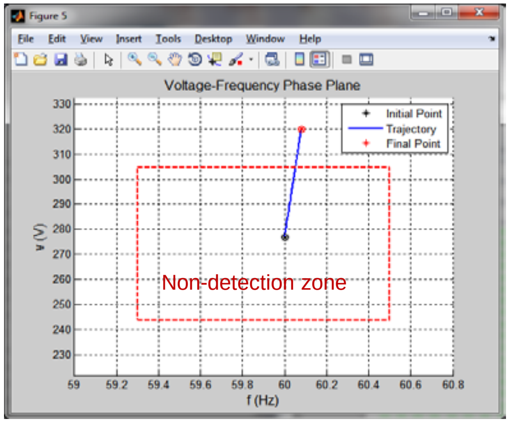
Inverter curtails real power at high frequency

Inverter increases real power as frequency decreases

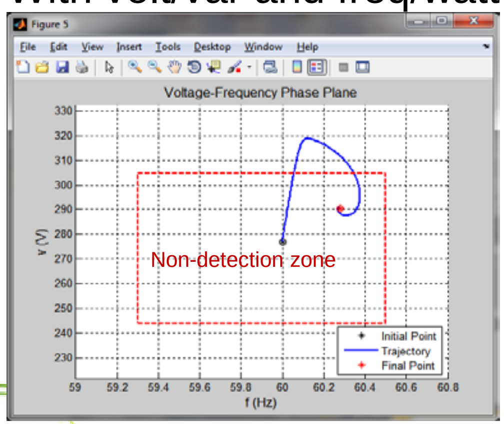
Sandia Anti-Islanding Modeling Indicates Issues

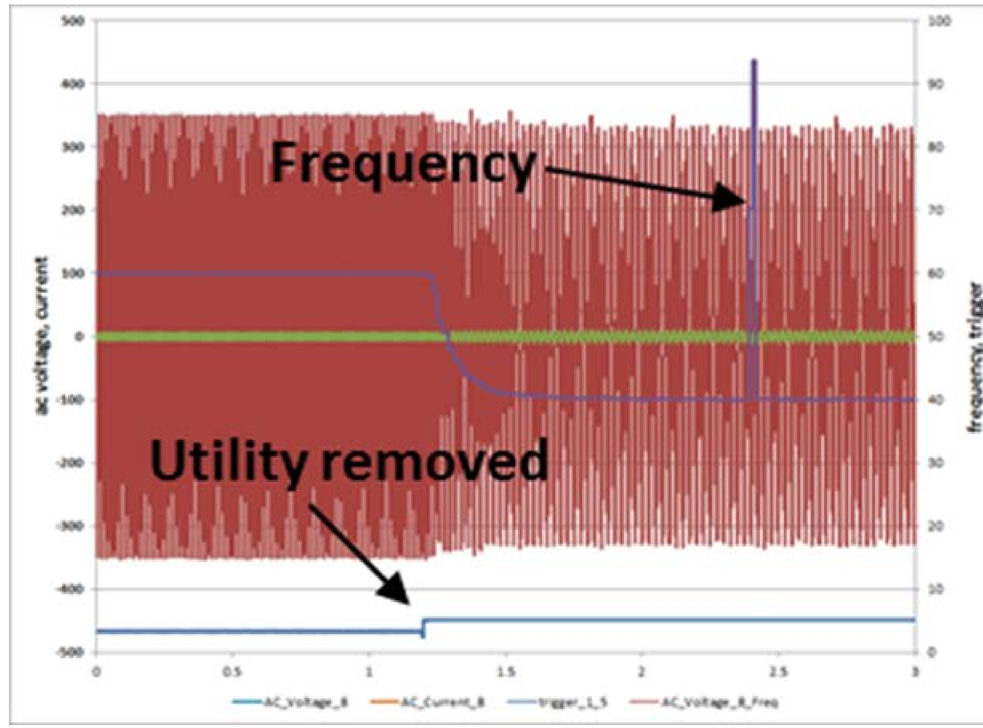
Analysis shows that volt/var & freq/watt functions can make certain anti-islanding methods less effective [12]

Without volt/var and freq/watt



With volt/var and freq/watt





Islanding test result with voltage/frequency Ride-through enabled. Inverter runs on longer than 2 seconds

Conclusions

- Full revision to Utility Interconnection Standard will include Electric Power System Support Functions
- Full revision to Utility Interconnection Standard will include Electric Power System disturbance ride-through requirements
- Support Functions will be implemented when mutually agreed the function benefits the utility
- Communication implementation of functions has the potential implement the function and to make necessary changes to the functions settings

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[[12] J. Neely, S. Gonzalez, M. Ropp, D. Schutz, "Accelerating Development of Advanced Inverters: Evaluation of Anti-Islanding Schemes with Grid Support Functions and Preliminary Laboratory Demonstration," Sandia National Laboratories Technical Report SAND2013-10231; November 2013.