

SANDIA NATIONAL LABORATORIES Department 6335 Solar Systems

Sigifredo Gonzalez, Scott Kuszmaul, Abraham Ellis

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LONG-TERM INVERTER OPERATION RE-CHARACTERIZATION REQUIREMENTS

Purpose

 Analyze the effects of long term operation and exposure on the performance of the utility interconnected PV inverter

Parameters

- Identify the influential parameters for performance
 model refinements
 - dc voltage
 - power level

Test Methodology

 Identify standards and protocols needed for determining the operating conditions to re-characterize the inverter IEEE 929-2000/UL 1741 CEC Inverter Performance Protocol



LONG-TERM INVERTER OPERATION RE-CHARACTERIZATION PROCESS

PV Array Configuration

 Discuss the Photovoltaic array configuration used to analyze the effects of long term operation on an utility interconnected PV inverter.

Inverter Test Set-up

 Provide a one-line diagram indicating the dc voltage and current test points and the ac voltage and current test points monitored during the detail laboratory evaluation.

Testing Procedure

• IEEE 929-2000/UL 1741

Determine voltage and frequency Ranges Determine responses to surges and sags on the voltage

CEC Inverter Performance Protocol
 weighted efficiency evaluations





PV Array Configuration and Module Performance Characteristics

- PV has 20+ year performance warranty
- PV has years of research studies
- PV typically has a 1%/year degradation rate

Inverter	Module model and	Voltages			Currents			Power Level	
	configuration	Voc	Vmp	System Vmp	Isc	Imp	System Imp	P STC (W)	Pmp @ 50C (W)
Inverter #1	AP-75 2-20 mod strings	21	17	340	4.8	4.4	8.4	3000	2597
Inverter #2	AP-75 2-20 mod strings	21	17	340	4.8	4.4	8.4	3000	2597
Inverter #3	BP 380 2-22 mod strings	22.1	17.6	387.2	4.8	4.55	9.1	3520	2996
Inverter #4	BP 380 2-22 mod strings	22.1	17.6	387.2	4.8	4.55	9.1	3520	2996





Arial View of PV array configuration





Typical PV Grid-Tied Inverter Laboratory Testing Configuration





Inverter Laboratory Testing Requirements

All utility compatibility evaluations adhere to IEEE 929-2000 IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems

Note: IEEE 929-2000 was used instead of IEEE 1547 due to inverter vintage

utility compatibility evaluations include

Voltage (at PCC)	Maximum Trip Time
V < 50%	6 cycles
50% ≤ V < 88%	120 cycles
88% ≤ V ≤ 110%	Normal operation
110% < V < 125%	120 cycles
125% ≤ V	2 cycles

Frequency Surge/sag test requirements

Frequency Hz (at PCC)	Maximum Trip Time
< 59.3	6 cycles
59.3 ≤ F ≤ 60.5	Normal Operation
> 60.5	6 cycles



Voltage Surge/Sag Utility Compatibility Evaluations per IEEE 929-2000

50% ≤ V < 88%





110% < V < 125%





Performance Test Protocol for Evaluating Inverters provides method for determining weighted efficiency (η)

The weighted η calculation places a value for each of the power levels in the following table. Correlates to the amount of time the inverter spends at that particular power level.

Weighted Efficiency equation

 $\eta_{DUT} = 0.04 \cdot \eta_{10} + 0.05 \cdot \eta_{20} + 0.12 \cdot \eta_{30} + 0.21 \cdot \eta_{50} + 0.54 \cdot \eta_{75} + 0.05 \cdot \eta_{100}$

Test	Vdc	Inverter DC Input Power Level						efficiency
1051		10%	20%	30%	50%	75%	100%	η
Α	Vnom	3.6	4.7	11.4	19.9	50.1	4.7	94.4
В	110% Vmin	3.6	4.7	11.3	19.8	50	4.7	94.1
С	90% Vmax	3.5	4.6	11.2	19.7	49.5	4.7	93.2

CEC weighted η is the average of the three totals CEC $\eta = 93.9$



Inverter Laboratory Re-Characterization Results (2005 vs 2007)





Inverter Laboratory Re-Characterization Results (2005 vs 2007)

Inverter # DETL	$\begin{array}{c} 2005 \\ \text{weighted } \eta \end{array}$	2007 weighted η	% change
1	93.9%	94.1%	.24%
2	92.6%	92.2%	43%
3	92.2%	92%	22%
4	91.8%*	92.5%*	.76%*
SWTDI			
5	92.4%	91.9%	54%
6	92.3%	91.9%	37%
7	91%*	90.7%*	33%*

*Inverters evaluated at only 1 dc voltage instead of 3 due to lack of inverter control



Sandia Inverter Performance Model

The inverter performance model is an empirical model that accurately determines the performance characteristics of the dc to ac conversion process.

- requires accurate, reliable, and representative data
- data needed to determine the coefficients
- relates the inverter's ac-power output to both the dc-power and the dc-voltage

Pac = {(Paco / (A - B)) - C \cdot (A - B)} \cdot (Pdc- B) + C \cdot (Pdc - B)² where: A = Pdco \cdot {1 + C1 \cdot (Vdc - Vdco)} B = Pso \cdot {1 + C2 \cdot (Vdc - Vdco)} C = Co \cdot {1 + C3 \cdot (Vdc - Vdco)}

Note: "o" are constant values obtained for manufacturers specification sheets or CEC Equipment Eligibility List Data















Conclusion

The first 2 years of operating the inverters with sufficient rated power during exposure to the elements has shown little effect on the performance of the inverter.

The worst case was a 0.7% change in the efficiency value of an inverter that had only a single efficiency value obtained.

This relatively low change in performance is inconclusive at this point in the test regiment and thus no determination can be stated yet as to whether long term operation of inverters lead to degradation in performance. Another round of inverter re-characterization is due late FY09.

