

# Sandia National Laboratories: Distributed Energy Technologies Laboratory (DETL) Overview



Photovoltaics and  
Grid Integration  
Department

28 June, 2011

# 1-Ø $\mu$ Grid Capabilities

## Utility interconnected to $\mu$ Grid transitional functional platform

- **Virtual Energy Management System (vEMS)**
  - **Coordination of Battery management**
    - Voltage or amp-hour dependent
  - **Maximization of PV utilization**
  - **Ramp rate control and variability**
- **System Control Functions**
  - **Inverter status and settings configuration**
  - **Automated safety alarms and grid interconnection controls**
  - **Distributed remote communications**
- **Automated test sequencing of sources and loads**
  - **Time or event based triggering**
  - **Commanded energy management profile**

# 1-Ø $\mu$ Grid Capabilities

## Full system and facility level diagnostics implemented

- **Signal Monitoring Capabilities**
  - $\mu$ Grid status
  - Battery Status
  - Source and Load Power
  - Frequency
  - Solar Status
  - Manufacturer's onboard capacities monitored at 0.5Hz
- **Digital Acquisition System (DAS) functionality**
  - 60kHz summaries and snapshots
  - Multi-channel steady state recorded 1.0Hz
- **Facility LAN and XanBus communication diagnostics**

# 1-Ø $\mu$ Grid Applications

## 1-Ø battery-based Inverter systems with PV sources in a $\mu$ Grid applications

- *Utility interconnected multi-source and load operation*
  - Simulated time-of-use energy management
  - Ramp-rate control
  - Transition into  $\mu$ Grid
- *$\mu$ Grid multi-source and load operation*
  - Cooperative load sharing
  - Battery management controls
  - Intentional island operation

# 3-Ø $\mu$ Grid Capabilities

## Utility interconnected to $\mu$ Grid transitional functional platform

- **Virtual Energy Management System (vEMS)**
  - Maximization of PV utilization
  - Ramp rate control and variability functionality
  - Voltage and frequency control for grid stability
- **System Control Functions**
  - Inverter and Generator status and settings configuration
  - Distributed remote communications
  - Load control (real and reactive)
  - PV ramp rate control
- **Automated test sequencing of sources and loads**
  - Time or event based triggering
  - Commanded energy management profile
  - Frequency and voltage controlled operation



# 3-Ø $\mu$ Grid Capabilities

## Full system and facility level diagnostics implemented

- **Signal Monitoring Capabilities**
  - $\mu$ Grid status
  - Source and Load Power
  - Frequency and Power Factor
  - DETL images
  -
- **Digital Acquisition System (DAS) functionality**
  - 60kHz summaries and snapshots
  - Multi-channel steady state recorded 1.0Hz
- **Facility LAN communication diagnostics**

# 3-Ø $\mu$ Grid Applications

## 3-Ø power systems with PV sources in a $\mu$ Grid applications

- $\mu$ Grid multi-source and load operation
  - Ramp-rate control
  - Transition into micro-grid
  - Cooperative load sharing
  - Intentional island operation
- Codes and Standards Testing
  - IEEE 1547
  - IEEE 1547.4
  - IEEE 1547.8

# DETL Capabilities

Test	Inverter	System	Standards/Protocols (in addition to DETL test protocol)
System performance (energy production) - System yield, perf ratio, perf index, etc.)		x	RUS Test Protocol (under development)
Inverter Efficiency (PV Array Powered)	x		CEC Inverter Performance Protocol
Inverter Efficiency (DC power supply)	x		CEC Inverter Performance Protocol
Inverter Rated Power (temperature)	x		CEC Inverter Performance Protocol
Start-up and Shut-down characteristics	x	x	DETL Internal
Nuisance trips	x	x	DETL Internal
Inverter MPPT Functionality	x	x	DETL Internal
Harmonic Distortion	x		DETL Internal, IEEE 519
Voltage and frequency steady-state trip limits	x		UL1741, IEEE 1547
Voltage and frequency transient response	x		UL1741, IEEE 1547
Power factor	x		DETL Internal
Anti-islanding with special load conditions	x		UL1741, IEEE 1547
Radio frequency interference (conducted - 450 kHz – 30 MHz)	x		FCC Part 15 Class A
Radio frequency interference (radiated 30 MHz – 1 GHz)	x		FCC Part 15 Class A
High voltage pulse susceptibility	x	x	UL 1741, ANSI C62.41
Insulation integrity		x	UL 1741
Code compliance (safety)		x	NEC
Battery management effectiveness		x	Internal
Component and subsystem temperatures	x	x	Internal
High-ambient temperature operation	x		Internal
User features	x	x	Internal
Remote monitoring and control	x	x	Internal
On-board metering accuracy	x	x	Internal

## Preparations Underway For...

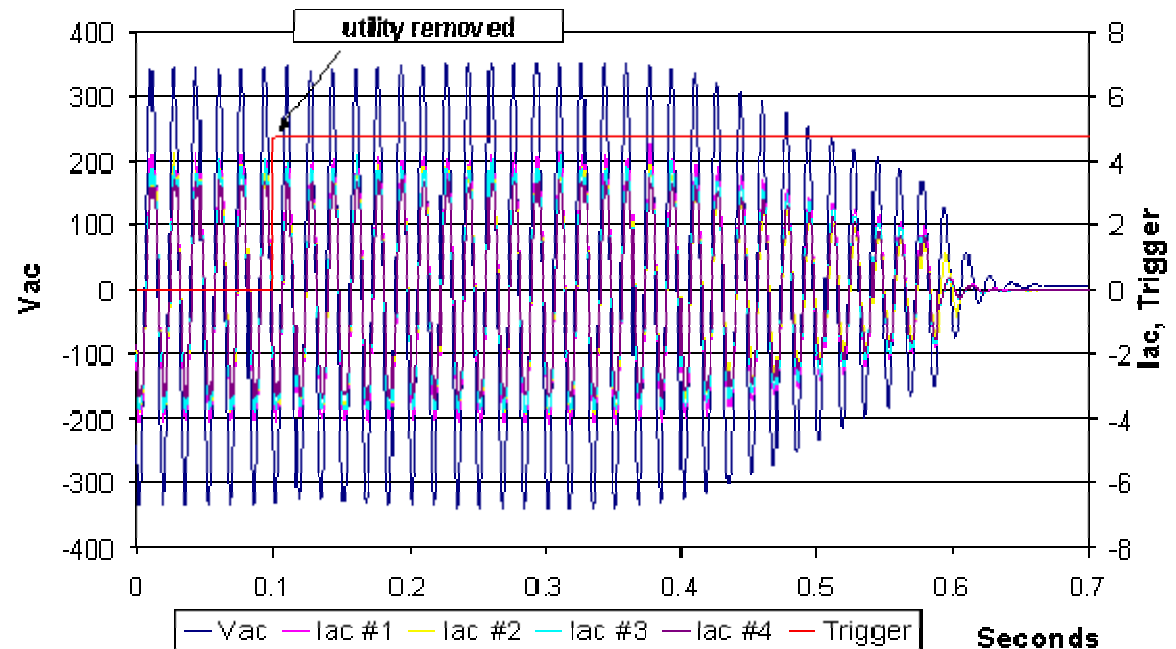
- Arc Fault (UL 1699 Draft)
- Intentional Islanding (IEEE 1547.4 Draft)
- Emerging Communication Protocols



## Multi-Inverter High-penetration islanding tests



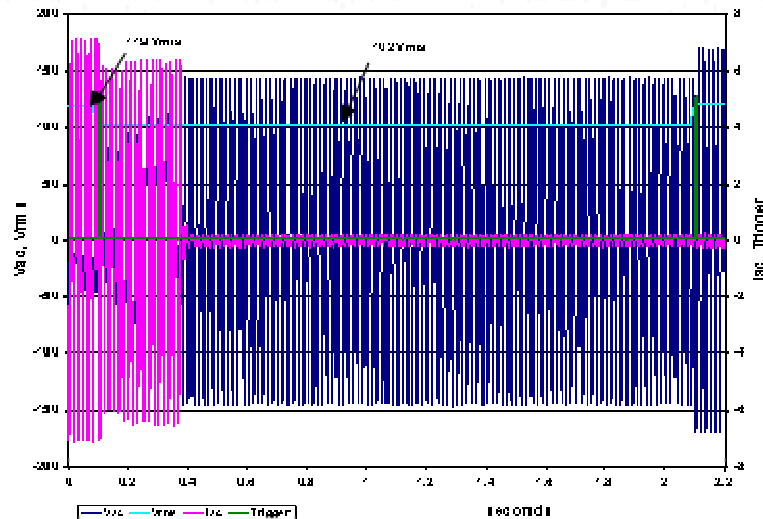
Example for  
4 parallel  
inverters



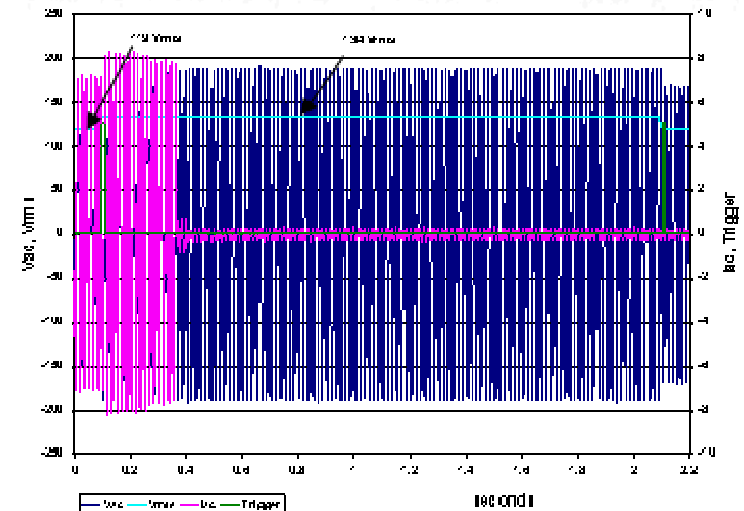
# DETL Capabilities

## Voltage Sag/Surge Utility Compatibility Tests

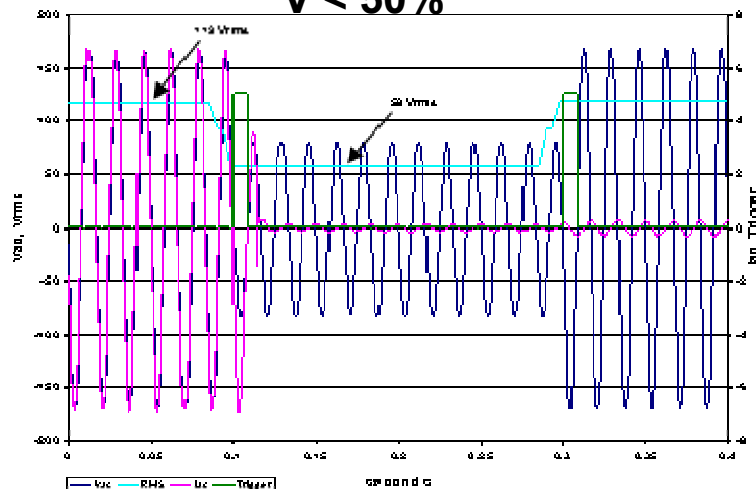
50% < V > 88%



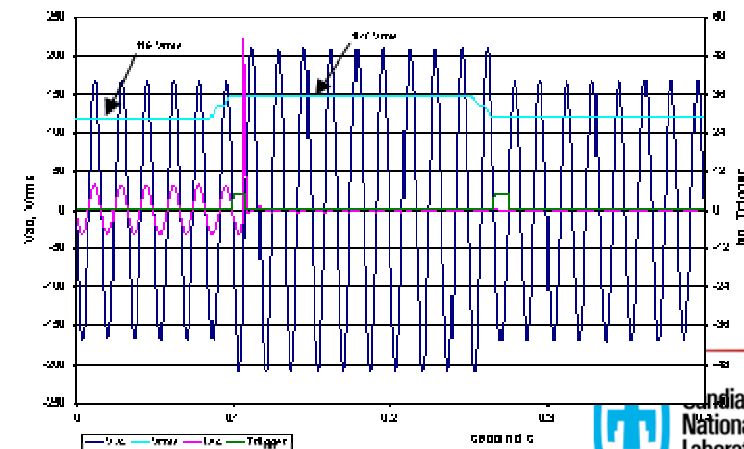
110% < V > 120%



V < 50%



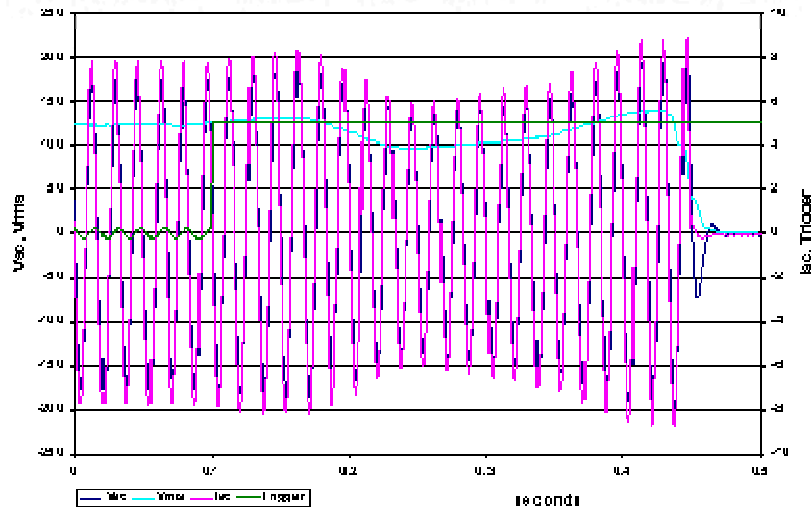
V > 120%



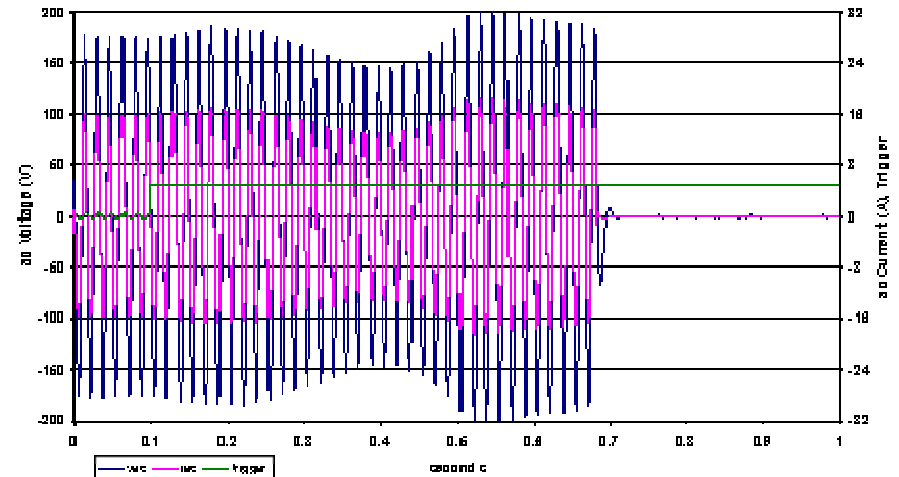
# DETL Capabilities

## IEEE/UL RLC Anti-Islanding Tests

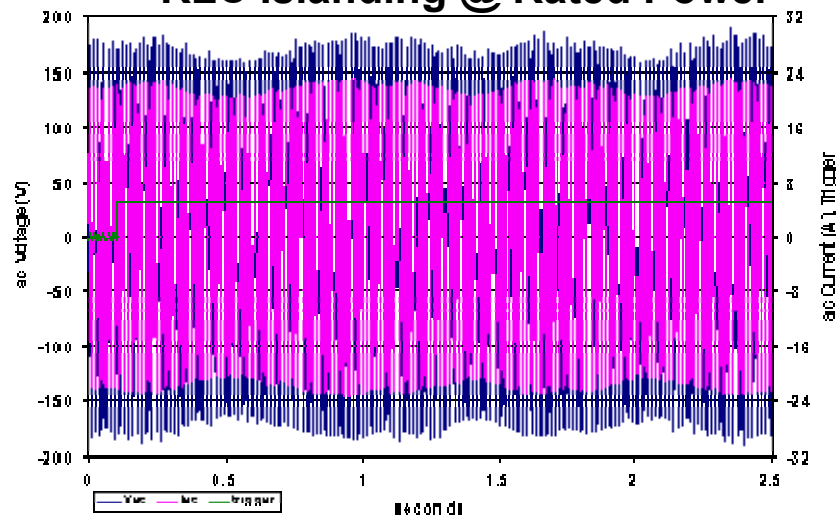
### RLC Islanding @ 33% of Rated Power



### RLC Islanding @ 66% of Rated Power



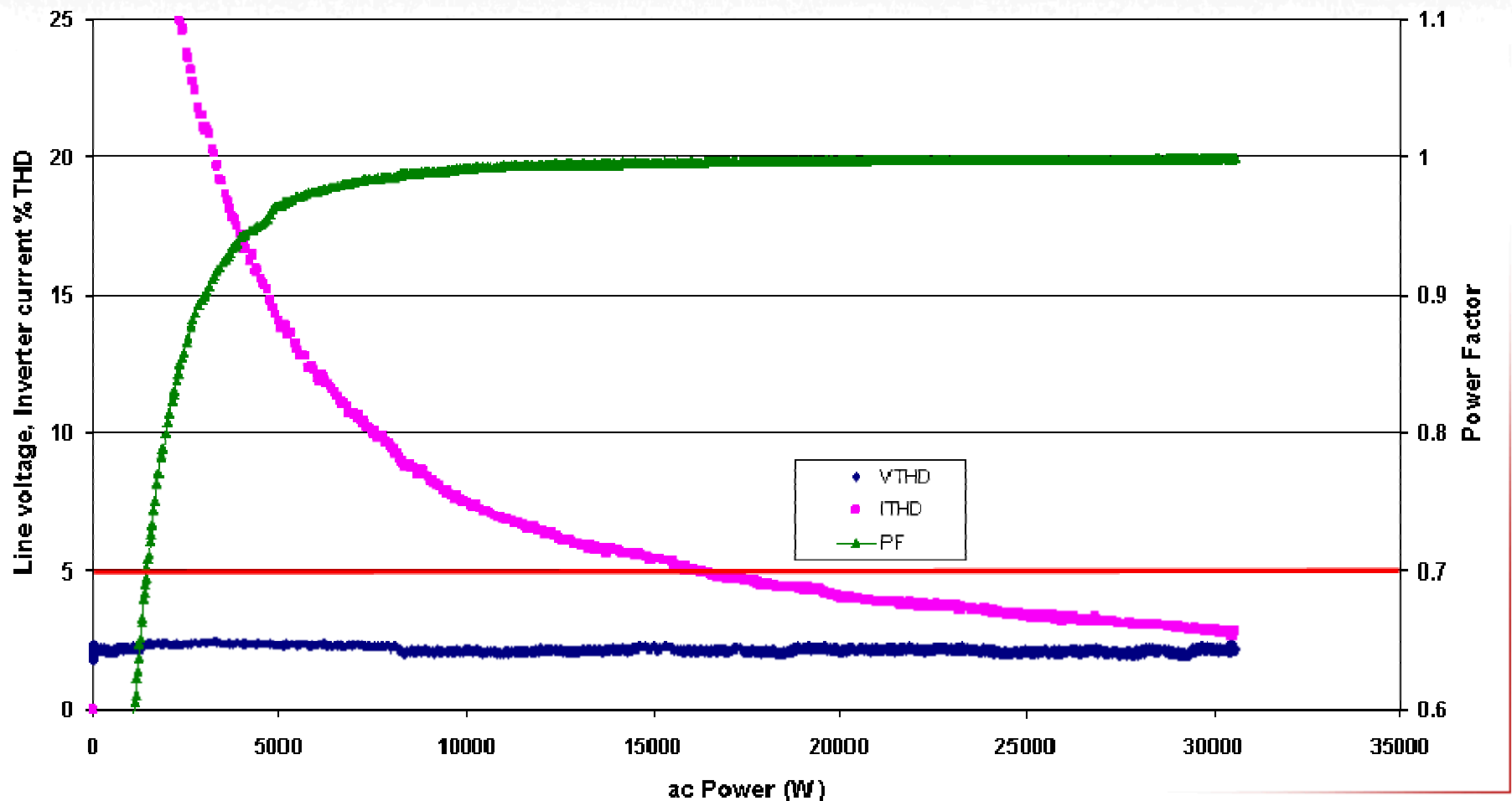
### RLC Islanding @ Rated Power



## IEEE 1547/UL1741 test example

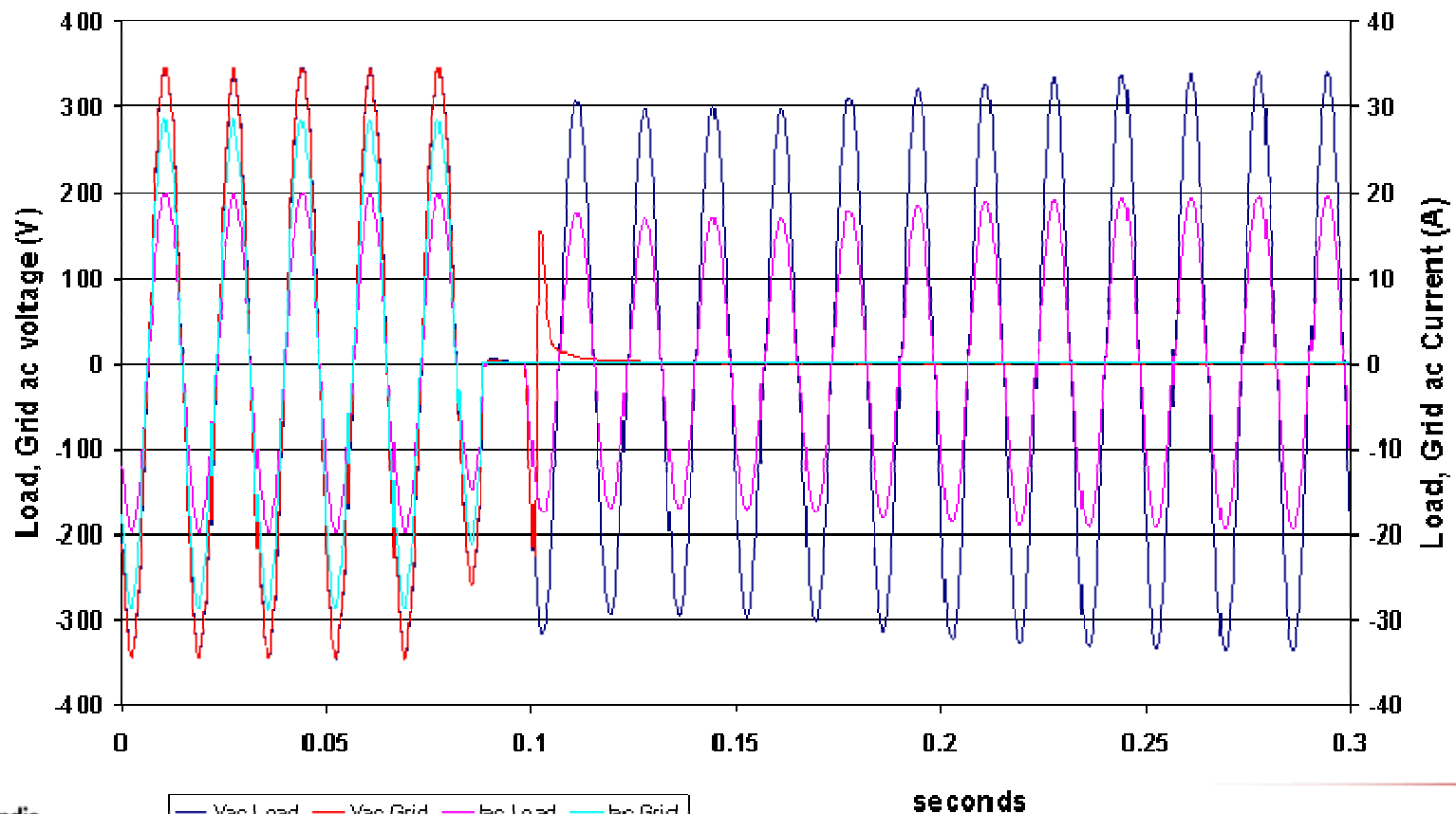
- Procedure requires testing at three power levels
- In this example, anti-islanding failed at rated power level with a run-on exceeding the 2 second disconnect requirement

## Grid-Tied Inverter Power Quality Evaluations



## Grid-Tied to Stand-alone Transition

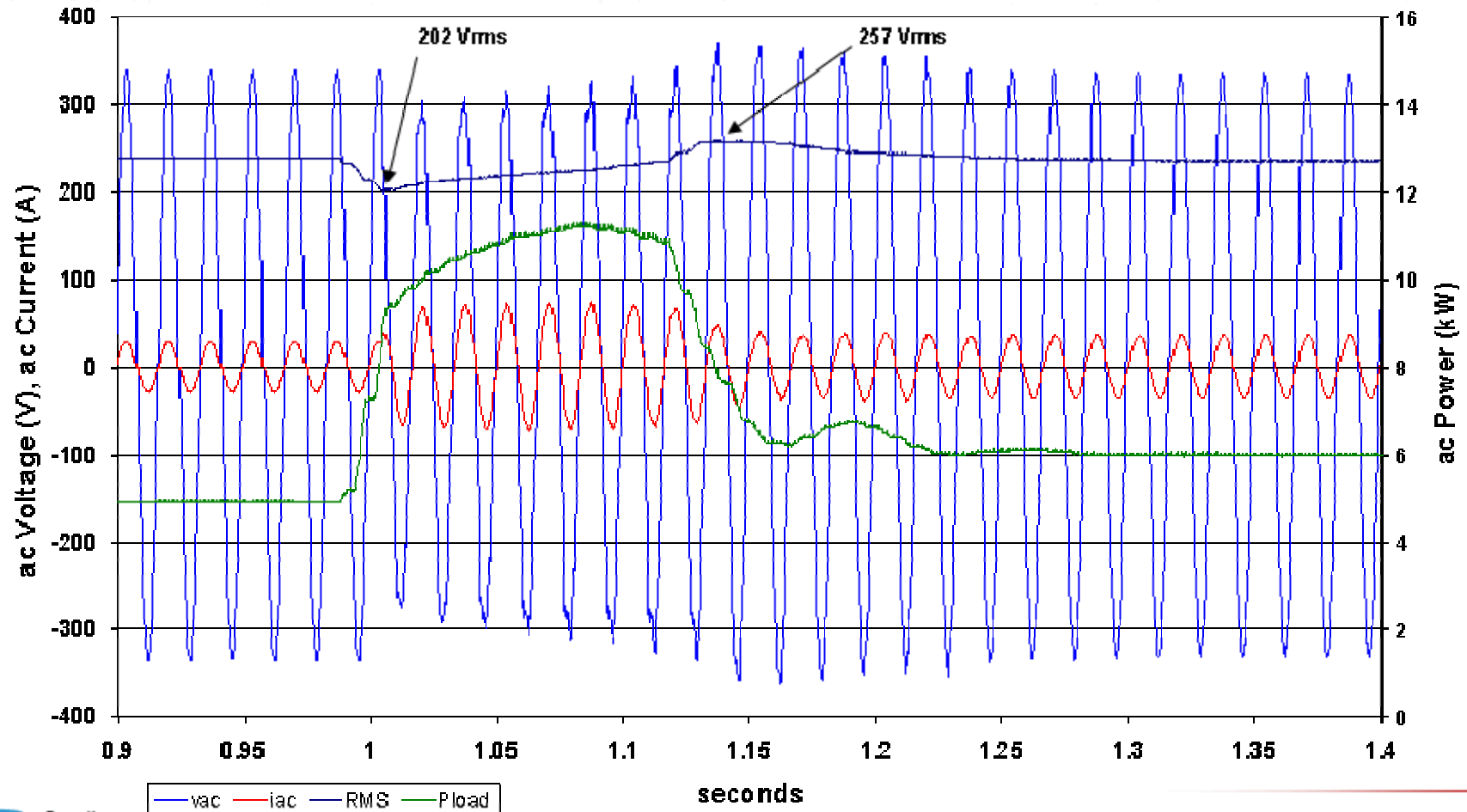
Grid Tied to Stand-alone Transition  
inverter charging at 2kW and by-pass mode supports 3kW resistive load



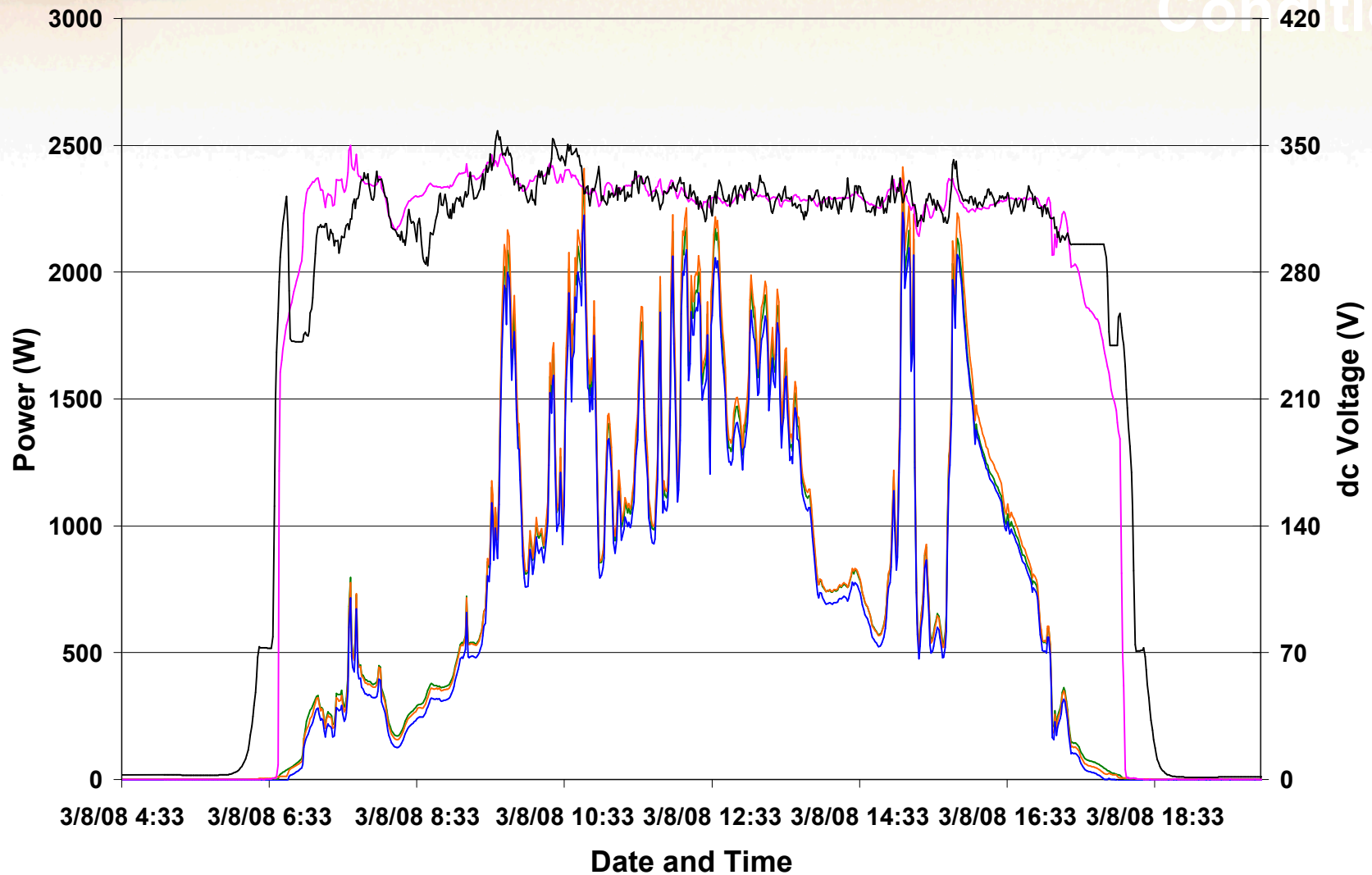


## Standalone Mode 1 HP Motor Start + 5kW Resistive load Waveform

1 HP Motor Start + 5kW of Resistive Load



# PV Dynamic Conditions



— Pmp Modeled — measured DC Power — measured AC Power — Vmp Modeled — measured Vdc

## Loads

- **Resistive load banks:**
  - 360 kW, 480 V, 3-phase
  - 150 kW, 480 V, 3-phase
  - 55 kW 480 V, 3-phase
  - 10 kW, 240 V, 1-phase
  - 10 kW, 120 V, 1-phase
- **Inductive load banks:**
  - 225 kvar, 480 V, 3-phase
  - 55 kvar, 480 V, 3-phase
- **Nonlinear load bank:**
  - 50 kVA, 277 V
- **Capacitive loads:**
  - 50 kvar, 480 V, 3-phase
  - 250 kvar, 480 V, 3-phase
- **Motors:**
  - 20-hp with fan load
  - 3-phase to 10 hp with dynamometer
  - 1-phase to  $\frac{3}{4}$  hp with dynamometer

## Sources and Storage

- **AC Sources**
  - Main utility service: 500 kVA, 480 Vac, 3-phase
  - Diesel generator: 92.5 kVA, 480 Vac, 3-phase,
  - Natural gas generator: 8.5 kVA, 120/240 Vac, 1-phase
  - Gasoline generator: 3 kVA, 120/240 Vac, 1-phase
  - Temporary generators: provision for up to 500 kVA, 480 Vac, 3-phase or 150 kW, 480 V, 3-phase
- **Programmable sources**
  - 62 kVA, 0-480 Vac, 1-phase (reduced rating) or 3-phase
    - 5.25 kVA, 0-480 Vac, 1-phase or 3-phase
- **PV Arrays and other DC sources**
  - 50 kW configurable crystalline Silicon
  - 25 kW configurable crystalline Silicon
    - 3 kW amorphous Silicon
  - PV Simulator: 64 kW
- **Power Supplies:** 350V, 35A (3 each); 55V, 180 A (8 each)
- **Battery Storage**
  - Flooded lead-acid: 640 kWh, 240 or 480 Vdc
  - Valve-regulated lead-acid: 200 kWh, 240 or 480 Vdc
  - Valve-regulated lead-acid: 52 kWh, 12, 24 or 48 Vdc
  - Valve-regulated lead-acid: 12 kWh, 48 Vdc (two)