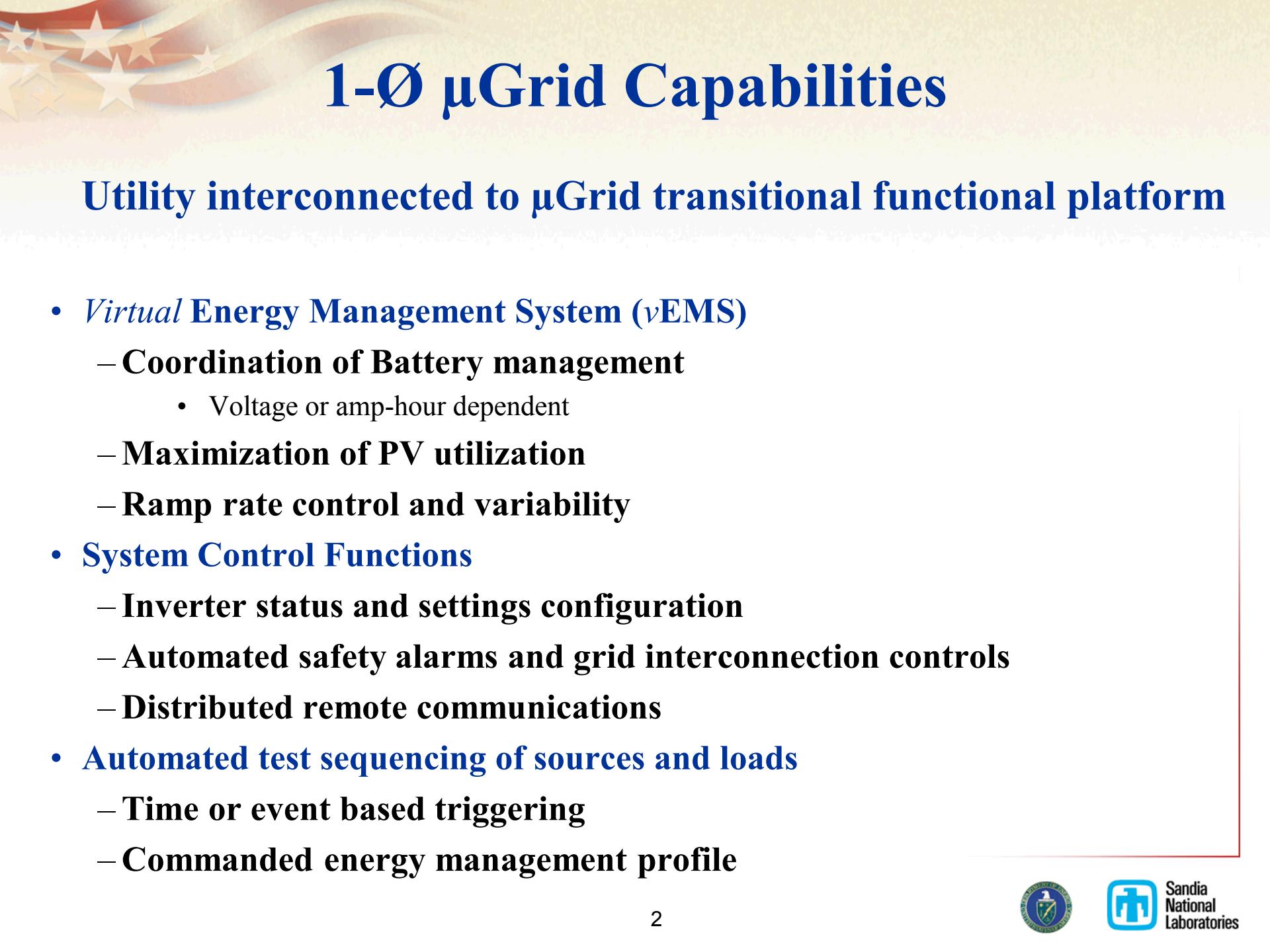


Sandia National Laboratories: Distributed Energy Technologies Laboratory (DETL) Overview



Photovoltaics and
Grid Integration
Department

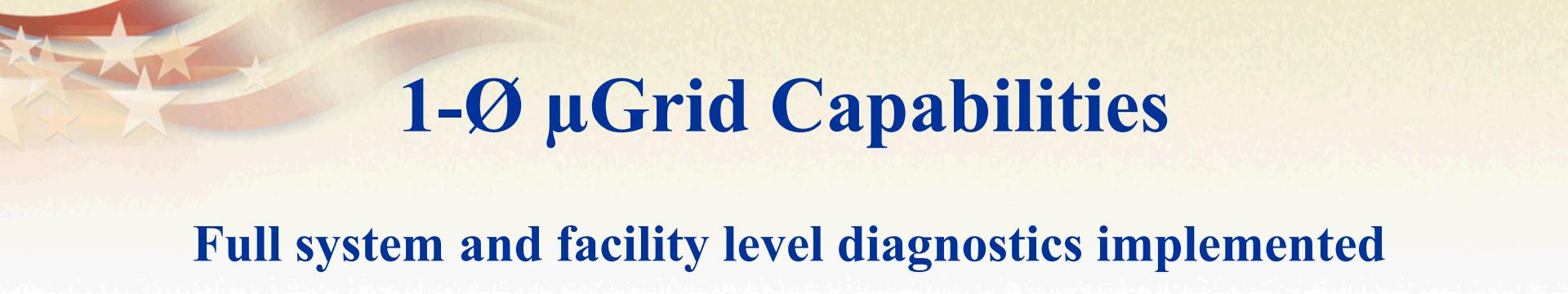
28 June, 2011



1-Ø µGrid Capabilities

Utility interconnected to µGrid 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 µGrid Capabilities

Full system and facility level diagnostics implemented

- **Signal Monitoring Capabilities**
 - µGrid 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 μ Grid Applications

1-Ø battery-based Inverter systems with PV sources in a μ Grid applications

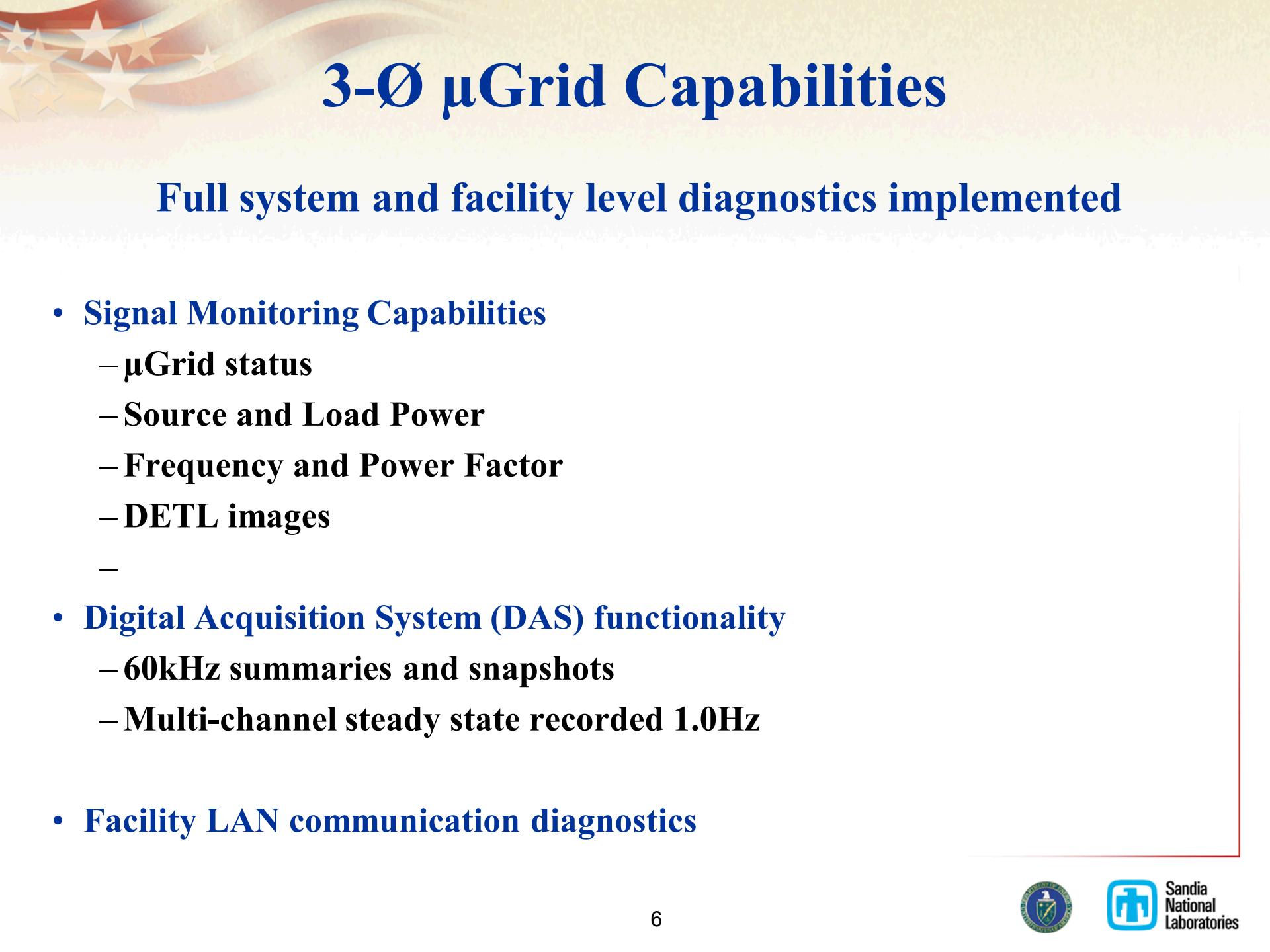
- *Utility interconnected* multi-source and load operation
 - Simulated time-of-use energy management
 - Ramp-rate control
 - Transition into μ Grid
- *μ Grid* multi-source and load operation
 - Cooperative load sharing
 - Battery management controls
 - Intentional island operation



3-Ø μGrid Capabilities

Utility interconnected to μGrid 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 μGrid Capabilities

Full system and facility level diagnostics implemented

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

3-Ø μGrid Applications

3-Ø power systems with PV sources in a μGrid applications

- **μGrid 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

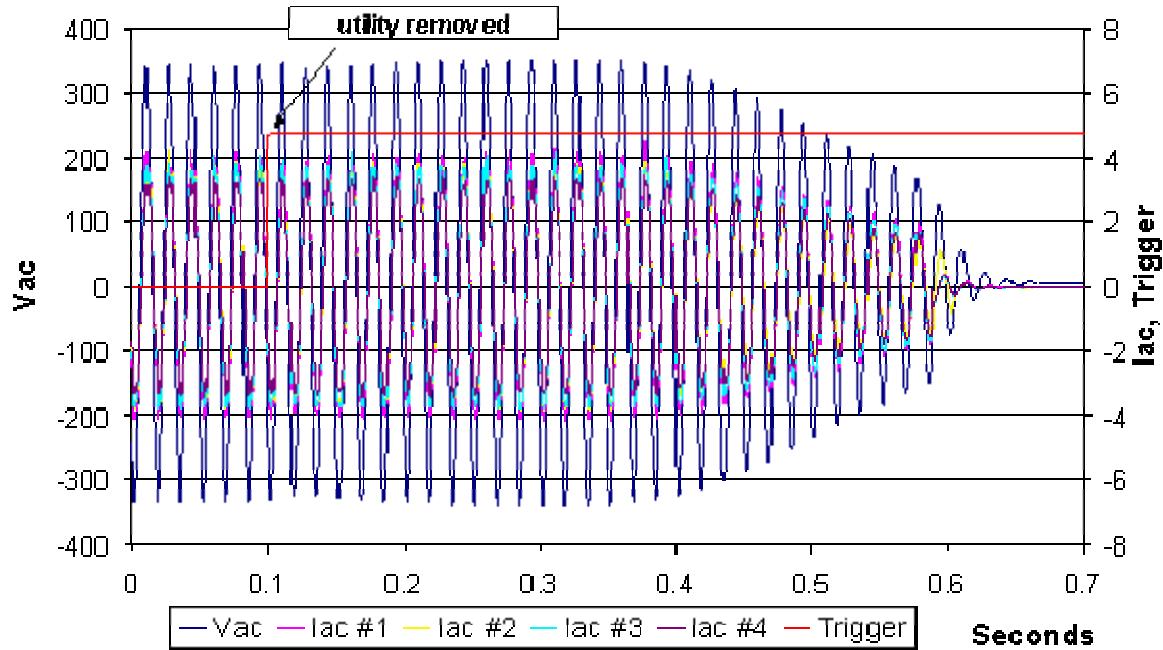
Preparations Underway For...

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

Multi-Inverter High-penetration islanding tests

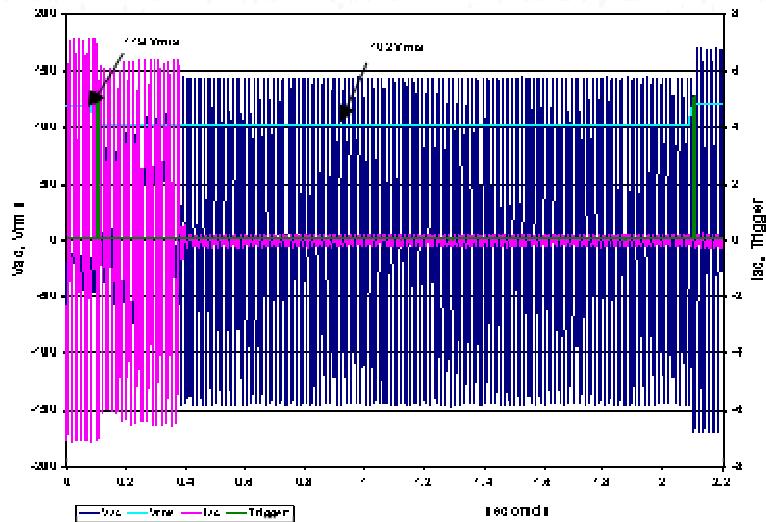


Example for
4 parallel
inverters

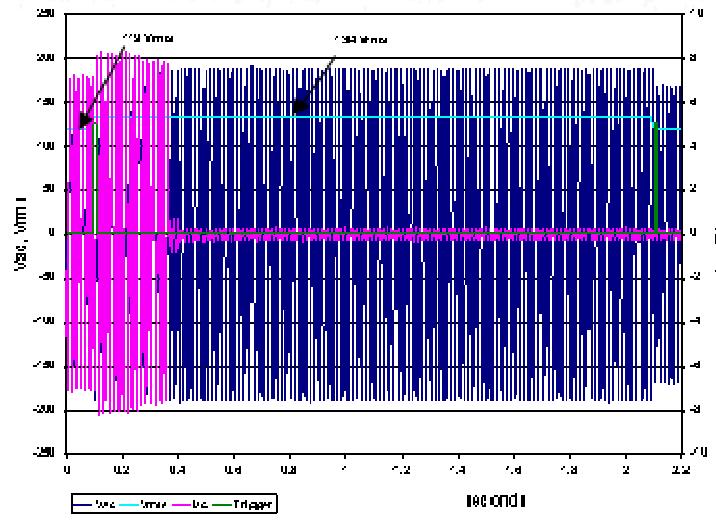


Voltage Sag/Surge Utility Compatibility Tests

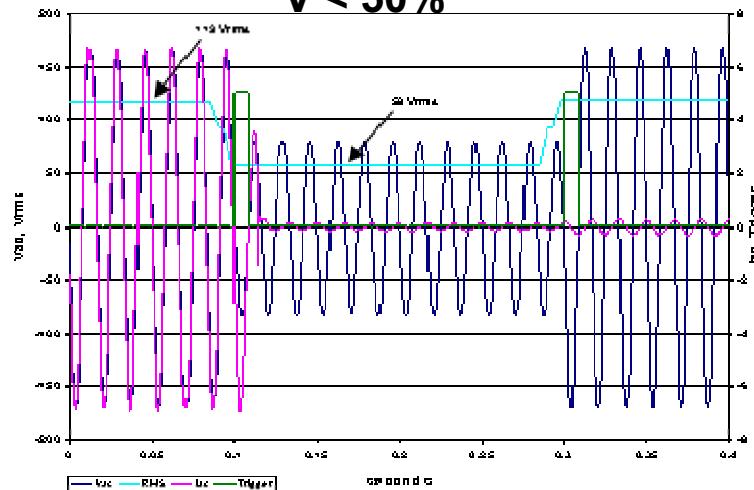
50% < V > 88%



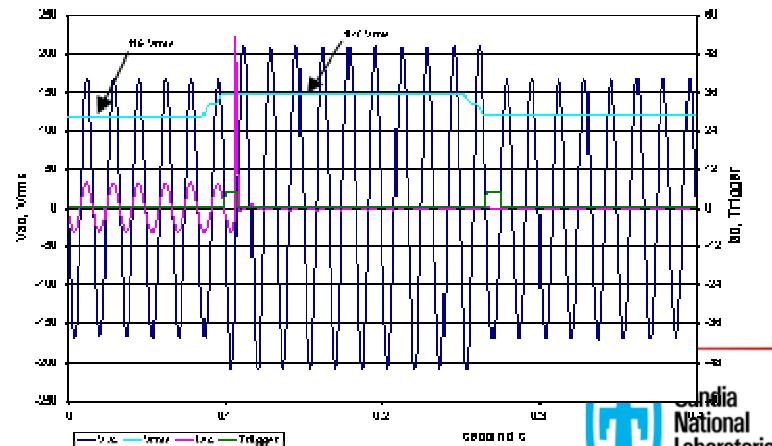
110% < V > 120%



$V < 50\%$

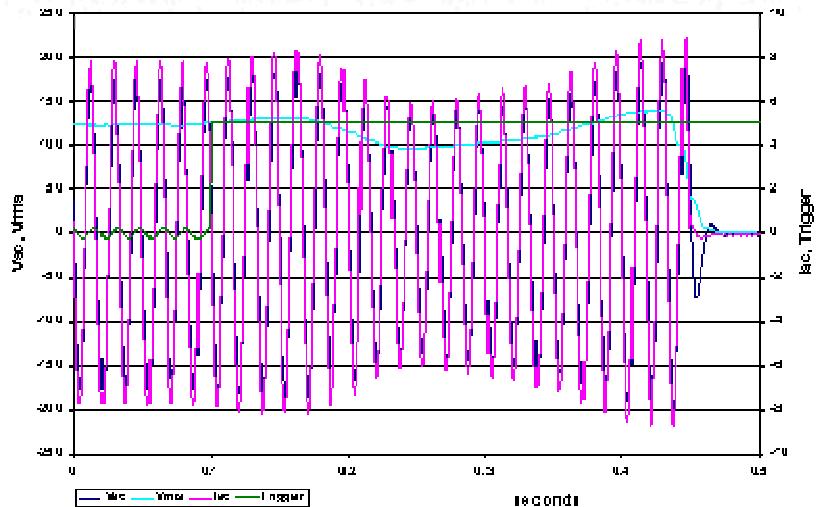


$V > 120\%$

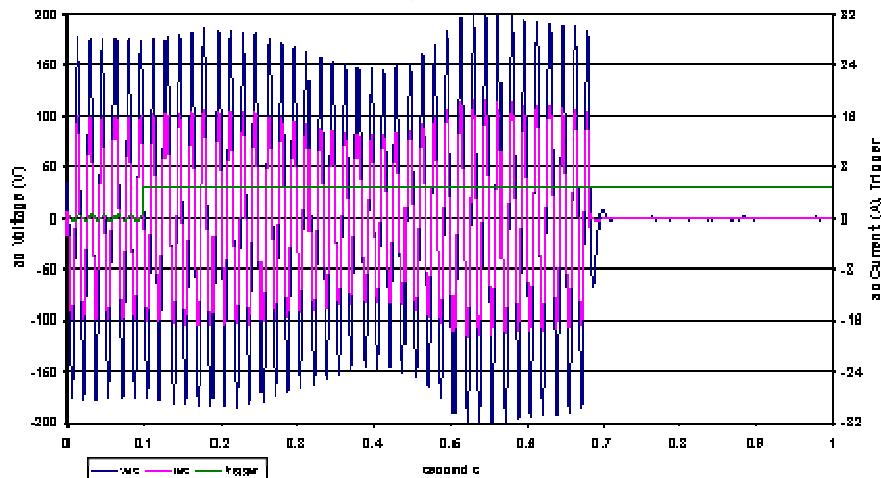


IEEE/UL RLC Anti-Islanding Tests

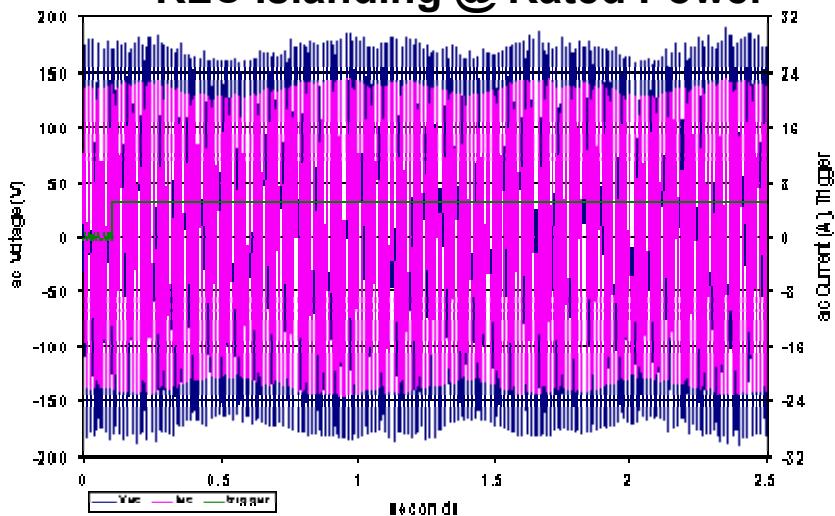
RLC Islanding @ 33% of Rated Power



RLC Islanding @ 66% of Rated Power



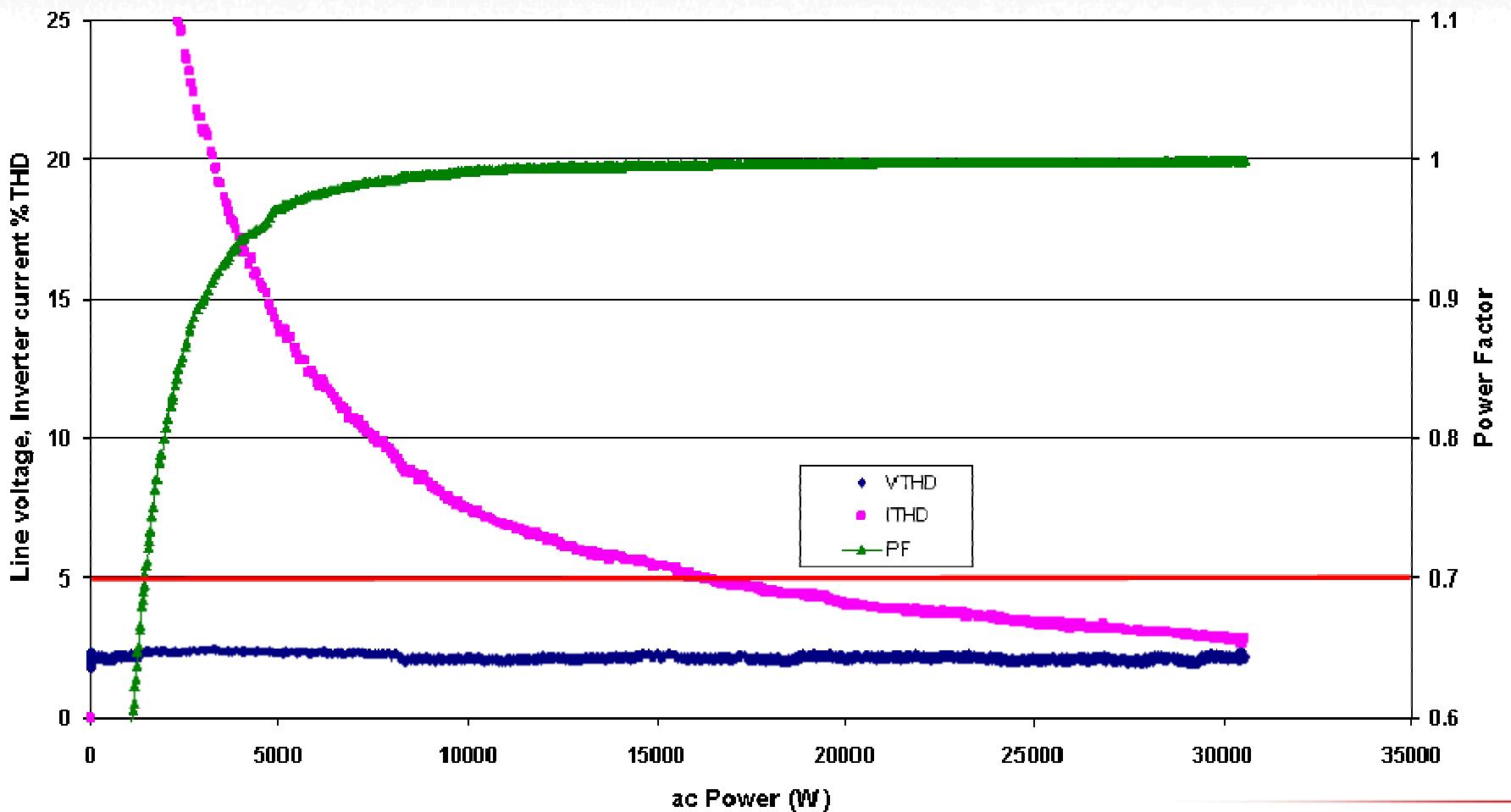
RLC Islanding @ Rated Power



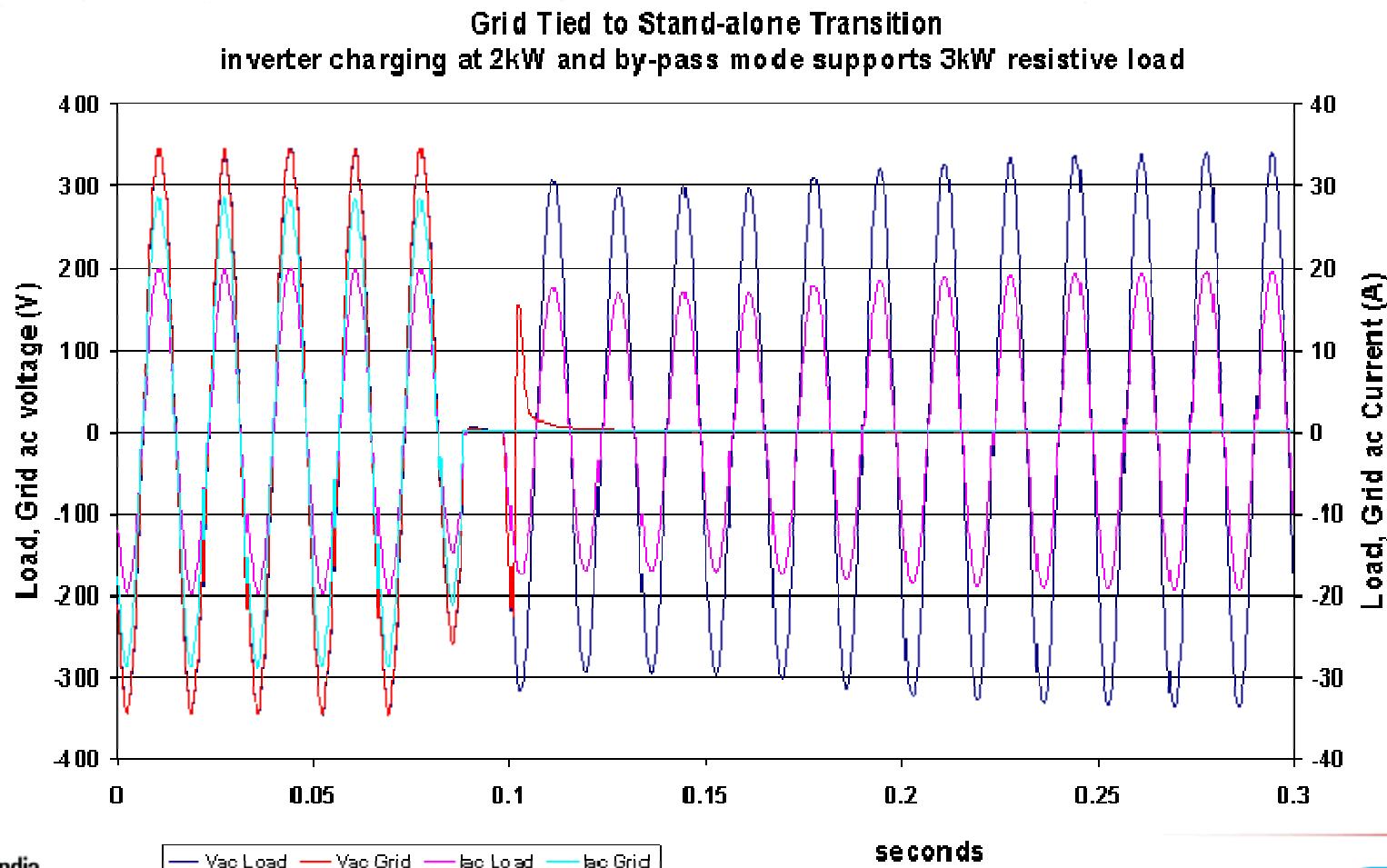
IEEE 1547/UL1741 test example

- 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

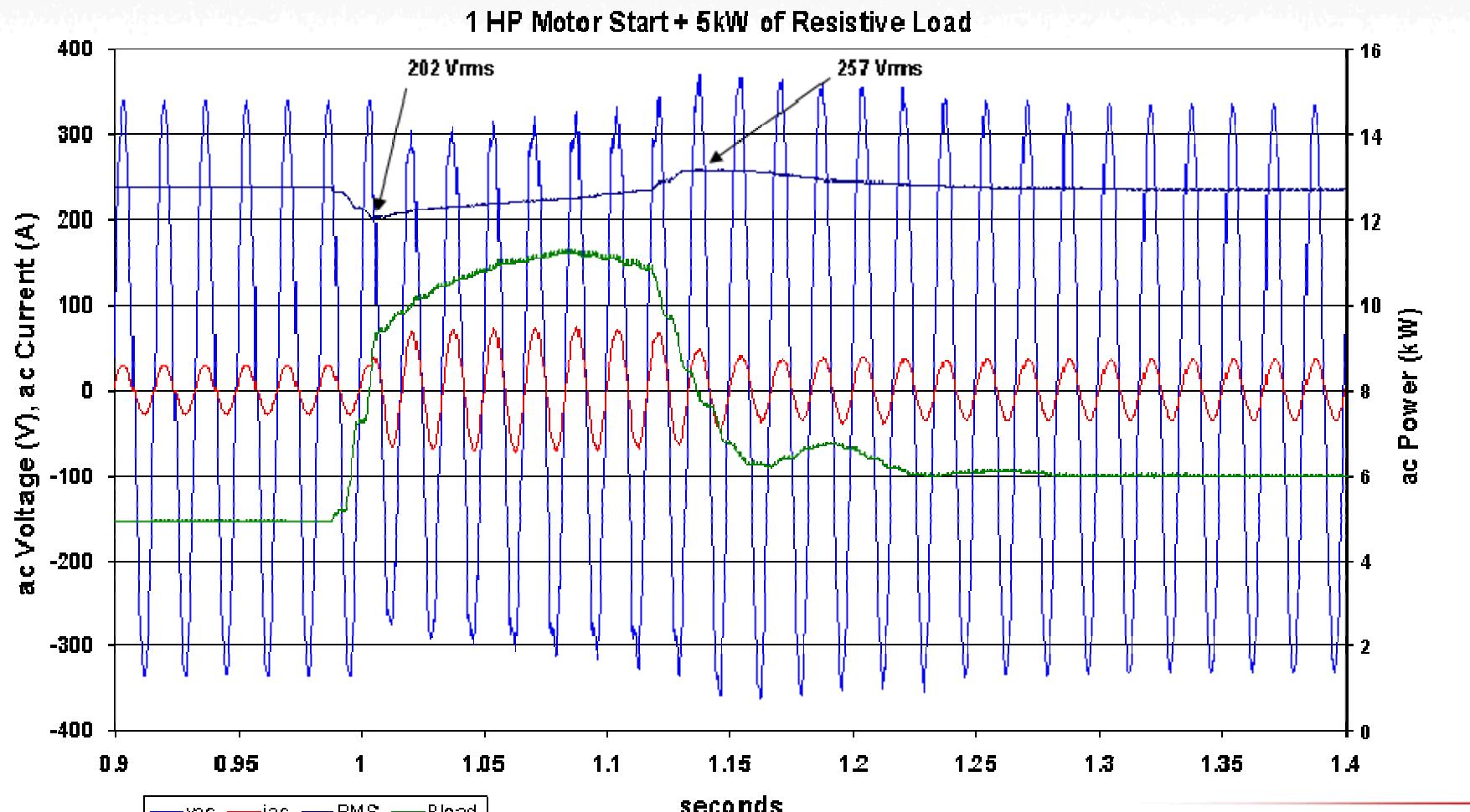
Grid-Tied Inverter Power Quality Evaluations



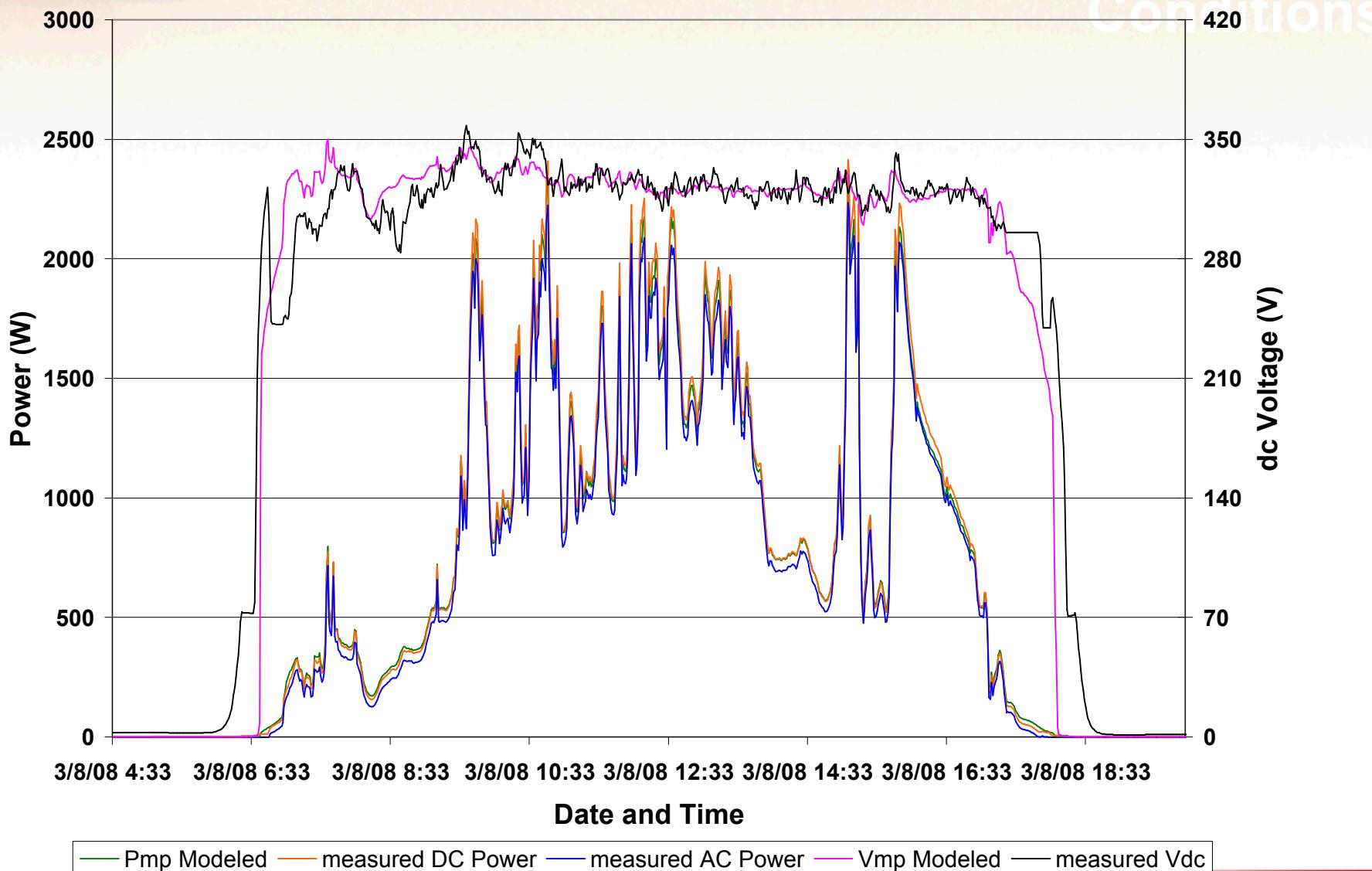
Grid-Tied to Stand-alone Transition



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



PV Dynamic Conditions



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)