Distributed Utility Integration Test (DUIT):

Facility and Unintentional Islanding Results

Distributed Utility Associates

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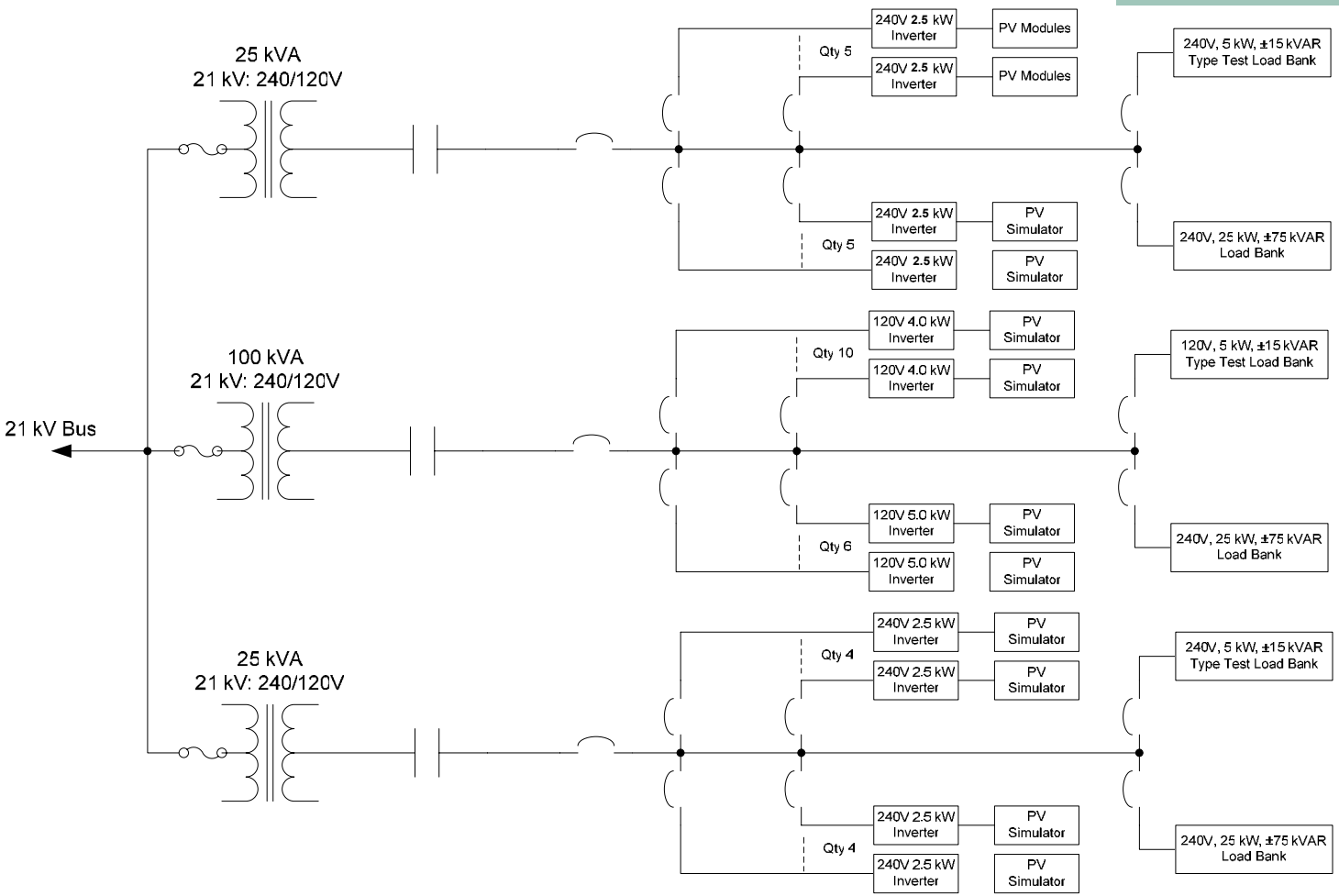
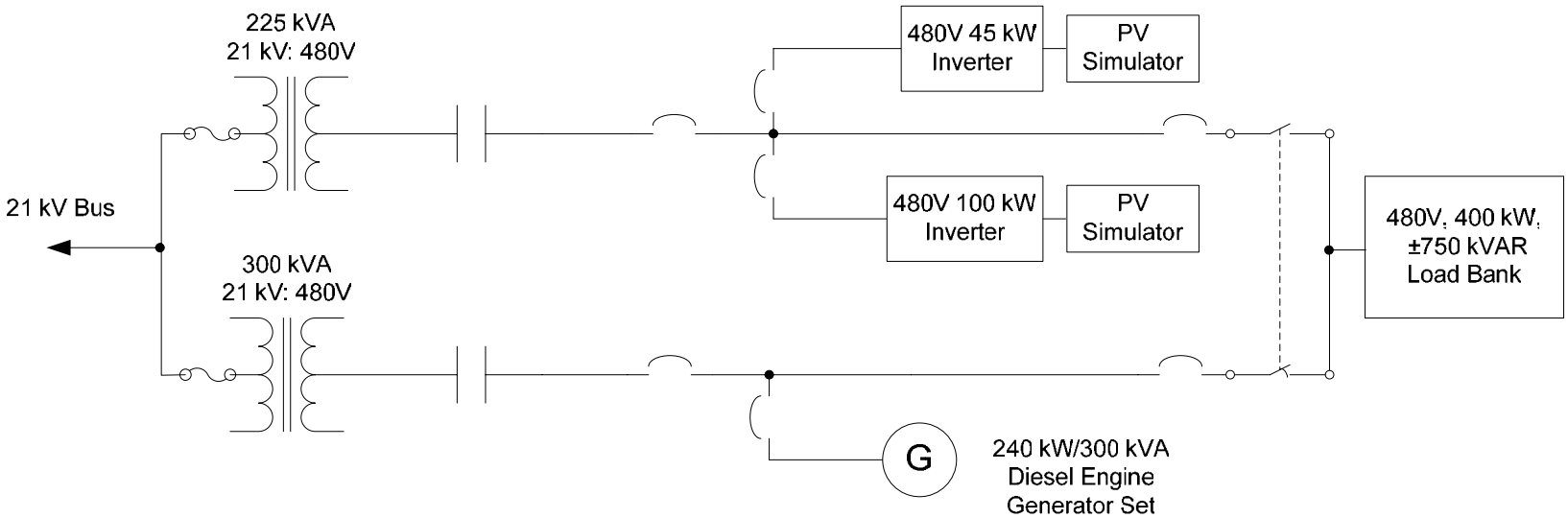
The DUIT Facility Overview

- Unique research facility for evaluating grid impacts of commercial-grade Distributed Resources (DR)
  - Islanding
  - Power Quality
  - Sectionalizing
  - Short Circuit Contribution
  - Stability
  - Voltage Regulation
  - Reclosing Coordination
  - Fuse Coordination
  - Capacitor Switching
  - Adjacent Feeder Faults
- Wide and growing range of both inverter-based and rotating machine-based technologies, all selected based on current and potential market impact
- Includes three classes of equipment (as of 6/04)
  - Residential (single-phase, ≤ 5 kW)
  - Commercial (three-phase, 30 kW to 250 kW)
  - Industrial (three-phase, ≥ 250 kW)

Single Line Diagram
Bay 1



Single Line Diagrams
Bay 2 and 3



The DUIT Facility
Bay 1 – Residential DR

- Distributed Resources
  - 2.5 kW, 240 VAC, 1-ph PV Inverters (10)
  - 4.0 kW, 120 VAC, 1-ph Battery-Based Inverters (10)
  - 2.5 kW, 240 VAC, 1-ph PV Inverters (8)
  - 5.0 kW, 120 VAC, 1-ph Battery-Based Inverters (6)
- Power Sources
  - 12.5 kW PV Array
  - Various power supplies rated from 60VDC to 600VDC at power ratings to 6 kW

- Load Banks
  - 120V & 240V “Type Test” load banks, 5 kW/±15 kVAR each, independent variac control on R, L and C
  - Three 25 kW/±75 kVAR load banks for multi-unit testing

The DUIT Facility
Bay 2 – Commercial DR

- Distributed Resources
  - 100 kW, 480V 3-ph PV Inverter
  - 45 kW, 480V 3-ph PV Inverter
- Power Sources
  - PV Simulator (Power Supply)
  - 300 to 600VDC, 2x300ADC
- Load Bank
  - 400 kW of resistive load, 750 kVAR each of inductive and capacitive load
  - Coarse control through discrete steps of R, L, C
  - Fine control through variacs on 25 kW of resistance, 25 kVAR of capacitance

The DUIT Facility
Bay 3 – Industrial DR

- Distributed Resource
  - 240 kW, 300 kVA, 480V 3-phase diesel engine-driven synchronous generator

- Load Bank
  - Shares 400 kW and ± 750 kVAR load with Bay 2

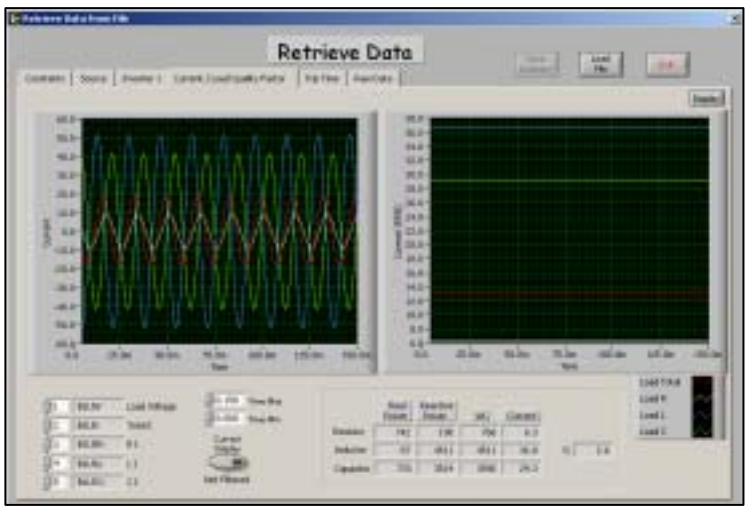
The DUIT Facility
Medium Voltage Distribution System

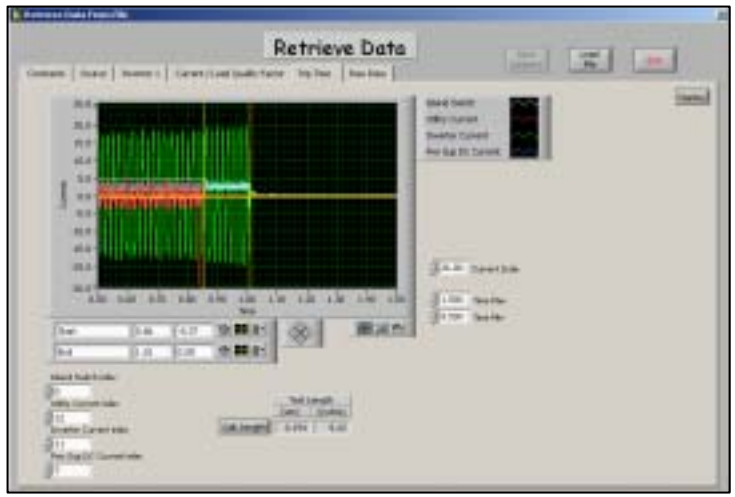
- Each bay tied into PG&E medium voltage distribution system via one or more pole-mount transformers

- 21 kV motor-operated load break switch allows for isolation of total DUIT facility from grid

The DUIT Facility
Data Acquisition and Control System

- National Instruments LabView™ based system
- 6 kHz sampled data collected for voltage and current at every relevant node in system for each test





Anti-Islanding Test Plan	Test Description and Sequence
6.1	*Basic Islanding Test* Individual unit testing
6.2	*Islanding with Multiple DRs* Homogeneous Groups Small Groups Progressions
6.3	*Non-Linear Loads, Anti-islanding Tests* Individual Units
6.4	*Islanding with Dynamic Load:Generation Ratios* Individual Units
6.5	*Anti-islanding with Rotating Loads* Individual Units
6.6	*Harmonic Content due to Anti-islanding Schemes* Individual Units
6.7	*Voltage/Frequency Trip Settings* Individual Units Homogeneous Groups Small Groups Progressions

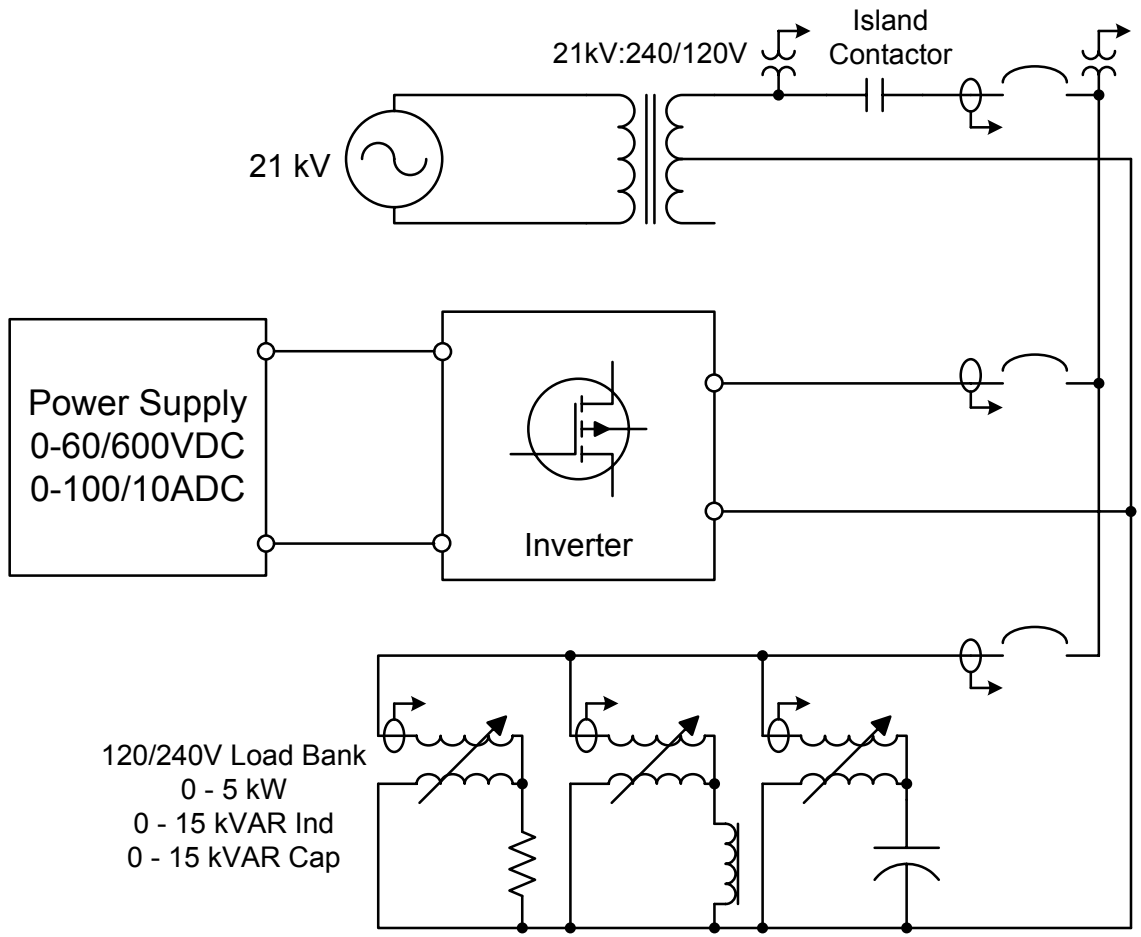
Single Unit Islanding Test Procedure

- "Basic" anti-islanding tests (DUIT Test Protocol 6.1) performed on a single unit for each DR model (two single units for single phase inverters)
- IEEE 1547/UL 1741/CA Rule 21 procedures
- Main purposes:
  - "Ring out" test setup and data acquisition in preparation for multi-unit islanding tests
  - Ensure test setup produces consistent results from unit to unit
  - Gain an understanding of manufacturers' anti-islanding methods to select appropriate combinations for multi-unit testing

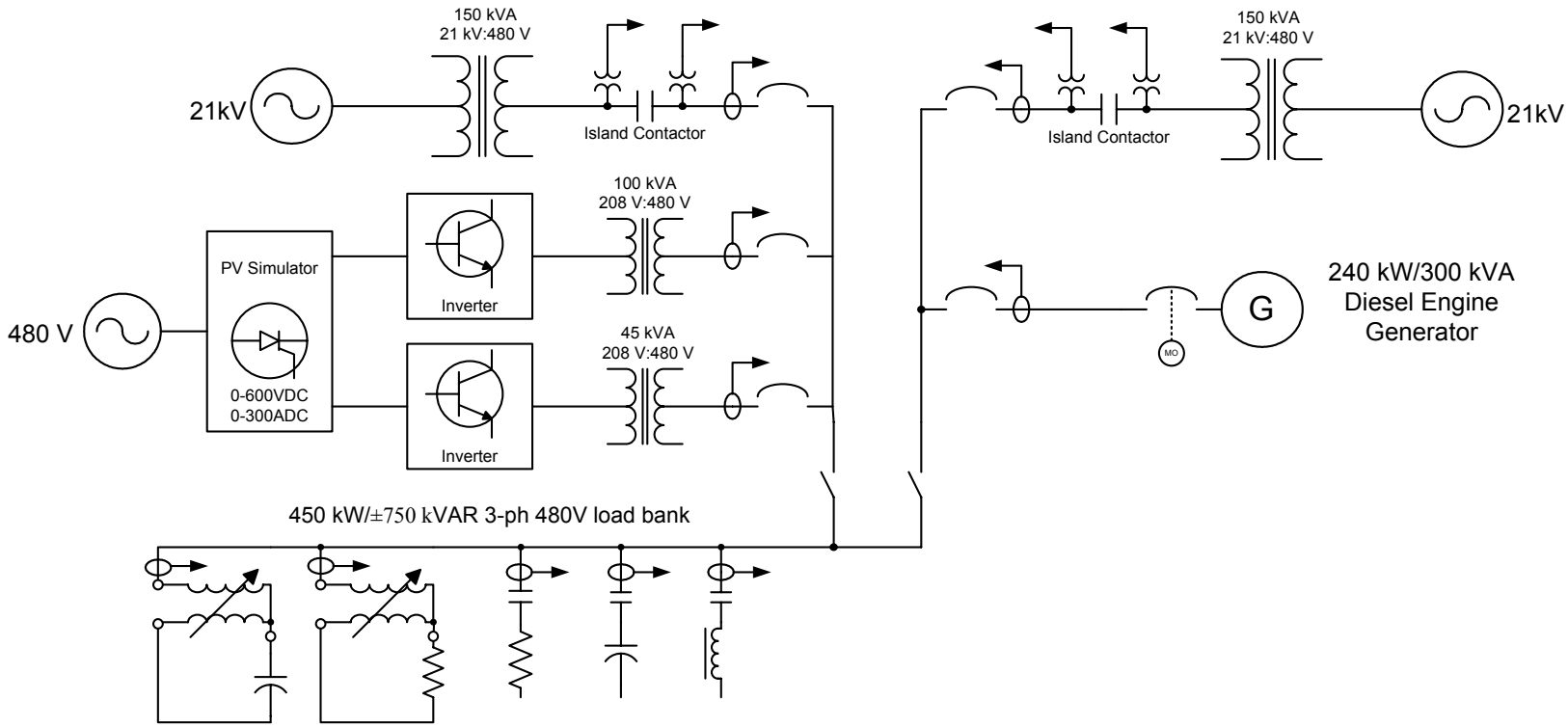
Single Unit Islanding Test Procedure

- Measure DR shutdown times under three generation/ load conditions
  - P_{gen} = 25%, P_{load} = 25%
  - P_{gen} = 50%, P_{load} = 50%
  - P_{gen} = 100%, P_{load} = 100%
- In each case, inductive and capacitive loads are adjusted to resonant frequency of 60 Hz with quality factor (Q) of 2.5 for first test
- L or C is adjusted in steps of 1% between -5% and +5% of nominal value used in first test
- Results in a total of 33 tests per DR

Single Phase Test Setup



Three Phase Test Setup



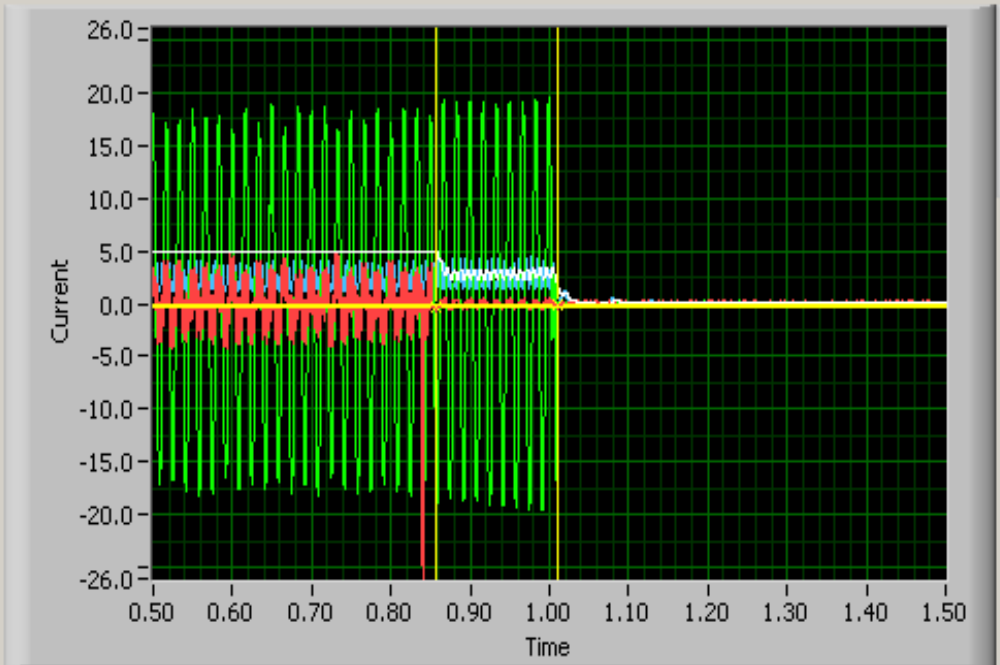
Retrieve Data From File

Retrieve Data

Save summary | Load File | Exit

Constants | Source | Inverter 1 | Current / Load Quality Factor | Trip Time | Raw Data

Display



Island Switch
Utility Current
Inverter Current
Pwr Sup DC Current

Start 0.86 -0.37

End 1.01 0.00

26.00 Current Scale

1.500 Time Max

0.500 Time Min

Island Switch index
0

Utility Current index
12

Inverter Current index
11

Pwr Sup DC Current index
7

Test Length

	(sec)	(cycles)
Calc Length	0.154	9.22

Single Unit Islanding Test Results Bay 2, Initial Testing

Device	Mean Trip Time	Median Trip Time	Standard Deviation	Trip Times > 2 seconds	Longest Trip Time
Device E	0.12 s	0.10 s	0.05 s	0 of 33	0.39 s
Device F	0.26 s	0.20 s	0.23 s	0 of 33	1.16 s

Single Unit Islanding Test Results Bay 3, Initial Testing

Device	Mean Trip Time	Median Trip Time	Standard Deviation	Trip Times > 2 seconds	Longest Trip Time
Device G*	**1.27 s**	**0.99 s**	**0.66 s**	**5 of 40**	**3.33 s**

* This device includes external anti-islanding controls that have not yet been NRTL-certified to UL.

Single Unit Islanding Test Results Bay 1, Initial Testing

Device	Mean Trip Time	Median Trip Time	Standard Deviation	Trip Times > 2 seconds	Longest Trip Time
A	0.34 s	0.34s	0.08 s	0 of 66	0.55 s
B	0.27 s	0.09 s	0.48 s	1 of 66	3.31 s
C	0.14 s	0.06 s	0.23 s	0 of 66	1.16 s
D	0.20 s	0.08 s	0.35 s	1 of 66	2.22 s

Single Unit Islanding Test Results Bay 1, Supplementary Testing

- Device B
  - Longest run-on in initial testing occurred at rated power; inverter operating in power limiting mode
  - Supplemental testing with device at power limit and DC input voltage near minimum of operating range resulted in some trip times exceeding 10 seconds with well-tuned load
- Device C
  - When power levels were decreased from 27% to 24% of device rating, run-ons in excess of 30 seconds were observed.
- Device D
  - Power limiting in initial testing achieved through changing inverter setpoints, consistent with UL methods
  - Supplemental testing performed by lowering input voltage to effect DC current limiting for achieving partial load points; some run-on times in excess of 30 seconds were observed with well-tuned load

Single Unit Islanding Test Results Resulting Follow-On Actions

- Recommended revisions to UL1741:
  - 1) Manufacturer to provide details of anti-islanding algorithm, *or* 2) device to be subjected to islanding tests in center and limits of input voltage window
  - 5% load (quadruples # of test points)
  - More explicit language regarding:
    - Definition of balanced test conditions
    - Test load linearity
    - Tolerances on pre-test voltage and frequency
    - Accounting for parasitic losses (real and reactive)

Anti-Islanding Test Plan	Test Description and Sequence
6.1	*Basic Islanding Test* Individual unit testing Done
6.2	*Islanding with Multiple DRs* Homogeneous Groups Small Groups Progressions In Progress
6.3	*Non-Linear Loads, Anti-islanding Tests* Individual Units
6.4	*Islanding with Dynamic Load:Generation Ratios* Individual Units
6.5	*Anti-islanding with Rotating Loads* Individual Units
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Distribution System Impact Study

Initial study performed to look at the probability of necessary conditions for an islanding event to occur

I Static P, Q balance	**0.001 to 0.01 per event (High penetration)** **1E-10 to 1E-8 per event (Low penetration)**
II Resonant Frequency	**1E-5 to 1E-2 per year**
III Fault events	**0.15 to 0.3 per year**
IV Time domain stability	**0.1 per year**

All conditions are statistically independent
High penetration: 1.5E-10 to 3E-6 islands per feeder per year
Low penetration:1.5E-17 to 3E-12 islands per feeder per year

Note: Study assumes over/under voltage and frequency protection only, i.e. no active anti-islanding schemes