Interconnection Testing and Applications

Ben Kroposki
Senior Engineer
National Renewable Energy Laboratory

Presented at the 2004 Power Engineering Society General Meeting
Special Technical Session

Presentation Outline

- IEEE 1574.1 Interconnection Tests
- NREL Test Facilities
- Test Procedure Validation
- Applications

IEEE 1547 Series

IEEE 1547-2003 - Standard for Interconnecting Distributed Resources with Electric Power Systems

This standard covers technical and testing requirements

IEEE 1547.1 – Draft Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems

This standard has detailed test procedures for meeting the requirements in IEEE 1547

IEEE 1547
Technical Requirements

- General Requirements
  - Voltage Regulation
  - Integration with Area EPS Grounding
  - Synchronization
  - Secondary and Spot Networks
  - •Inadvertent Energizing of the Area EPS
  - •Monitoring
  - •Isolation Device
- Response to Area EPS Abnormal Conditions
  - Voltage Disturbances
  - Frequency Disturbances
  - Disconnection for Faults
  - •Loss of Synchronism
  - •Feeder Reclosing Coordination
- Power Quality
  - Limitation of DC Injection
  - Limitation of Voltage Flicker
  - Induced by the DR
  - •Immunity Protection
  - •Harmonics
  - •Surge Capability
- Islanding

IEEE 1547.1 Interconnection Tests

Scope

This standard specifies the Type, Production, and Commissioning tests that shall be performed to demonstrate that the interconnection functions and equipment of the DR conform to IEEE Std. 1547.

Purpose

Interconnection equipment that connects DR to an EPS must meet the requirements specified in IEEE 1547. Standardized test procedures are necessary to establish and verify compliance with those requirements. These test procedures must provide both repeatable results, independent of test location, and flexibility to accommodate the variety of DR technologies.

Current Schedule

- **Draft 4.1 Issued for comments back by May 14**
- **Next Working Group Meeting August 3-4**
- **Plan to ballot Draft Standard in December 2004**

IEEE 1547.1 Interconnection Tests

5.0 Type (Design) Tests

- 5.1 Temperature Stability

  This test verifies that the interconnection equipment maintains measurement accuracy of parameters over its specified temperature range.

- 5.2 Response to Abnormal Voltage

  This test verifies that DR interconnection component or system ceases to energize the Area EPS as specified in IEEE 1547 with respect to overvoltage conditions. This test determines the magnitude and trip time for each overvoltage function.

- 5.3 Response to Abnormal Frequency

  Same as Voltage except for abnormal frequency

- 5.4 Synchronization

  This test demonstrates the interconnection equipment will accurately and reliably synchronize to the Area EPS according the requirements of IEEE 1547. Two basic test methods are provided: Method 1 verifies that a synchronization control function will cause the paralleling device to close only when key synchronization parameters are within allowable limits; Method 2 determines the magnitude of the synchronization startup current.

IEEE 1547.1 Interconnection Tests

5.0 Type (Design) Tests

- 5.5 Interconnection Integrity

  These tests includes 1) Protection From Electromagnetic Interference (EMI), 2) Surge Withstand Performance, and a 3) dielectric test on the paralleling device. These tests are based on protocol in IEEE C37.90.1, C37.90.2, C62.41.2, and C62.45.

- 5.6 DC injection

  This test verifies that an inverter-based DR system complies with the DC current injection limit specified in of IEEE 1547.

- 5.7 Unintentional Islanding

  This test provides a means to determine that a DR or its interconnection system will cease to energize the connection with the Area EPS when an unintentional island condition is present. This test is currently based on matching the DR output to a resonant load.

- 5.8 Reverse Power

  Since one of the ways in which DR often meet the unintentional islanding requirement is to use a reverse or minimum power relay, this test is performed to characterize the accuracy of the reverse-power protection magnitude setting(s) of the interconnection equipment.

IEEE 1547.1 Interconnection Tests

5.0 Type (Design) Tests

- 5.9 Cease to Energize Functionality and Loss of Phase

  This test verifies that DR interconnection system ceases to energize the Area EPS as specified in IEEE 1547 with respect to individual open phase conditions.

- 5.10 Reconnect Time

  This test verifies the functionality of the DR interconnection component or system reconnect timer, which delays the DR reconnection to the Area EPS following a trip event.

- 5.11 Harmonics

  This test measures the individual current harmonics and total demand distortion (TDD) of the DR interconnection component or system under normal operating conditions and see that they are within the limits of IEEE 1547.

- 5.12 Flicker

  No specific type test procedures since flicker is site dependent

IEEE 1547.1 Interconnection Tests

6 - Production Tests

Production tests verify the operability of every unit of interconnect equipment manufactured for customer use.

- Response to Abnormal Voltage
- Response to Abnormal Frequency
- Synchronization

7 - Commissioning Tests

Commissioning tests are conducted after the interconnection system is installed and is ready for operation.

- Verification and Inspections
- Field Conducted type and Production Tests

IEEE 1547.1 Interconnection Tests incorporated into UL 1741 for product pre-certification

NREL Interconnection Pre-Certification Approach

IEEE 1547

Interconnection System Requirements

- Voltage Regulation
- Grounding
- Disconnects
- Monitoring
- Islanding

IEEE 1547.1

- **Interconnection System Testing**
- O/U Voltage
- and Frequency
- Synchronization
- EMI
- Surge Withstand
- DC injection
- Harmonics
- Islanding
- Reconnection

UL 1741

Interconnection Equipment

- Construction
- Protection against risks of injury to persons
- Rating, Marking
- Specific DR Tests for various technologies

NREL DER Test Facility

NREL Testing Capabilities

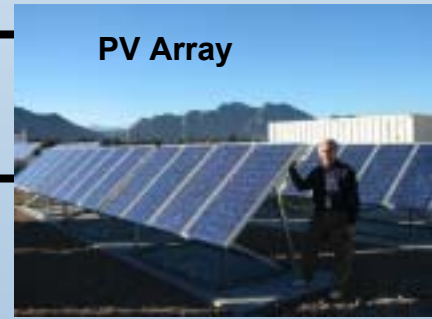
3 AC Buses

Utility Grid

Wind Turbines

3 DC
Buses

Electrolyzer



NREL Testing Capabilities

DC Bus – Allows up to 10 DC device (Battery, PV) connections

AC Bus (3Phase, 480V, 400A rated) – Allows up to 15 AC device (inverters, microturbine, generators) connections

Switch Panel – Computer controlled. Allows tester to easily configure systems. Ability to run 3 independent systems simultaneously.

Interconnection Testing

Distributed Energy Resources


Fuel Cell


PV


Microturbine


Wind


Energy Storage


Generator

Interconnection Technologies

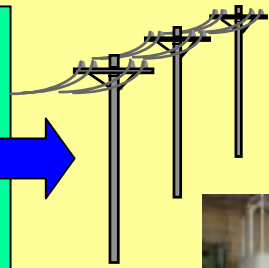

Inverter

Functions

- Power Conversion
- Power Conditioning (PQ)
- Protection
- DER and Load Control
- Ancillary Services
- Communications
- Metering


Switchgear, Relays, & Controls

Electric Power Systems


Utility Grid


Utility Grid Simulator
Micro Grids

Loads

Local Loads

Load Simulators

Interconnection Equipment

GE Universal Interconnection Technology (UIT)

ASCO – Soft-Load Transfer Switch

Validation of IEEE P1547 Interconnection Standard Tests

- Over/Under Voltage and Frequency Response
- Unintentional islanding test

Test Results – System Configuration

200kW Grid Simulator

Transfer Switch

Onan 125kW Generator

Programmable Load Banks

Test Results – IEEE 1547 Response Times

Response to Abnormal Voltage

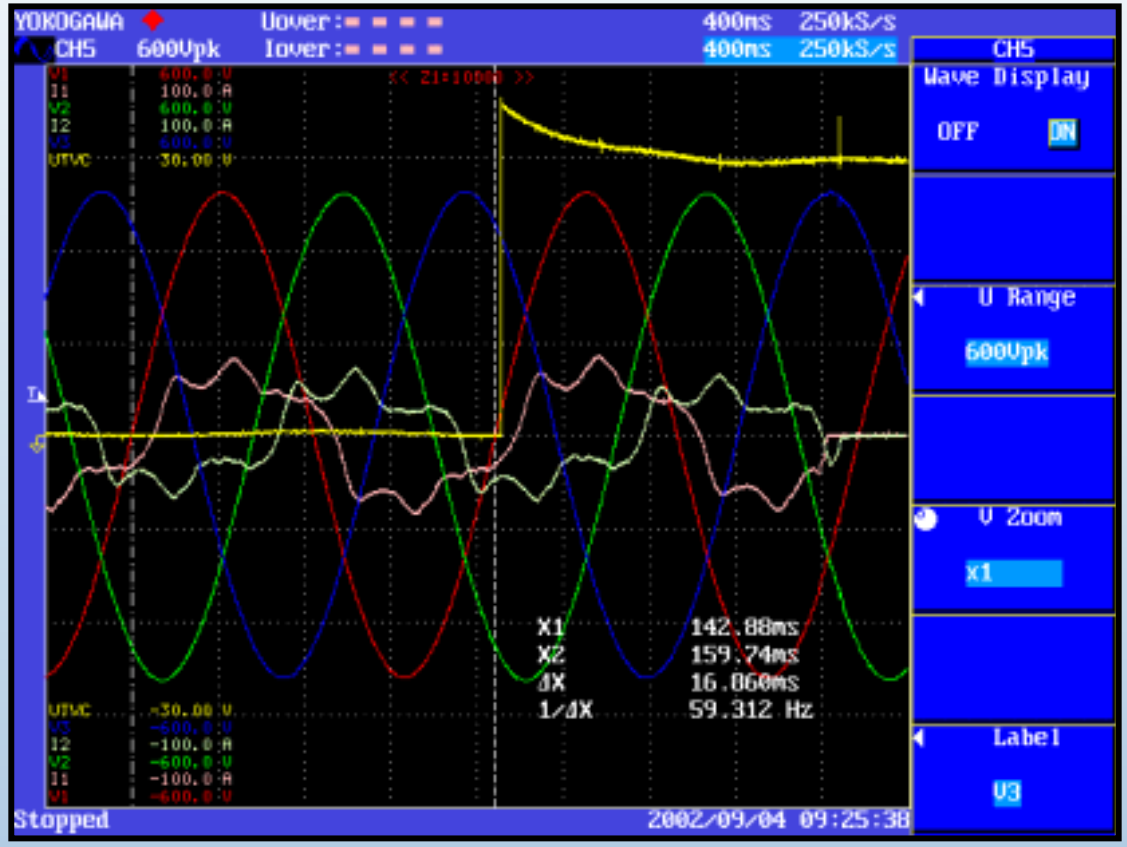
Voltage Range (Based on 480 V)	Clearing Time (s)
V<240	0.16
240≤V<422.4	2
528<V<576	1
V≥576	0.16

Response to Abnormal Frequency

DR SIZE	Frequency Range (Hz)	Clearing Time (s)
≤30 kW	>60.5	0.16
	<59.3	0.16
>30 kW	>60.5	0.16
	<{59.8–57.0} (adjustable setpoint)	Adjustable 0.16–300
	<57.0	0.16

Test Results

- Testing Results from ASCO SLTS – Underfrequency Magnitude Test



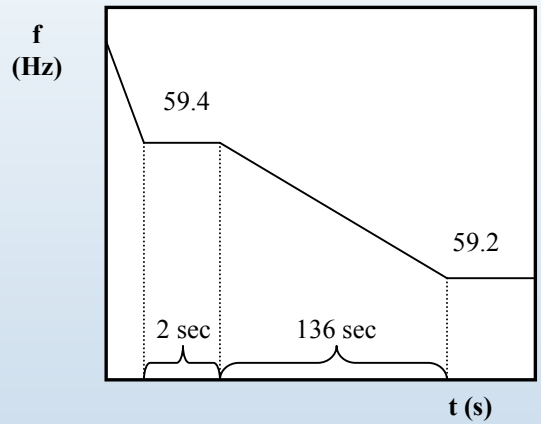
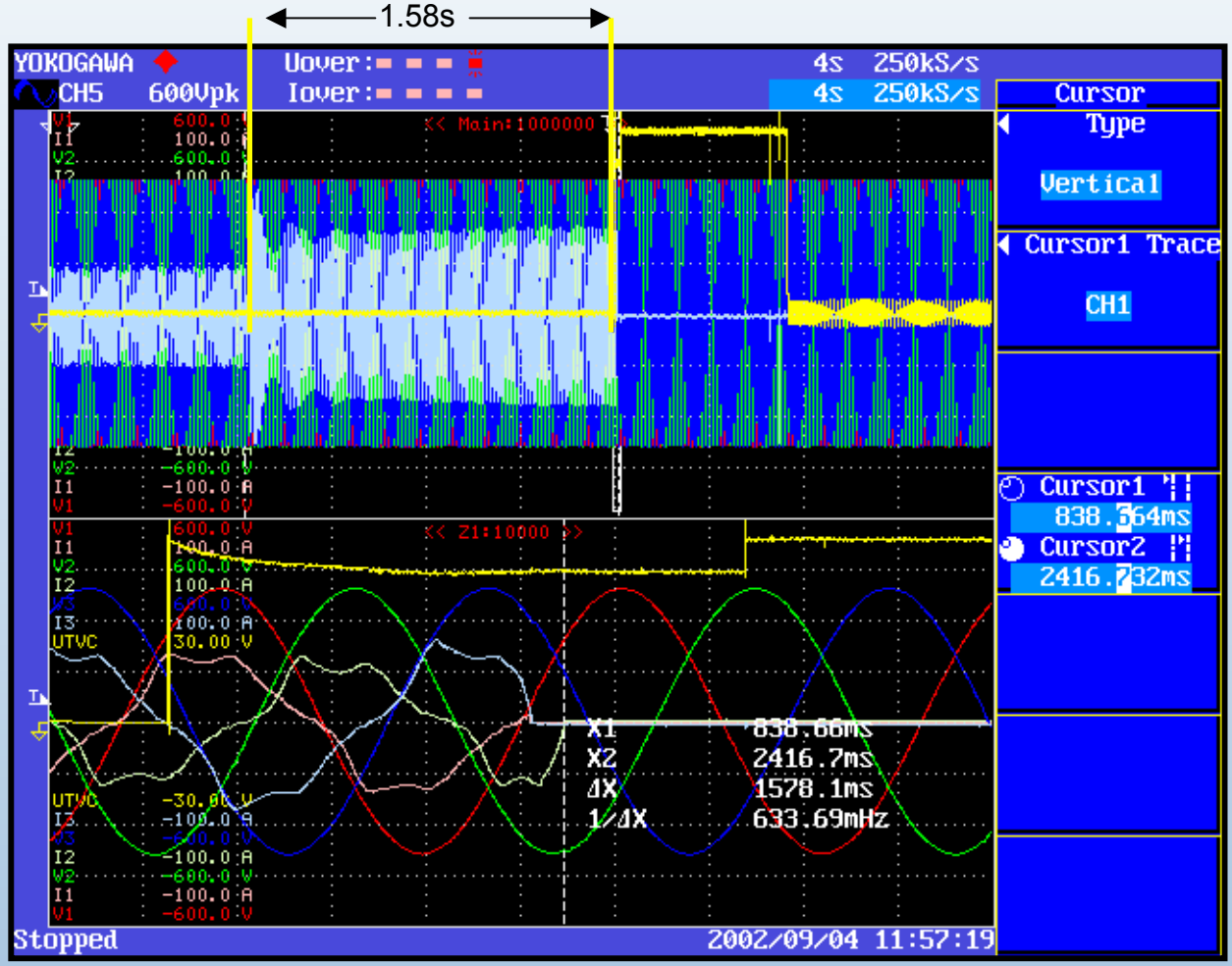


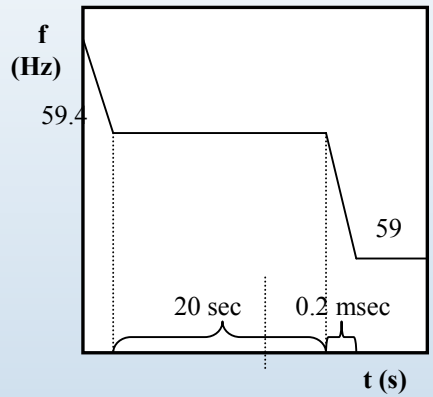
Table 1. Underfrequency Magnitude

Underfrequency Magnitude	
Trial Number	Trip Frequency
1	59.301
2	59.311
3	59.298
4	59.312
5	59.284
Average	**59.301**
Setting	**59.3**

Testing Results

- Testing Results from ASCO SLTS – Underfrequency Time Test



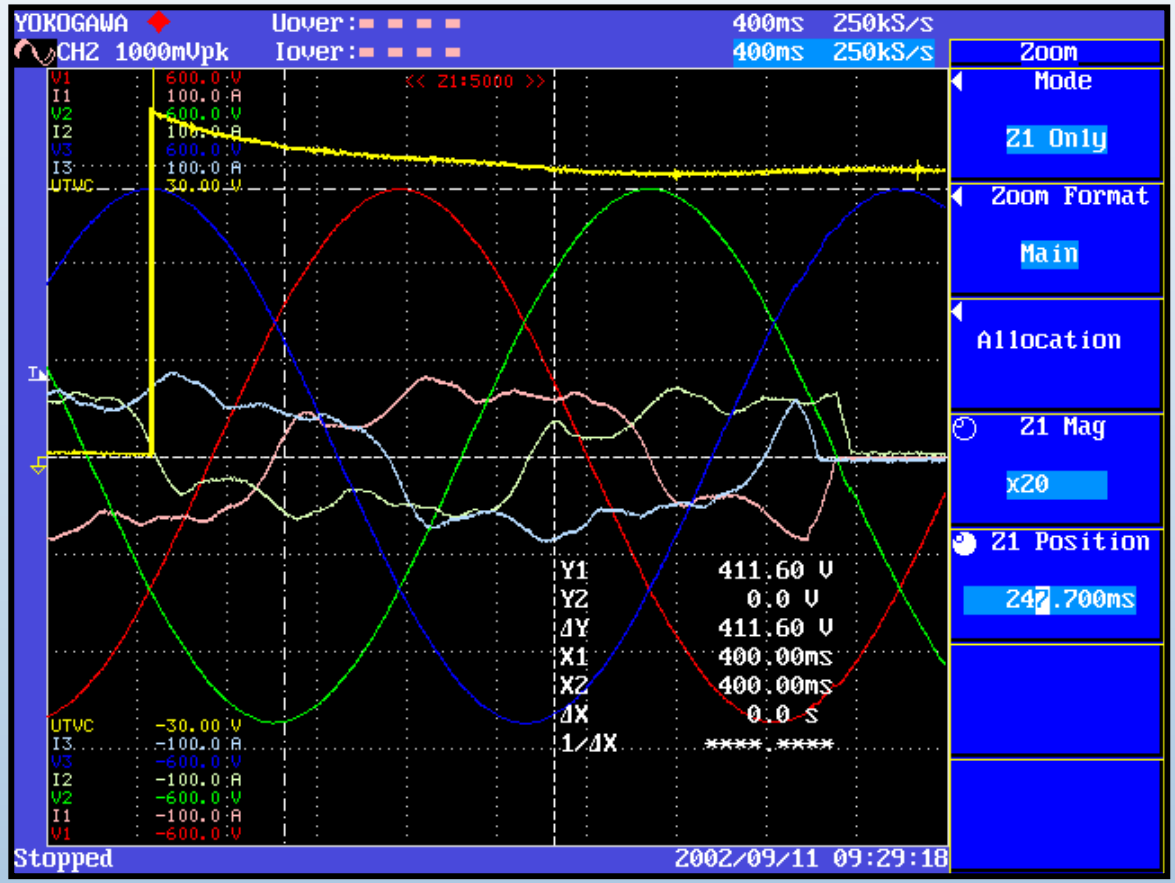


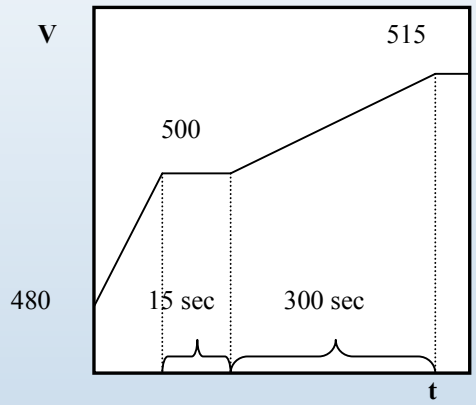
Underfrequency Time

Underfrequency Time	
Trial Number	Trip Time (s)
1	1.58
2	1.48
3	1.58
4	1.57
5	1.54
Average	**1.55**
Required	**1.70**

Test Results

- Testing Results from ASCO SLTS – Overvoltage Magnitude Test



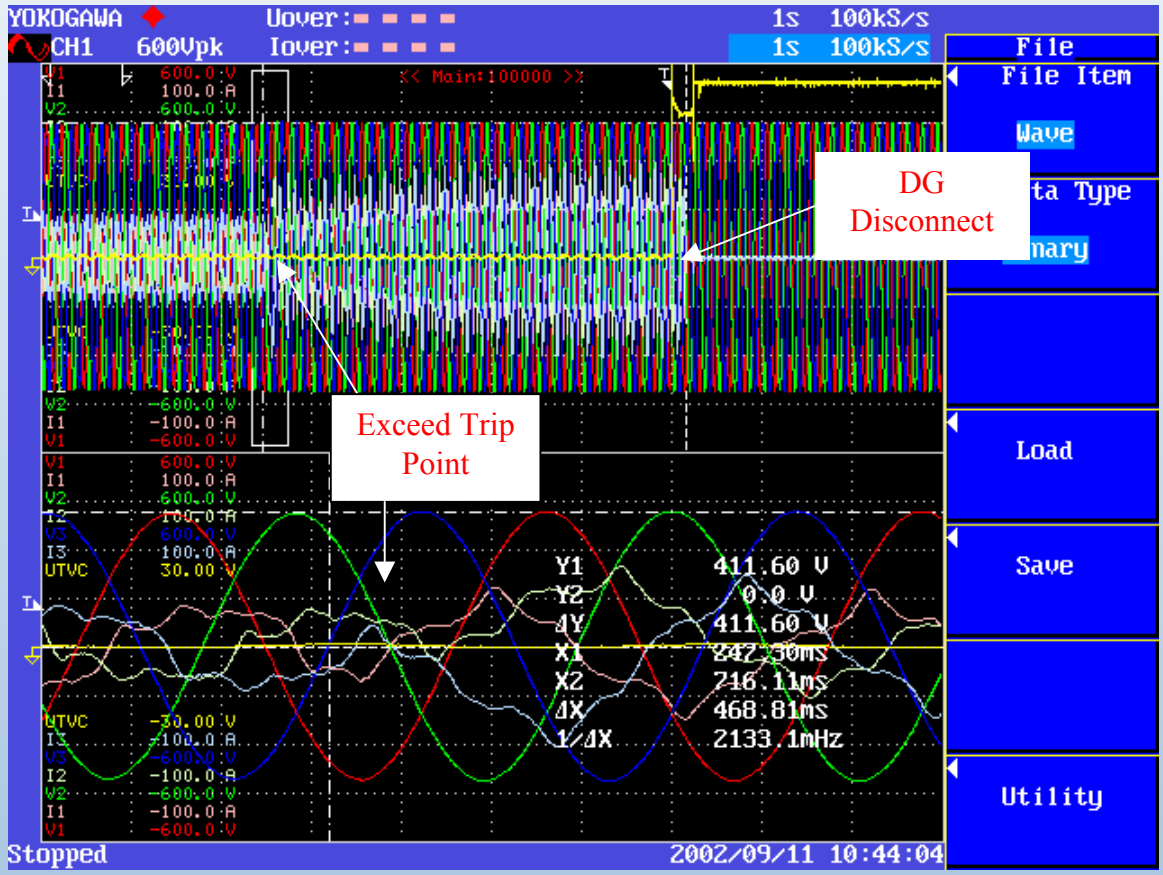


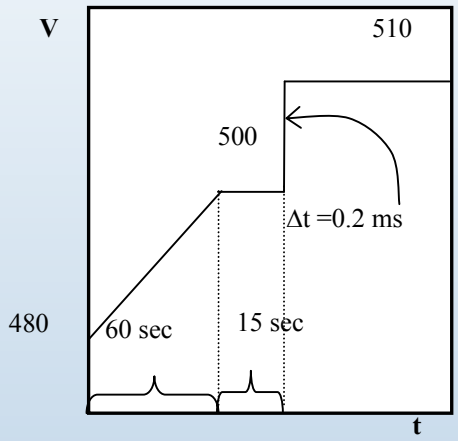
Overvoltage Magnitude

Overvoltage Magnitude	
Trial Number	Trip Voltage
1	504.300
2	502.500
3	504.700
4	504.600
5	504.150
Average	**504.050**
Setting	**504.0**

Test Results

- Testing Results from ASCO SLTS – Overvoltage Time Test



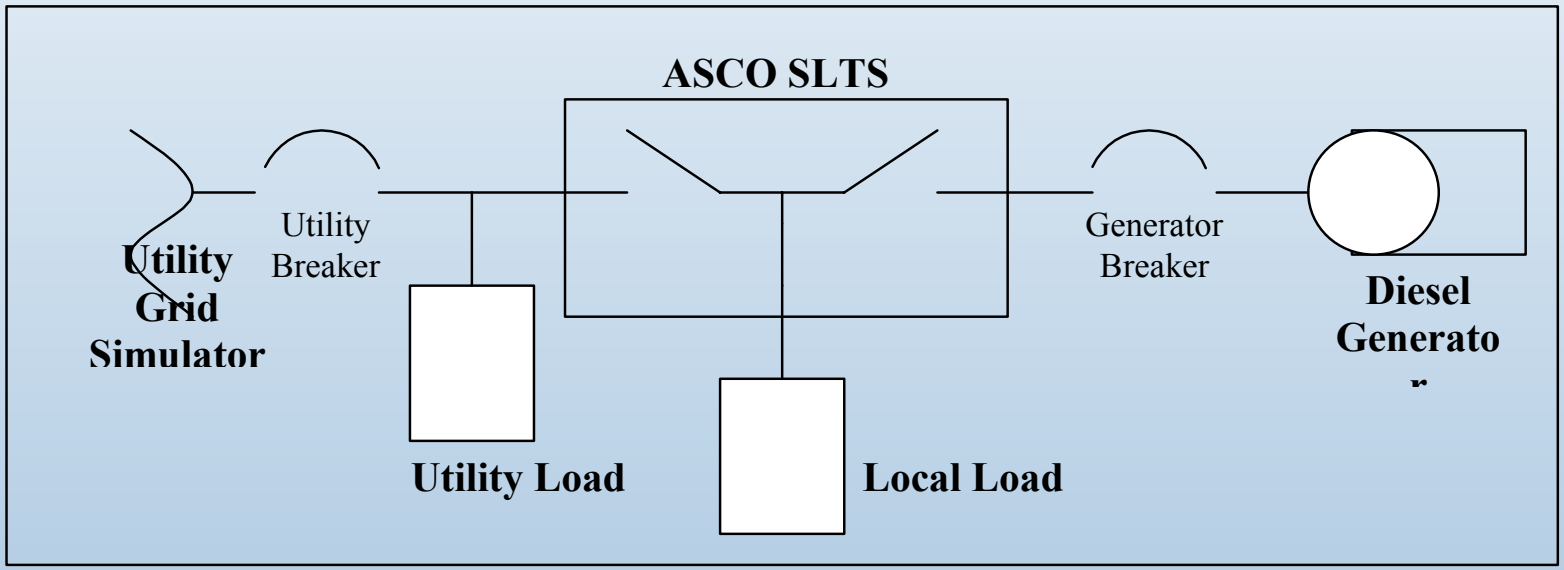


Overvoltage Time

Overvoltage Time	
Trial Number	Trip Time (s)
1	0.436
2	0.428
3	0.378
4	0.396
5	0.468
Average	**0.421**
Required	**1.00**

Test Results

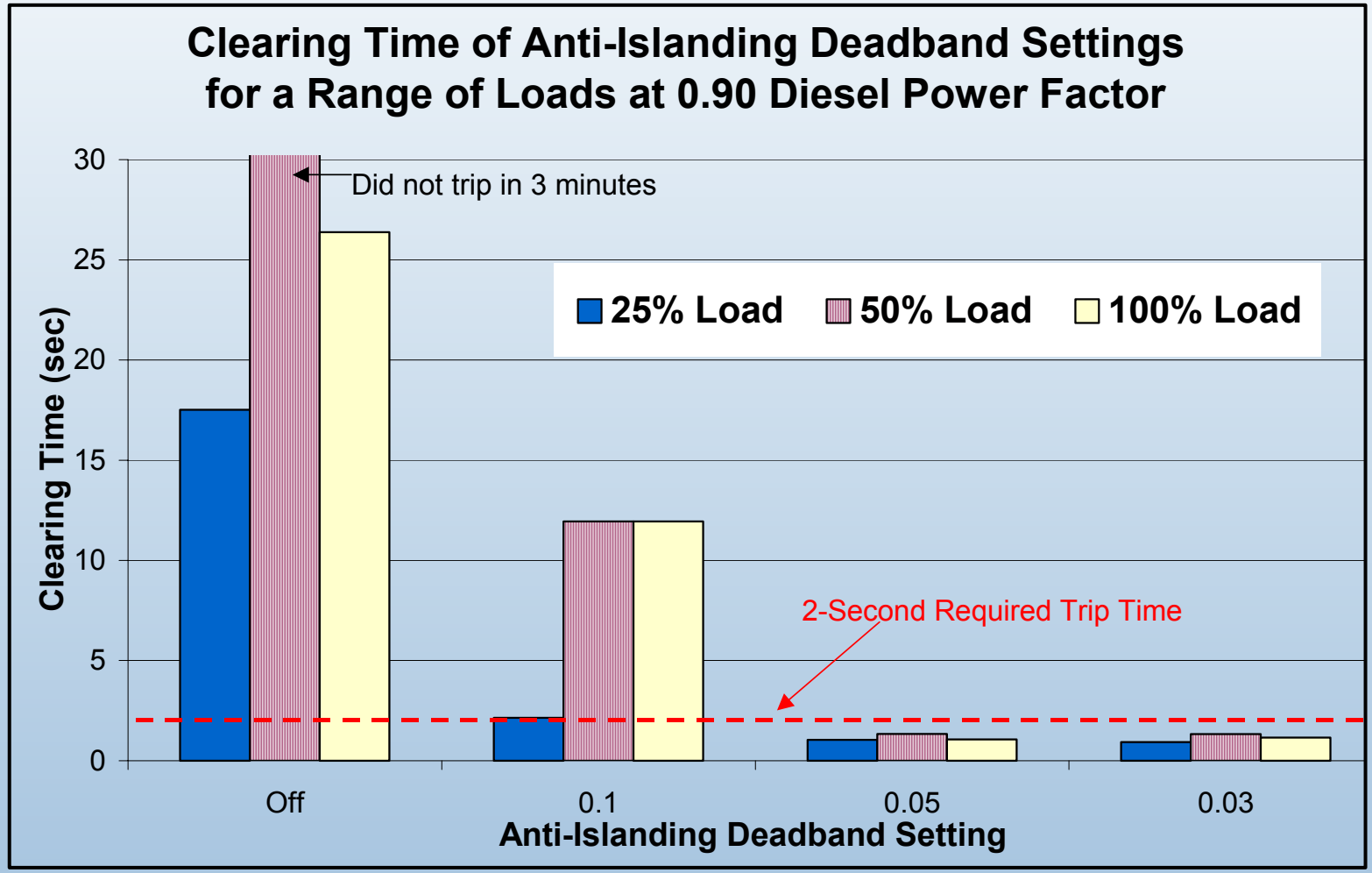
- Testing Results from ASCO SLTS – Unintentional Islanding
- IEEE 1547 requirement is to disconnect within 2 seconds of island formation



Anti-islanding test setup

Test Results

- Testing Results from ASCO SLTS – Unintentional Islanding



Test Results – GE UIT

Size of Non-Detect Zone (NDZ) reduces as power level increases

Results from anti-islanding NDZ testing.

DG output (kW)	Active Load (kW)	Reactive Load (kVAR)	Power Mismatch (kW)	NDZ Size (% of $P_{DG, nom}$)
20	23	36	3	2.4
35	37.5	62.5	2.5	2.0
50	51.25	90	1.25	1.0
80	81.5	144	1.5	1.2

Examine the effects of switching in load while the DG was islanded and supplying a local load. That is, after the DG and load islanded (without being detected), how much load step would cause the island to be detected.

The test showed that steps less than 0.8% transient power would not cause the DG to trip.

Using small DG steps, the DG would continue to remain connected even if total change is much larger (up to rating of DG).

Testing Summary

- This presentation outlines some of the specific interconnection tests being validated for inclusion in IEEE 1547.1.
- Generic monitoring, measurement, and testing strategies could be useful in P1547.1. The file size, sampling rate, and correct sampling window were significant factors of testing that could be mentioned in P1547.1. Advice and warnings of issues to be aware of to aid smooth and accurate testing should also be included.
- Some values from the earlier draft of P1547.1 standard were incompatible with the testing setup and will need modification. This information has been passed on to members of the IEEE P1547.1 working group for revision in future drafts.
- Care must be taken to test each parameter individually without other protective functions operating.
- For More Information and Copies of the full testing reports go to www.eren.doe.gov/distributedpower or www.nrel.gov

Residential and Commercial Applications

Photovoltaics

Fuel Cells

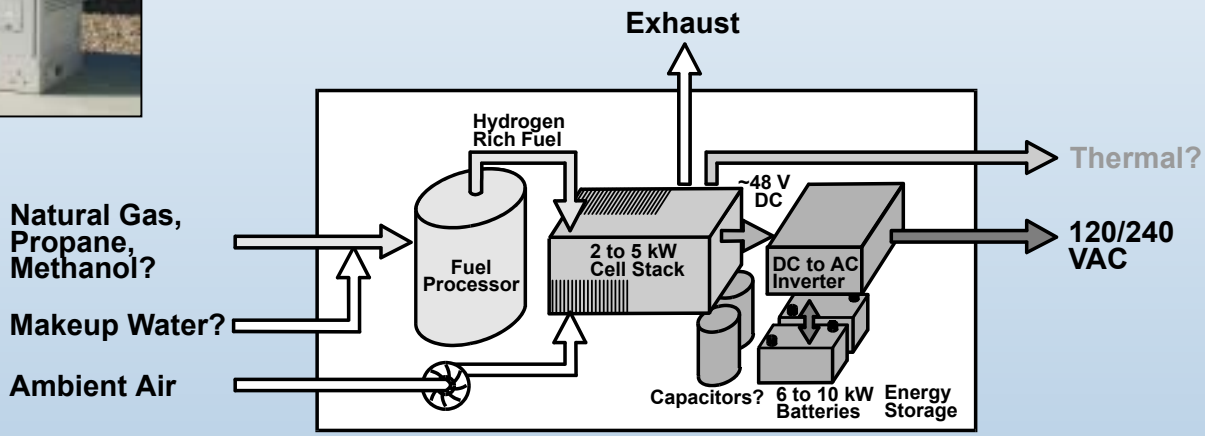
Wind

Generators

Microturbines

Residential Applications

Fuel Cells

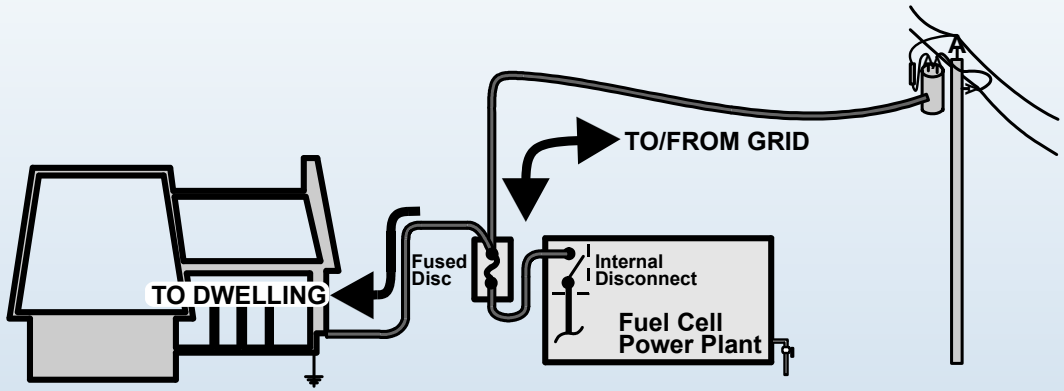


The CRN Residential Fuel Cell Demonstration Handbook serves as a comprehensive guide to residential fuel cell technology and related issues.

http://www.nrel.gov/docs/fy02osti/32455.pdf.

Residential Applications

Grid Parallel

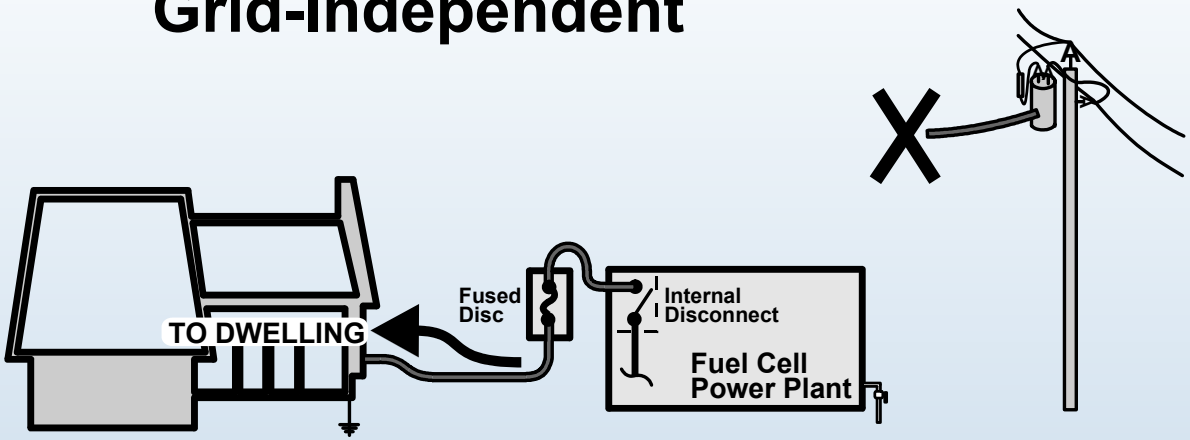


Power Flow: Power flows from the fuel cell to the customer's dwelling and to/from the grid, both of which are connected in parallel. Dependent on the time of day, the fuel cell capacity versus dwelling loads, state of fuel cell battery charge, any anti-export controls or settings, etc. power may flow from or to the grid. The typical configuration would likely have limited export at certain times of the day and strive for no export at night.

Interconnect: The fuel cell interconnects with the grid through a fused disconnect, which is accessible to distribution service personnel, and an internal disconnect under control of the power plant. In the event of a short-term grid upset, the inverter typically interrupts or stops commuting. In the event of a longer upset, the inverter opens an internal disconnect and likely goes to idle while monitoring the grid and waiting to reconnect after a preset time delay after the grid returns to normal.

Residential Applications

Grid-Independent

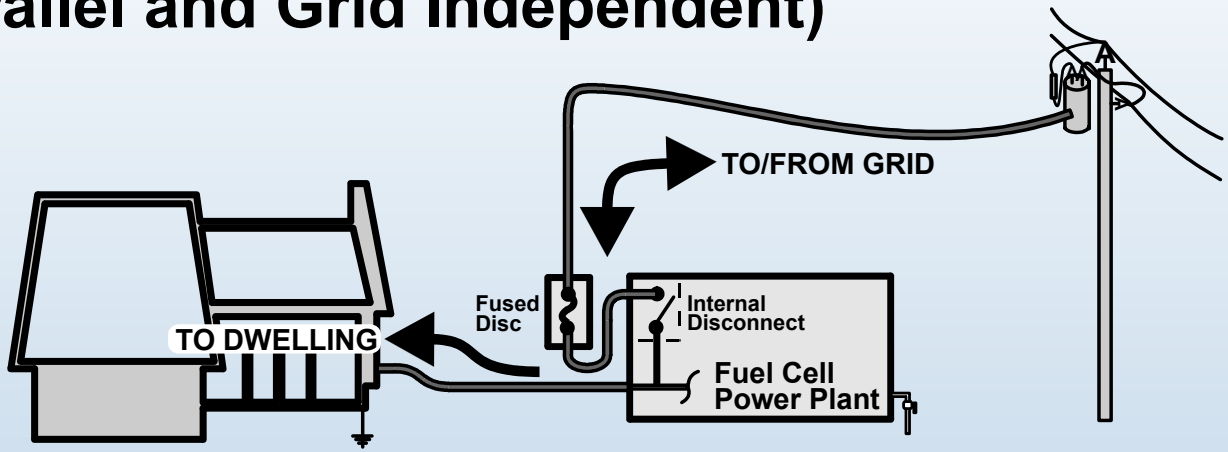


Power Flow:
Power flows only from the fuel cell to the customer's dwelling. Thus, the fuel cell must meet all dwelling loads. This requires application preplanning and perhaps load monitoring before installation. The fuel cell will likely have a substantial battery storage system charged by the cell stack at night to supplement the cell stack during peak daytime loads.

Interconnect:
The fuel cell connects to the dwelling through a fused disconnect and perhaps an internal disconnect for certain fault-clearing events.

Residential Applications

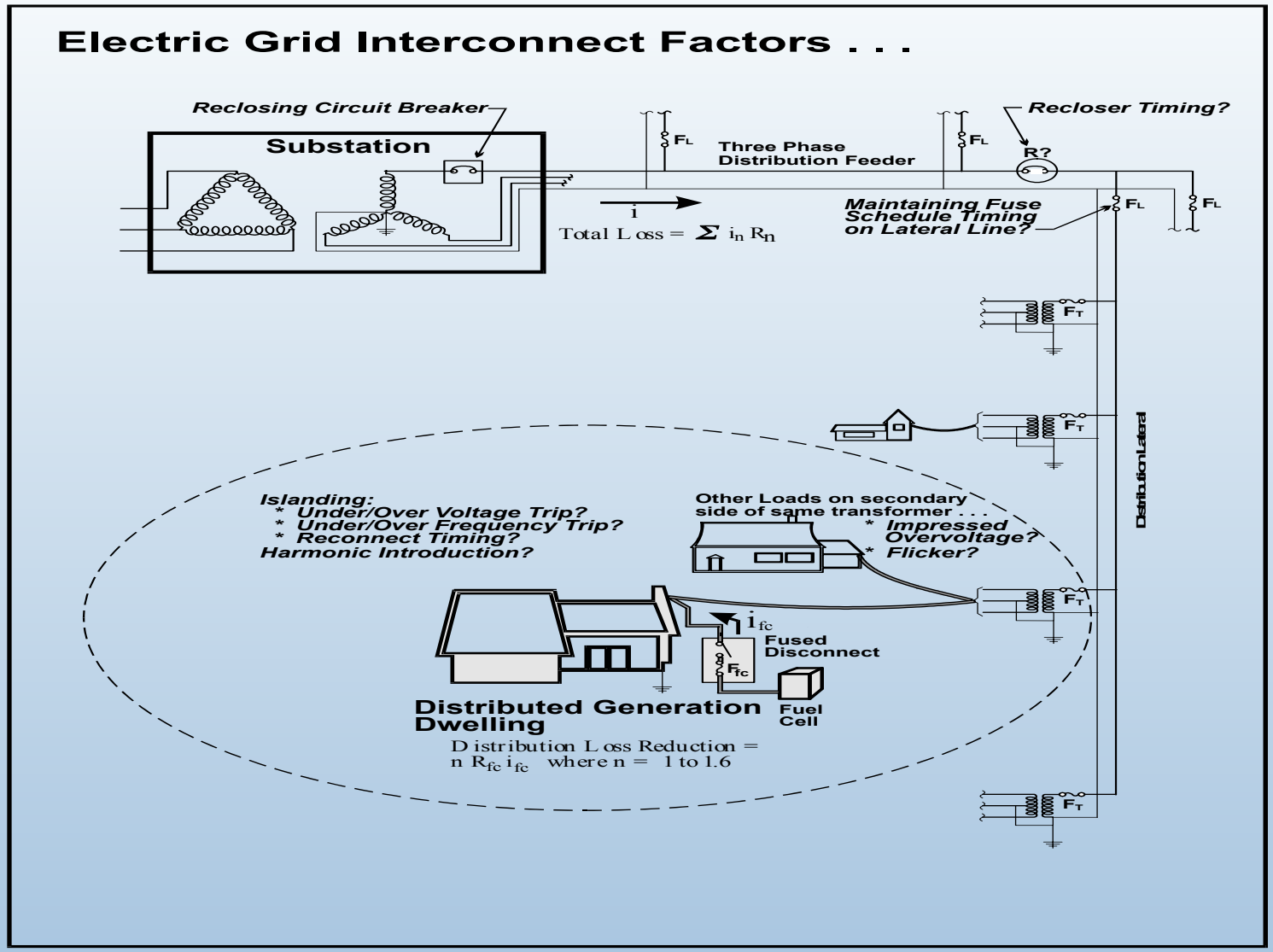
Dual Mode (Combination Grid Parallel and Grid Independent)



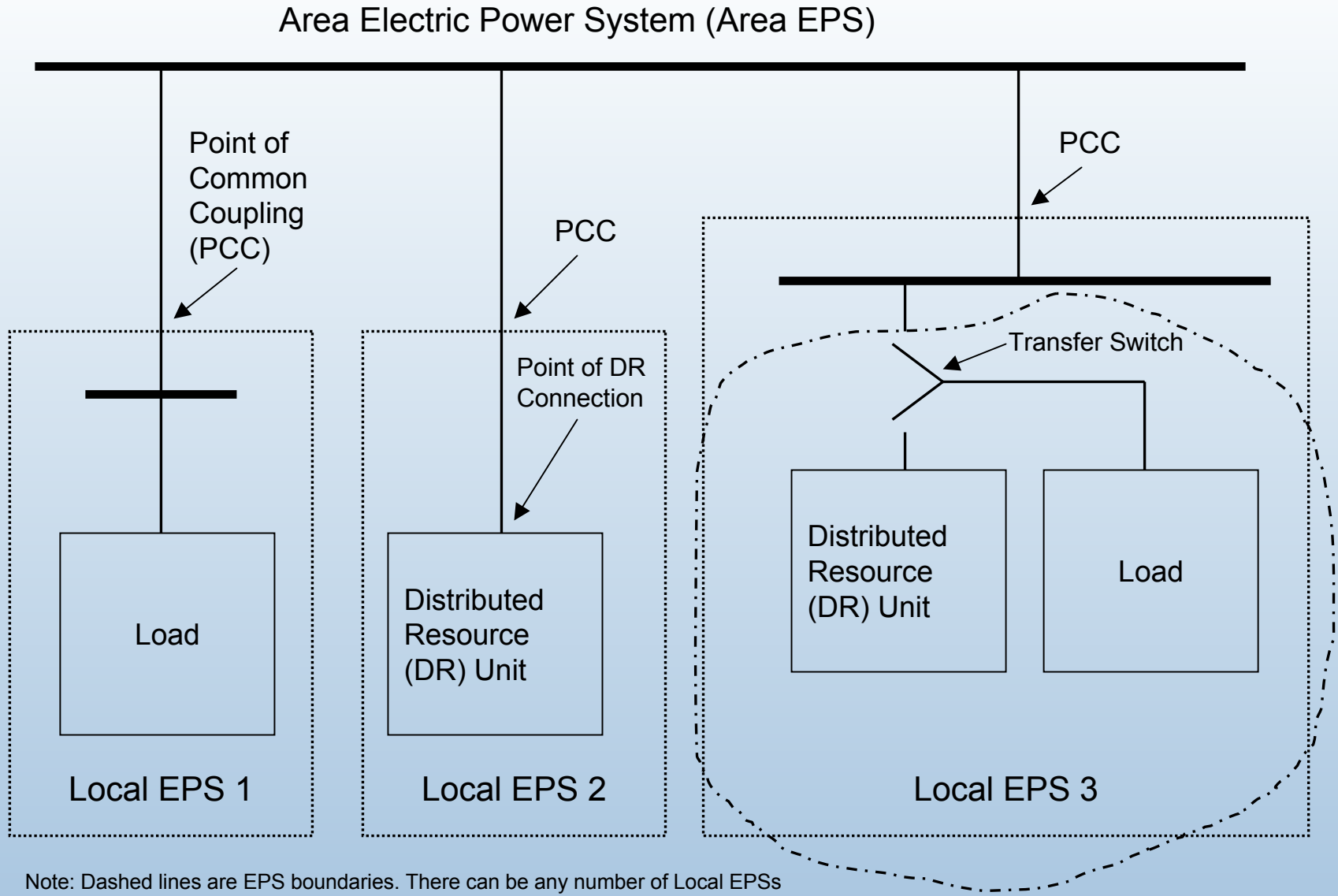
Power Flow:
Power flows from the fuel cell to the customer's dwelling and to/from the grid in normal operation. In the event of a grid upset, the power plant interrupts. In the event of a serious grid event, it disconnects itself and the dwelling from the grid and runs independently. After a suitable delay after the grid returns to normal, the inverter interrupts, and grid-parallel operation is restored.

Interconnect:
The fuel cell interconnects with the grid through a fused disconnect. An internal fuel cell disconnect is provided for certain grid-parallel upsets and may be provided for certain dwelling grid-independent fault-clearing events.

Residential Applications

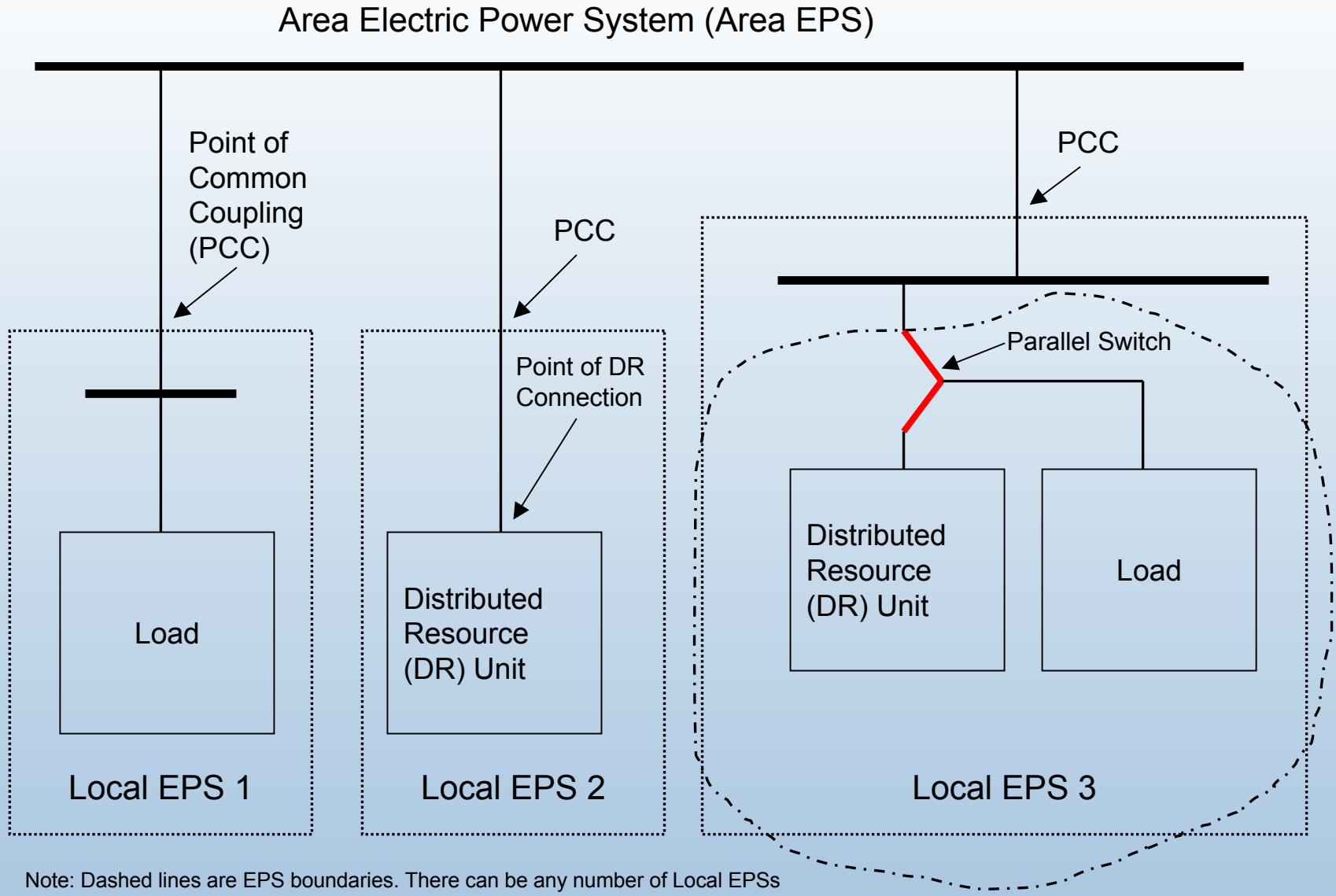


Commercial Applications – Transfer Switch



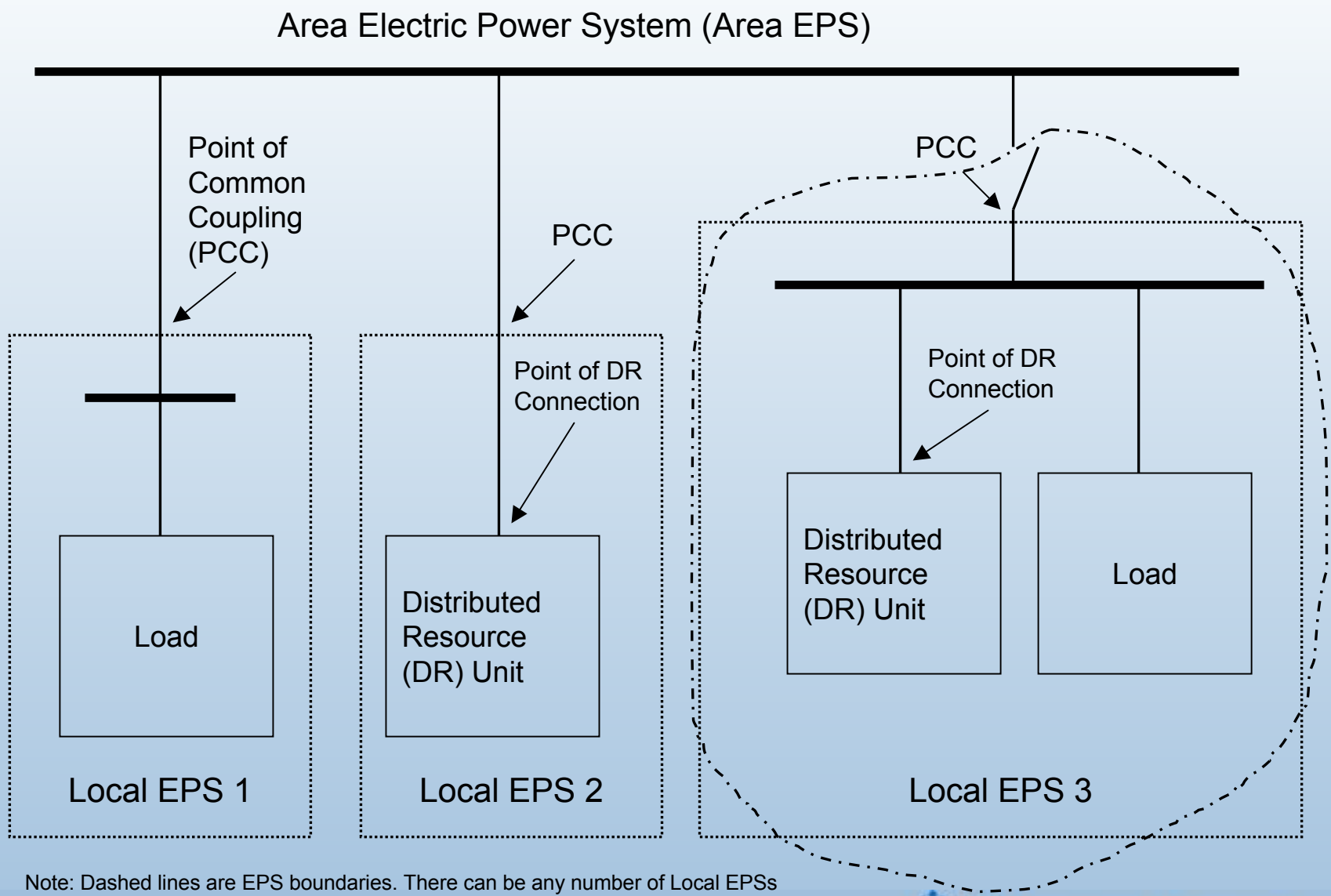
Note: Dashed lines are EPS boundaries. There can be any number of Local EPSs

Commercial Applications – Parallel Switch



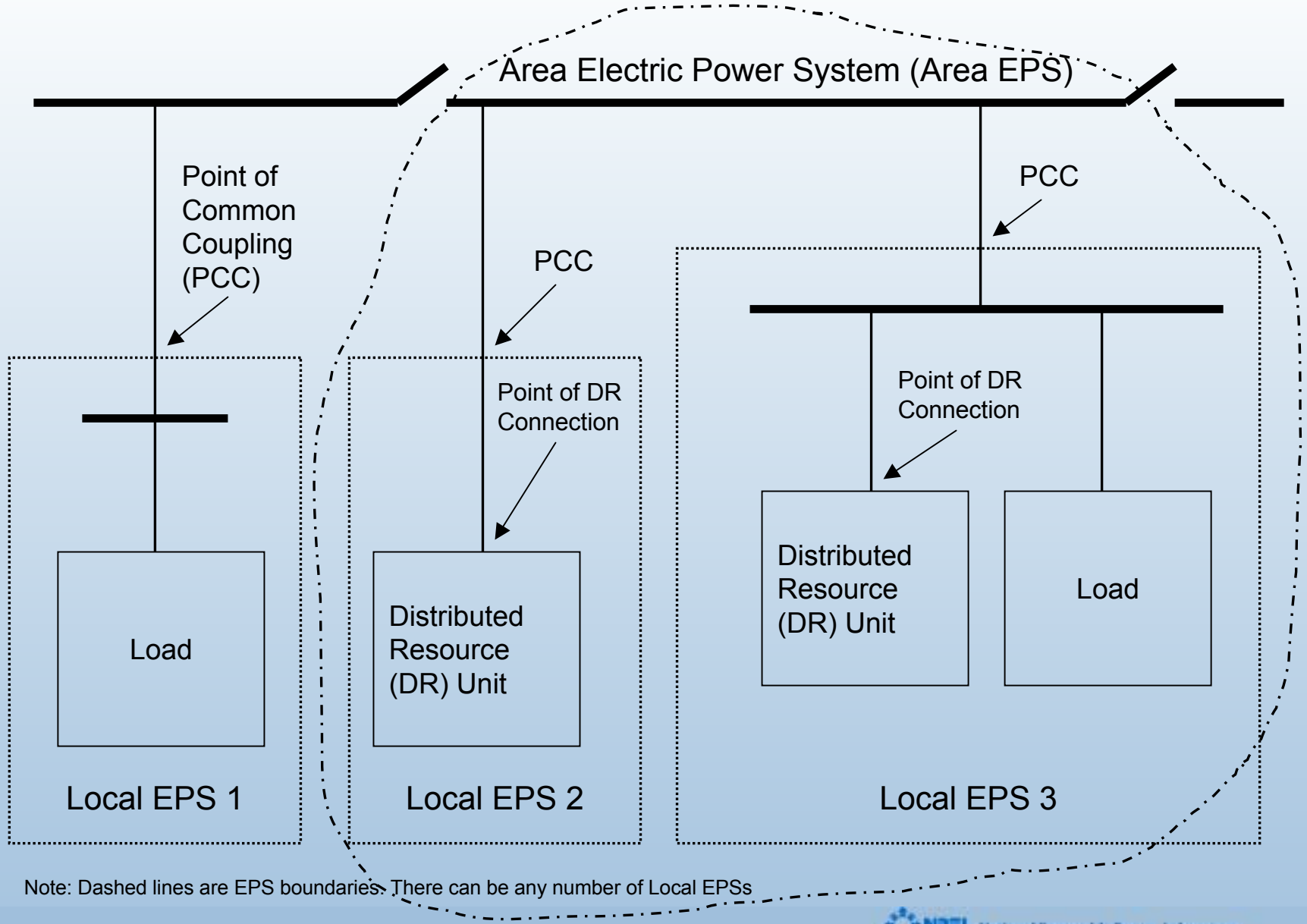
Note: Dashed lines are EPS boundaries. There can be any number of Local EPSs

Commercial Applications – Facility Microgrid



Note: Dashed lines are EPS boundaries. There can be any number of Local EPSs

Commercial Applications – Area EPS Microgrid



Note: Dashed lines are EPS boundaries. There can be any number of Local EPSs

Interconnection Standard Series

1547 Standard for Interconnecting Distributed Resources with Electric Power Systems. **Published 7/03**

Current Projects

P1547.1
Conformance Test Procedures for Equipment Interconnecting DR with EPS

P1547.2
Application Guide for IEEE 1547 Standard for Interconnecting DR with EPS

P1547.3
Guide for Monitoring, Information Exchange and Control of DR

P1547.4
Guide for Design, Operation, and Integration of DR Island Systems with EPS

Future Projects

DG Specifications and Performance

Interconnection System Certification Guide

Guide for Network Interconnection

Guide for Grid/DG Impacts Determination