IEEE 1547 Interconnection Standards

IEEE Std 1547 (2003)

IEEE Standard for Interconnecting Distributed Resources With the Electric Power System

IEEE PES Meeting
June 9, 2004

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Secretary: IEEE SCC21, Std 1547, P1547.2 & P1547.3 & P1547.4;
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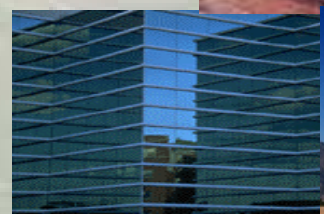
National Renewable Energy Laboratory
Golden, Colorado







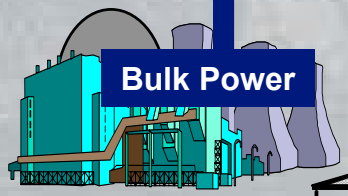

Outline

- **Background:** Distributed Energy Resources (DER or DR)
- **Introduction:** Standards & Technology Development.
- **IEEE SCC21:** Standards Coordinating Committee 21
- **IEEE 1547 Series of Interconnection Stds**
  - **ANSI/IEEE Std 1547 (2003): interconnection system & interconnection test requirements for interconnecting DR with Electric Power Systems (EPS)**
  - **P1547.1 standard for interconnection test procedures**
  - **P1547.2 guide to 1547 standard**
  - **P1547.3 guide for information exchange for DR interconnected with EPS**
  - **P1547.4 guide for DR island systems**
- **Moving Forward**

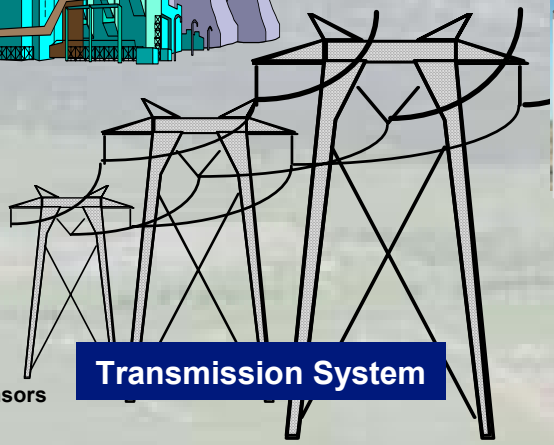
Summary Remarks

- Standards Are Being Developed and Validated In a Timely, Ongoing and Cohesive Manner.
- Standards Are Promoting Advanced Technology Development That Is Successfully Incorporating Next Generation Standardized Functionalities.
- Standardization Is Enhancing Systems Integration of Sound Distributed Energy Resources With The Grid That Are Contributing To Modernizing Our Electric Infrastructure.

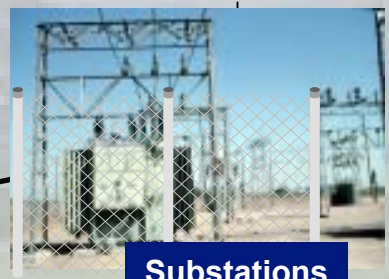
Transmission and Distribution System



Bulk Power

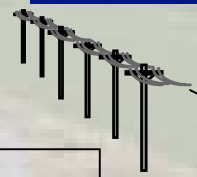


Transmission System



Substations

Distribution Systems

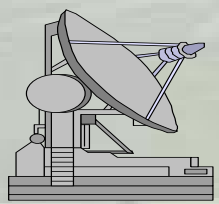


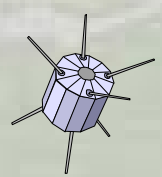
Load Management

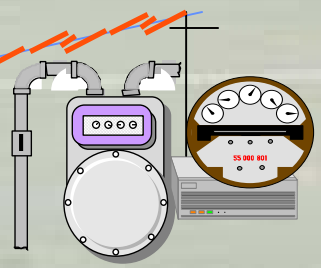
sensors

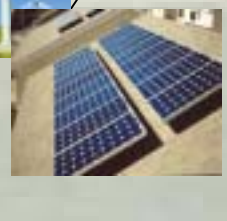
Communications – Information Flow, Data Management, Monitor & Control

Interconnection

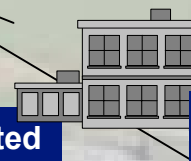








Distributed Generation



Combined Heat & Power

sensors

What is a DER ?

DER* is defined as a small-scale electric generator located next to and connected to the load being served either with or without an electric grid interconnection

* sometimes referred to as a DG (distributed generator)

DER Technology Portfolio

Examples

Advanced Turbines

Reciprocating Engines

Fuel Cells

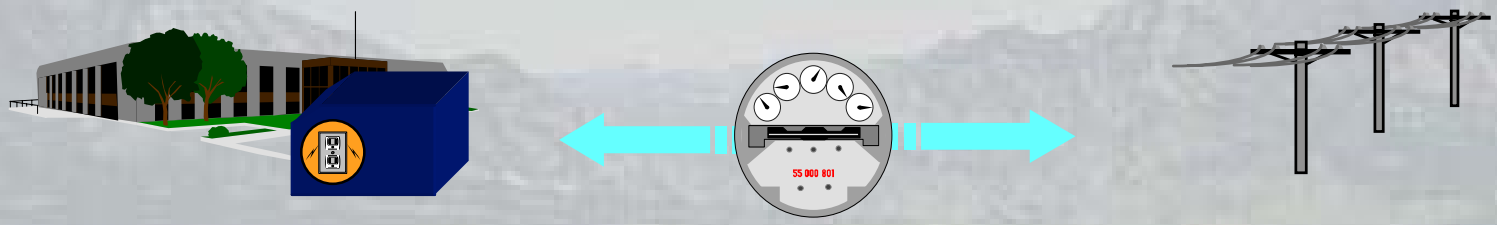
Photovoltaics

Wind

Thermally Activated Technologies

Microturbines

DER Grid Interconnection



Potential Consumer Benefits

- Clean energy
- Lower cost electricity
- Reduced price volatility
- Greater reliability and power quality
- Energy and load management
- Combined Heat and Power

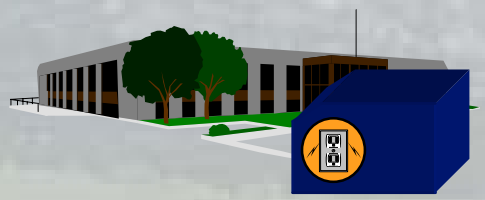
Potential Supplier Benefits

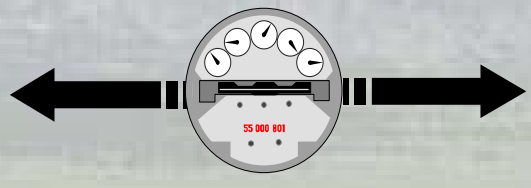
- Reduced electric line loss
- Reduced T&D congestion
- Grid investment deferment and improved grid asset utilization
- Improved grid reliability
- Ancillary services, e.g., voltage support and stability, VARs, contingency reserves, and black start capability

➔Greater flexibility and energy security←

Proven technologies, customer choice, open market access, and easy interconnection are required to achieve these benefits

Standards & Technology Standardization





Standards Development and Validation

- Safeguards against hazards
- Fostering quality design and manufacture
- Increased competitiveness in industry
- Create and expand markets
- Facilitate Trade and Commerce
- Assurance is provided when products meet quality standards, then users need not be concerned with further testing or evaluation of the product

IEEE Interconnection Standards

- American National Standard IEEE1547 Published 2003
- Developed by IEEE Standards Coordinating Committee 21 (IEEE SCC21)
- SCC21 developing 1547 Series of Interconnection Standards
- SCC 21 responsible for standards development in areas of
  - Fuel cells
  - Photovoltaics
  - Dispersed generation
  - Energy storage
- 400 SCC21 work group members (all work groups)

IEEE Standards Coordinating Committee 21 (SCC21) '*Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage*'

Oversees the development of standards in the areas of Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage, and coordinates efforts in these fields among the various IEEE Societies and other affected organizations to ensure that all standards are consistent and properly reflect the views of all applicable disciplines.

IEEE SCC21reviews all proposed IEEE standards in these fields before their submission to the IEEE-SA Standards Board for approval and coordinates submission to other organizations.

IEEE SCC21 Approach

- National consensus standards established via industry driven partnerships under IEEE SCC21; SCC21 also provides liaison activities.
- Harmonization of national and international standards, codes, and certification/laboratory accreditation
  - International Electro-technical Commission (IEC) dual logo arrangement for IEC to adopt IEEE standards for electronics, telecom, and power generation.
  - IEC Technical Committee 8 (electrical systems) scope and purpose was reformulated spring 2003.

IEC TC8 System Aspects for Electrical Energy Supply

(International Electro-technical Commission Technical Committee 8)

TC8 Scope – To prepare the necessary standards framework and co-ordinate the development, in co-operation with other TC/SCs, of the international standards needed to facilitate the functioning of electricity supply systems in open markets. (former scope – standardize voltages, current ratings, and frequencies).

TC8 Focus Areas – electrical system adequacy (availability of supply), connection practices, operations, network responsibility, Measurement and monitoring, data exchange, communication, security, terminology.

Interface with other TC' s (1,9,13,17,22,28,57,64,65,73,77,82,88,95,99,105), and SC17C, SC77, ACENELEC, CIGRE, CIRED EURELECTRIC, IEEE, IEEJ, NERC, ORGAIM, NAESB, etc.

USNC–TC8 TAG (Technical Advisory Group) Administrator - NREL designated as TAG Administrator for the USNC TAG for IEC/TC-8

USTAG TC8 Membership:

established Feb 2004; Technical Advisors T. Basso and J. Koepfinger

American National Standard
ANSI/IEEE 1547 Std

→ IEEE Std 1547 (2003) published summer 2003 ←

- **Affirmative IEEE Ballot February 2003**
  - Voting Membership
    - 230 members (31% general interest, 4% government, 30% producer, 35% user)
    - 91% affirmatives
  - 444 Work Group and Ballot Group Members at time of ballot

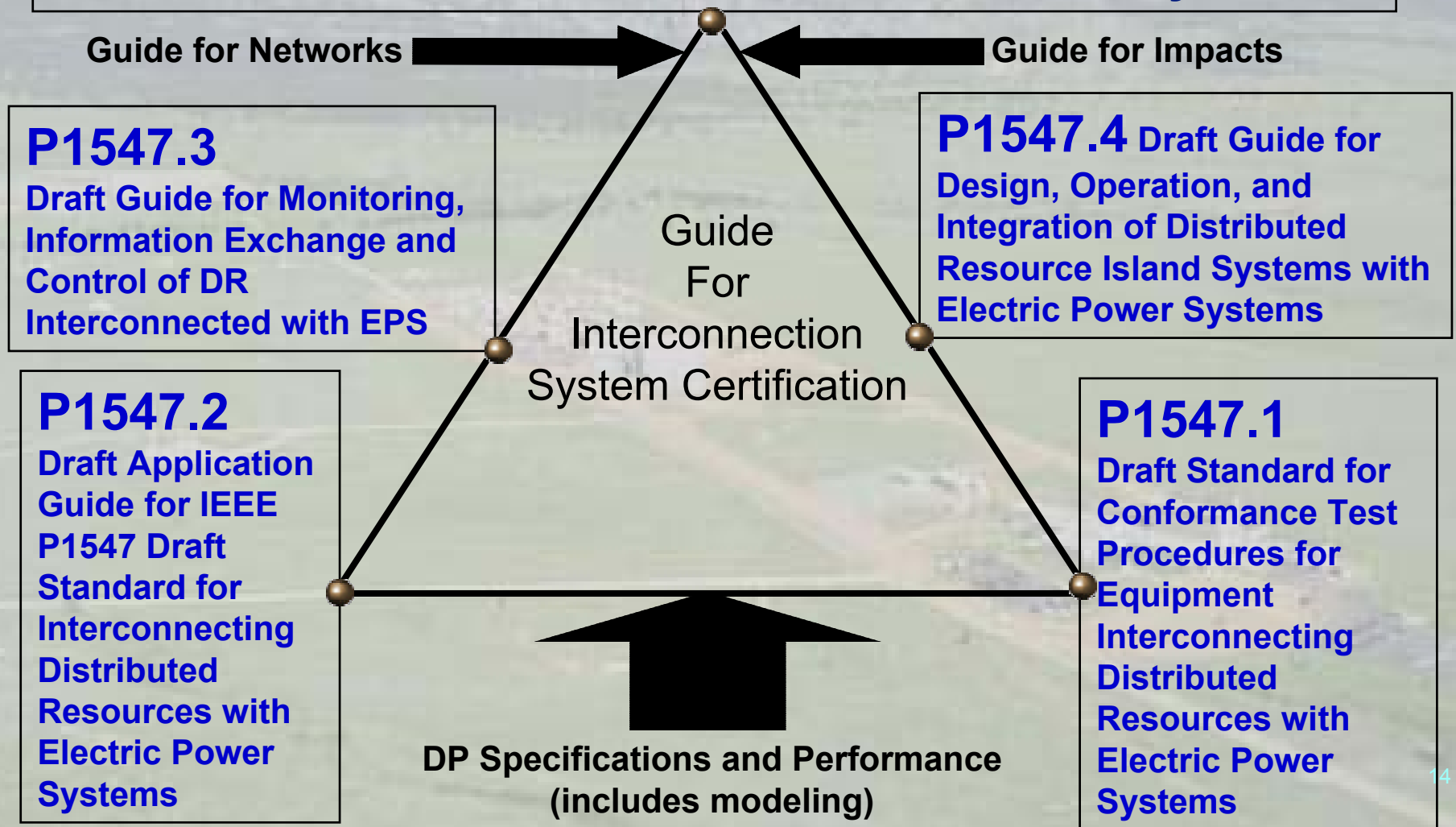
- **Approved by IEEE Standards Board June 12, 2003**

- **American National Standard designation**

(**ANSI/IEEE Std 1547** - October 20, 2003)

IEEE SCC21 1547 Standard & series of interconnection projects

IEEE Std 1547™ (2003) Standard for Interconnecting Distributed Resources with Electric Power Systems



IEEE 1547 Interconnection Standard & Projects

Title	Scope & Purpose
IEEE Std 1547™ (2003) Standard for Interconnecting Distributed Resources with Electric Power Systems (published June 2003)	• This Standard establishes criteria and requirements for interconnection of distributed resources (DR) with electric power systems (EPS). • This document provides a uniform standard for interconnection of distributed resources with electric power systems. It provides requirements relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection.
P1547.1 Draft Standard for Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems	• This Standard specifies the type, production, and commissioning tests that shall be performed to demonstrate that interconnection functions and equipment of a distributed resource (DR) conform to IEEE Std 1547. • Interconnection equipment that connects distributed resources (DR) to an electric power system (EPS) must meet the requirements specified in IEEE Standard P1547. 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 a variety of DR technologies.

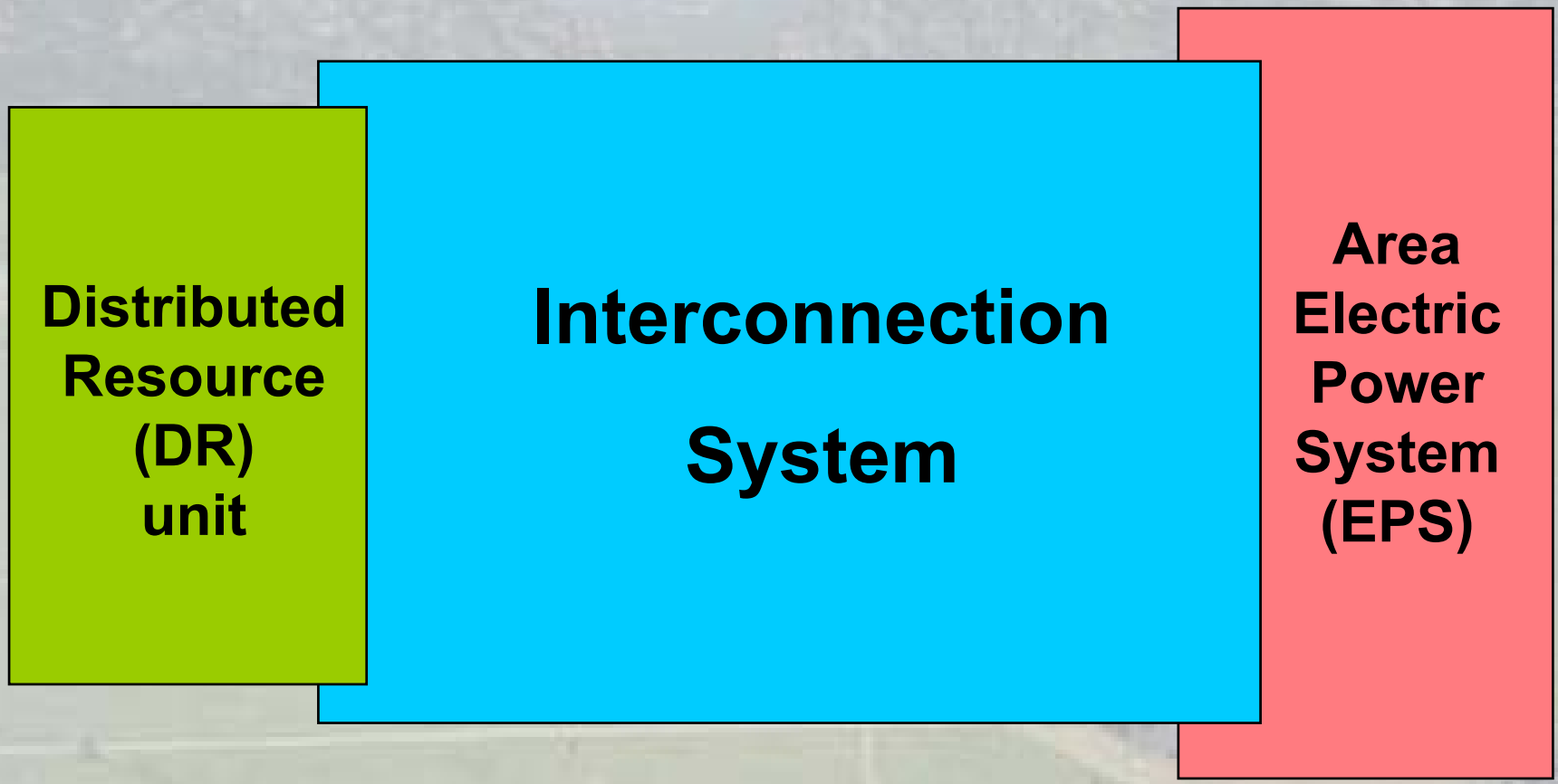
IEEE 1547 Interconnection Projects

Title	Scope and Purpose
P1547.2 Draft Application Guide for IEEE Standard 1547 for Interconnecting Distributed Resources with Electric Power Systems	• This Guide provides technical background and application details to support the understanding of IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems. • This document facilitates the use of IEEE 1547 by characterizing the various forms of distributed resource technologies and the associated interconnection issues. Additionally, the background and rationale of the technical requirements are discussed in terms of the operation of the distributed resource interconnection with the electric power system. Presented in the document are technical descriptions and schematics, applications guidance and interconnection examples to enhance the use of IEEE 1547.
P1547.3: Draft Guide for Monitoring, Information Exchange and Control of Distributed Resources Interconnected with Electric Power Systems	• This document provides guidelines for monitoring, information exchange, and control for distributed resources (DR) interconnected with electric power systems (EPS). • This document facilitates the interoperability of one or more distributed resources interconnected with electric power systems. It describes functionality, parameters and methodologies for monitoring, information exchange and control for the interconnected distributed resources with, or associated with, electric power systems. Distributed resources include systems in the areas of fuel cells, photovoltaics, wind turbines, microturbines, other distributed generators, and, distributed energy storage systems.

IEEE 1547 Interconnection Projects

Title	Scope and Purpose
P1547.4 Draft Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems	• This document provides alternative approaches and good practices for the design, operation, and integration of distributed resource (DR) island systems with electric power systems (EPS). This includes the ability to separate from and reconnect to part of the area EPS while providing power to the islanded local EPSs. This guide includes the distributed resources, interconnection systems, and participating electric power systems. • This guide is intended to be used by EPS designers, operators, system integrators, and equipment manufacturers. The document is intended to provide an introduction, overview and address engineering concerns of DR island systems. It is relevant to the design, operation, and integration of DR island systems. Implementation of this guide will expand the benefits of using DR by targeting improved electric power system reliability and build upon the interconnection requirements of IEEE 1547.

Std 1547: Interconnection Is The Focus



Interconnection system requirements and specifications and test requirements and specifications

P1547.1 Std Development

IEEE P1547.1 *test standard for 1547* -- plan ballot ready draft 2004; this standard specifies the type, production, and commissioning tests that shall be performed to demonstrate that interconnection functions and equipment of a distributed resource (DR) conform to IEEE Std 1547.

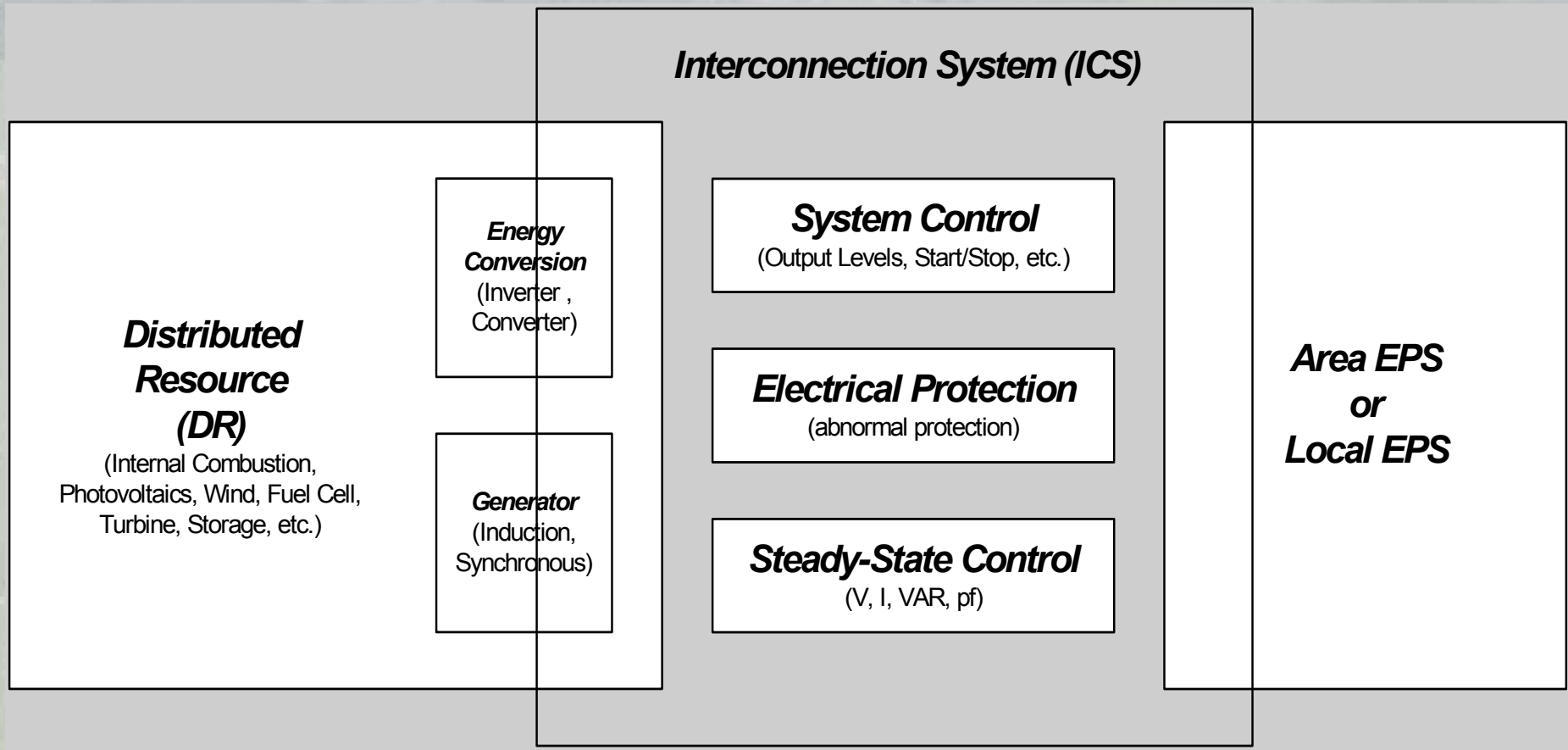


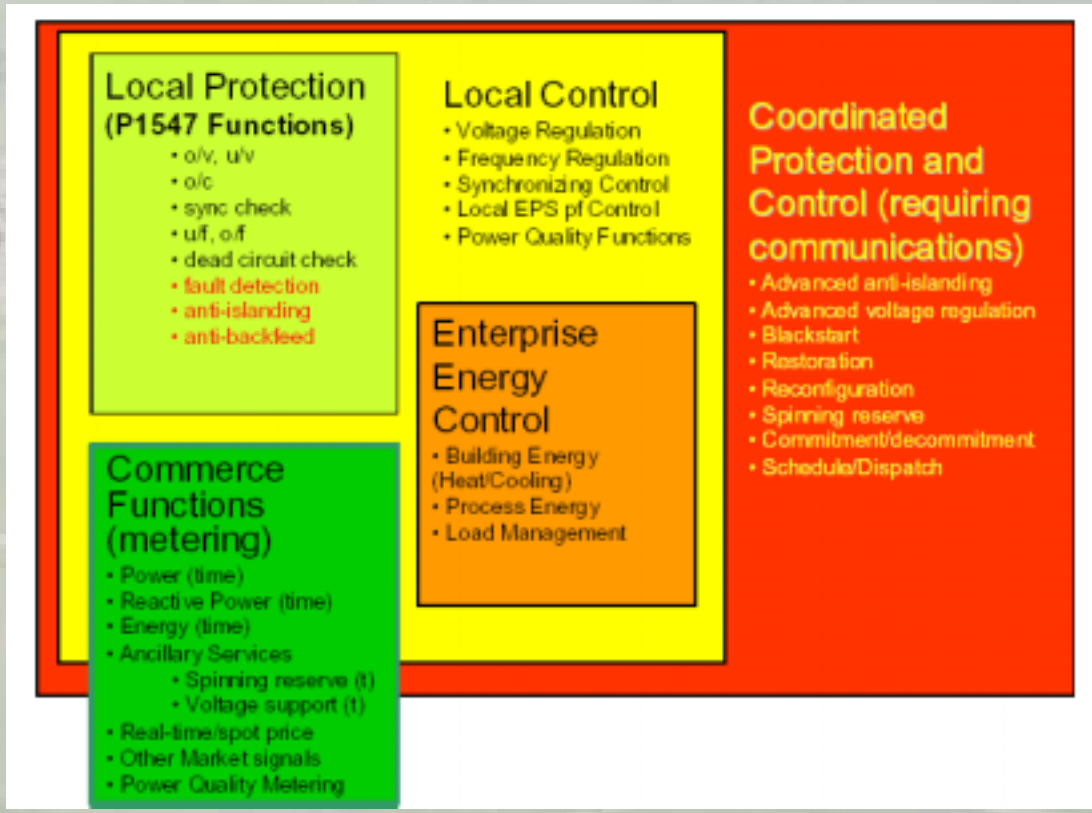
Figure 1. Definition of the installation and its content. (P1547.1 Draft 4 4/04)

P1547.2 Draft Development

IEEE P1547.2 *application guide to 1547* is being developed; “guide” offers alternate approaches – e.g., practical applications guidance, tips, techniques and rules of thumb for applying IEEE 1547 to specific interconnection situations on specific utility distribution feeders. Industry identified this as critically important practical companion to 1547.

Example of an alternate approach to 1547 requirements.

(Graphic From "Universal Interconnection Technology (UIT) Workshop Proceedings” NREL/BK-560-32865.)



P1547.3 Draft Development

P1547.3 guide to information exchange, monitoring and control for DR is being developed; “guide” offers alternate approaches – e.g., power industry communications guidance for specific cases of DR interconnection situations.

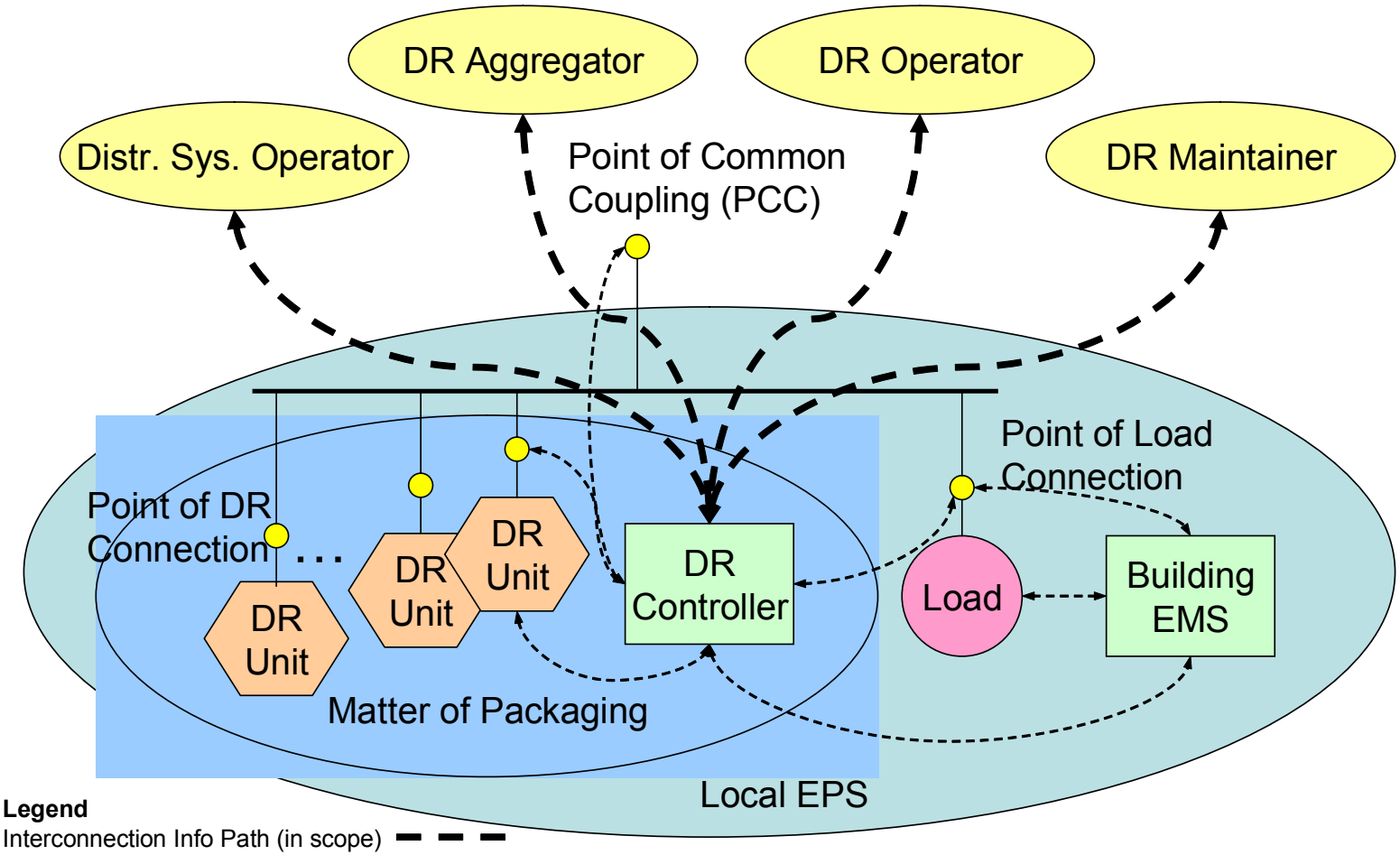


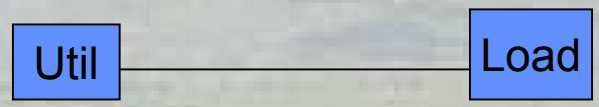
Figure 1: Information Exchange Reference Diagram (P1547.3 Draft 11/03)

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

-- Work Group Inaugural Meeting Aug 5-6, 2004 --

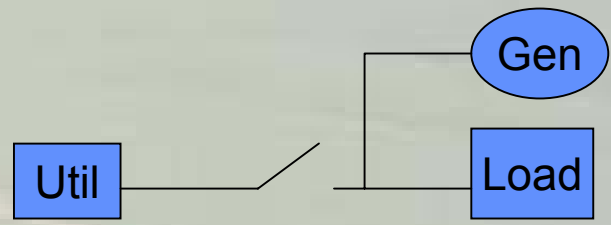
Background: Operating Concepts for the Distribution System

- Radial Distribution System: The most common type of connection between utility and load. Power only flows from utility to load.

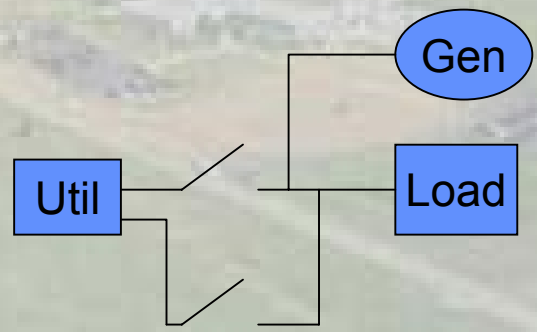


- Microgrid or Intentional Island: Aggregation of loads and sources capable of operating either in parallel with or to end users. Depending on configuration, power flows only within microgrid or can export power to utility.

  Independent from a larger electric grid, while providing continuous power.



- Networked Distribution System w/ 2-way power flow: Distribution in which the secondaries of the distribution transformers are connected in a grid, typically energized at the customers' utilization voltage, to serve multiple loads.



IEEE Std 1547 Contents

IEEE 1547 Table of Contents

IEEE 1547 IS:

- **A Technical Standard – Functional Requirements For**
  - the interconnection itself
  - the interconnection test
- **Technology neutral,** e.g., does not specify any particular equipment nor equipment type
- **A single (whole) document** of mandatory, uniform, universal, requirements
- **Should be sufficient for most installations**

IEEE 1547 Is NOT:

- a design handbook
- an application guide
- an interconnection agreement
- prescriptive, e.g., does not address DR self-protection, nor planning, designing, operating, or maintaining the Area EPS.

IEEE 1547 Interconnection

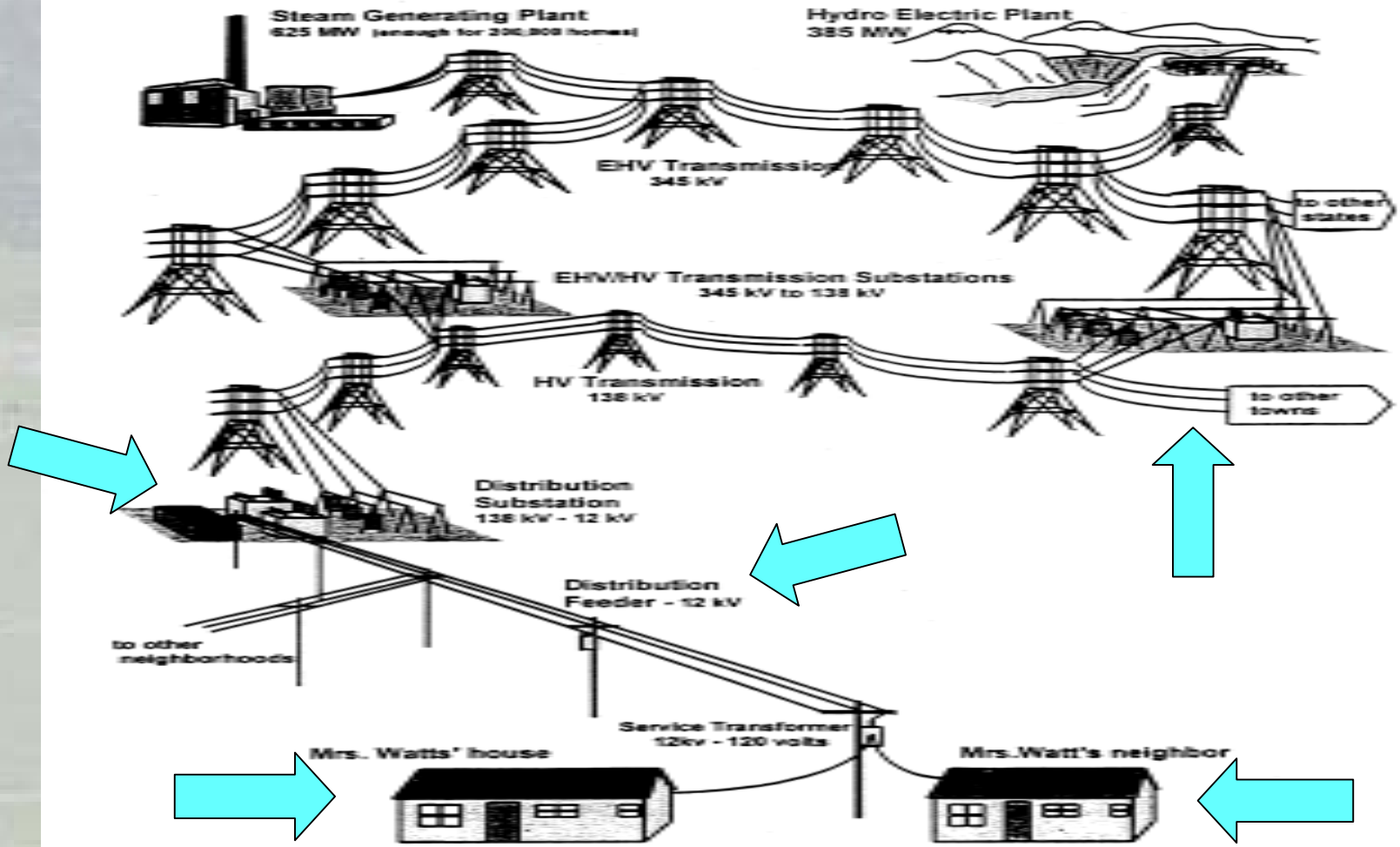
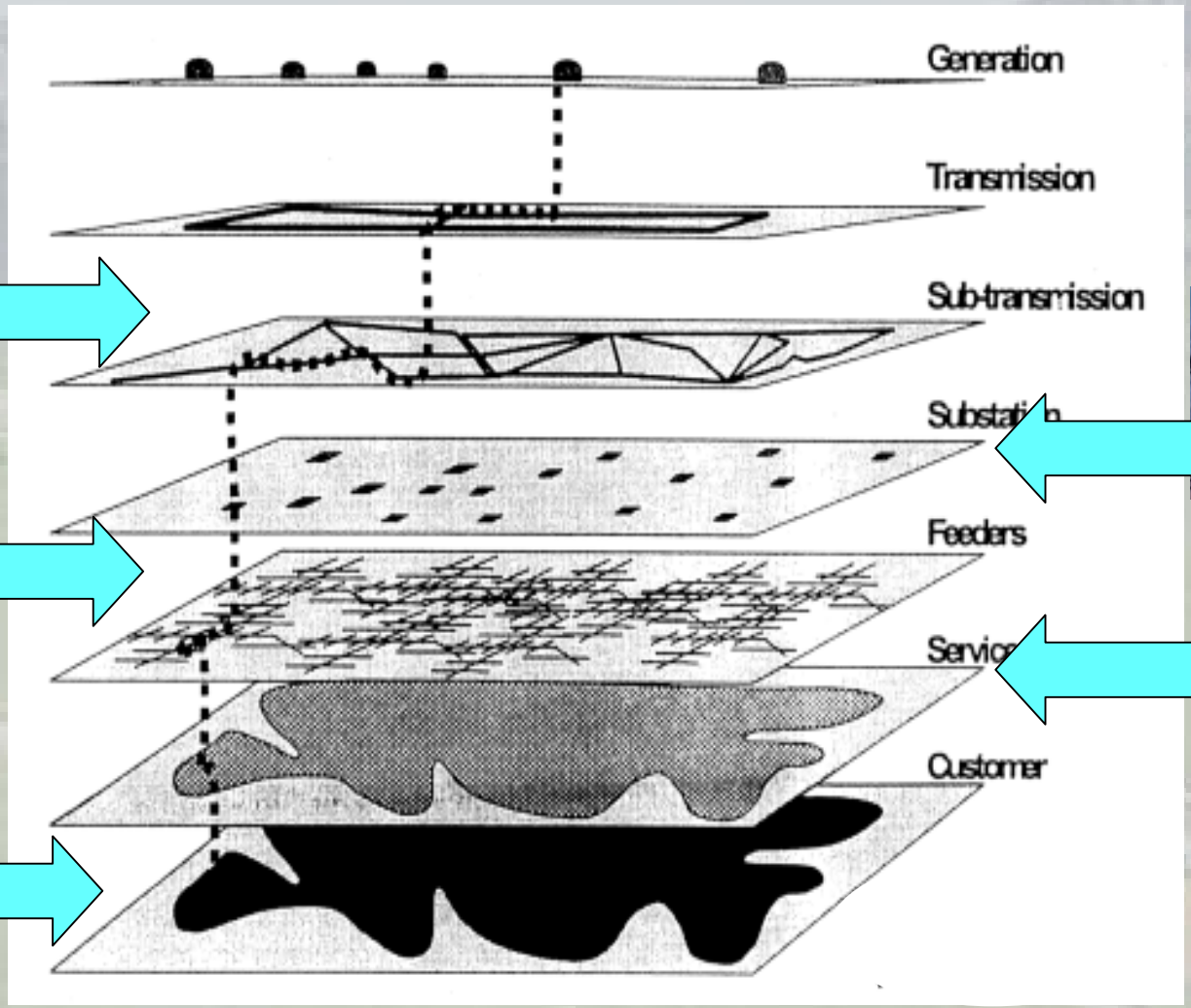


Figure 7.8 A power system consists of several levels: generation, extra high voltage (EHV) transmission, high voltage (HV) transmission, distribution, and utilization.

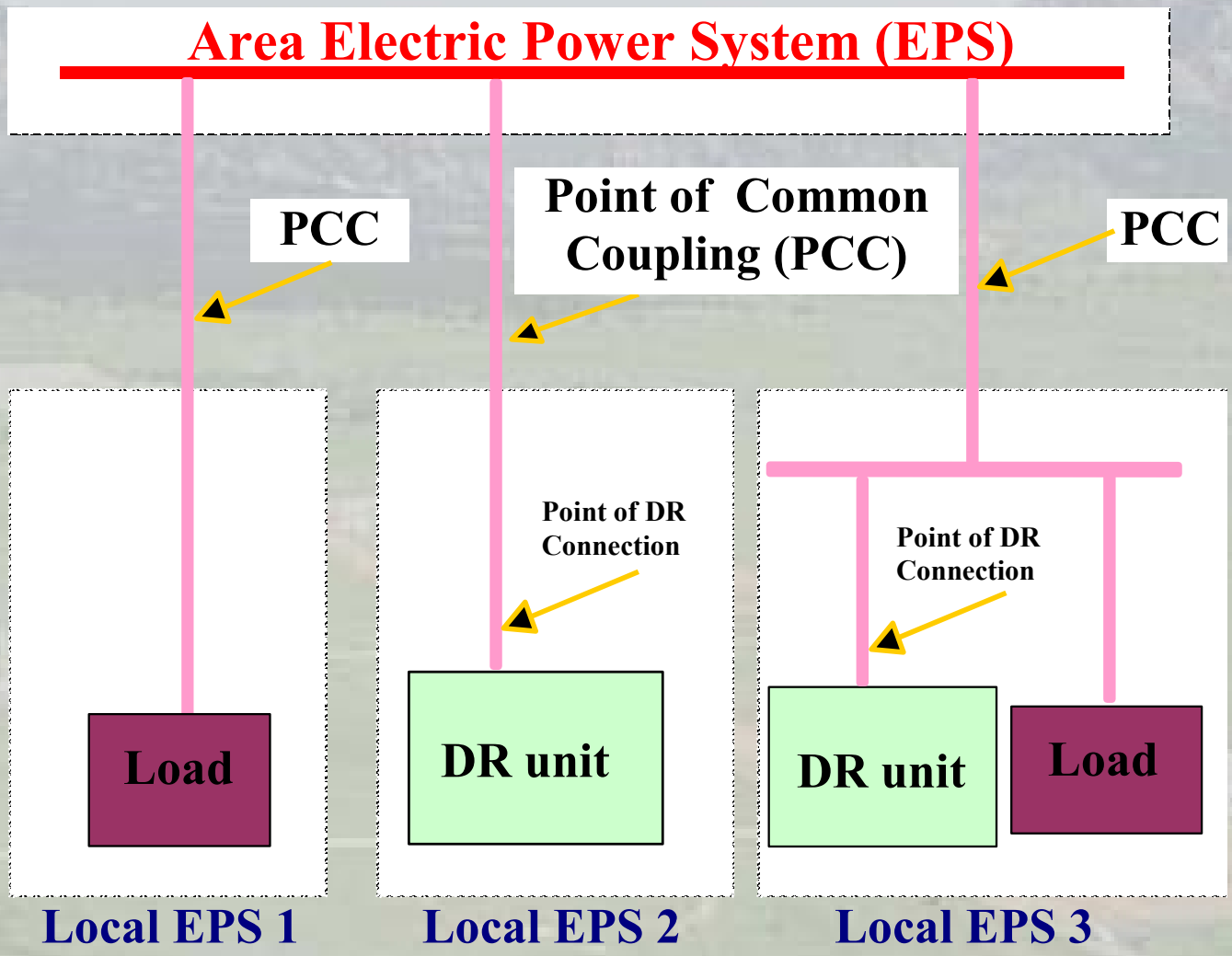
IEEE 1547 Interconnection



IEEE 1547 Interconnection Definitions

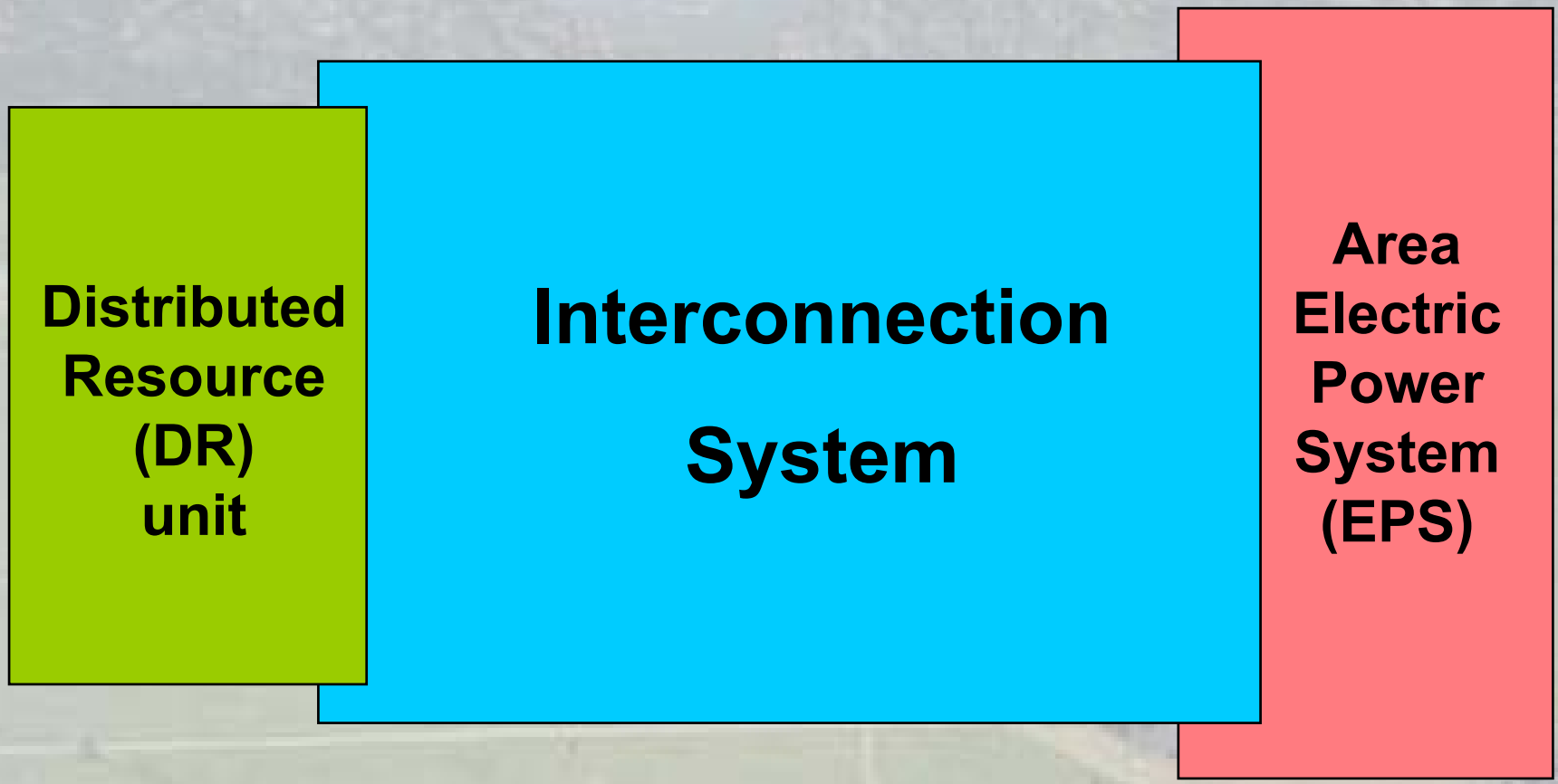
- **Distributed generator (DG)** –electric generation facilities connected to an Area EPS through a PCC; a subset of DR.
- **Distributed resources (DR)** – sources of electric power that are not directl connected to a bulk power transmission system. DR includes both generator and energy storage technologies.
- **Electric power system (EPS)** – facilities that deliver power to a load.
- **Area EPS** – an EPS that serves local EPSs.
- **Local EPS** – an EPS entirely within a single premises or a group of premises.
- **Interconnection** – the result of the process of adding a DR unit to an area EPS
- **Interconnection equipment** – individual or multiple devices used in an interconnection system
- **Interconnection system** – the collection of all interconnection equipment, taken as a group, used to interconnect a DR unit(s) to an area EPS
- **Point of common coupling (PCC)** – the point where a local EPS is connected to the Area EPS.
- **Pont of DR connection** – the point where a DR unit is electrically connected in an EPS.

1547 Interconnection Terms



Note: There can be any number of Local EPSs.

Std 1547: Interconnection Is The Focus



4.0 INTERCONNECTION TECHNICAL SPECIFICATIONS AND REQUIREMENTS

4.1 General Requirements

- Voltage Regulation
- Integration with Area EPS Grounding
- Synchronization
- DR on Secondary Grid and Spot Networks

- Inadvertent Energizing of the Area EPS
- Monitoring Provisions
- Isolation Device
- Interconnect Integrity

4.2 Response to Area EPS Abnormal Conditions

- Area EPS Faults
- AREA EPS Reclosing Coordination
- Voltage
- Frequency
- Loss of Synchronism
- Reconnection to Area EPS

4.3 Power Quality

- Limitation of DC Injection
- Limitation of Voltage Flicker Induced by the DR
- Harmonics

4.4 Islanding

- Unintentional Islanding
- Intentional Islanding

5.0 INTERCONNECTION TEST SPECIFICATIONS AND REQUIREMENTS

5.1 Design Test

- Abnormal voltage and frequency
- Synchronization
- Interconnection integrity
- Unintentional islanding
- Limitation of DC injection
- Harmonics

5.2 Production Tests

- Meet requirements of:
  - response to abnormal voltage and frequency
  - synchronization
  - may be performed at the factory or at time of commissioning

5.3 Interconnection Installation Evaluation

- Grounding Integration with area EPS
- Isolation Device
- Monitoring provisions
- Area EPS faults
- Area EPS reclosing coordination

5.4 Commissioning Tests

- Visual Inspection
- Operability test on the isolation device
- Unintentional islanding functionality test
- Cease to energize functionality test

5.5 Periodic Interconnection Tests

- All interconnection-related protective functions and associated batteries

Annex A. Bibliography

Application of 1547 (e.g, P1547.2)

- "Prime mover" traditionally performs fuel/primary-input energy conversion, e.g., recip engine, fuel cell, PV panel

  Prime mover characteristics have had limited interaction effects on utility grid; they drive the electric generators: (synchronous, induction, or inverter–based).

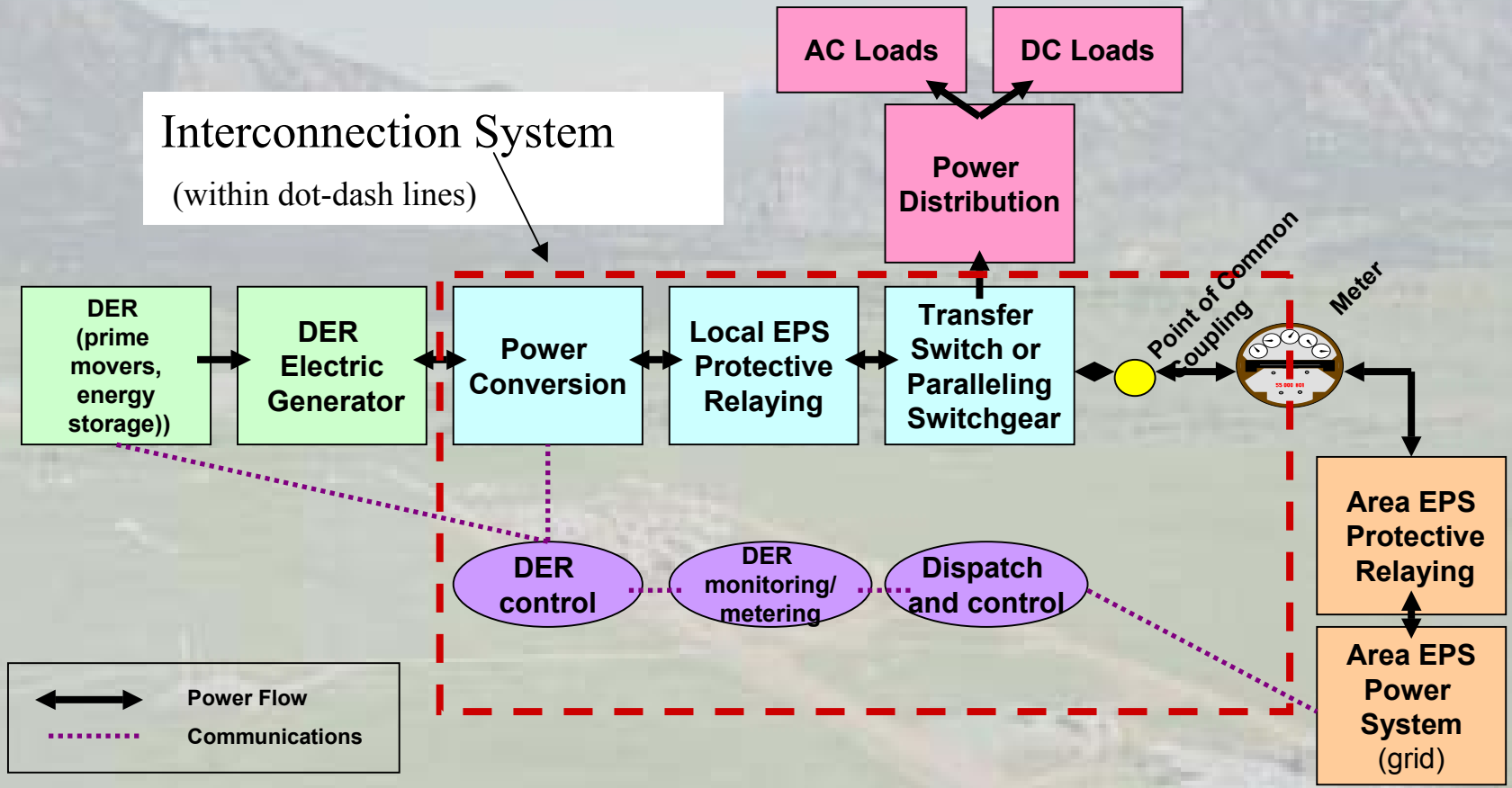
- DG-grid interface is via *"power conversion"* devices and, *relaying and switching protective devices/schemes.*

  Power conversion characteristics largely contribute to DG-grid interaction effects; relaying, switching and protection devices/schemes largely contribute to DG-grid coordination/operation interactions,

- Equipment technologies/approaches often combine above differentiations of technical functionalities.

  Std 1547 functional technical requirements remain valid.

E.g., Interconnection System Functional Block Diagram

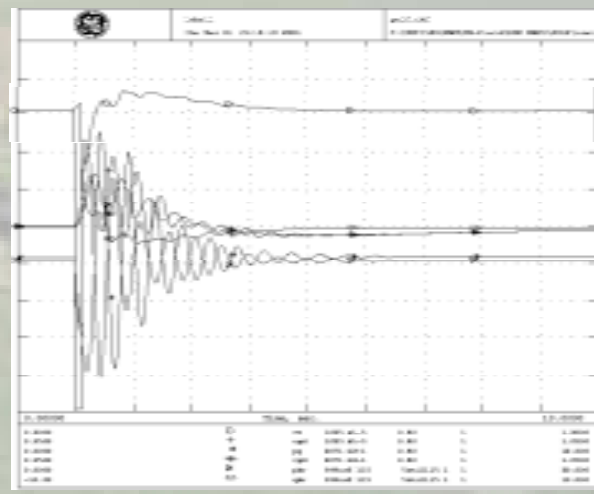


The interconnection system (within the dotted line) is designed to handle the power between and serve as the communication and control gateway among the DER, the Area EPS and the customer loads. Workshops with industry provided a forum for furthering this activity and several manufacturers are working on developing and validating standardized, advanced, universal interconnection technologies [NREL/SR-560-32459].

Synchronous Machines

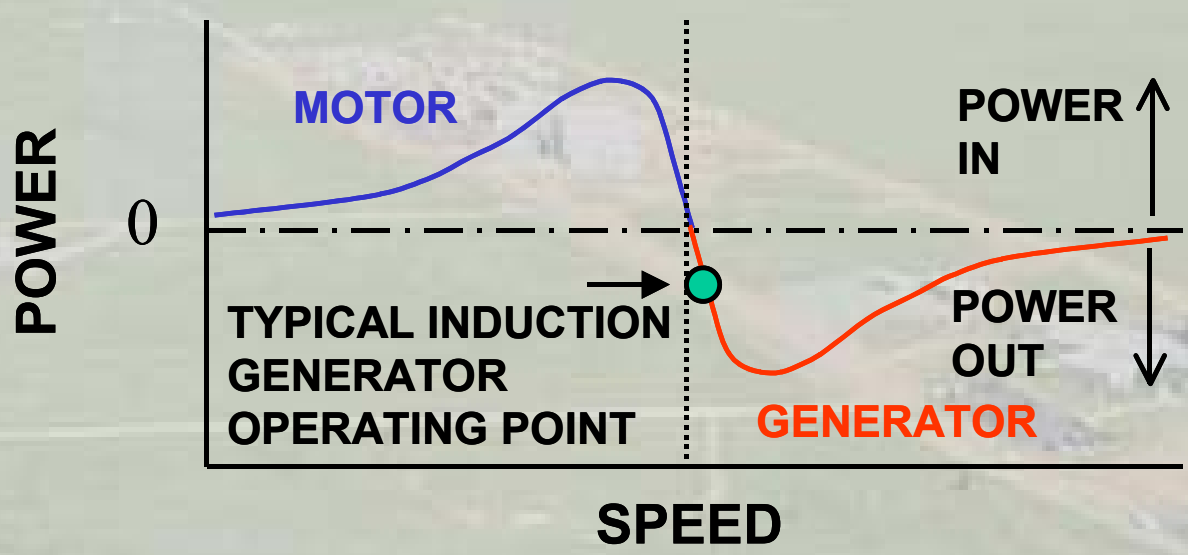
- Synchronous DG similar to large utility generation
- Runs at a constant speed in synch with grid
- Subject to dynamic angle swings following disturbances
  - Can go unstable, pull out of synch for long fault or weak system connection
- Provides substantial short-circuit current contribution e.g., 5x - 6x rating

Most larger DERs today use conventional synchronous machine technology

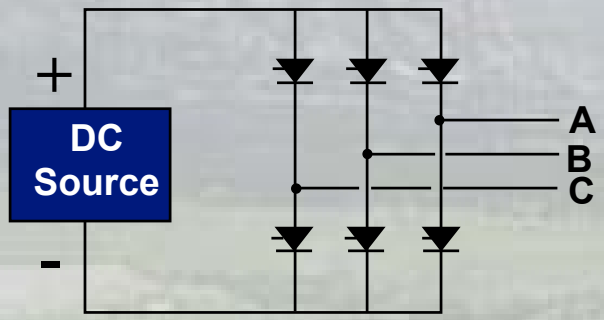


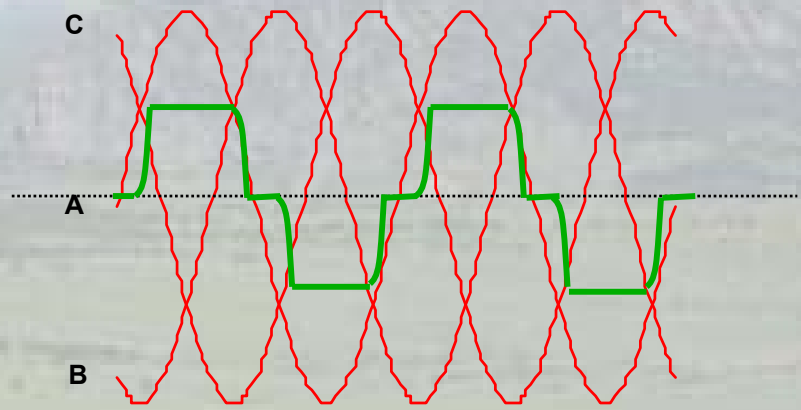
Induction Machines

- Similar to induction motor, turned faster than synchronous speed (7200rpm / number of poles)
- Variable speed operation, over a limited range
- Requires a source of reactive power



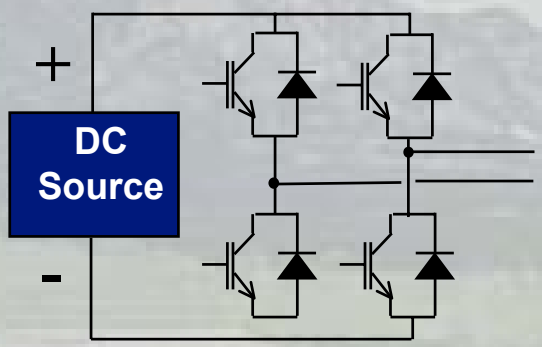
System Commutated Inverter

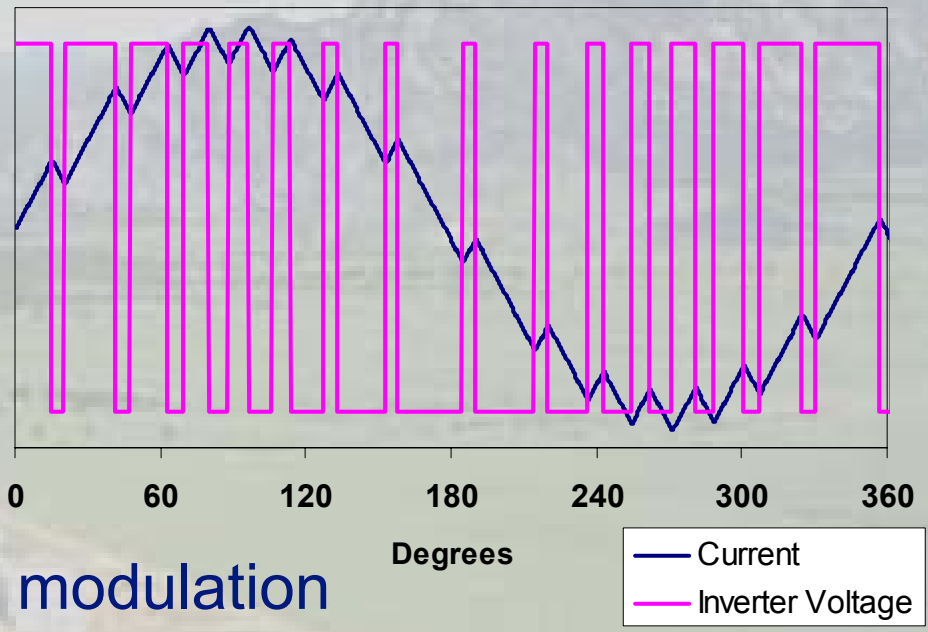




- Requires system with external source
  - short-circuit strength
  - reactive power demand
- Sensitive to voltage dips and glitches
- Produces substantial current harmonics
  - square-wave-like current
  - often needs harmonic filters
- Low cost, low loss

Voltage Source Inverter





- Uses pulse-width modulation
- 1-ph or 3-ph
- Can operate isolated
- Can produce or consume reactive power
- Lower total harmonic distortion
  - at higher frequency, easier to filter
  - distortion depends on design

Comparison of "Converters"

	Synchronous	Induction	Line-Comm.	VSI
Short Circuit Current	5-6 x rated, indefinitely	5-6 x rated few cycles	No	≈ load current
Reactive Power	Supply or absorb	Absorb	Absorb	Supply or absorb
Stand-alone operation	Yes	Once started, with VARs	No	Yes (control mode shift)
Requires synching	Yes, carefully	No	Inherent	Inherent
Stability issue?	Electro-mechanical	No	Control	Control
Harmonics producer?	Small	Small	Significant, need filters	Moderate, at high freq.

Application of 1547: DR-Grid Interconnection

- Short circuit contribution
- Protection coordination
- Voltage regulation
- Unintentional islanding
- Grounding and overvoltages
- Network issues

--- --- ---

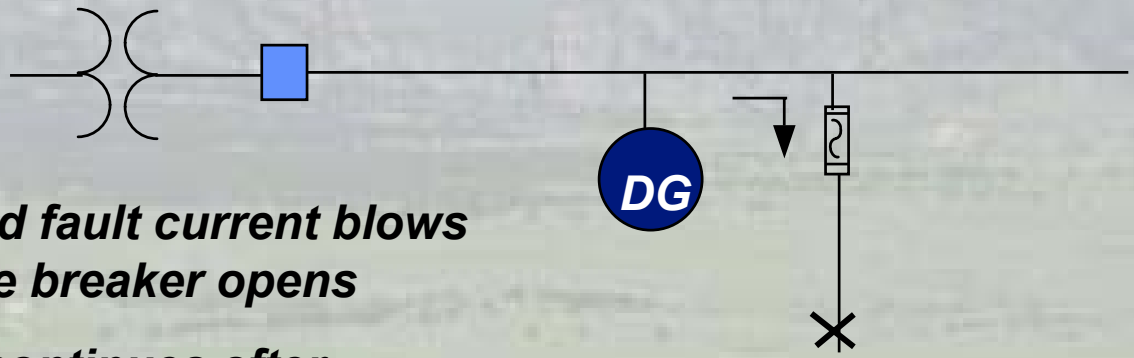
Interconnection issues are real and resolvable:

e.g., specific to: equipment, design, location, application, etc.

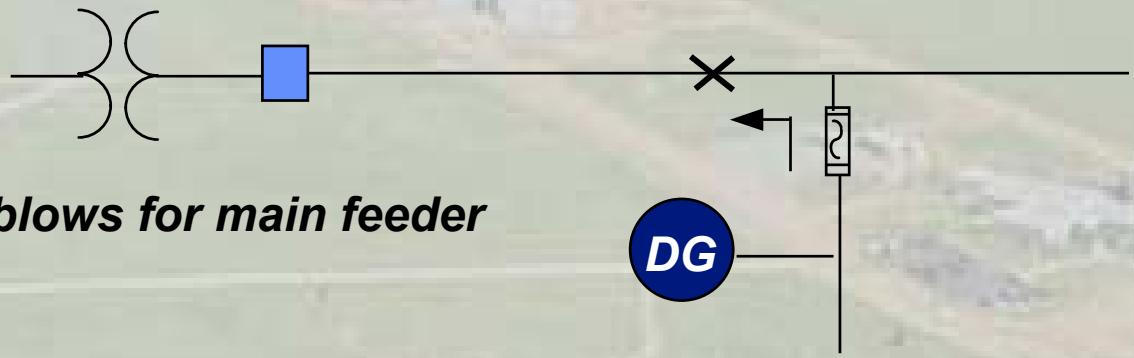
Distribution Protection/Coordination

- Philosophies vary from utility to utility
  - Fuse Saving Schemes
  - Fuse Blowing Schemes
  - Instantaneous Reclose
  - Delayed Reclose
- No “Absolute” Solutions
- Recognize the Potential Misapplication

Nuisance Fuse Operations



- *Increased fault current blows fuse before breaker opens*
- *current continues after breaker opens*

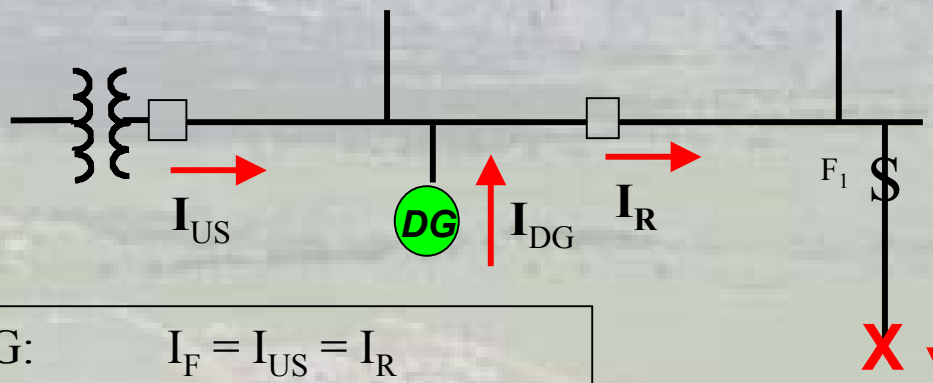


- *Fuse blows for main feeder fault*

DG & System Protection

- Traditional “radial” thinking
- Fault current magnitudes
- Fault current directions
- Fuses
- Reclosers

Recloser and Line Fuse Located Down-line from DG



I_F = 1470 A

I_F = 1825 A

Without DG: $I_F = I_{US} = I_R$

With DG: $I_F = I_{US} + I_{DG}$

and

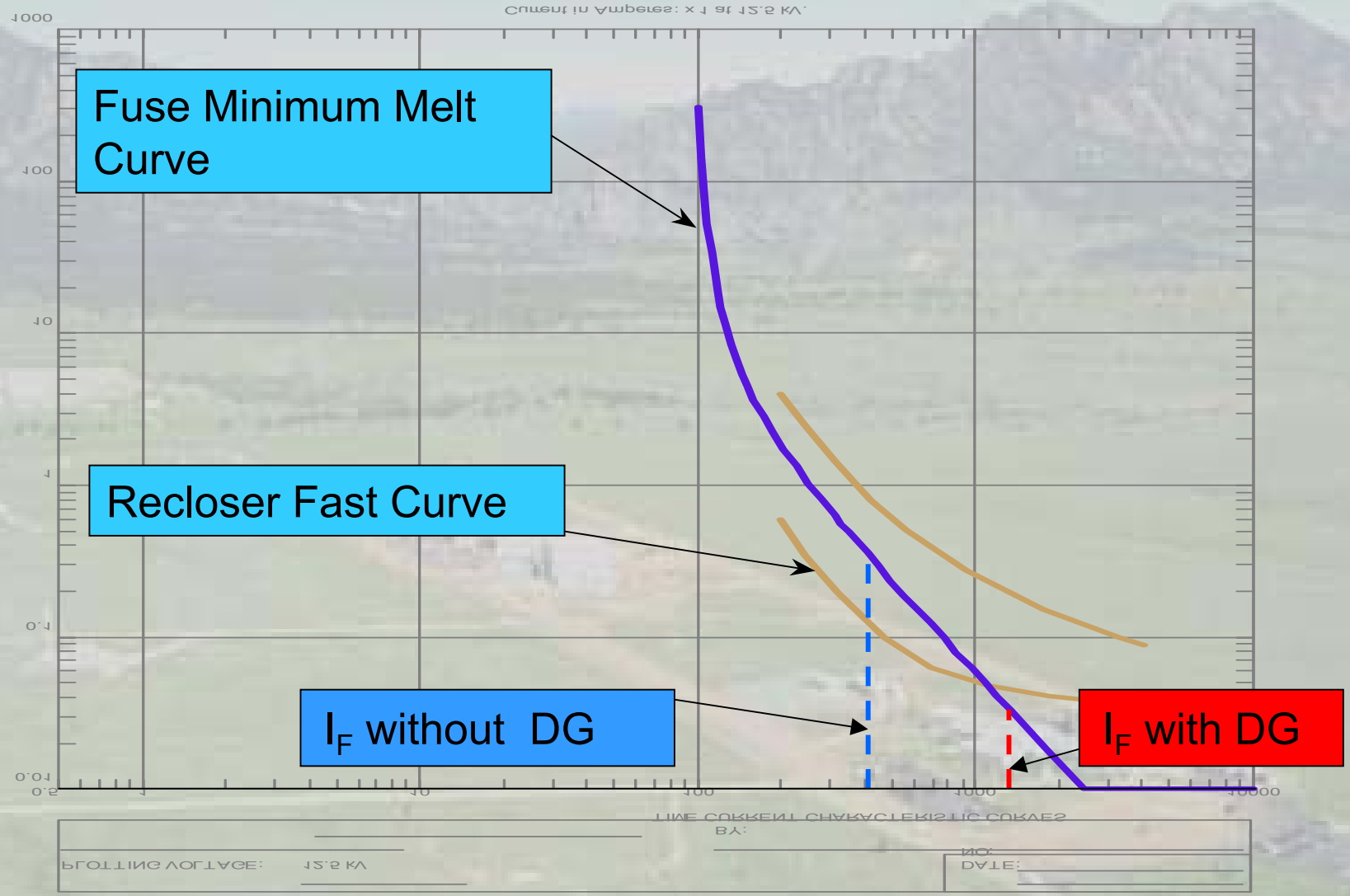
$I_R = I_F$

but

$I_R \neq I_{US}$

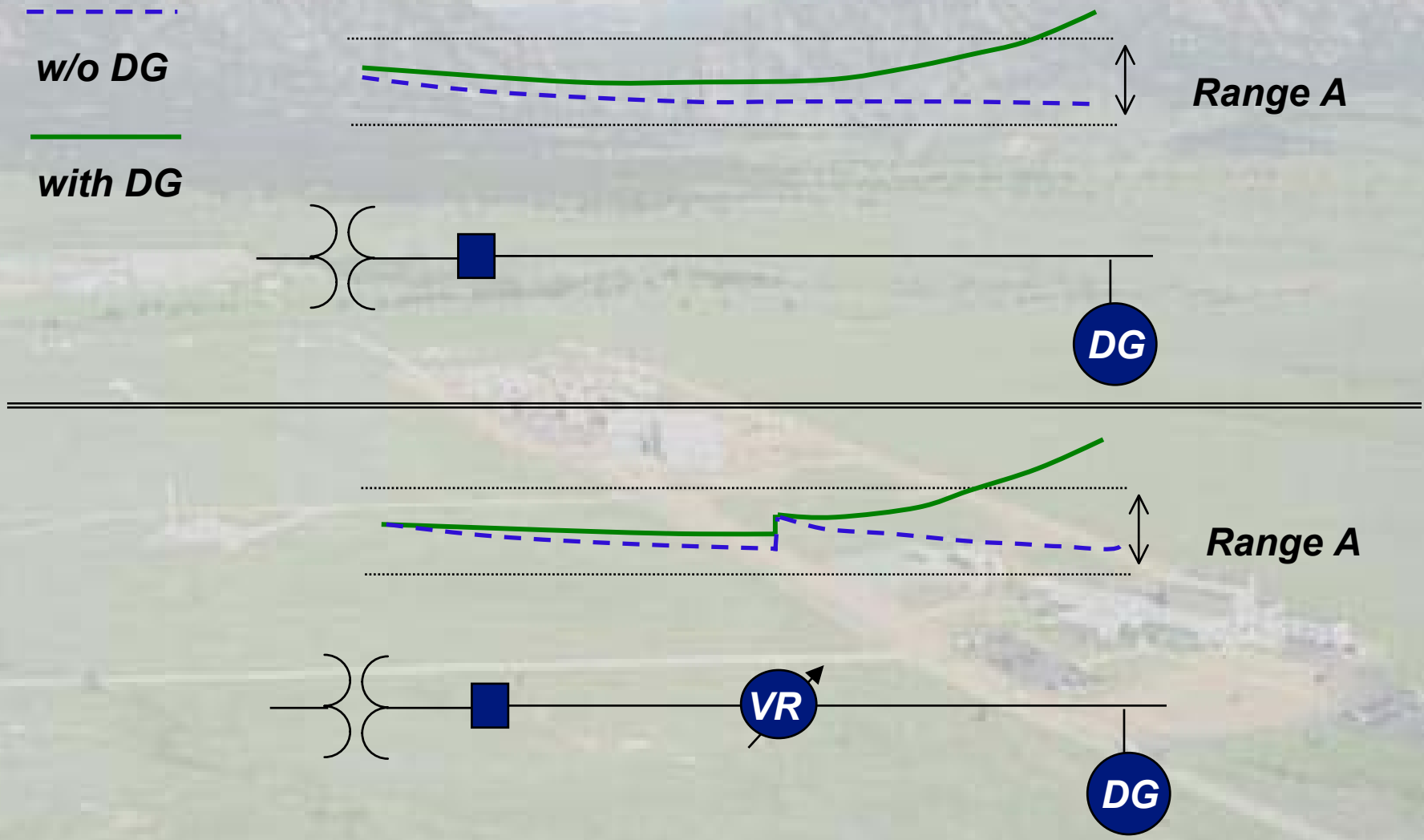
I_F = phase-to-ground without DG

I_F = phase-to-ground with DG



Time-current curves of recloser and fuse.

Voltage Regulation Issues



Moving Forward:

Some Key 1547 Standards Issues (Research Activities)

- Develop interconnection technology (hardware)
- Address field testing vs. type testing
- Interconnection equipment certification
- Evaluate secondary grid and spot networks
- Develop grid/DG monitoring and control
- Understand voltage regulation/stability
- Address grounding/faults
- Establish basis for DG penetration/aggregation
- Develop islanding methods and requirements

Moving Forward: Grid Modernization & 1547 Activities

Validation of, and Research on Integration of DR with Advanced Distribution Operating Concepts:

- IEEE 1547 covers Unintentional Islanding, Intentional Islanding, Secondary Networks, and Spot Networks.
- The current version of IEEE 1547 minimizes the utilization of distributed resources in the event of system disturbances.
- Research on the system integration of DR with all types of distribution operational concepts is necessary to revise IEEE 1547 to maximize the use of DR and realize the potential operational benefits at the transmission and distribution level.
- E.g., ***P1547.4 Guide for DR Island Systems*** -- Work Group inaugural meeting August 5 – 6, 2004.

Distributed Energy Resources

Fuel Cell

PV

Microturbine

Wind

Energy Storage

Generator

Interconnection Technologies

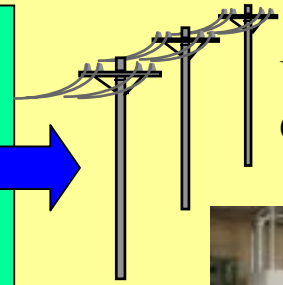
Inverter

Switchgear, Relays, & Controls

Functions

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

Electric Power Systems



Utility Grid

Utility Grid Simulator
Micro Grids

Loads

Local Loads

Load Simulators

Closing Remarks

- **Industry driven partnerships a success** for 1547 stakeholders.
- **DOE and NREL support --** facilitating and leading IEEE industry driven efforts.
- **IEEE 1547 American National Standard Published**

  (order at 800-678-4333, or http://shop.ieee.org/store/ search 1547)

- **1547 Series of Standards Development**

  Next meeting August 3-6, 2004

  - P1547.1 standard for interconnection test procedures
  - P1547.2 guide to 1547 standard
  - P1547.3 guide for information exchange for DR interconnected with EPS
  - P1547.4 guide for DR island systems

Contact & Resource Information

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- Ben Kroposki Phone 303-275-2979 – Email ben_kroposki@nrel.gov
- Dick DeBlasio Email deblasid@tcplink.nrel.gov
- NREL publications http://www.nrel.gov/publications or http://www.osti.gov/bridge (for help Amy_Vaughn@nrel.gov)

IEEE 1547 Standards Development

- IEEE SCC21 http://grouper.ieee.org/groups/scc21/dr_shared/
- IEEE Std 1547 (2003) Standard for Interconnecting Distributed Resources With Electric Power Systems http://standards.ieee.org/

Resource Information:

Basso, T.S. and DeBlasio, R. "IEEE P1547 Series of Standards for Interconnection: Preprint for IEEE Power Engineering Society Transmission and Distribution 2003 Conference and Exhibition" NREL/CP-560-34003. Golden, CO: NREL, May 2003.

Basso T.S. and DeBlasio, R. “IEEE 1547 Series of Standards: Interconnection Issues.” NREL Report No. 34882. September 2003.

Kroposki, B., Basso, T. and DeBlasio, R. “Interconnection Testing of Distributed Resources” Preprint for 2004 PES General Meeting, June 2004, NREL/CP-560-35569. Golden, CO: NREL.

NREL/SR-560-32459 Distributed Energy Resources Interconnection Systems: Technology Review and Research

NREL/BK-560-32865 Universal Interconnection Technology Workshop Proceedings