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INTRODUCTION TO THE IEEE 1547 STANDARD FOR DER GRID INTERCONNECTION, WITH ADDITIONAL ES CONSIDERATIONS

FOR THE LDES NATIONAL CONSORTIUM ANNUAL WORKSHOP

SESSION #2 REGULATORS/STANDARDS PANEL

IEEE STANDARDS COMMITTEE 21
SEPTEMBER 10, 2024

MICHAEL ROPP, SANDIA NATIONAL LAB, IEEE P1547.4 WORKING GROUP CHAIR

CHARLIE VARTANIAN, SANDIA (CONTRACTOR), IEEE SC21 EDUCATION COORDINATOR

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DISCLAIMER & ACKNOWLEDGMENTS

This presentation on IEEE Std 1547-2018 and its current revision, IEEE P1547, conveys the views of the author and is not the formal explanation or position of the IEEE.

Many thanks to IEEE P1547 Officers, Working Group members, and balloters who contributed their time and efforts to develop this standard.

OUTLINE

1. **IEEE 1547-2018 Introduction**

2. **IEEE 1547-2018 applied to Energy Storage including LDES**
   IEEE 1547.9 – new guide for applying IEEE 1547 to ES-DER

3. **Information and Educational Resources**

Key Takeaway

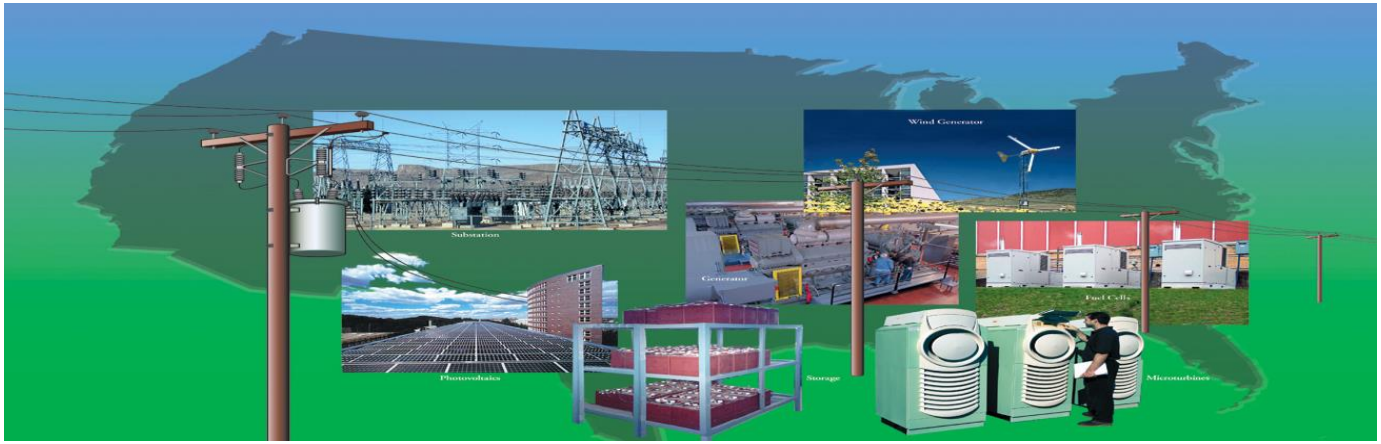
Don't reinvent the wheel for LDES projects' interconnection process: interconnection application, evaluation, and approval. Leverage existing interconnection standards, practices, and tools.

1. IEEE 1547-2018 Introduction

A high-level overview of IEEE Std 1547-2018, i.e. drivers, scope, applicability, and ongoing activities.

IMPORTANCE OF IEEE STD 1547

- **Energy Policy Act (2005) cites and requires consideration of IEEE 1547 Standards and Best Practices for Interconnection; all states use or cite IEEE Std 1547.**
- **Energy Independence and Security Act (2007): IEEE cited as a standards development organization partner to NIST as Lead to coordinate framework and roadmap for Smart Grid Interoperability standards and protocols {IEEE Std 1547 & 2030 series being expanded}.**
- **Federal ARRA (2009): Smart Grid & High Penetration DER projects {*use IEEE standards*}.**



IEEE STD 1547: USES

IEEE Std 1547 is:

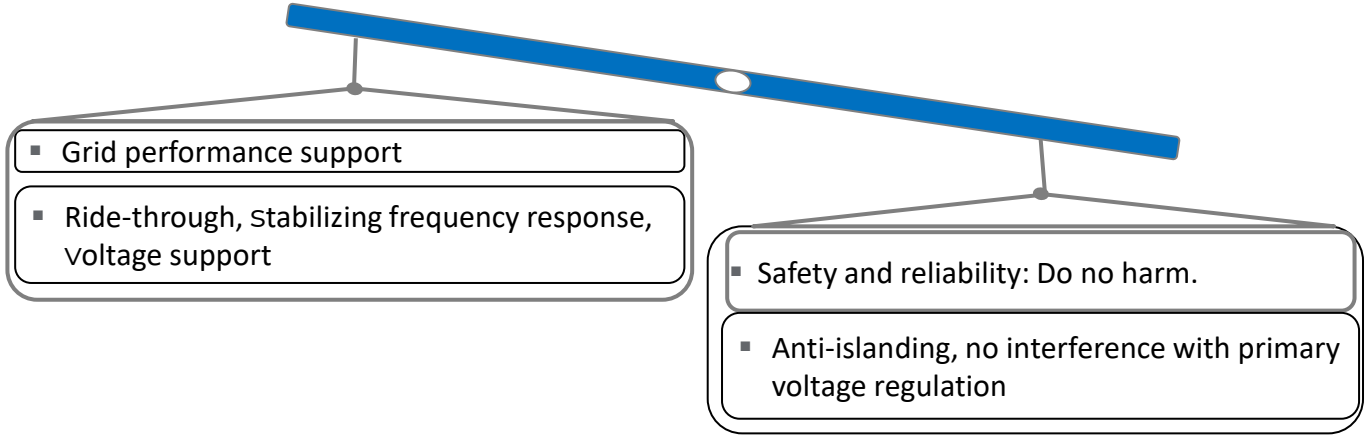
- A technical standard—functional requirements for the interconnection itself and interconnection testing
- A single (whole) document of mandatory, uniform, universal requirements that apply at the point of common coupling (PCC) or point of DER connection (PoC)
- Technology neutral—i.e., it does not specify particular equipment or type
- Should be sufficient for most installations

IEEE Std 1547 is not:

- A design handbook
- An application guide (see IEEE Std 1547.2)
- An interconnection agreement
- Prescriptive—i.e., it does not prescribe other important functions and requirements such as cyber-physical security, planning, designing, operating, or maintaining the area EPS with DER

GRID PLANNING AND OPERATION CHALLENGES

Increasing DER penetration was a major driver for revising IEEE Std 1547-2018



IEEE 1547 SCOPE AND PURPOSE AND IEEE P1547

Title: IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces

Scope: This standard establishes criteria and requirements for interconnection of distributed energy resources (DER) with electric power systems (EPS), and associated interfaces.

Purpose: This document provides a uniform standard for the interconnection and interoperability of distributed energy resources (DER) with electric power systems (EPS). It provides requirements relevant to the interconnection and interoperability, operation, testing, safety, maintenance and security considerations.

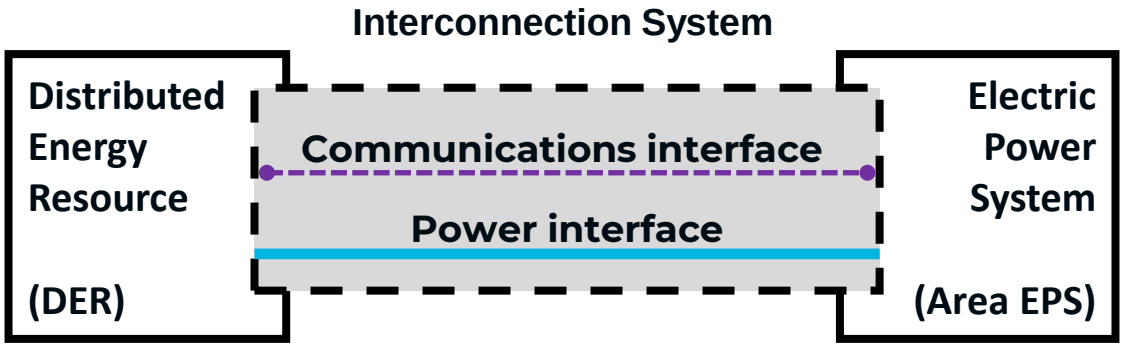


Image based on IEEE Std 1547-2018

Interconnection system: The collection of all interconnection equipment and functions, taken as a group, used to interconnect DER to an area EPS. Note: In addition to the power interface, DER should have a communications interface.

Interface: A logical interconnection from one entity to another that supports one or more data flows implemented with one or more data links.

IEEE STD 1547-2018: DOCUMENT OUTLINE (CLAUSES)

1. Overview
2. Normative references
3. Definitions and acronyms
4. General specifications and requirements
5. *[normal grid]* Reactive power, voltage/power control
6. Response to Area EPS abnormal conditions
7. Power quality
8. Islanding
9. Distribution secondary grid and spot networks
10. Interoperability
11. Test and verification
12. Seven new annexes (Informative)

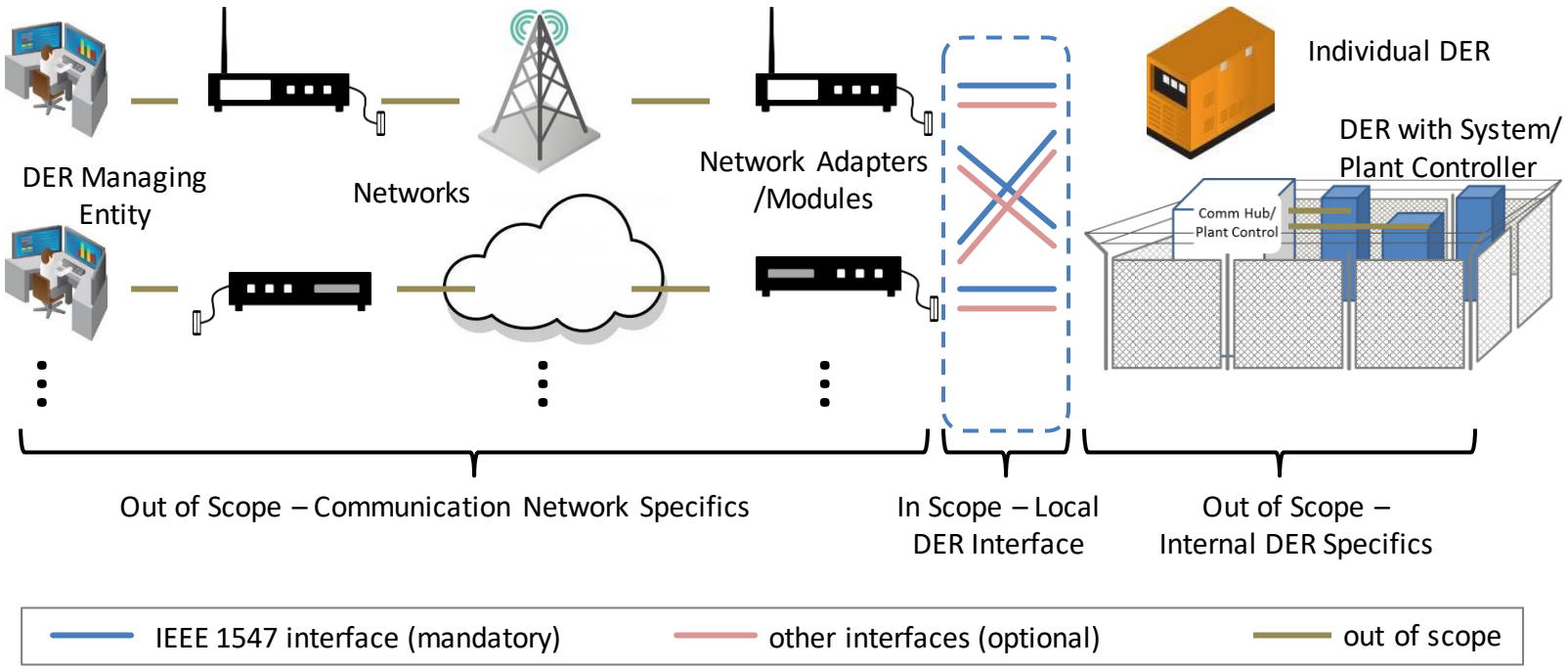
IEEE 1547-2019 CLAUSE 1.4, GENERAL REMARKS AND LIMITATIONS

- **Applicable to all DER connected at typical primary or secondary distribution voltage levels.**
  - Removed the 10 MVA limit from previous versions.
  - BUT: Not applicable for transmission or networked sub-transmission connected resources.
- **Specifies performance and not design of DER.**
- **Specifies capabilities and functions and not utilization of these.**
- **Does not address planning, designing, operating, or maintaining the Area EPS with DER.**
- **Emergency and standby DER are exempt from certain requirements of this standard.**
  - E.g., voltage and frequency ride-through, interoperability and communications.
- **Gives precedence to synchronous generator (SG) design standards for DER with SG units rated 10 MVA and greater.**
  - E.g., IEEE Std C50.12, IEEE Std C50.13.

1547-2018 ADDED INTEROPERABILITY REQUIREMENTS IN CLAUSE 10, LIST OF 1547-COMPLIANT COMMUNICATIONS PROTOCOLS

Protocol	Transport	Physical Layer
IEEE Std 2030.5™ (SEP2)	TCP/IP	Ethernet
IEEE Std 1815™ (DNP3)	TCP/IP	Ethernet
SunSpec Modbus	TCP/IP	Ethernet
	N/A	RS-485

SCOPE OF INTEROPERABILITY REQUIREMENTS



1547.9 GUIDE FOR USING 1547 WITH ES, LOWERING BARRIERS TO ADOPTION

Interoperability, information exchange, info. models and protocols.

Clause 10 of 1547.9 discusses energy storage-specific changes in the interoperability requirements laid down in the base standard.

Most **of the examples are cases of ES-specific parameters that need to be added to the reporting requirements.**

One example is shown at right (ESS-specific additions to Table 29 in 1547-2018).

Table 29—Monitoring information [1547]

In Table 29 [1547], the following rows should be added:

Parameter	Description
State of charge	
Temperature [a]	Temperature in degrees Celsius

[a] This temperature can be the overall temperature of the ES DER unit or, for large installations, the temperatures of individual cells and/or other units.

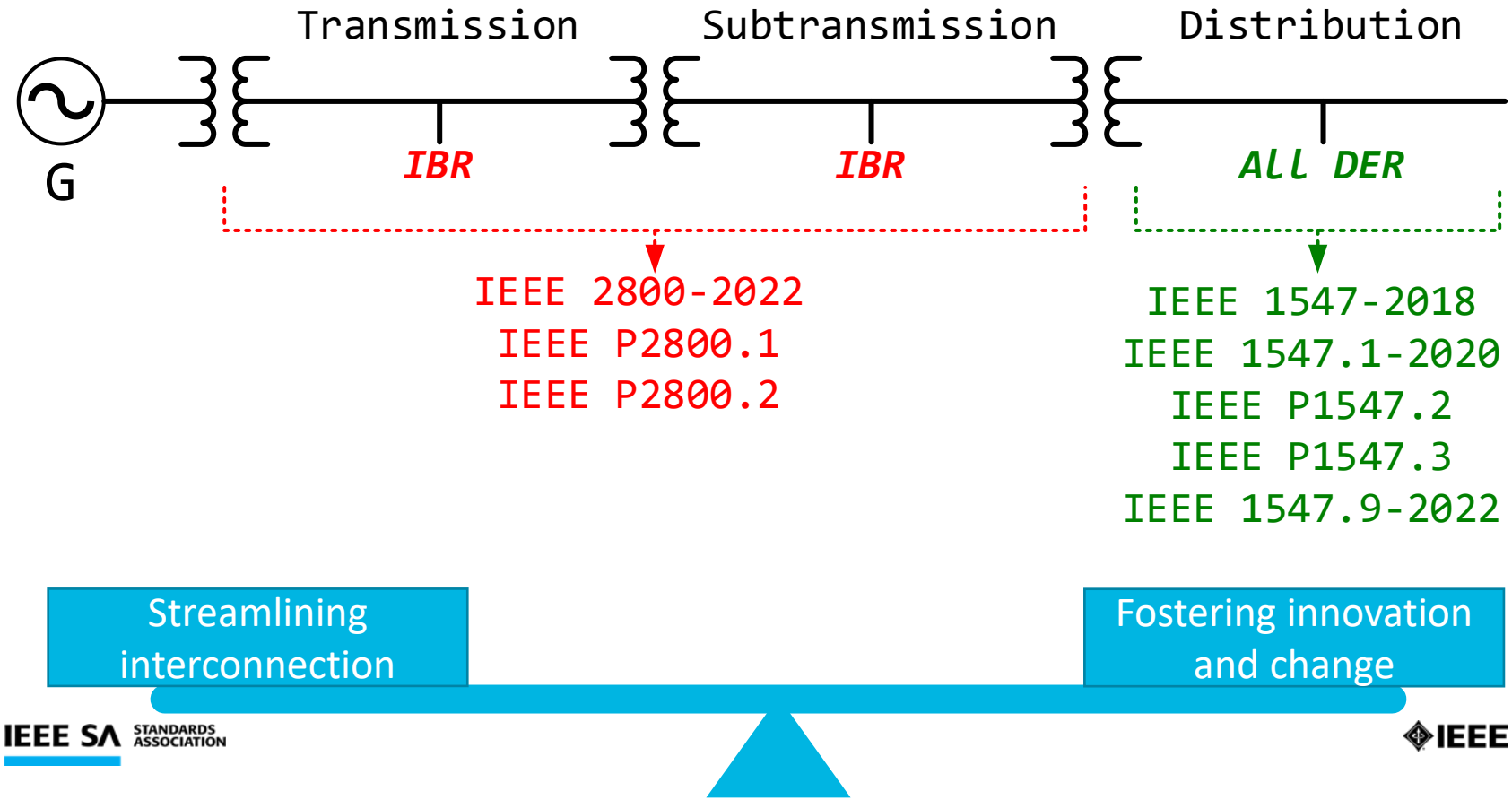
In Table 29 [1547], the following rows should be added if the ES DER has such parameters:

Parameter	Description
Smoke Detection	Smoke has been detected indicating fire
Flame Detection	Flame has been detected indicating fire
Off-Gas Detection	Hydrogen has been detected
Fire Protection System Detection	The fire protection system has activated

In Table 29 [1547], for ES DER the following rows should be changed as shown (**emphasis** added to identify the change):

Parameter	Description
Operational State	Operational state of the DER. The operational state should represent the current state of the DER. The minimum supported states are on and off, but additional states may also be supported. **Include charging and discharging as operational states of the DER.**

IEEE STANDARDS APPLICABLE TO INTERCONNECTION, COORDINATING ACROSS T&D



ABNORMAL PERFORMANCE CATEGORIES, SPECIFIED BY AN AUTHORITY HAVING JURISDICTION (E.G. PUC) PER JURISDICTION NEEDS AND INPUT

Category	Objective	Foundation
I	Essential bulk system needs and reasonably achievable by all current state-of-art DER technologies	German grid code for synchronous generator DER
II	Full coordination with bulk power system needs	Based on NERC PRC-024, adjusted for distribution voltage differences (delayed voltage recovery)
III	Ride-through designed for distribution support as well as bulk system	Based on California Rule 21 and Hawaii Rule 14H

Category II and III are sufficient to support bulk system reliability.

IMPORTANT RESOURCE FOR TRANSMISSION LEVEL INTERCONNECTION APPLICATION AND STUDIES: VALIDATED BESS AND IBR MODELS

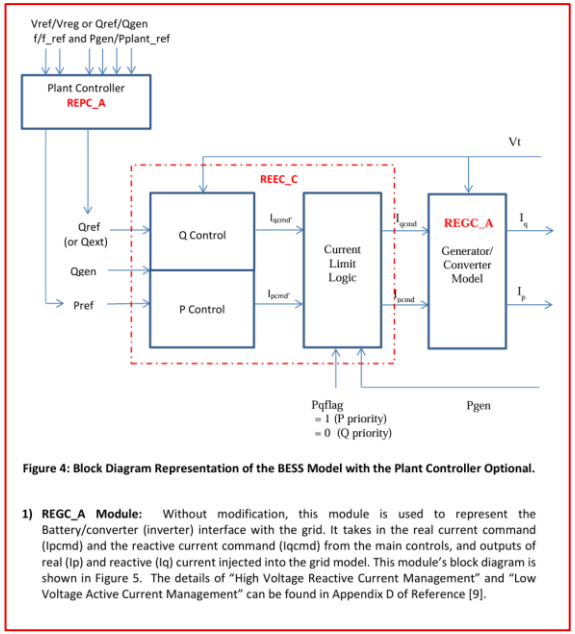


Figure 4: Block Diagram Representation of the BESS Model with the Plant Controller Optional.

1) **REGC_A Module:** Without modification, this module is used to represent the Battery/converter (inverter) interface with the grid. It takes in the real current command (Ipcmd) and the reactive current command (Iqcmd) from the main controls, and outputs of real (Ip) and reactive (Iq) current injected into the grid model. This module's block diagram is shown in Figure 5. The details of "High Voltage Reactive Current Management" and "Low Voltage Active Current Management" can be found in Appendix D of Reference [9].

Source, WECC

Source, PNNL

GFM Model very important to accessing full ES performance potential

Lowering barriers: this ES model is applicable to ***existing*** system simulation tools as used for interconnection System Impact Studies

2. IEEE 1547-2018 and Energy Storage including LDES

IEEE 1547.9 – new guide for applying IEEE 1547 to ES-DER

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WHAT'S IN 1547.9?

1547.9 focuses on applying 1547 to energy storage. Examples:

- ES-specific terminology (e.g., "operational SoC" and "operational capacity")
- Black Start
- Clarifying volt-var support modes
- Fast Frequency Response
- Voltage and Frequency Ride-through Exemptions
- ES DERs in Secondary Networks
- ES Specific Changes in Interoperability requirements
- ES DER's specific testing requirements
- Safety
- V2G

WHAT'S IN 1547.9?

Scope clarification. I.e. 'When is ES in-scope of 1547?'

Any energy storage DER that is "capable of active power export" is in-scope. What does that mean?

capable of exporting active power = any ES DER that is capable of serving load simultaneously with the Area EPS.

Examples of systems and whether they are in-scope:

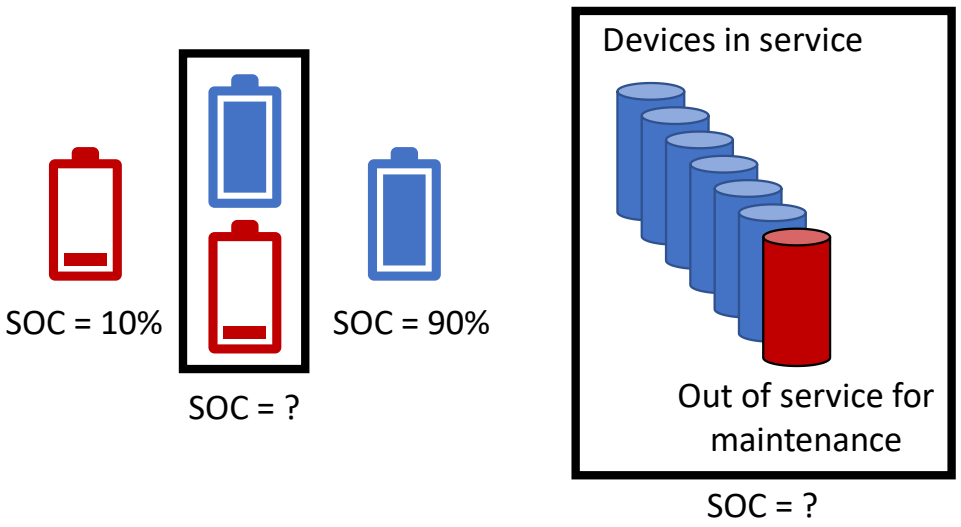
UPS?	PV + ES?	V1G?	V2G?
No	Yes	No	Yes

WHAT'S IN 1547.9?

Defines Operational State of Charge. A term used in IEEE 1547-2018.

operational state of charge: the usable energy stored as a proportion of the operational capacity, expressed as a percentage.

operational capacity: the estimated energy that an energy storage system can provide on discharge, subject to operational constraints. Examples of factors influencing operational capacity include rated energy, state of health, discharge rate, temperature, and usable state-of-charge range.



WHAT'S IN 1547.9?

Operational models.

Operational state of charge and operational capacity aren't sufficient for automated control or state forecasting. For that, an operational model is needed, and 1547.9 discusses that. The figure at the right demonstrates some of what an operational model can tell you.

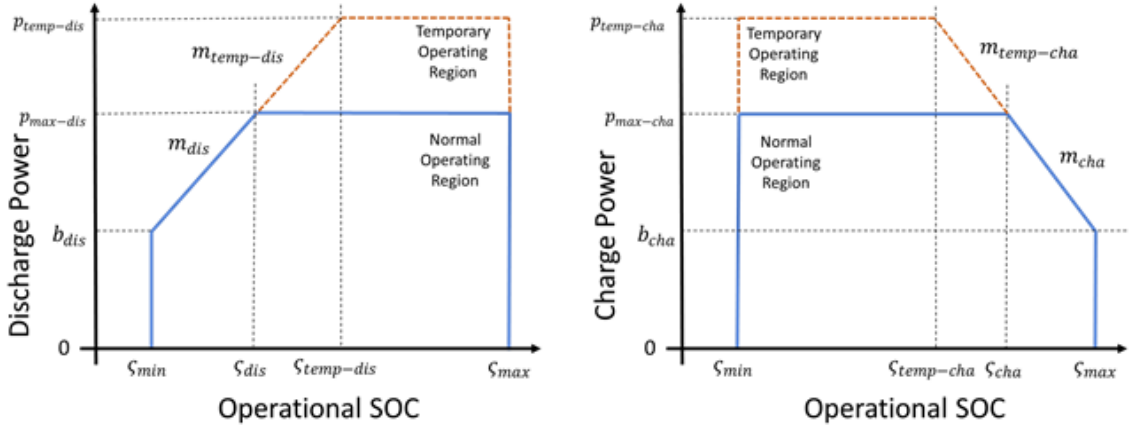


Figure 3—Discharge power (left) and charge power (right) operating regions defined by the operational model constraints

What's in 1547.9?

Participation in black start/system restoration

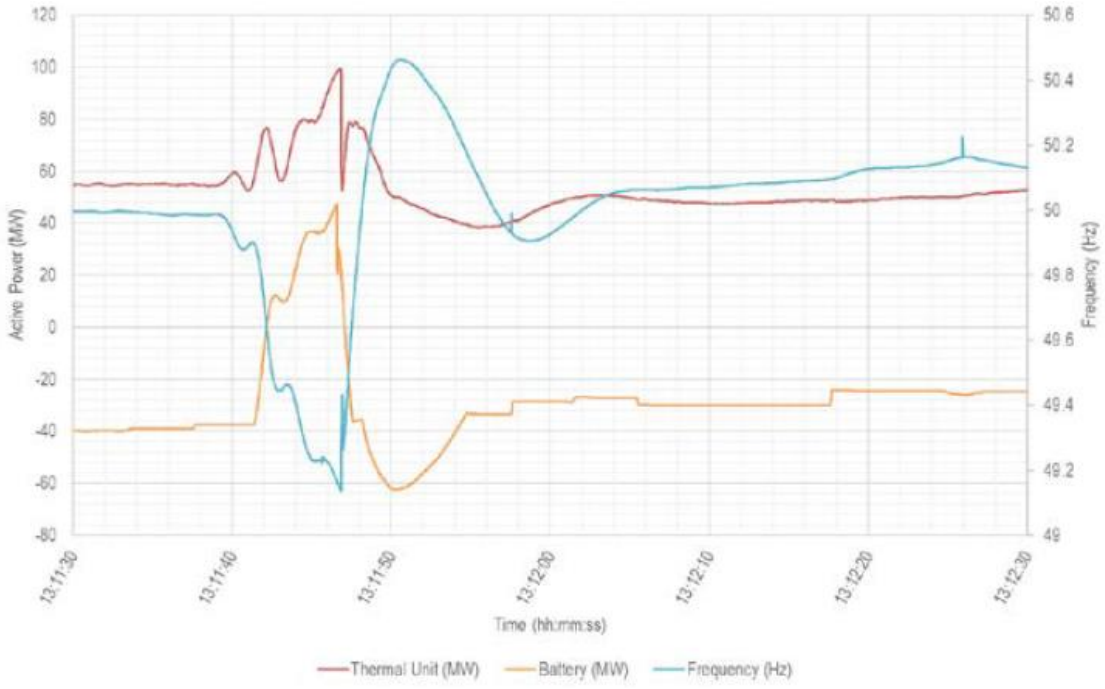
- ❑ **An ES DER with isochronous control capability might energize an intentional (planned) island.**
- ❑ **If that ES DER is allowed to temporarily energize some part of the Area EPS outside of the planned island, then it may assist in system restoration after an outage.**
- ❑ **However, 1547-2018 only discusses reconnexion of an intentional island system to an Area EPS *that is already energized*. There is no provision for connecting a de-energized part of an Area EPS to an energized intentional island.**
- ❑ **1547.9 suggests that this kind of assistance with restoration can be allowed, in coordination with the Area EPS operator. Synchronization conditions, adjustments to some parameters, and ensuring ES DER operator awareness of the responsibilities concomitant with participation in system restoration are all discussed.**

WHAT'S IN 1547.9?

Fast Frequency Response (FRR).

1547-2018 permits, but does not require or further describe, fast frequency response (FFR). FFR comes in different forms such as synthetic inertial response (power $\propto df/dt$). It is likely that FFR will be deployed in many ES DERs.

1547.9 discusses inertial response and its deployment in ES DERs. ***(Note: IEEE 2800-2022 does require FFR capability and goes into detail on FFRs for transmission-connected ESSs.)***



IMPACT OF REVISING 1547-2003 ON ES APPLICATIONS, UPDATES MADE TO 1547-2018 REMOVED OTHERWISE UNINTENDED BARRIERS TO SOME ES APPLICATIONS

Category	Storage "End Use"
ISO/Market	• Frequency regulation • Spin/non-spin/replacement reserves • Ramp • Black start • Real time energy balancing • Energy price arbitrage • Resource adequacy
VER Generation	• Intermittent resource integration: wind (ramp/voltage support) • Intermittent resource integration: photovoltaic (time shift, voltage sag, rapid demand support) • Supply firming
Transmission/ Distribution	• Peak shaving: off-to-on peak energy shifting (operational) • Transmission peak capacity support (upgrade deferral) • Transmission operation (short duration performance, inertia, system reliability) • Transmission congestion relief • Distribution peak capacity support (upgrade deferral) • Distribution operation (Voltage Support/VAR Support) • Outage mitigation: micro-grid
Customer 7	• Time-of-use /demand charge bill management (load shift) • Power quality • Peak shaving (demand response), Back-up power

1547-2003 vs. new CA 21 & 1547Revision

Source (original table): CA PUC, AB2514 workshop 3/25/2013

FINAL THOUGHTS ON GRID INTERCONNECTION AND LDES

ES-enhancements to 1547 Standard via new 1547.9 'Guide for ES Interconnection' apply to LDES.

But, latest updates and new interconnection standard (IEEE 2800) are Inverter or 'IBR' centric. Industry awareness and education may be needed to leverage similar mapping of rotating-machine-connected-LDES to established interconnection models, standards, and processes for rotating-machine based grid resources

The models developed for BESS's for use in grid System Impact Studies apply to LDES. Note, for grid impact studies, the timeframes are instantaneous (load flow) and 0-15 seconds (dynamic stability). The longer discharge capability of LDES impacts the applications and economics considerations addressed in other project development tasks. That being said, …

One caution – watch for and avoid inadvertent limitations to delivering 'firm capacity' related to the grid interconnection evaluation and/or approval for an LDES project.

Improving the interconnection process, e.g. addressing application backlog and 'queuing' is a general industry challenge that LDES stakeholders should consider tracking or even engaging. One resource is, [Interconnection Innovation e-Xchange | Department of Energy]

3. Information and Education Resources

Learning more about grid interconnection standards and practices benefits all ES stakeholders

IEEE 1547-2018 ADVANCEMENT

THE IEEE 1547 FAMILY OF STANDARDS

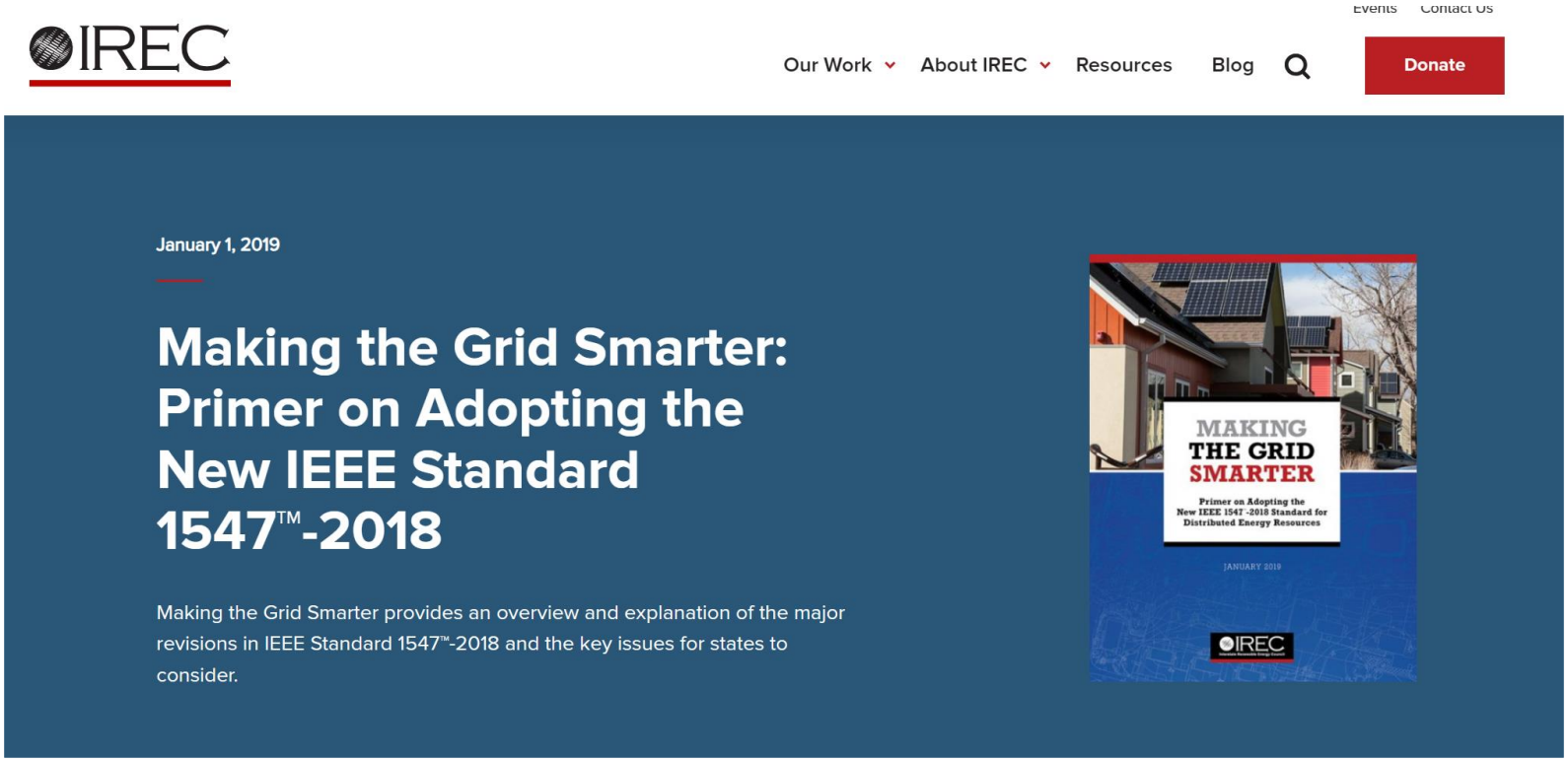
Standard number	Standard title	Status
IEEE 1547-2018™	IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces	Active; revision underway
IEEE 1547.1-2020™	IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces	Active
IEEE 1547.2-2008™	Application Guide for IEEE Std 1547™	New version in balloting
IEEE 1547.3-2023™	Guide for Cybersecurity of Distributed Energy Resources Interconnected with Electric Power Systems	Active
IEEE 1547.4-2011TM	IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems	Revision underway; target for publication is June 2027
IEEE 1547.6-2011™	IEEE Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Networks	Inactive—candidate for revision
IEEE 1547.7-2013™	IEEE Guide for Conducting Distribution Impact Studies for Distributed Resource Interconnection	Active—forming revision WG soon
IEEE 1547.9-2022™	Draft Guide to Using IEEE Std 1547™ for Interconnection of Energy Storage Distributed Energy Resources with Electric Power Systems	Active
IEEE P1547.10	Recommended Practice for Distributed Energy Resources (DER) Gateway Platforms	New standard; WG active

IEEE SA STANDARDS ASSOCIATION

IEEE 32

Source, IEEE Standards Committee 21 (IEEE SC21) sponsor of the IEEE 1547 family of standards and guides

IEEE 1547-2018 ADOPTION-SUPPORT RESOURCE



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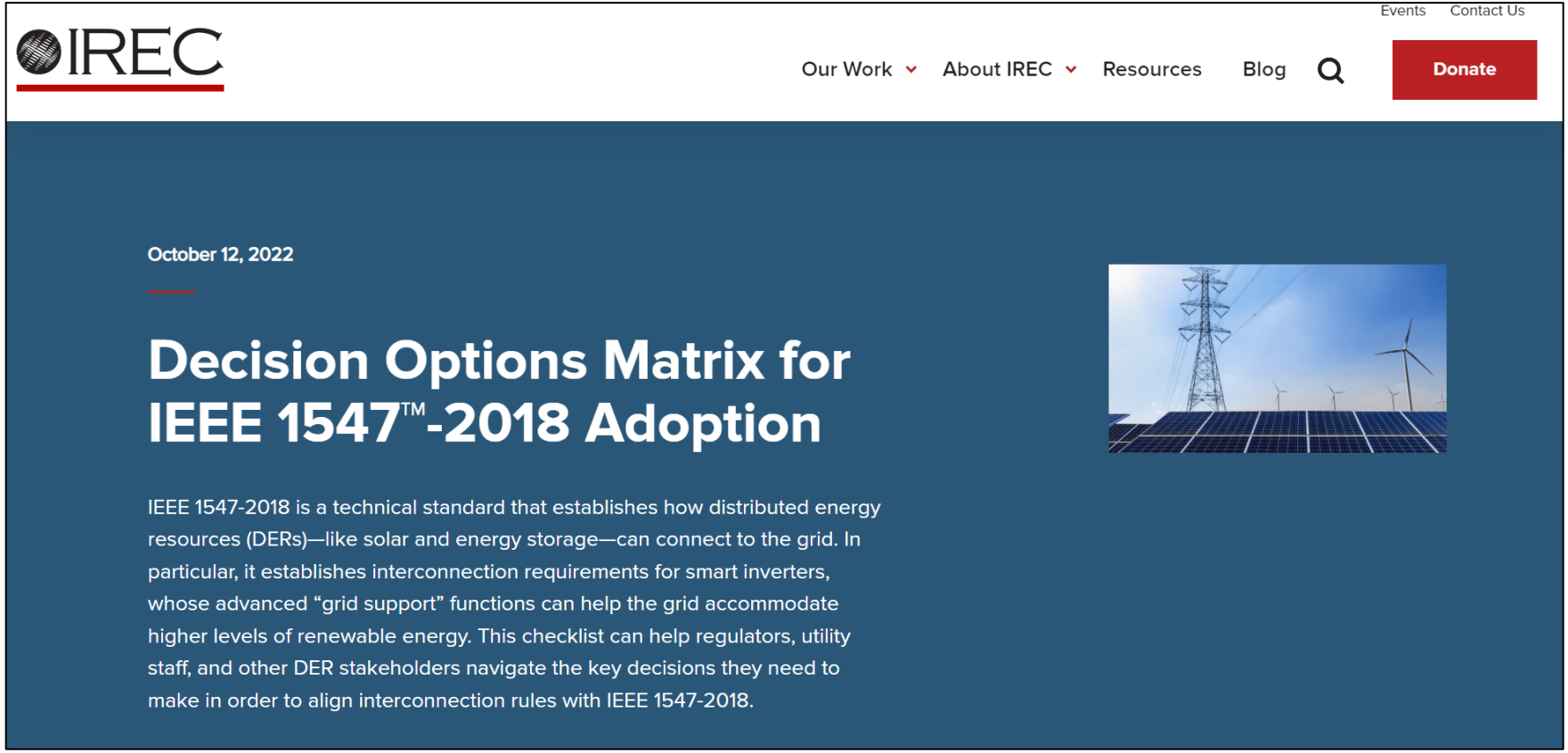
IEEE 1547-2018 ADOPTION-SUPPORT RESOURCE



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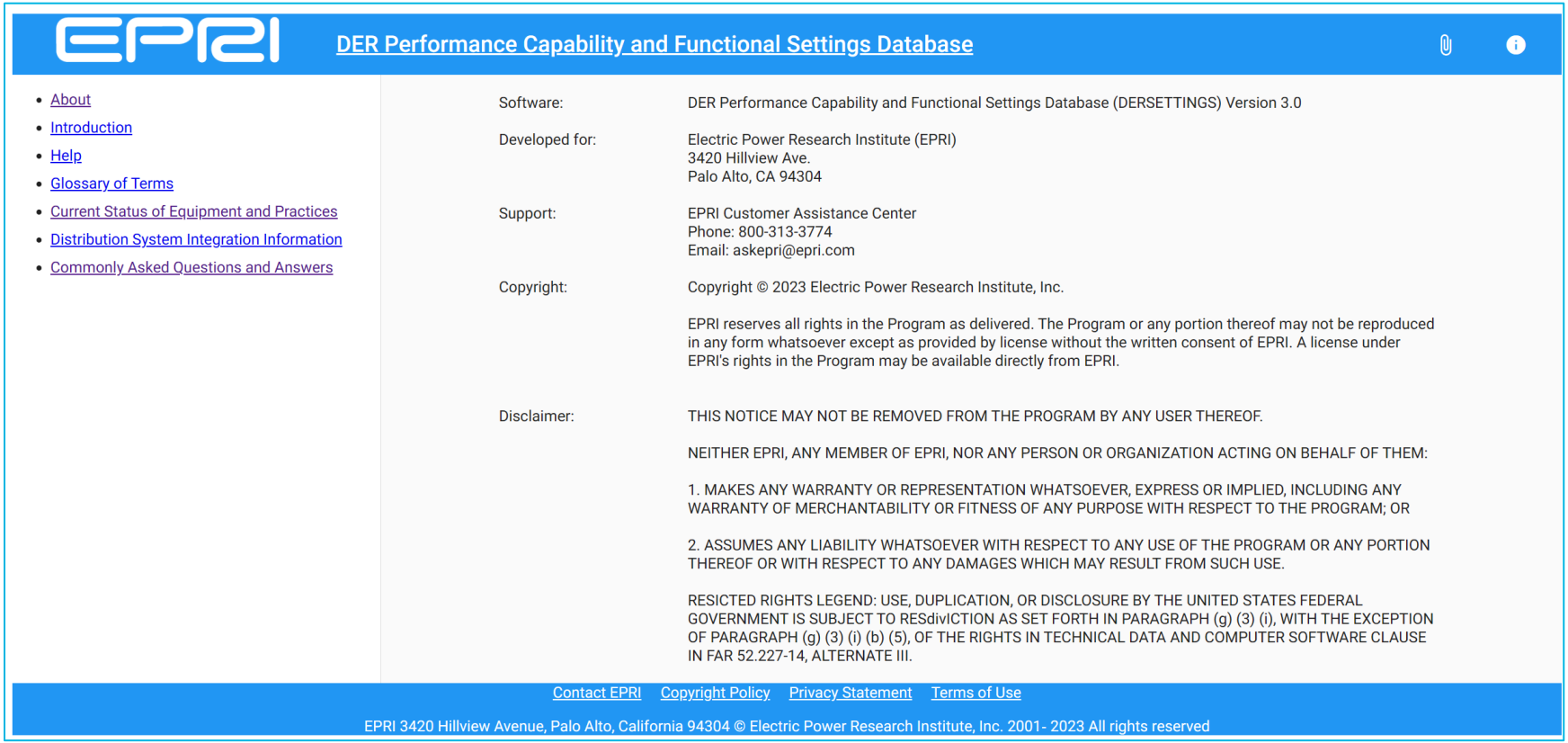
IEEE 1547-2018 APPLICATION RESOURCE



DER Performance Capability and Functional Settings Database

- About
- Introduction
- Help
- Glossary of Terms
- Current Status of Equipment and Practices
- Distribution System Integration Information
- Commonly Asked Questions and Answers

Software: DER Performance Capability and Functional Settings Database (DERSETTINGS) Version 3.0

Developed for: Electric Power Research Institute (EPRI)
3420 Hillview Ave.
Palo Alto, CA 94304

Support: EPRI Customer Assistance Center
Phone: 800-313-3774
Email: askepri@epri.com

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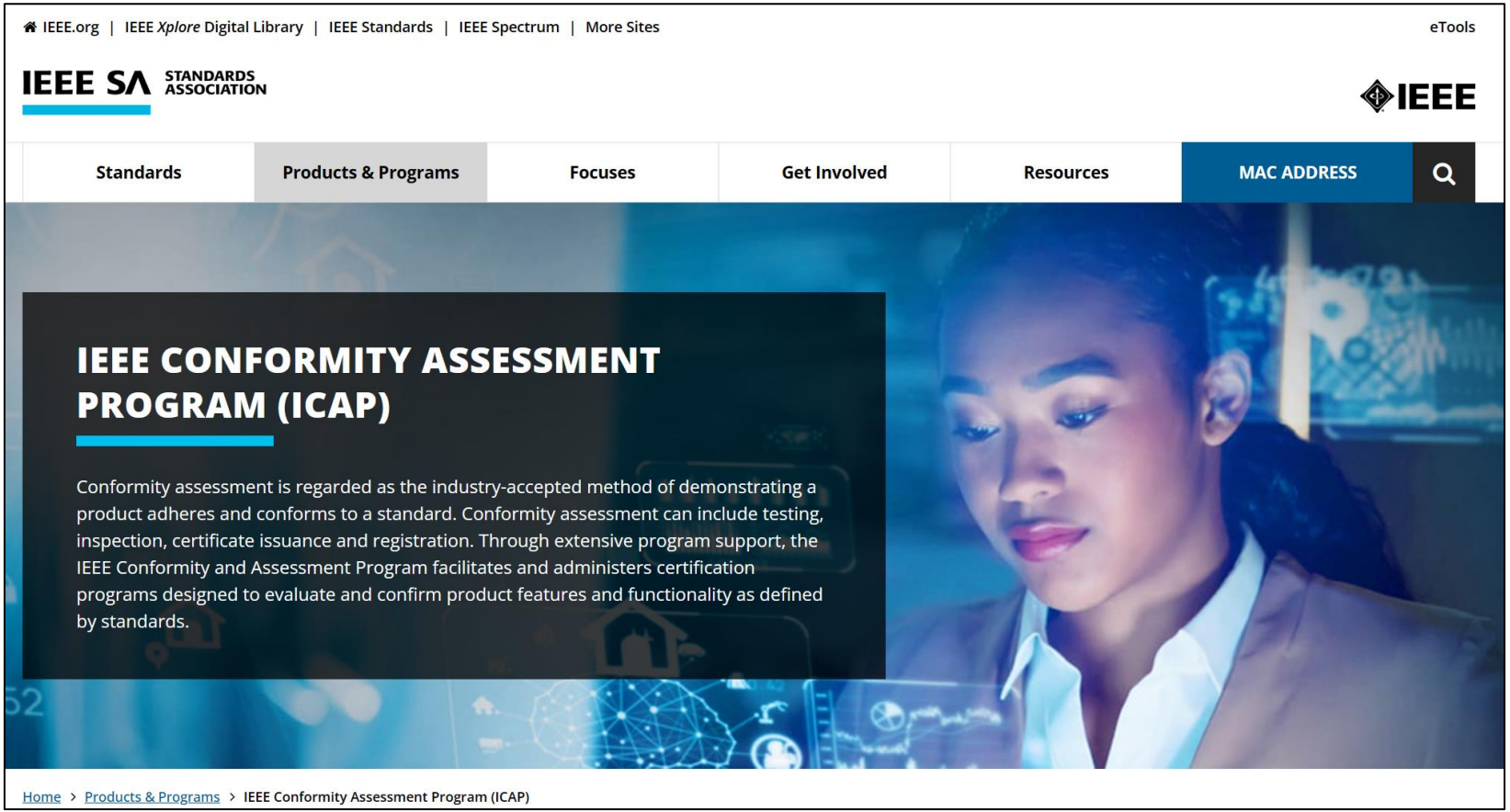

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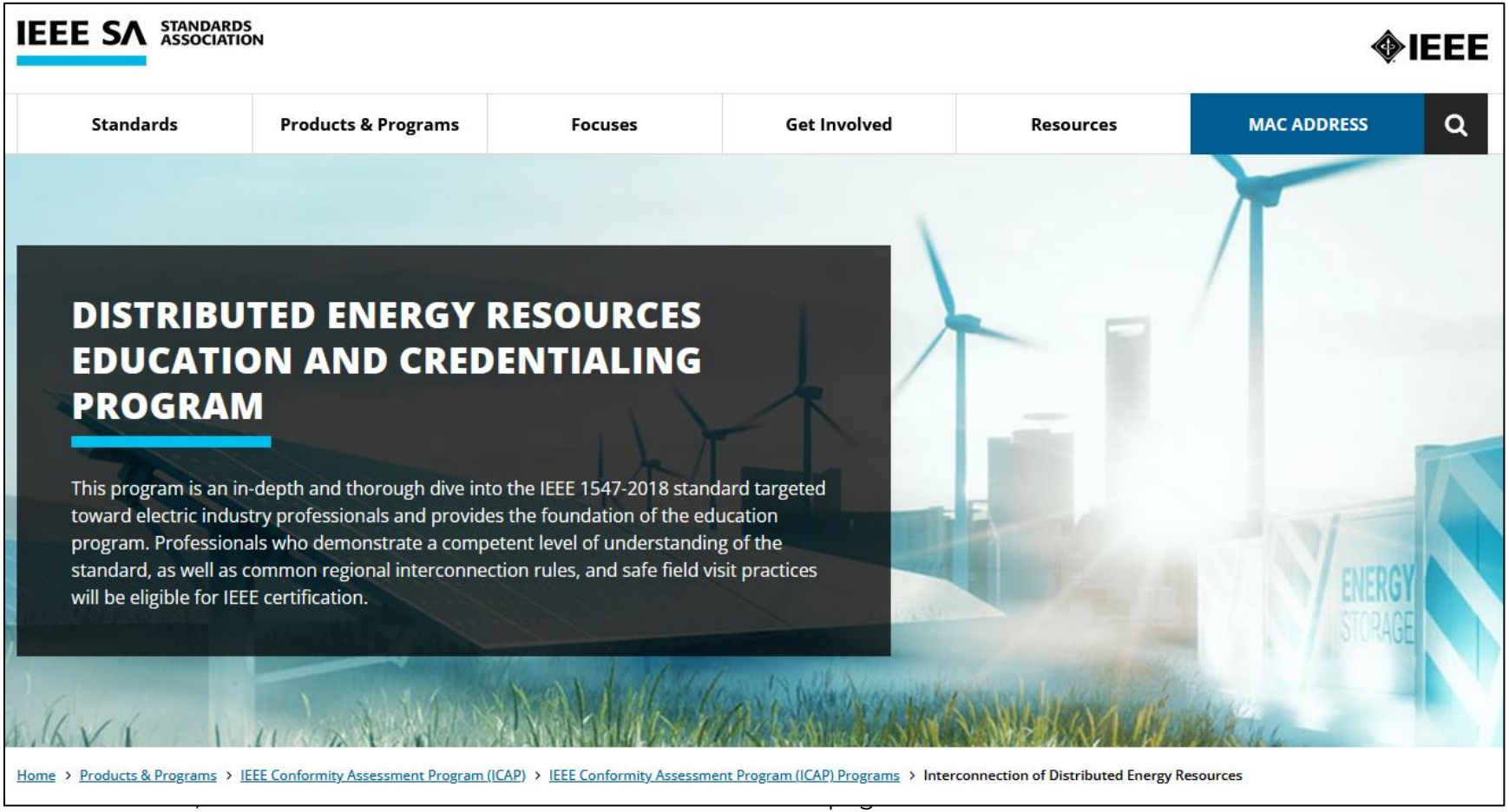

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IEEE SA - IEEE Conformity Assessment Program (ICAP)

IEEE SA – IEEE Distributed Energy Resources Education and Credentialing program

Making the Grid Smarter: Primer on Adopting the New IEEE Standard 1547™-2018 - Interstate Renewable Energy Council (IREC) (irecusa.org)

Decision Options Matrix for IEEE 1547™-2018 Adoption - Interstate Renewable Energy Council (IREC) (irecusa.org)

DER Settings Database (epri.com)

Rule 21 Interconnection (ca.gov)

UL 1741 | UL Standards & Engagement | UL Standard (shopulstandards.com)

Learn More about NFPA | The National Fire Protection Association

ESD Modeling Guidelines - Final (wecc.org)

THANK YOU!

Please feel free to email me with questions:

meropp@sandia.gov

Special thanks to DOE – Office of Electricity, Energy Storage Program.