12-5-19 v. Final

MDV-SEIA Advanced Inverter Workshop
December 5, 2019

"Maximizing the Use of Advanced Inverters and the New IEEE 1547-2018 Standards to Meet the District of Columbia's Solar and Clean Energy Mandates"

Event Description

Sponsor: MDV-Solar Energy Industries Association (SEIA)
https://mdvseia.org/

Purpose

The workshop will provide background education to local solar, storage and other DER industry staff on maximizing the use of advanced inverter functions (both autonomous and utility controlled) at present and under the new IEEE 1547-2018 standard being deployed nationally in 2022, to meet the District of Columbia's aggressive new statutory solar carve-outs and overall clean energy mandates.

Event Details

Date: Thursday, December 5, 2019
Time: 10:00 am – 2:00 pm *Lunch will be served*
Location: SEIA Headquarters, 1425 K Street, NW, Suite 1000, Washington, DC 20005

RSVP: This event is by invitation, space is limited.
Please contact David Murray at email below if you are interested in attending.
Address Questions to: David Murray, dmurray@mdvseia.org

MDV-SEIA Advanced Inverter Workshop
December 5, 2019
AGENDA

"Maximizing the Use of Advanced Inverters and the New IEEE 1547-2018 Standards to Meet the District of Columbia's Solar and Clean Energy Mandates"

Introduction
10:00 am – 10:15 am **Workshop Mission & Goals**

A. **Achieving the District of Columbia's Aggressive Solar Carve Out and Clean Energy Mandates**
B. **Educating Local Solar Industry on Maximizing the Use of Advanced Inverters and new IEEE 1547-2018 Standards for**

optimal DER on the District's Grid – at present and going forward

C. Workshop Outline

.Introducer: Mike Healy, Vice President of the Board, MDV-SEIA. Former Treasurer, Board of Directors, SEIA. Founder & CEO, New Columbia Solar, Washington, DC. He is a leader and influencer in DER development in the District of Columbia. His 10 years of expertise in the clean energy industry include serving as Founder & partner of Nextility Inc. and ConnectDER.

Session I

10:15 am – 10:45 am **Overview of Advanced Inverter Capabilities and New Functions under IEEE 1547-2018 Standards**

A. What are they? What can they do? Now? Soon? In the medium term?
B. Inverter Autonomous Functions
C. Inverter Utility/Grid Controlled Functions

.Speaker: Harry Warren, Mechanical Engineer, President, CleanGrid Advisors LLC, Co-Founder, Center for Renewables Integration. He is currently a Visiting Fellow at Princeton University's Andlinger Center for Energy and Environment, working with faculty, staff and students on grid decarbonization research. His decades of experience in the power industry includes 17 years as President, Washington Gas Energy Services. Recently, he has been the leader of the Smart Inverter Subgroup in the Maryland grid modernization docket.

10:45 am – 11:00 am **Discussion**

Session II

11:00 am – 11:40 am **The District of Columbia's Unique Grid Challenges & Constraints**

A. Requirements of the District's ("Downtown") Mesh Low-Voltage Network
B. Features of the District's Radial Grid
C. Local Solar and DER Industry Case Study in Interconnection & Hosting Capacity Challenges

. Speaker: Jorge Camacho, Electrical Engineer - Power Sector, Serves on IEEE Standard 1547 Interconnection Conformity Assessment Steering Committee. Formerly Chief, Office of Infrastructure & System Planning, D.C. Public Service Commission.

. Discussants/ Respondents, including:
Albert Lafrance, Operations and Maintenance, New Columbia Solar. He has been a Solar Industry technical professional for 20 for years, largely focused on the District of Columbia.

11:45 am – 12:00 am **Discussion**

12:00 pm – 12:45 pm **Lunch**

Session III

12:45 pm – 1:45 pm **Fully Utilizing Advanced Inverters to Lift Barriers for Maximizing Solar and DER installation on the District of Columbia Grids – Now & Going Forward – On the Radial & Networked Systems**

A. Present: Maximizing Use of Interim Standards Autonomous Inverter Features Available Now to Lift Hosting Capacity and Other Barriers Based on Other Jurisdictions' Experience (e.g., California and Hawai'i standards that predate IEEE 1547-2018).

B. Near Term: Adopting the New IEEE 1547-2018 Inverter Standard To Further Break Down DER Integration Barriers: Identifying key considerations that should guide the selection of Inverter Modes and Settings (and associated Management Software) in time for the January 2022 full deployment of the IEEE 1547-18 Standards*

C. Medium Term: Inverter Functionalities Under Future Phase of The 1547-2018 Standards (now under development) That Will Allow For Utility Controls of Inverters, Further Breaking Down Barriers to DER Integration and Enabling new DER Benefits to the Grid. What would be the reasons for not going for this maximum inverter capacity and planning for it as of now?

D. Next Steps

. Speaker 1: Charlie Vartanian, Electrical Engineer, Sr. Technical Advisor for Pacific Northwest National Labs (PNNL). He has 25 years of power industry experience deploying advanced grid technologies, performing electric system studies, and contributing to technical standards development, with industry, the California Energy Commission and So. California Edison utility. He is on the IEEE 1547 Leadership Team.

. Speaker 2: Clayton Stice, Principal Engineer of Emerging Technologies at the Electric Reliability Council of Texas (ERCOT), assists with efforts to maintain long term reliability of the ERCOT grid by including and developing strategies for accommodating Distributed Energy Resources. Formerly, Power System Principal Engineer, Austin Energy, he has over 10 years of experience in distribution systems with an emphasis on DERs and interconnections. He has IEEE standard 1547 specialization in networked distribution grids.

.Discussants/Respondents: will include prior speakers.

1:45 pm – 2:10 pm: **Discussion**

2:10 pm – 2:15 pm: **Wrap-Up**
MDV-SEIA Representative

[*B-C-D will focus on Guiding Considerations. We recognize that the actual details of how inverter functions should be configured when the Standards are fully deployed (by Jan. 2022) need to be worked out in a collaborative process, one that must involve Pepco. And that our District of Columbia Public Service Commission plays the key role in requiring Pepco to bring recommendations forward, hopefully with stakeholder input.]

Smart Inverter Fundamentals

a presentation for MDVSEIA members and D.C. stakeholders

Center for
Renewables
Integration

Harry Warren
hwarren@center4ri.org
703-408-6455

Today’s Presentation

- About the Center for Renewables Integration
- What is a ”smart inverter”?
- Standards development and applications
- Status of standards development – IEEE-1547-2018™
- Ride-through
- Voltage and reactive/active power control
- Communications
- Battery storage
- Adoption of smart inverter standards in local jurisdictions

Center for Renewables Integration

Center for Renewables Integration, Inc.

is a 501(c)(3) non–profit organization,

founded in 2017,

dedicated to educating and working with state and local policymakers, and other key stakeholders

seeking to enable high levels of clean energy deployment while maintaining grid reliability at the lowest cost.

CRI's co-founders are

Jeanne Fox, Educator

former President, New Jersey Board of Public Utilities

Kerinia Cusick, Principal Consultant, Distributed Energy Innovation

former Vice President, Energy Storage and Managing Director, Government Affairs, SunEdison

Harry Warren, President, CleanGrid Advisors

former President, Washington Gas Energy Services

What is a “Smart Inverter”

“Smart Inverter” is a commonly used, but imprecisely defined, term that refers to inverters with some or all of the following advanced features:

- Autonomous “ride-through” capabilities
- Autonomous voltage and reactive/active power control capabilities
- Communication capabilities

Many inverters on the market today are equipped with advanced features, and the completion of new national standards will result in these features being incorporated into all inverters.

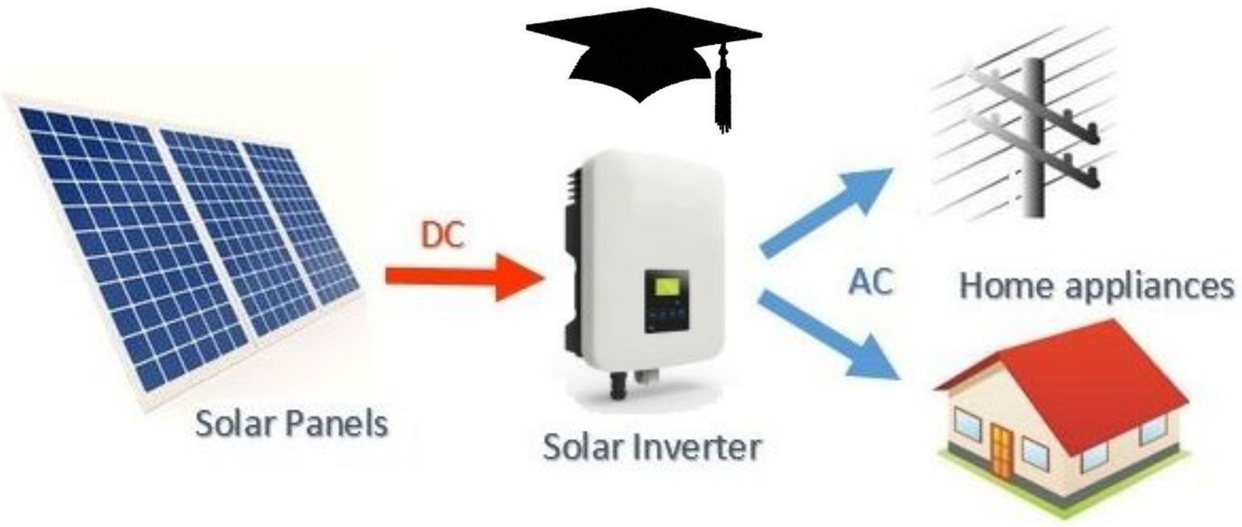


Illustration – Clean Energy Reviews

Standards Development and Applications

TBD

Communications to support grid services and external inverter control.

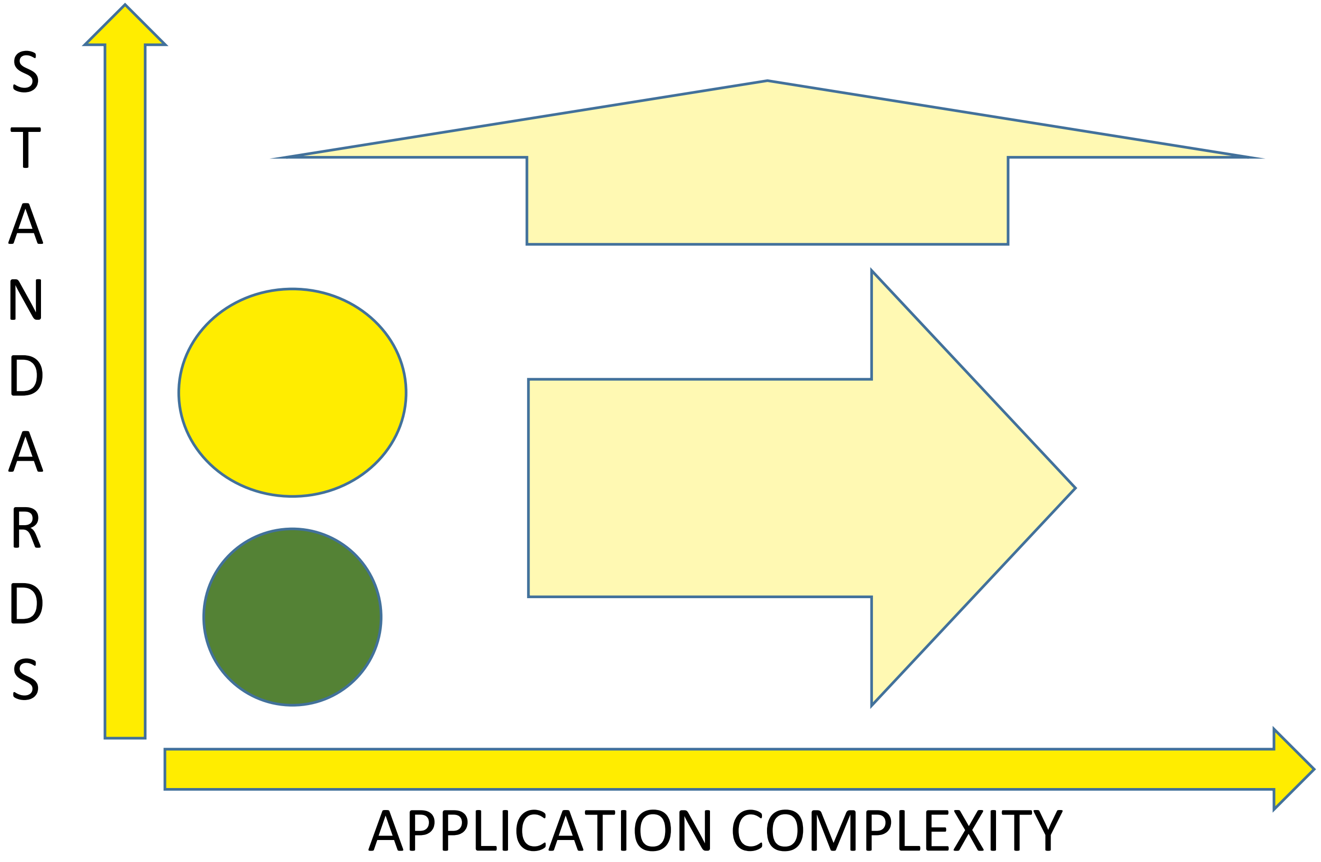
2022

IEEE 1547-2018 compliant

”Smart Inverters” Available

TODAY

Advanced inverter features compliant with interim standards



Solar on Radial Lines

Solar on Spot or Area Networks

Solar plus Storage

Status of Standards Development

- IEEE-1547-2018™, "Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces" was published in April 2018.
- A companion equipment testing standard IEEE-1547.1 is under development and is scheduled for publication in the first half of 2020.
- A companion certification testing protocol UL-1741 will likely be released shortly after IEEE 1547.1
- Inverters with UL certification could be available as early as late 2020, with a broad range of certified products available by the start of 2022.

IEEE STANDARDS ASSOCIATION ◆IEEE

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

IEEE Standards Coordinating Committee 21

Sponsored by the
IEEE Standards Coordinating Committee 21 on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 1547™-2018
(Revision of IEEE Std 1547-2003)

Ride-Through

Ride-though allows an inverter to continue to function through a short frequency or voltage disturbance on the grid.

- Inverters in place today trip off line very quickly in response to frequency and voltage fluctuations, but do not resume operation quickly. As renewable energy penetration on the grid increases, this could cause massive amounts of power to be lost due to transient fluctuations.
- Potential problems in states with high renewables penetration (California and Hawaii) have led those states to develop their own inverter standards (e.g. California Rule 21).

California Blue Cut Fire 2016 – Transmission Fault Cleared in 41.7 milliseconds

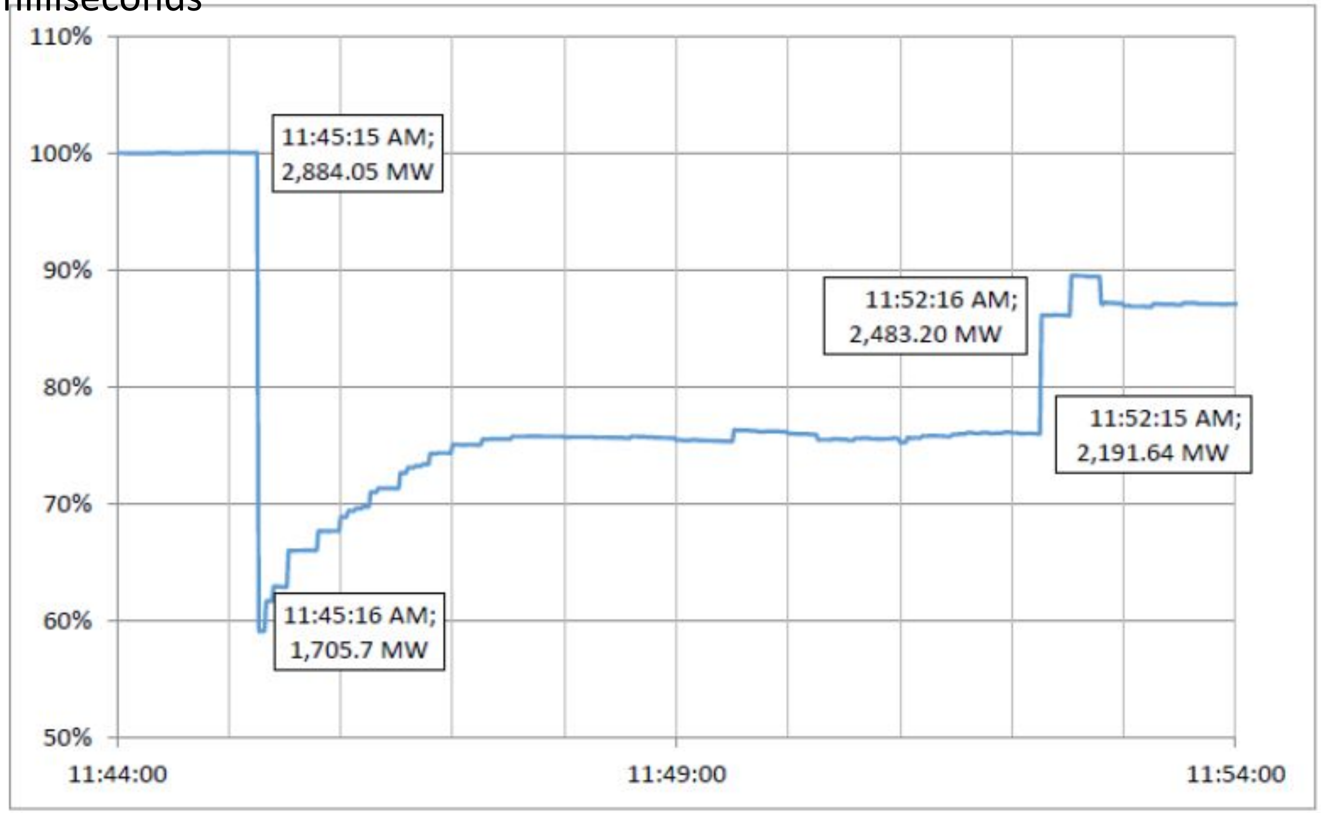


Figure - NERC

Ride-Through

A PJM stakeholder process is almost completed to establish the ride-through modes of operation and settings within the new IEEE-1547-2018 framework that will best assure future grid stability within the RTO.

- PJM's efforts will result in recommended practices to be adopted by states for distributed energy resources. The recommendations are in the final stages of internal approval and should be finalized soon.
- PJM has no authority over distribution-connected resources, so states need to adopt the recommendations into their regulations, utility tariffs and other policies and practices as needed.

pjm

Problem Statement

"Inverter-based DER Ride Through"

Inverter-based DER Ride Through and Trip Settings and IEEE standard 1

Problem / Opportunity Statement

As the number of inverter-based Distributed Energy Resources (DER) grows in PJM, need for PJM, transmission owners, electric distribution companies, state regulatory stakeholders to coordinate on the inverters' operational performance requirements ar Electric System (BES)[i,ii,iii]. For BES reliability, the key performance requirements for ride through. Ride through requires resources to stay connected to the system for a v event of a wide area disturbance, rather than trip offline and potentially exacerbate al

Failures of inverter-based resources to properly ride through contingencies have cau California[iv,v], Texas[vi], and Europe[vii]. In Australia, such a failure to ride through contrib order to mitigate these concerns, ride through requirements for DER have been imple deployment, such as California, Hawaii, Germany, and Australia.

A recently revised version of the DER interconnection standard IEEE 1547 now spec that may meet the reliability needs of the Bulk Electric System. The Institute of Electr or IEEE, is an international industry organization that, among other things, produces interested parties. The IEEE standard 1547, first developed in 2003, has been widely and in distribution utility requirements. The 1547 standard is also cited in PJM require DER that fall under FERC jurisdiction[ix].

The former edition of the IEEE 1547 standard specified a single (albeit adjustable) tri through requirement. The revised standard, IEEE 1547-2018, offers three different ca voltage ride through and trip settings that the authority governing interconnection req regulatory commission) would specify. Even within each of the three categories offer an ability to modify the default trip settings within limits. Therefore, with the implemen new engineering judgements must be made among distribution, transmission, and ot which performance category (together with optional adjustments) should apply.

PJM recognizes that, in implementation of ride through requirements, a key engineer lineworkers facing arc-flash risks while performing hot work on primary distribution lin

In order to facilitate a smooth transition to the new standard, and to ensure all DER a reliability in a predictable way during wide area abnormal conditions, PJM and stakeh coordinating the implementation of ride through and trip settings for DER interconnec

There is an opportunity to use the outcome of this technical coordination effort to ser interconnect under FERC jurisdiction[x], as well as, and perhaps more importantly, a te utilities and states can use in their implementation of the ride through and trip require

pjm

Issue Charge

"Inverter-based DER Ride Through"

DER Ride Through and Trip Settings and IEEE standard 1547-2018

Includes Problem/Opportunity Statement

Issue Source

PJM

Stakeholder Group Assignment

The work is technical, and will require full-day workshops with stakeholders that cannot be done as part of the existing Standing Committee meetings. Additionally, it will be helpful to have a separate listserv and website for document sharing. Therefore, the work will be assigned to a new Task Force reporting to the Planning Committee, under the name *DER Ride Through Task Force*.

Key Work Activities

1. Education on the new IEEE 1547 – 2018 standard, specifically the portion of the standard that details new Category I, Category II, and Category III voltage ride through settings.
2. Technical workshop(s) to discuss and debate the merits of Category I, Category II, or Category III and the adjustable trip settings therein.
3. Updates on local-jurisdictional and other activities across PJM and elsewhere to implement IEEE 1547-2018.
4. Develop a rule in the appropriate PJM manual implementing the ride through and trip provisions of IEEE 1547-2018 to be applied to wholesale inverter-based DER interconnecting under FERC jurisdiction.
5. Produce a guidance document for local jurisdictions seeking to implement the ride through and trip provisions of IEEE 1547-2018.

Expected Deliverables

1. Manual language in PJM business manual M-14D (or other as appropriate) implementing the ride through and trip provisions of IEEE 1547-2018 to be applied to wholesale inverter-based DER interconnecting under FERC jurisdiction. The goal is to specify a single PJM-wide IEEE 1547-2018 profile consisting of an abnormal voltage and frequency performance category and specified trip settings, if adjusted from the defaults. As a second-best alternative, the rule can instead specify minimum acceptable ride-through and trip times, and defer to distribution utilities on the specific implementation and/or performance category.
2. Policy document describing results of the process and discusses the considerations and justification for the new PJM rule. States, local regulators, and utilities can use this document to inform state and local rulemaking processes to implement the new IEEE 1547-2018 standard for DER interconnecting under state jurisdiction to ensure they behave in a way that is coordinated with the BES, as required by the standard[i].
   a. In the event consensus cannot be reached, PJM will publish a 'best practice' document on same.

Voltage and Reactive/Active Power Control

Distributed energy resources that use inverters (solar PV systems and batteries) can introduce voltage fluctuations into distribution grids as their power production or discharge vary over time. They also need to respond to distribution grid voltage status.

- Smart inverter voltage control features can mitigate impacts on the distribution system by modulating real and reactive power through one of a number of operating mode alternatives.
- By mitigating distribution system impacts, smart inverters can increase the “hosting capacity” of distribution circuits, allowing deeper penetration of renewables without costly distribution system upgrades.
- There is the potential for smart inverters to improve voltage control on distribution lines being caused by other factors (e.g. load fluctuations).

Table 6—Voltage and reactive/active power control function requirements for DER normal operating performance categories

DER category	Category A	Category B
Voltage regulation by reactive power control		
Constant power factor mode	Mandatory	Mandatory
Voltage—reactive power mode[a]	Mandatory	Mandatory
Active power—reactive power mode[b]	Not required	Mandatory
Constant reactive power mode	Mandatory	Mandatory
Voltage and active power control		
Voltage—active power (volt-watt) mode	Not required	Mandatory

[a]Voltage-reactive power mode may also be commonly referred to as “volt-var” mode.
[b]Active power-reactive power mode may be commonly referred to as “watt-var” mode.

Table 9—Active power-reactive power settings for normal operating performance Category A and Category B DER

Active power-reactive power parameters	Default settings		Ranges of allowable settings	
	Category A	Category B	Minimum	Maximum
P_3	P_{rated}		$P_2 + 0.1\ P_{rated}$	P_{rated}
P_2	$0.5\ P_{rated}$		$0.4\ P_{rated}$	$0.8\ P_{rated}$
P_1	The greater of $0.2\ P_{rated}$ and P_{min}		P_{min}	$P_2 - 0.1\ P_{rated}$
P'_1	The lesser of $0.2 \times P'_{rated}$ and P'_{min}		$P'_2 - 0.1\ P'_{rated}$	P'_{min}
P'_2	$0.5\ P'_{rated}$		$0.8\ P'_{rated}$	$0.4\ P'_{rated}$
P'_3	P'_{rated}		P'_{rated}	$P'_2 + 0.1\ P'_{rated}$
Q_3	25% of nameplate apparent power rating, absorption	44% of nameplate apparent power rating, absorption	100% of nameplate reactive power absorption capability	100% of nameplate reactive power injection capability
Q_2	0			
Q_1	0			
Q'_1	0			
Q'_2	0			
Q'_3	44% of nameplate apparent power rating, injection			

NOTE— P_{rated} is the nameplate active power rating of the DER.
P'_{rated} is the maximum active power that the DER can absorb.
P_{min} is the minimum active power output of the DER.
P'_{min} is the minimum, in amplitude, active power that the DER can absorb.
P' parameters are negative in value.

Tables – IEEE-1547-2018

Communications

IEEE-1547-2018 covers certain inverter capabilities needed to allow utilities to control and communicate with inverters. This control could provide improved grid management.

- Utility control over smart inverters raises additional issues, however, such as secure, low cost communications systems and distributed resource management systems (DERMS)

IEEE 2030.5/CSIP

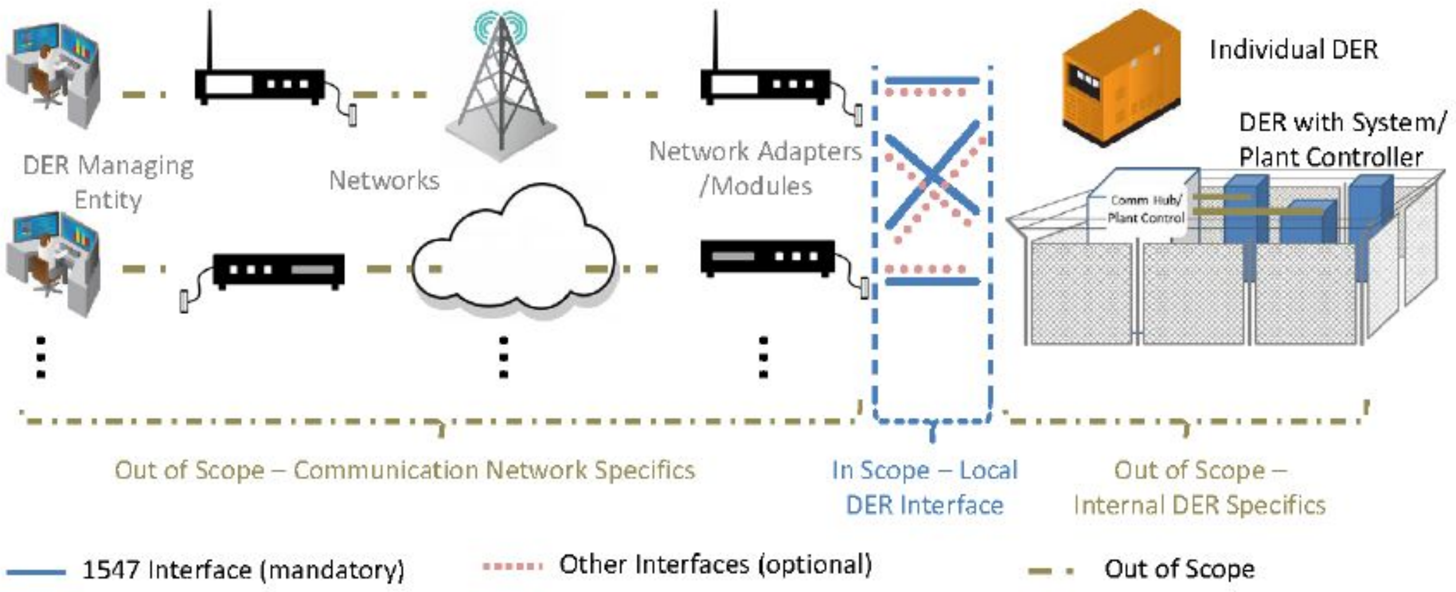


Figure 4 —Control protocol in/out of scope mapping

Figure – IEEE-1547-2018

Battery Storage

Battery storage systems require inverters /charge controllers, and include additional controls to manage various operating modes.

These issues are not fully covered under IEEE-1547-2018 and need to be addressed separately.

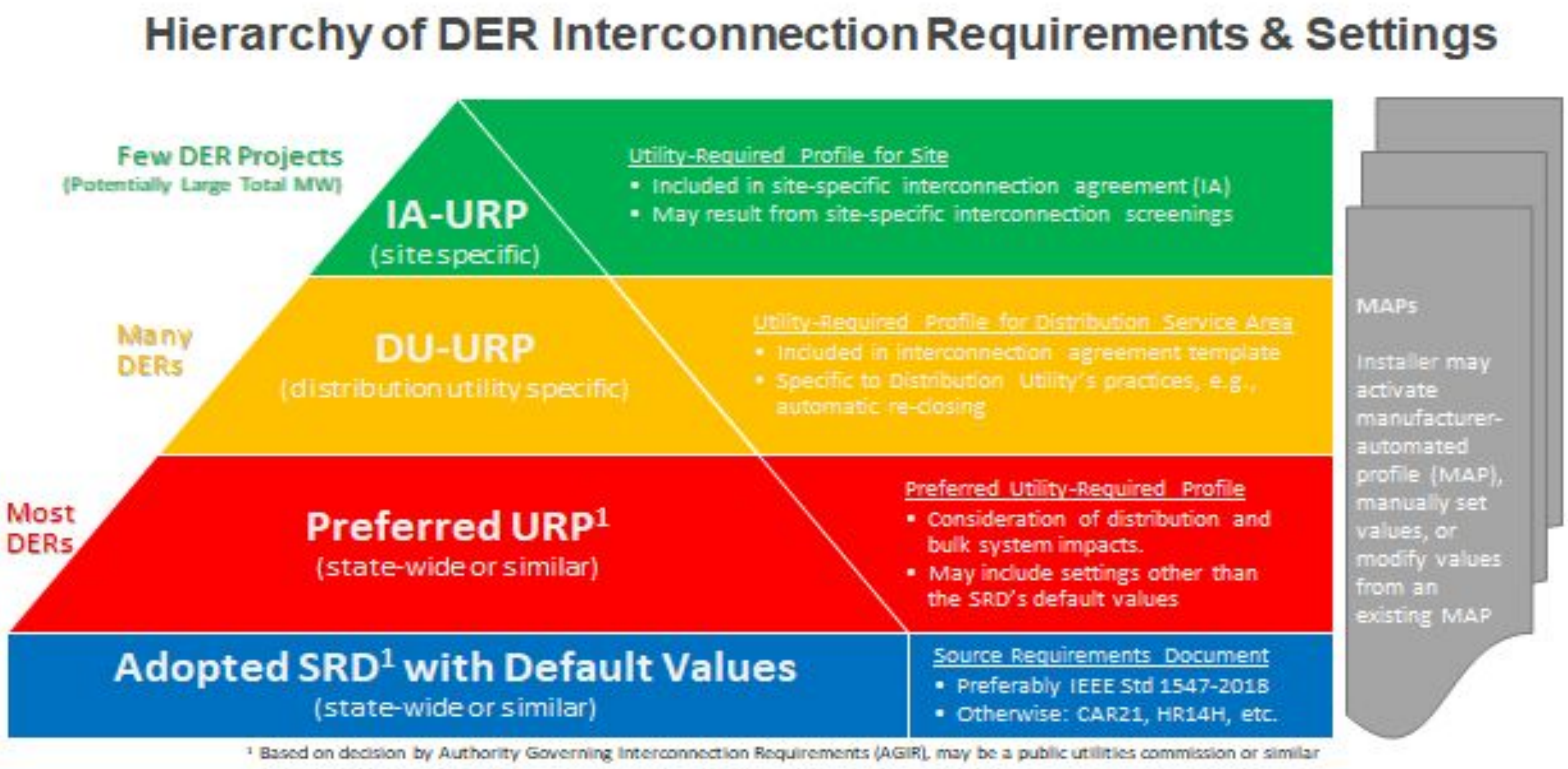
IEEE 2030.2.1-2019

Proposed Use: The operational characteristics of a small generator facility upon which the applicant's technical review is based and under which the small generator facility is bound to operate upon the execution of the interconnection agreement. The proposed use for a small generator facility may include a combination of electric generators and **energy storage devices operating in specified modes during specified time periods including but not limited to export, load management, backup, and market participation.**

Net System Capacity: The nameplate capacity of a small generator facility, or the total of the nameplate capacities of the units comprising a small generator facility, as designated by the manufacturer(s) of the unit(s) minus the consumption of: electrical power of the unit(s), and if applicable, as limited through the use of a control system, power relay(s), or other similar device settings or adjustments.

Inadvertent Export: The unscheduled export of active power from a Generating Facility, beyond a specified magnitude and for a limited duration, generally due to fluctuations in load-following behavior.

Adoption of Smart Inverter Standards in Local Jurisdictions



Adoption of Smart Inverter Standards in Local Jurisdictions

Maryland

In September 2018, the Maryland PSC adopted revised interconnection regulations allowing utilities and interconnecting customers to use smart inverter features approved under interim standards by mutual agreement.

- Equipment certified under the latest published editions of IEEE 1547, IEEE 1547.1 and UL 1741 shall be permitted to be used for monitoring or control upon mutual agreement of the utility and the interconnection customer.

Adoption of Smart Inverter Standards in Local Jurisdictions

Maryland

In September 2019, the Maryland PSC published revised interconnection regulations that set forth requirements for the use of smart inverters compliant with IEEE-1547-2018™

- "Smart Inverter" means any inverter hardware system certified to be compliant with IEEE 1547-2018 or subsequent revisions to these standards.
- "Utility required inverter settings profile" means smart inverter settings for a small generator facility that are established by a utility.

  (a) A "state-wide" utility required inverter settings profile" or "grid code" is a set of smart inverter settings optimized for use state-wide that can be used by utilities and manufacturers in establishing defaults.

  (b) A "default" utility required inverter settings profile is a utility set of default smart inverter settings optimized for use across a utility's service territory.

  (c) A "site-specific" utility required inverter settings profile is a set of smart inverter settings optimized for use at a specific site on a utility's electric system.

Adoption of Smart Inverter Standards in Local Jurisdictions

Maryland

- Smart Inverters.

  (1) After January 1, 2022, any small generator facility requiring an inverter that submits an interconnection request shall use a smart inverter with either a default or site-specific utility required inverter settings profile as determined by a utility.

  (2) Any small generator facility may replace an existing inverter with a similar spare inverter that was purchased prior to January 1, 2022 for use at the small generator facility.

  (3) Prior to January 1, 2022, all utilities will establish default utility required inverter settings profiles for smart inverters pursuant to §N(5) of this Section. A utility may use a state-wide utility required inverter settings profile as their default utility required inverter settings profile.

  (4) To the extent reasonable, pursuant to any modifications required by §N(5) of this Section, all utility required inverter setting profiles shall be consistent with applicable smart inverter recommendations from PJM Interconnection, LLC that are applicable.

Adoption of Smart Inverter Standards in Local Jurisdictions

Maryland

- Smart Inverters.

  (5) A default utility required inverter settings profile shall be established by a utility to optimize the safe and reliable operation of the electric distribution system, and shall serve the following objectives:

    (a) The primary objective is to incur no involuntary real power inverter curtailments incurred during normal operating conditions and minimal real power involuntary curtailments during abnormal operating conditions.

    (b) The secondary objective is to enhance electric distribution system hosting capacity and to optimize the provision of grid support services.

  (6) A site-specific utility required inverter settings profile may be established by a utility as necessary to optimally meet the objectives established in §N(5) of this Section.

  (7) All default and site-specific utility required inverter settings profiles will be documented in interconnection agreements.

  (8) A default utility required inverter settings profile will be published on the utility's website.

  (9) A list of acceptable smart inverters shall be published on a utility's website.

Adoption of Smart Inverter Standards in Local Jurisdictions

Maryland

- In its report to the Commission accompanying the draft proposed regulations, the Commission Staff noted that:

  "the Workgroup proposes that utilities determine their default DU-URPs by the end of 2020. In early 2021, it is proposed that the Workgroup meet in a workshop to discuss each utility's default DU-URPs and the rationale behind them. If consensus is not reached at the workshop on a state-wide Preferred URP, the Workgroup will schedule additional meetings in an attempt to gain consensus. The end result of the workshop will be either a recommendation by the Workgroup to the Commission for a state-wide Preferred URP71 or the steps needed to overcome any non-consensus in developing a state-wide Preferred URP."

- The Commission asked that the PC-44 Interconnection Work Group continue to meet:
  - The Smart Inverter Subgroup will continue to report periodically on the status of IEEE 1547.1 and UL 1741 completion at WG meetings
  - Utilities will provide periodic report-outs on their progress developing DU-URPs at future WG meetings

- The next Maryland Interconnection Work Group meeting is scheduled for January 28, 2019.

Adoption of Smart Inverter Standards in Local Jurisdictions

Delaware

CRI made a presentation to the Delaware Public Service Commission in August 2018 on the fundamentals of smart inverters and the IEEE and UL standards development process. No specific processes to determine standards are yet underway.

Virginia

On December 3, 2019 the VASCC published new draft interconnection regulations for review and comment. See PUR-2018-00107. Comments are due February 21, 2020.

No specific references to smart inverter adoption or standards developments were included in proposed regulations put forward by the Commission Staff in September 2019. The Staff did note in its filing, that addressing smart inverters might be important once all applicable standards are in place.

Center for Renewables Integration

Further Reading

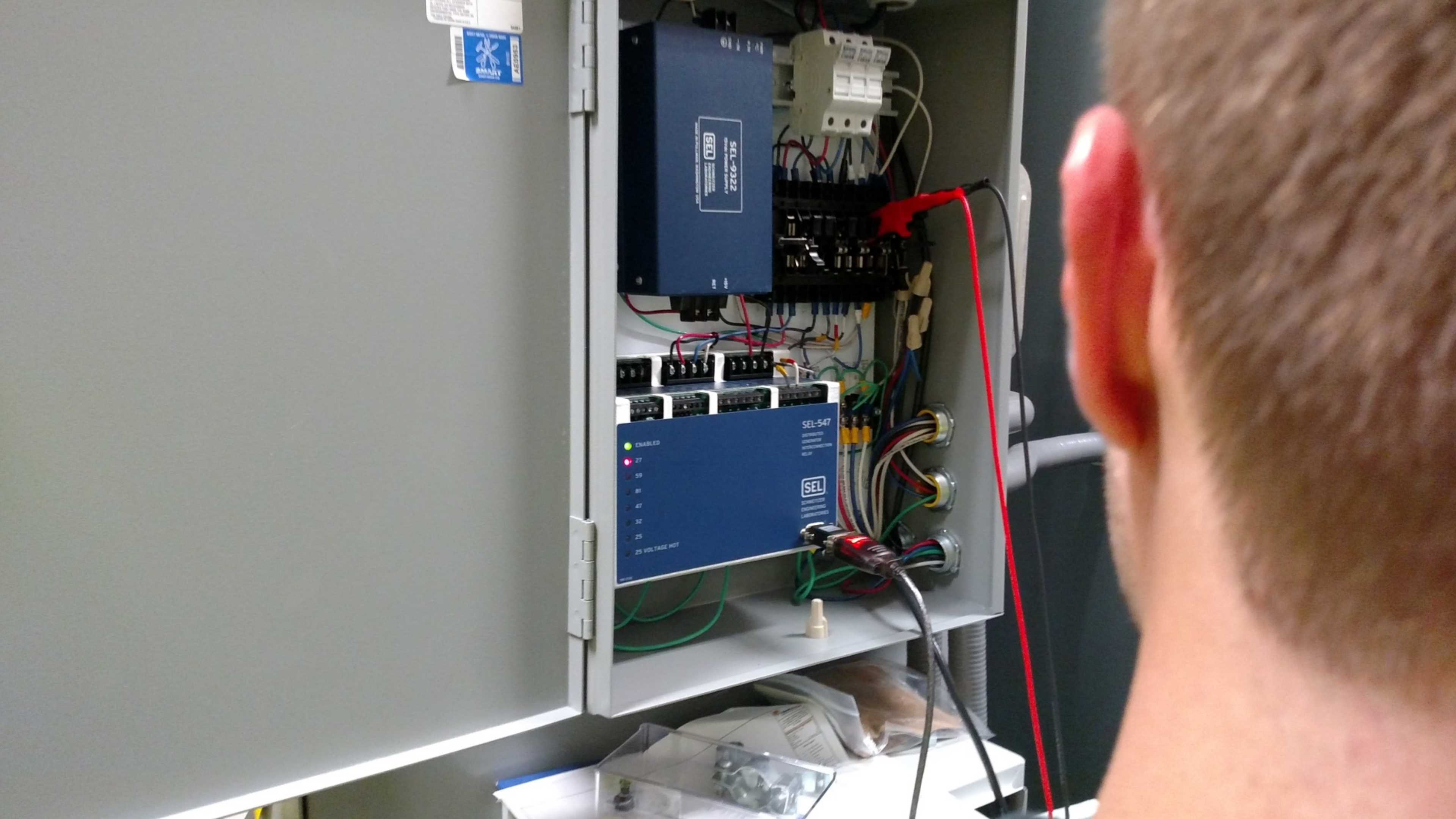
"It's Time for States to Get Smart About Smart Inverters",
Center for Renewables Integration, Inc., September 2019
https://www.center4ri.org/publications

"Making the Grid Smarter: Primer on Adopting the New IEEE Standard 1547™-2018 for Distributed Energy Resources", Interstate Renewable Energy Council, January 2019
https://irecusa.org/regulatory-reform/smart-inverters/

Maryland PSC Staff filing Maillog #226408, and further proceedings in Maryland Rulemaking 68.
https://www.psc.state.md.us

District of Columbia's
Distributed Energy Resources Integration
Technical Challenges and Opportunities

Jorge Camacho, P.E.
IEEE Std 1547 Conformity Assessment Steering Committee
j.a.camacho@ieee.org


SEL-9322
SEL-547
ENABLED
27
59
81
47
32
25
25 VOLTAGE HOT
SEL

Grid Planning and Operation Challenges

Increasing DER Penetration Was a Major Driver for Revising IEEE 1547.

- Grid performance support
- Ride-through, stabilizing frequency response, voltage support

- Safety and reliability: Do no harm.
- Anti-islanding, no interference with primary voltage regulation

Interconnection requirements for DERs should also adequately address transmission *and* distribution system needs. Coordination with national and regional bulk power system regulators as well as state authorities is needed.

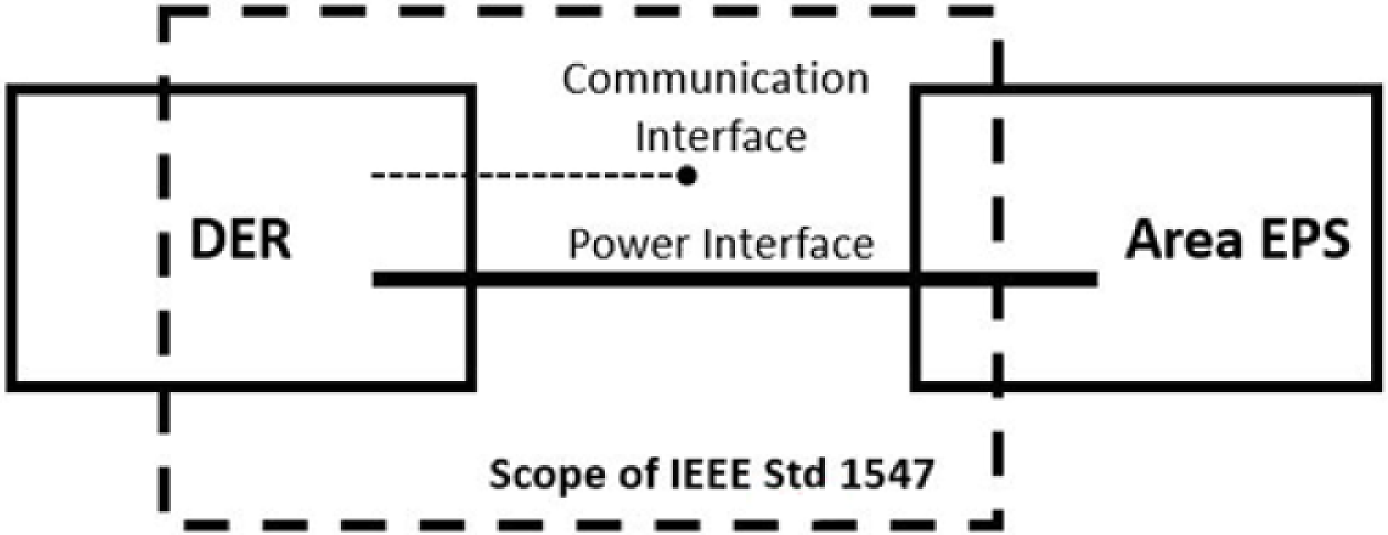
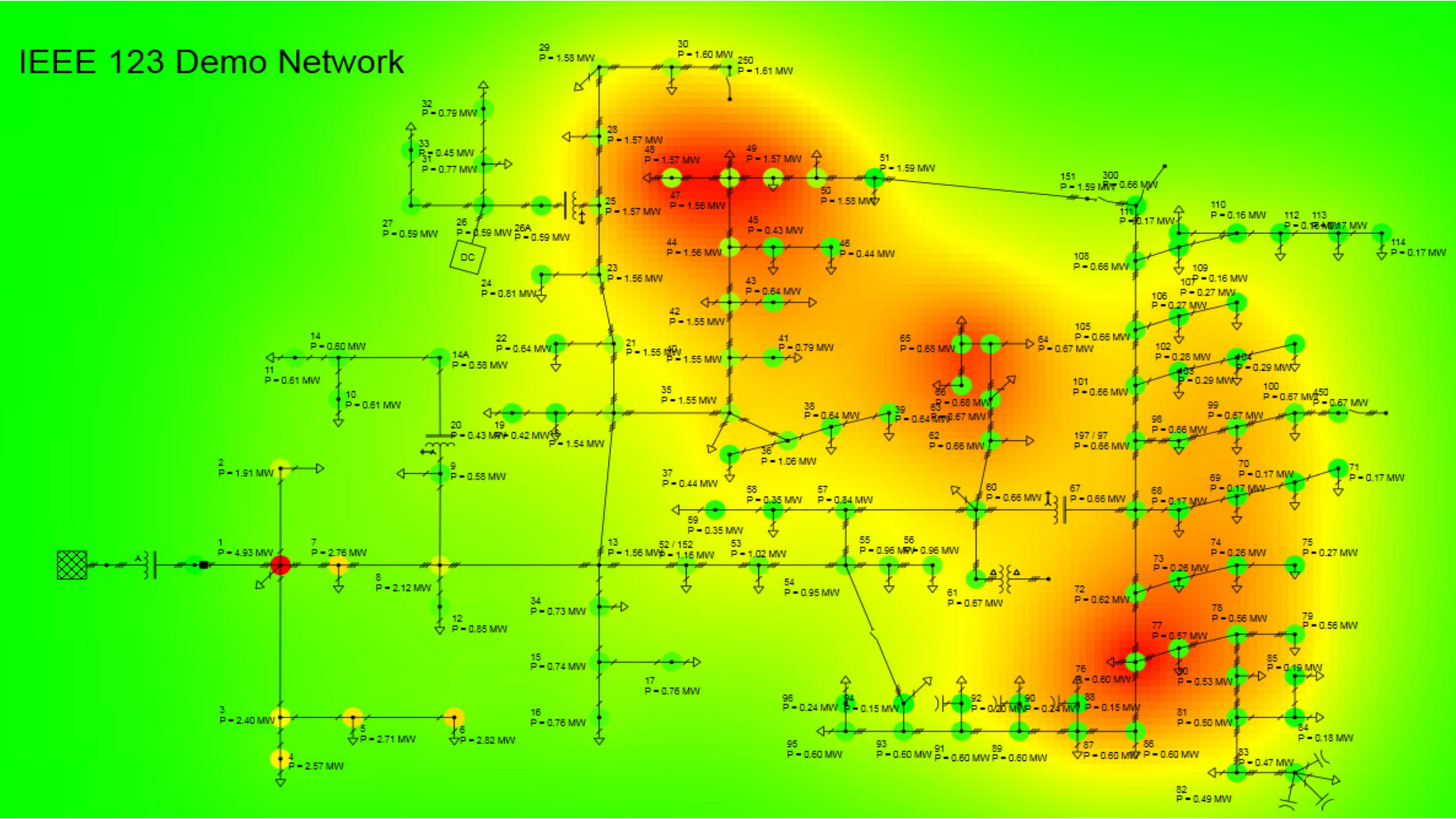
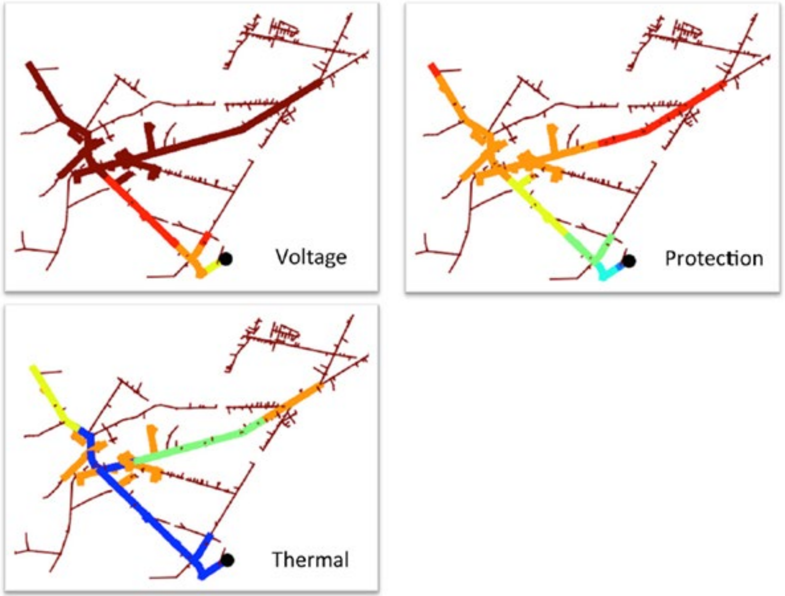
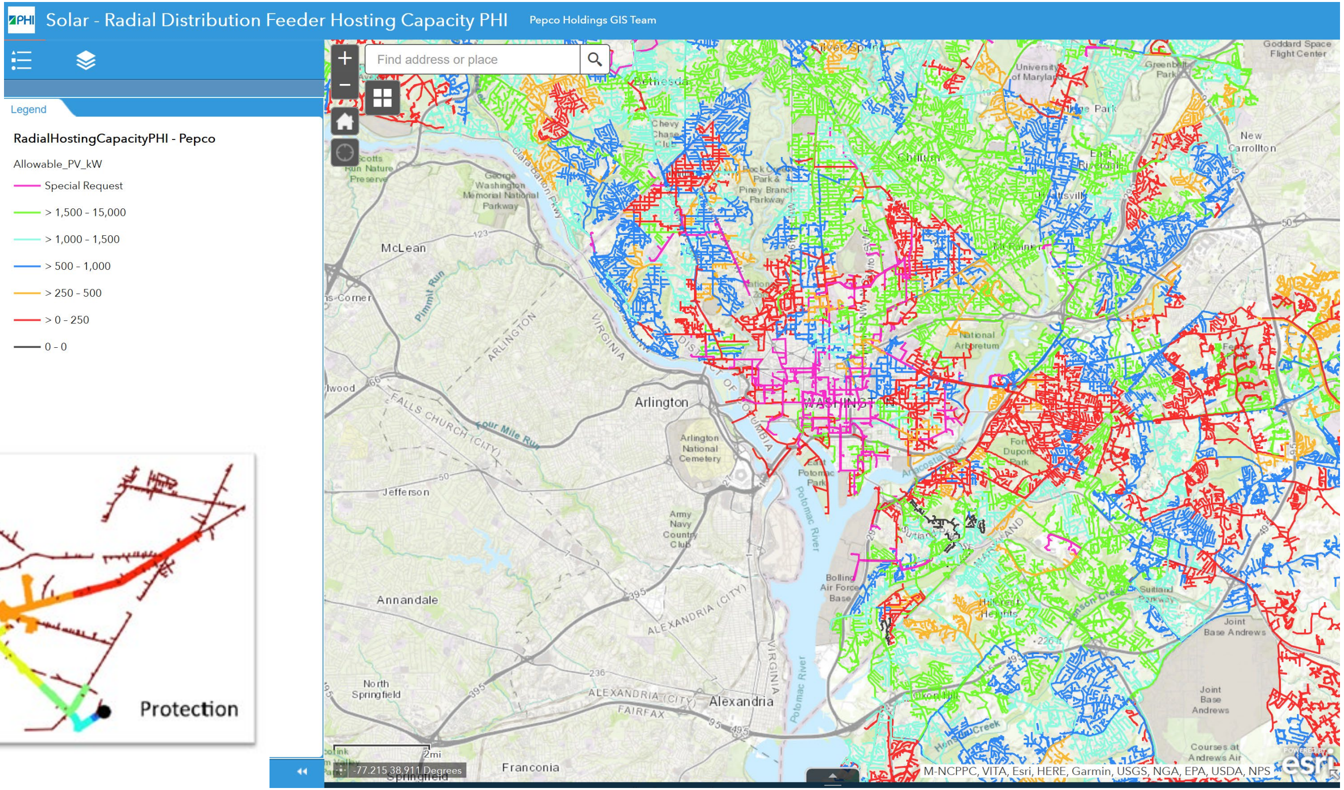


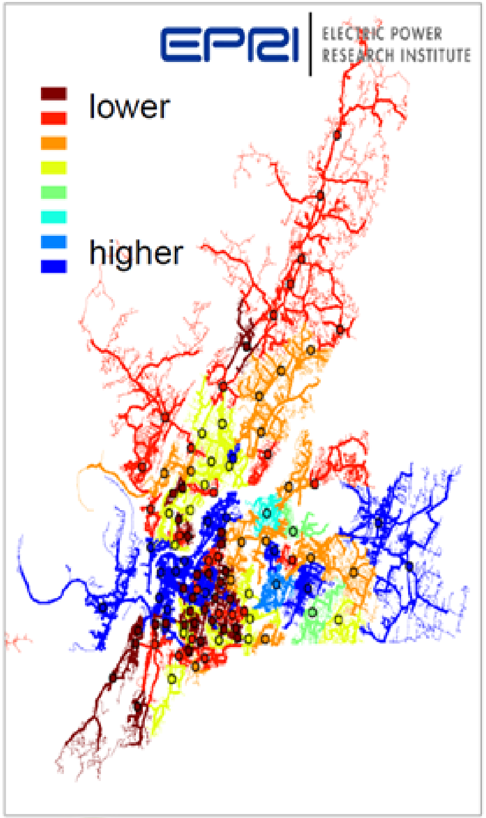
Figure 1 – IEEE STD 1547-2018

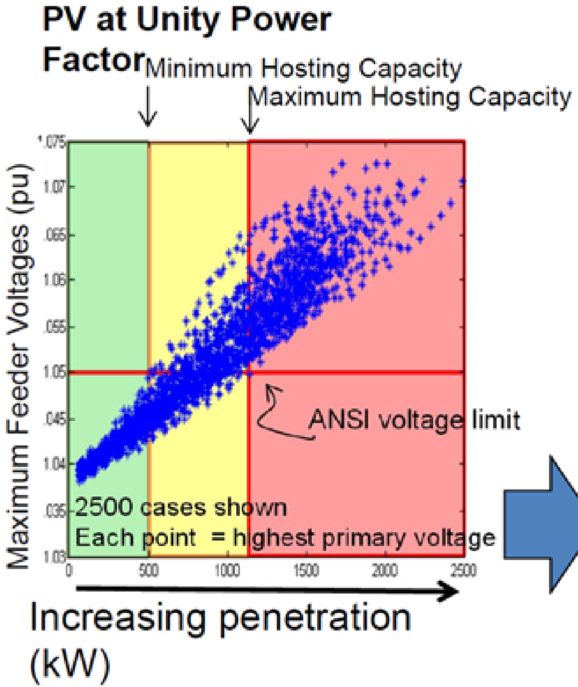

IEEE 123 Demo Network

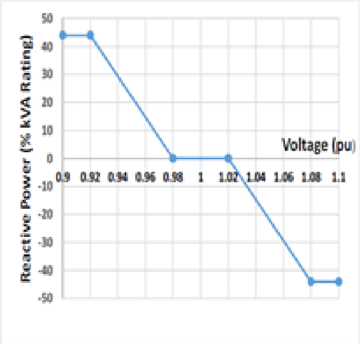

Voltage
Protection
Thermal

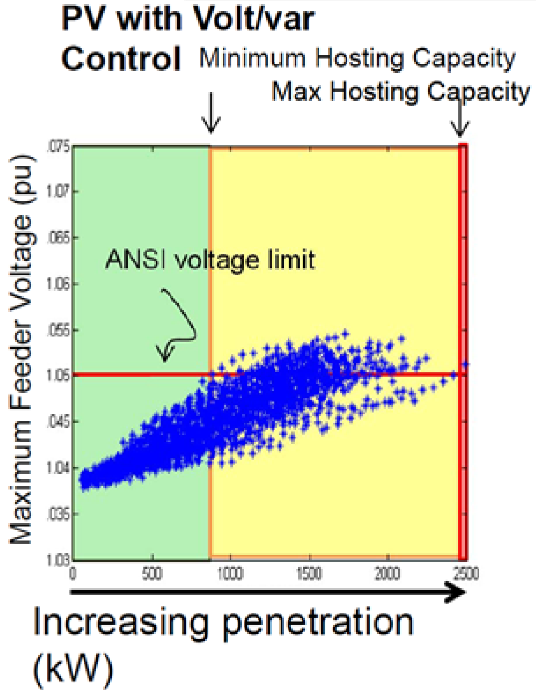

Solar - Radial Distribution Feeder Hosting Capacity PHI
Pepco Holdings GIS Team
Find address or place
Legend
RadialHostingCapacityPHI - Pepco
Allowable_PV_kW
Special Request
> 1,500 - 15,000
> 1,000 - 1,500
> 500 - 1,000
> 250 - 500
> 0 - 250
0 - 0
McLean
Arlington
Arlington National Cemetery
Army Navy Country Club
Annandale
Alexandria
North Springfield
Franconia
Jefferson
Bethesda
Chillum
National Arboretum
Bolling Air Force Base
Joint Base Andrews
Potomac River
-77.215 38.911 Degrees
2mi
M-NCPPC, VITA, Esri, HERE, Garmin, USGS, NGA, EPA, USDA, NPS

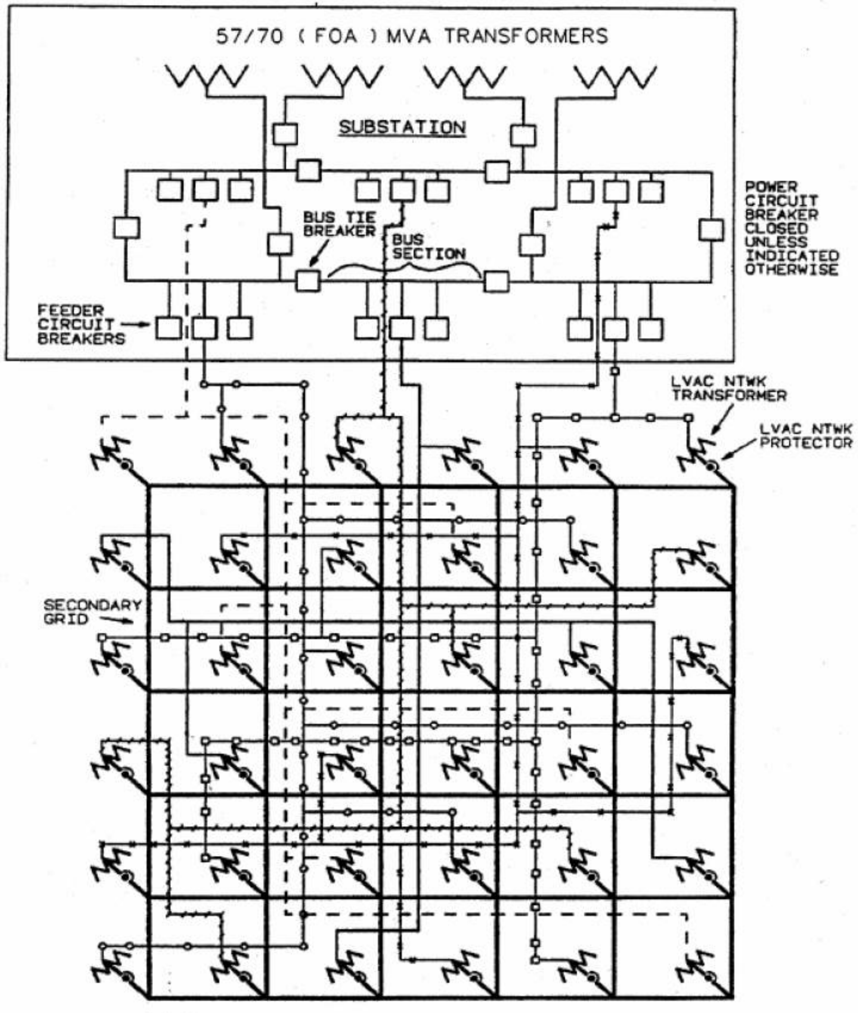
Hosting Capacity











TYPICAL PEPCO LVAC NETWORK ONE LINE SCHEMATIC

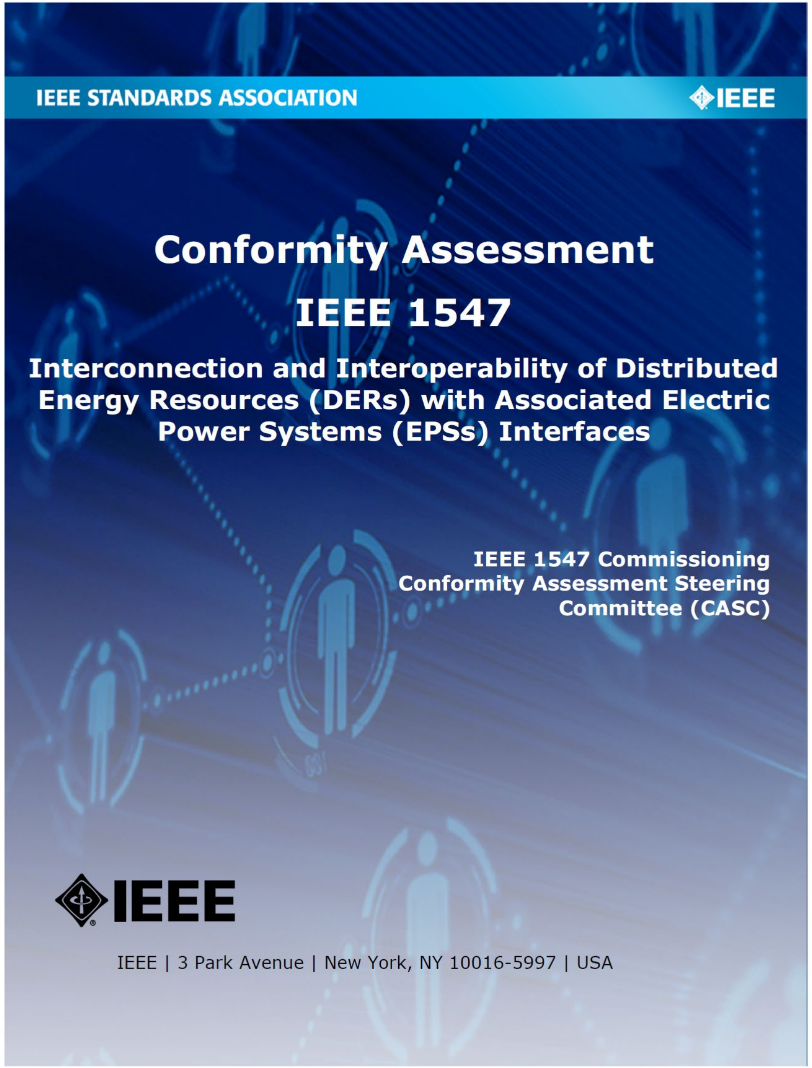
Clause 9 – IEEE STD 1547-2018

Secondary Area Networks [LVAC]

"**Monitor instantaneous power flow at the PCC** of the DER interconnected to the secondary grid or spot network for reverse power relaying, minimum import relaying, dynamically controlled inverter functions and similar applications to prevent reverse power flow through network protectors."

The **Function**:

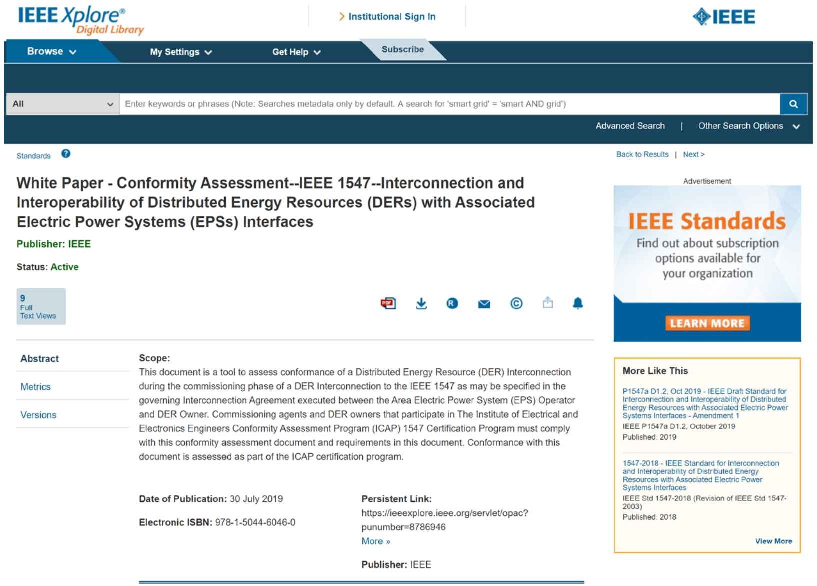
Monitor instantaneous power flow at the PCC



Independent, Transparent, and Technical Sound DER Integration Process

IEEE Conformity Assessment Program (ICAP)

- IEEE approved Commissioning Agent (CA)



https://ieeexplore.ieee.org/document/8786948

Impact of Pepco Minimum-Import Requirements for PV on Secondary Spot Networks in DC

- First cost (EPC)
- Financial uncertainty
- Lost environmental benefits
- O&M expense

Evolution of Pepco Operating Requirements for PV on Secondary Spot Networks in DC

180 KW (AC) - ATI June 2018	200 KW (AC) - ATI October 2019
Controls	
• 18 KW minimum import • Relay mentioned but inverter-based curtailment acceptable	• 38 KW minimum import • Protection relay with specific functions required; relay model and settings must be approved by Pepco • Curtailment optional

Evolution of Pepco Operating Requirements for PV on Secondary Spot Networks in DC

180 KW (AC) - ATI June 2018	200 KW (AC) - ATI October 2019

Curtailment/Trip Timing

180 KW (AC) - ATI June 2018	200 KW (AC) - ATI October 2019
• None specified	• Trip “must occur instantaneously” • Relay “must trip before the Network Protector”

Evolution of Pepco Operating Requirements for PV on Secondary Spot Networks in DC

180 KW (AC) - ATI June 2018	200 KW (AC) - ATI October 2019

Communications

180 KW (AC) - ATI June 2018	200 KW (AC) - ATI October 2019
• System events to be reported to Pepco by e-mail • Customer to provide Pepco with web access to system monitoring • Communications medium not specified	• System to provide metering and status data to Pepco by telemetry • Data points and format specified by Pepco • Customer to purchase and install Pepco radio communications box

Evolution of Pepco Operating Requirements for PV on Secondary Spot Networks in DC

180 KW (AC) - ATI June 2018	200 KW (AC) - ATI October 2019

Witness Test/Commissioning

180 KW (AC) - ATI June 2018	200 KW (AC) - ATI October 2019
• Test to demonstrate curtailment	• Test to demonstrate tripping and (optional) curtailment • Commissioning to demonstrate telemetry of metering and status to Pepco

IEEE 1547 DER Interconnection Standard

for the MDV-SEIA Workshop,

"Maximizing the Use of Advanced Inverters and the New IEEE 1547-2018 Standards to Meet the District of Columbia's Solar and Clean Energy Mandates"

Charlie Vartanian, PE – Pacific Northwest National Laboratory, and IEEE 1547 Working Group

December 5, 2019

SEIA Headquarters, Washington DC

Disclaimer and Acknowledgment

- *This presentation on IEEE 1547-2018 represents the author's views and are not the formal position, explanation or position of the IEEE, the IEEE Standards Association, or PNNL.*
- *This slide deck has been peer-reviewed by IEEE Standard Coordination Committee 21 (SCC21) and IEEE P1547 Officers.*
- *The presenter acknowledges the contribution of the IEEE 1547-2018 Working Group, Balloters and Officers*

Outline, Workshop IEEE 1547 Module

Red-colored text copied from event Agenda

1. **IEEE 1547 Introduction**, a high level overview of IEEE 1547

2. **IEEE 1547-2018 Revision Overview,** focusing on new requirements
   General Requirements
   Reactive Power (VAR) Capacity and Voltage Regulation Modes
   Abnormal Condition Response
   Interoperability Requirements
   P1547.9 Future Guide for DER-ES Interconnection

3. **Energy Storage(ES), and ES+PV Interconnection Considerations**

4. **DER and Distribution Networks Considerations (separate slide deck)**

5. **IEEE 1547-2018 Adoption,** and early movers, CA Rule 21, HA Rule 14, and UL-1741-SA

Adopting the New Hardware Standards: Identifying Key Considerations That Should Guide the Selection of Inverter Modes and Settings

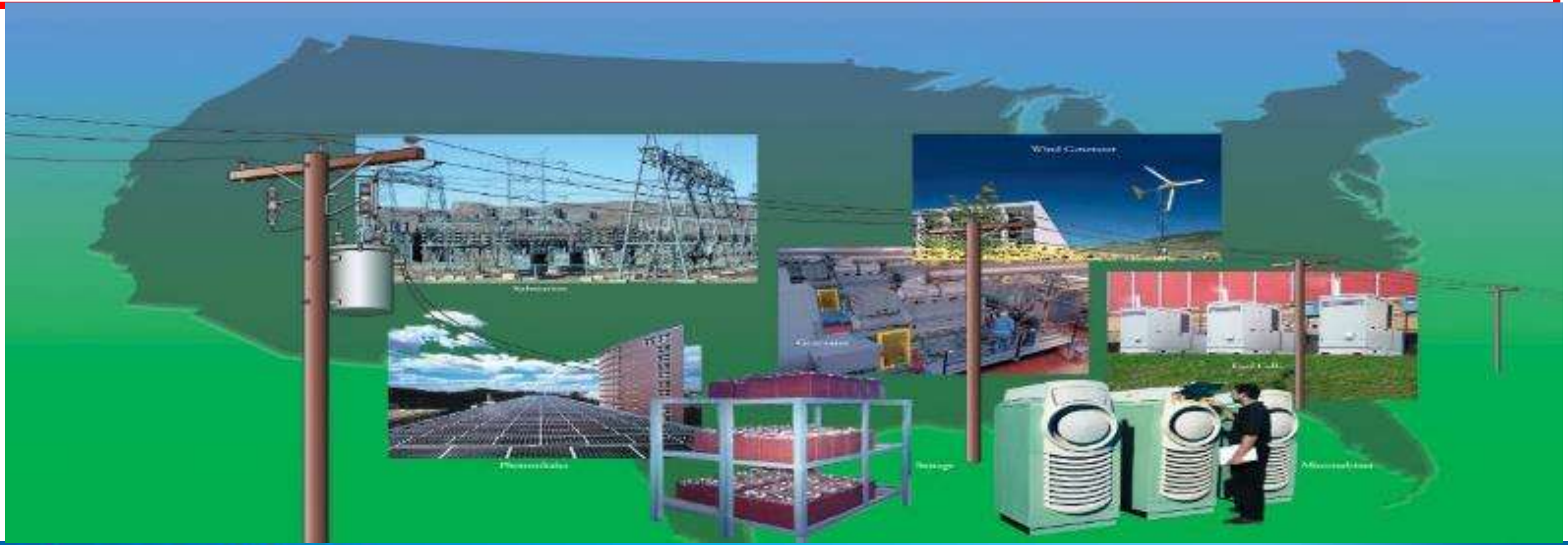
What Would be the Reasons for not Going for Maximum Capacity of New Inverter Functionalities Under the new Standards?

Maximizing Use of Interim Standards Available Now (e.g., California and Hawai'i standards that predate IEEE 1547-2018) and Autonomous Inverter Features, Based On Other Jurisdictions' Experience

IEEE Std 1547-2018 Introduction

Importance of IEEE 1547

- Energy Policy Act (2005) Cites and requires consideration of IEEE 1547 Standards and Best Practices for Interconnection; all states use or cite 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 1547 & 2030 series being expanded};
- Federal ARRA (2009) Smart Grid & High Penetration DER projects {*use IEEE stds*}.



IEEE 1547-2018 Scope and Purpose

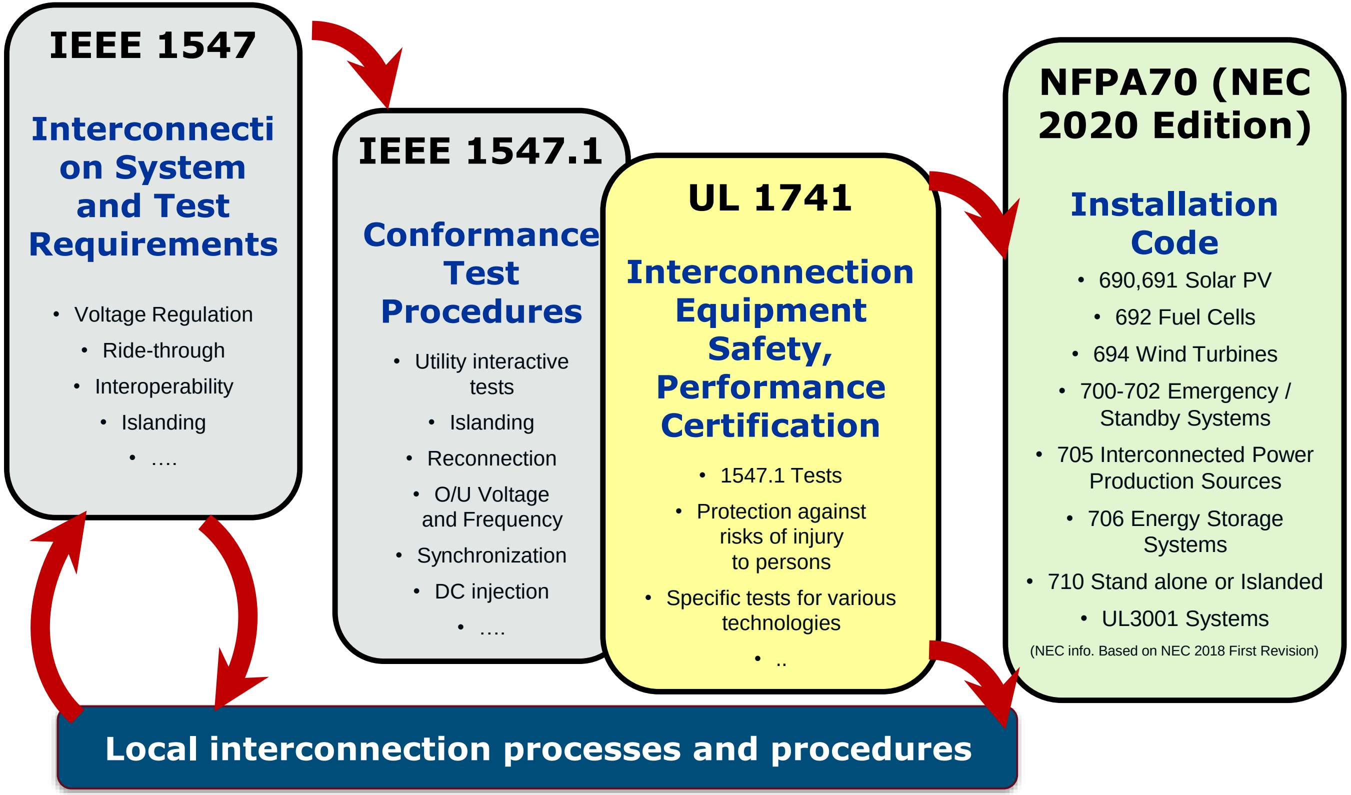
Title: *Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces*

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 performance, operation, and testing, and, safety, maintenance and security considerations.*

Changes from IEEE 1547-2003 shown in red

IEEE 1547 Interconnection Example Use in United States



IEEE 1547-2018 Document Outline (Clauses)

1. Introduction
2. Overview
3. Normative references, definitions and acronyms
4. ***General specifications and requirements***
5. ***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

Focus for this tutorial

1547-2018 General Specifications & Requirements

Clause 4

1.4 General remarks and limitations

- Applicable to all DERs 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 the use 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) standards for DER with SG units rated 10 MVA and greater.
  - E.g., IEEE Std C50.12, IEEE Std C50.13.

Reactive power, voltage/power control

Clause 5

New Reactive Power Requirements

5.2 Reactive power capability of the DER

The DER shall be capable of injecting reactive power (over-excited) and absorbing reactive power (under-excited) for active power output levels greater than or equal to the minimum steady-state active power capability (P_{min}), or 5% of rated active power, P_{rated} (kW) of the DER, whichever is greater.

When operating at active power output greater than 5% and less than 20% of rated active power, the DER shall be capable of exchanging reactive power up to the minimum reactive power value given in Table 7 multiplied by the active power output divided by 20% of rated active power.

Operation at any active power output above 20% of rated active power shall not constrain the delivery of reactive power injection or absorption, up to the capability specified in Table 7, as required by the active control function at the time, as defined in 5.3. Curtailment of active power to meet apparent power constraints is permissible. These reactive power requirements are illustrated in informative Figure H.3.[60]

Table 7—Minimum reactive power injection and absorption capability

Category	Injection capability as % of nameplate apparent power (kVA) rating	Absorption capability as % of nameplate apparent power (kVa) rating
A (at DER rated voltage)	44	25
B (over the full extent of ANSI C84.1 range A)	44	44

Categories of DER grid support – DER's VAR capacity and voltage regulation capabilities

Category A

- Meets minimum performance capabilities needed for Area EPS voltage regulation
- Reasonably attainable by all state-of-the-art DER technologies
- Reactive power capability: 0.25 p.u. lagging, 0.44 p.u. leading

Category B

- Meets all requirements in Category A plus…
- Supplemental capabilities for high DER penetration, where the DER power output is subject to frequent large variations.
- Attainable by most smart inverters
- Reactive power capability: 0.44 p.u. lagging, 0.44 p.u. leading

Category assignment specified by Area EPS Operator

Active voltage regulation capability requirements

DER must possess <u>capability</u> – <u>implementation</u> is at the discretion of area EPS Operator (mode and parameters)

Capability required of all DER – (Cat A, B)

Constant power factor mode

Constant reactive power mode (“reactive power priority”)

Voltage-reactive power mode (“volt-var”)

“State-of the art” DER – Cat B

Active power-reactive power mode (“watt-var”)

Voltage-active power mode (“volt-watt”)

.

Response to abnormal conditions

Clause 6

Assignment of new IEEE 1547-2018 Performance Categories

Normal and abnormal operating performance categories

Category I
Category A
Ride-Through
Voltage Regulation
Category II
Category B
Category III

Control / trip settings
- Ranges of allowable settings
- Default parameters

DER Vendors

Authorities Governing Interconnection Requirements (AGIRs)[1]

RULE 21 Consistent w/Cat III-B

Market Analysis
- Costs
- Market segment
- Etc.

Impact Assessment
- Technical conditions:
  - Type, capacity, & future penetration of DERs
  - Type of grid configuration, etc.
- Non-technical issues: DER use case, impacts on environment, emissions, and sustainability, etc.

Stakeholder Engagement
- Distribution utilities
- Bulk system operators & planners
- DER developers
- Others

[1] State Regulator, Area EPS or bulk system operator, etc.

- **Category III ~ Greatest ride-through capabilities**
- **Category B ~ Greatest voltage support capabilities (most inverter-based DERs)**

Performance Categories – Abnormal Operating Conditions

Ride Through Capabilities

Category I

- Essential bulk power system needs
- Attainable by all state-of-the-art DER technologies.

Category II

- Supports bulk power system reliability requirements, e.g. ride through
- Coordinated with existing reliability standards to avoid tripping for a wider range of disturbances (more robust than Category I)

Category III

- Designed for bulk system needs, and distribution system reliability/power quality needs
- Coordinated with existing standards for very high DER levels

Categories for DER response to abnormal EPS conditions

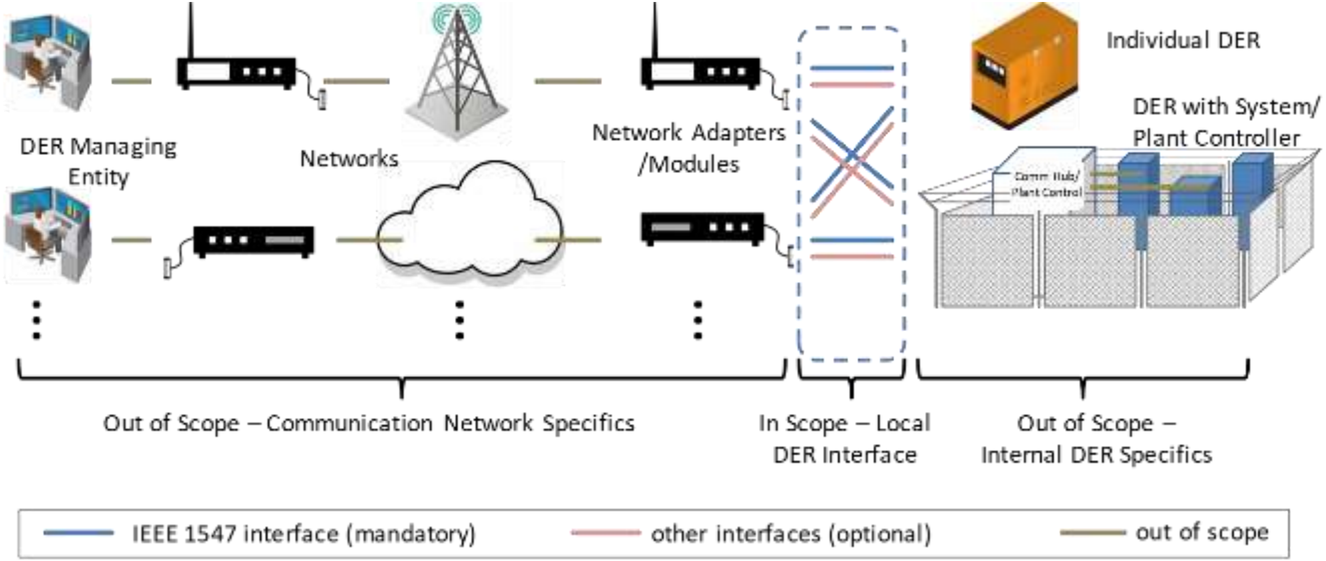
Category	Objective	Foundation
I	Essential bulk system needs and reasonably achievable by all current state-of-art DER technologies	German grid code for synchronous generator DER
II	Full coordination with bulk power system needs	Based on NERC PRC-024, adjusted for distribution voltage differences (delayed 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 for bulk system reliability.

Interoperability

Clause 10

Interoperability requirements



IEEE 1547-2018 defines communication interface

List of Eligible 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

Energy Storage(ES), and ES+PV Interconnection Considerations

P1547.9 a Future Guide for ES-DER Interconnection

Representative Grid Connected BESS

IDENTIFY:
- **AREA EPS**
- **LOCAL EPS**
- **POC**
- **PCC (or POI)**

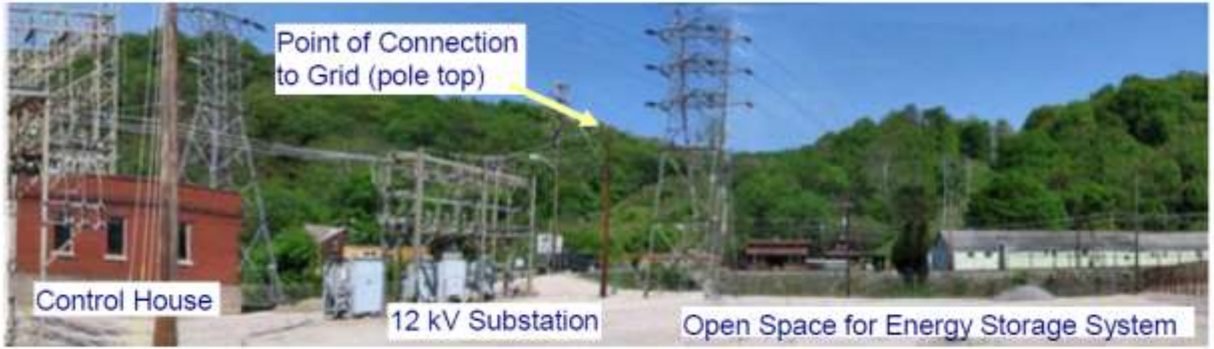
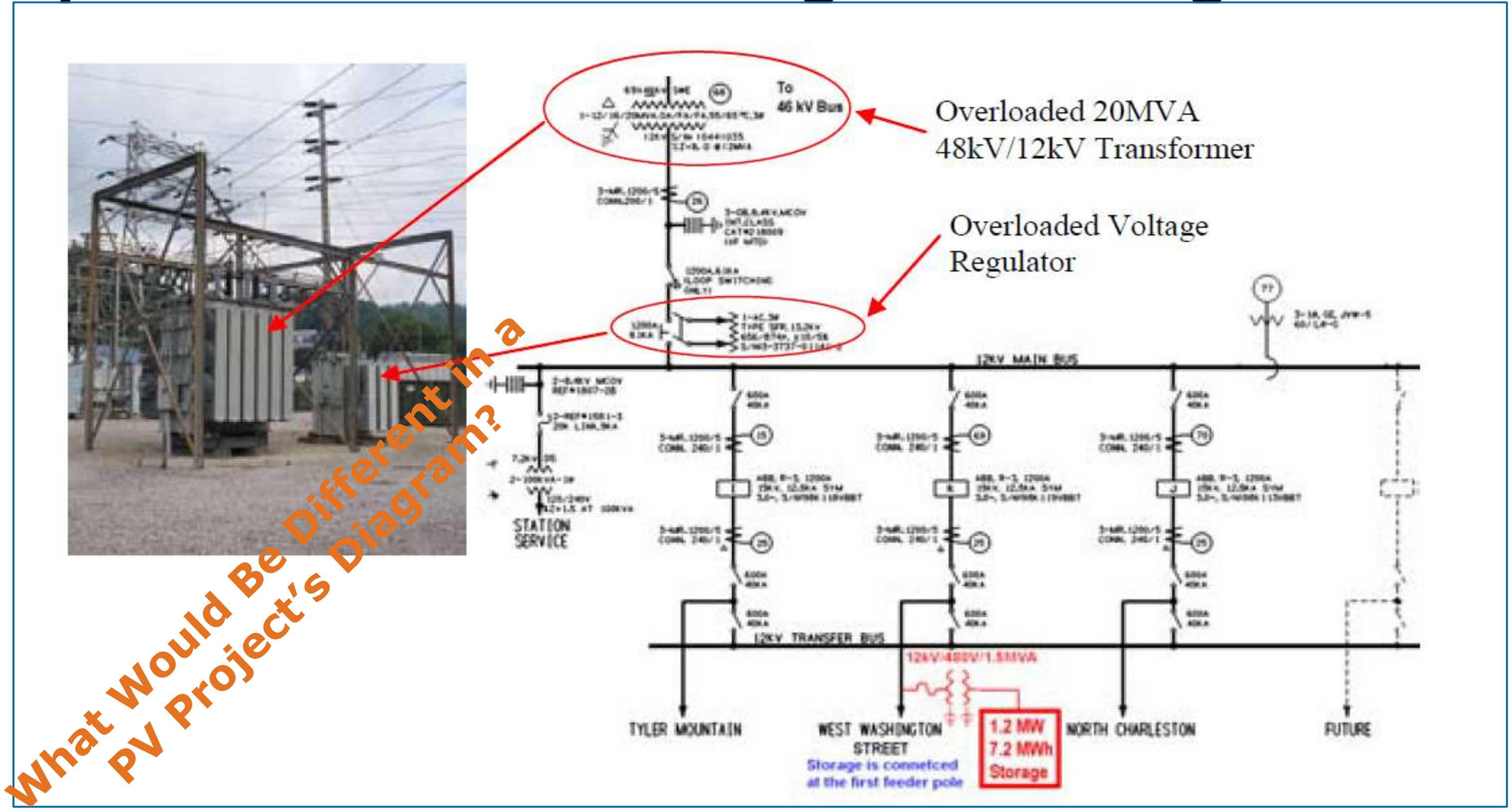


Figure 14 – Photographs of AEP's Chemical Substation before & after installation of 1.2 MW DESS in line with a 12kV feeder

Source, AEP
From, SANDIA REPORT, Installation of the First Distributed Energy Storage System (DESS) at American Electric Power (AEP), SAND2007-3580, June 2007

Representative BESS Single Line Diagram



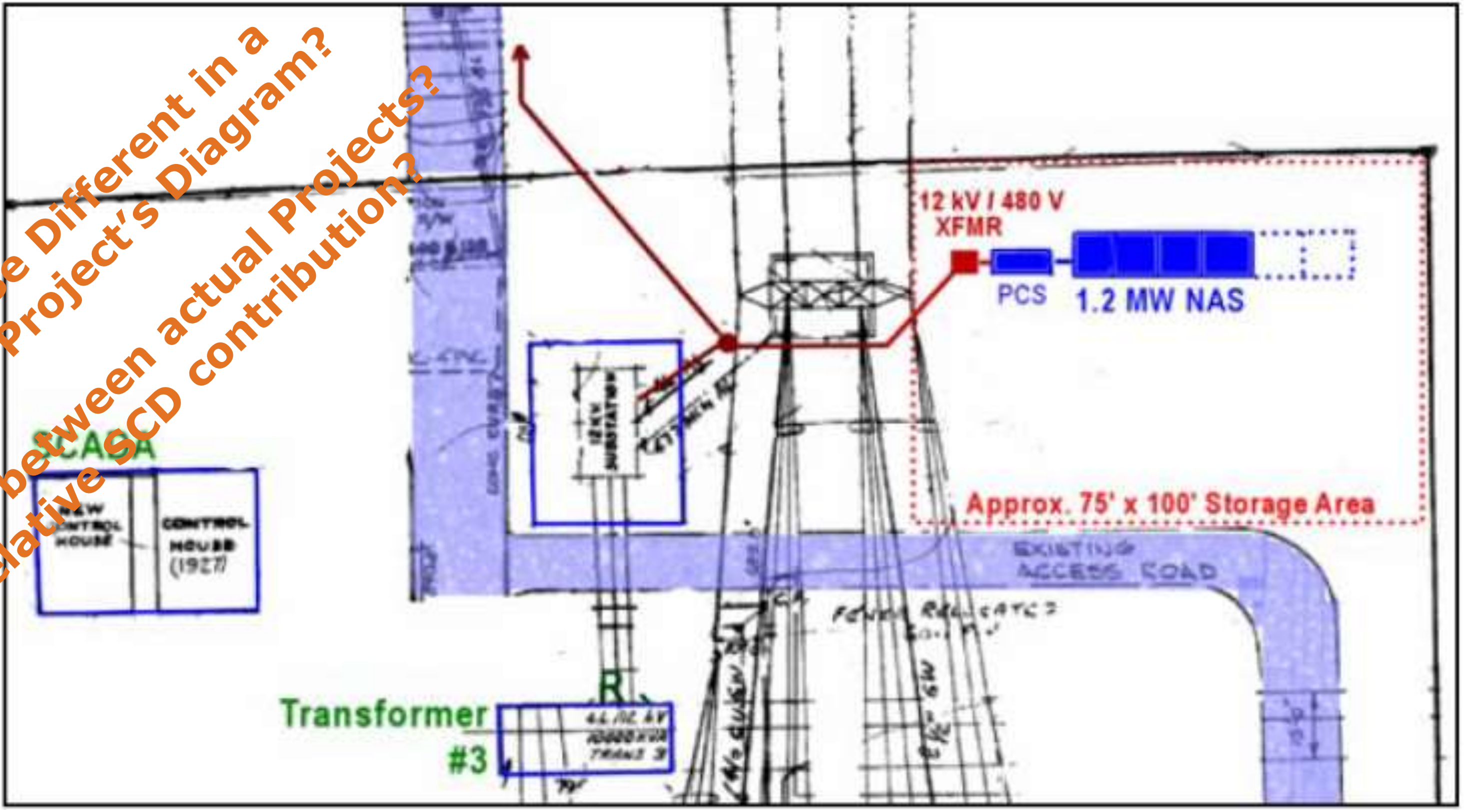
Source, AEP

From, SANDIA REPORT, Installation of the First Distributed Energy Storage System (DESS) at American Electric Power (AEP), SAND2007-3580, June 2007

Representative BESS Plot Plan

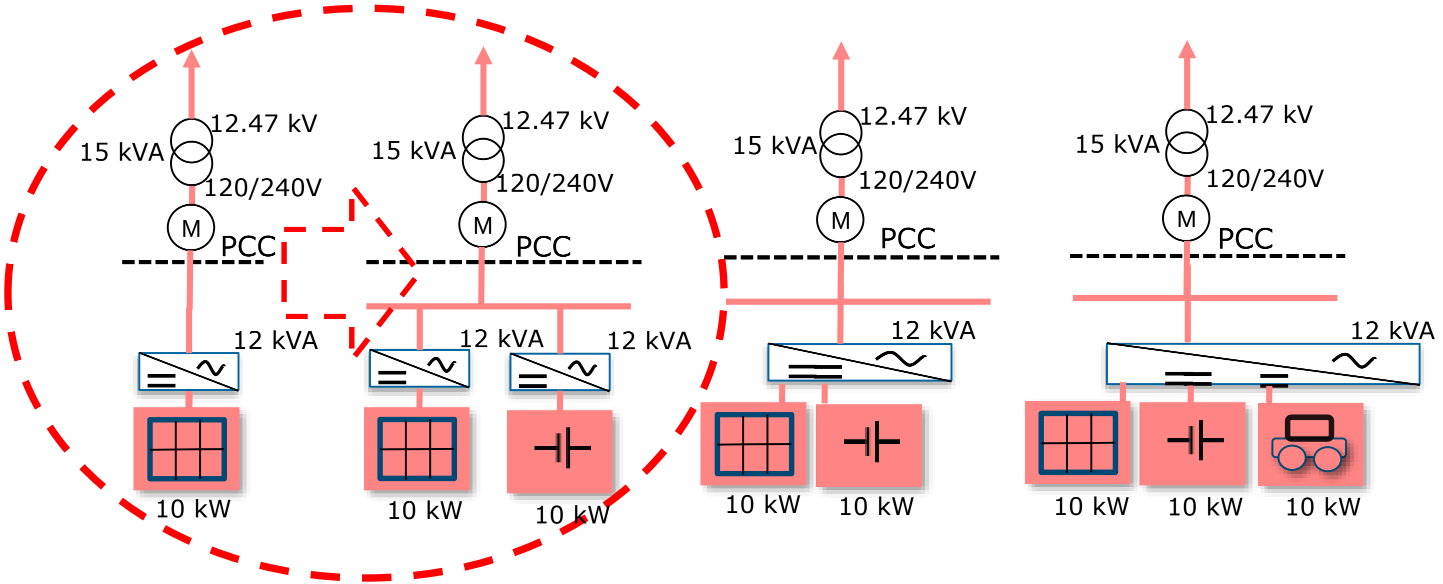
What Would Be Different in a PV or PV+ES Project's Diagram?

Differences between actual Projects? e.g. relative SCD contribution?



Source, AEP
From, SANDIA REPORT, Installation of the First Distributed Energy Storage System (DESS) at American Electric Power (AEP), SAND2007-3580, June 2007

Power Capability vs Controlled Capacity vs Rating at the Point of Common Coupling (PCC)



What's the interconnection rating and/or requirement at the PCC?

Who determines? On what basis?
Does amount of metered demand, and how its connected, have an impact?

Without Updated Standards Plus Adoption by AHJ's, Some Services from ES & PV+ES Won't Be Deliverable

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

Which " End Uses" Require a Dispatchable Resource?

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

IEEE P1547.9 Project

Approved by the IEEE SASB on March 8, 2018

Title: Draft Guide to Using IEEE Standard 1547 for Interconnection of Energy Storage Distributed Energy Resources with Electric Power Systems

Scope: This Guide provides information on and examples of how to apply the IEEE Std 1547, for the interconnection of Energy Storage Distributed Energy Resources (DER ES). Scope includes DER ES connected to area Electric Power Systems (local EPSs) that are capable of bidirectional real and reactive power flow, and are capable of exporting real power to the EPS. Guidance is also provided for non-exporting DER ES, such as Uninterruptible Power Supply (UPS) type systems that support onsite loads, or Electric Vehicle (EV) chargers, with charging attributes that could have power system impacts, e.g. modulating rate of charge proportionally to system frequency.

Purpose: The purpose of this guide is to provide guidance on prudent and technically sound approaches to interconnection of DER ES to power systems. This guideline will also consider ES-related topics not currently addressed or fully covered in the main IEEE 1547 Standard document. For example:
1). Guidance for interconnection of EV charging stations with the ability for exporting (i.e., bidirectional real or reactive power exchange) to the connected power system (i.e., "V2G").
2). Guidance on when ES are or are not within the scope of P1547. For example, 1547.9 would expand on the exceptions for systems that are non-exporting, e.g. UPS that receive energy from the grid, but only use it for premise loads while off-grid.
3). Guidance on charging and generation constraints to minimize negative impacts in the distribution system.

P1547.9 TIMELINE

Dates	Activities	Status
February 28, 2019	P1547.9 WG meeting – WG initiated	Done
June 6, 2019	P1547.9 WG Meeting – Draft 1 initiated	Plan
October 2019	P1547.9 WG Meeting (online meeting)	Plan
February 2020	P1547.9 WG Meeting (co-located with ESSB)	Plan
Summer 2020	P1547.9 WG Meeting	Plan
Fall/Winter 2020	P1547.9 WG Meeting	Plan
Spring/Summer 2021	P1547.9 WG Meeting	Plan
TBD	P1547.9 Ballot draft approved by WG	
TBD	P1547.9 To IEEE-SA for ballot	
TBD	IEEE Std 1547.9-20XX Published	

DER and Distribution Networks Considerations

See Separate Slide Deck, M. Coddington, NREL

Extract from IEEE 1547-2018 Subclause 9.1 "Network protectors and automatic transfer scheme requirements"

DER on grid or spot networks shall have provisions to

- Monitor instantaneous power flow at the PCC of the DER interconnected to the secondary grid or spot network for reverse power relaying, minimum import relaying, dynamically controlled inverter functions and similar applications to prevent reverse power flow through network protectors.
- Maintain a minimum import level at the PCC as determined by the Area EPS operator.
- Control DER operation or disconnect the DER from the Area EPS based on an autonomous setting at the PCC and/or a signal sent by the Area EPS operator.

DER on grid or spot networks shall not

- Cause any NP to exceed its loading or fault-interrupting capability.
- Cause any NP to separate dynamic sources.
- Cause any NP to connect two dynamic systems together.
- Cause any NP to operate more frequently than prior to DER operation.
- Prevent or delay the NP from opening for faults on the Area EPS.
- Delay or prevent NP closure.
- Energize any portion of an Area EPS when the Area EPS is de-energized.
- Require the NP settings to be adjusted except by consent of the Area EPS operator.
- Prevent reclosing of any network protectors installed on the network. This coordination shall be accomplished without requiring any changes to prevailing network protector *clearing time* practices of the Area EPS.

IEEE 1547-2018 Adoption,

and early movers, CA Rule 21, HI Rule 14, and UL-1741-SA

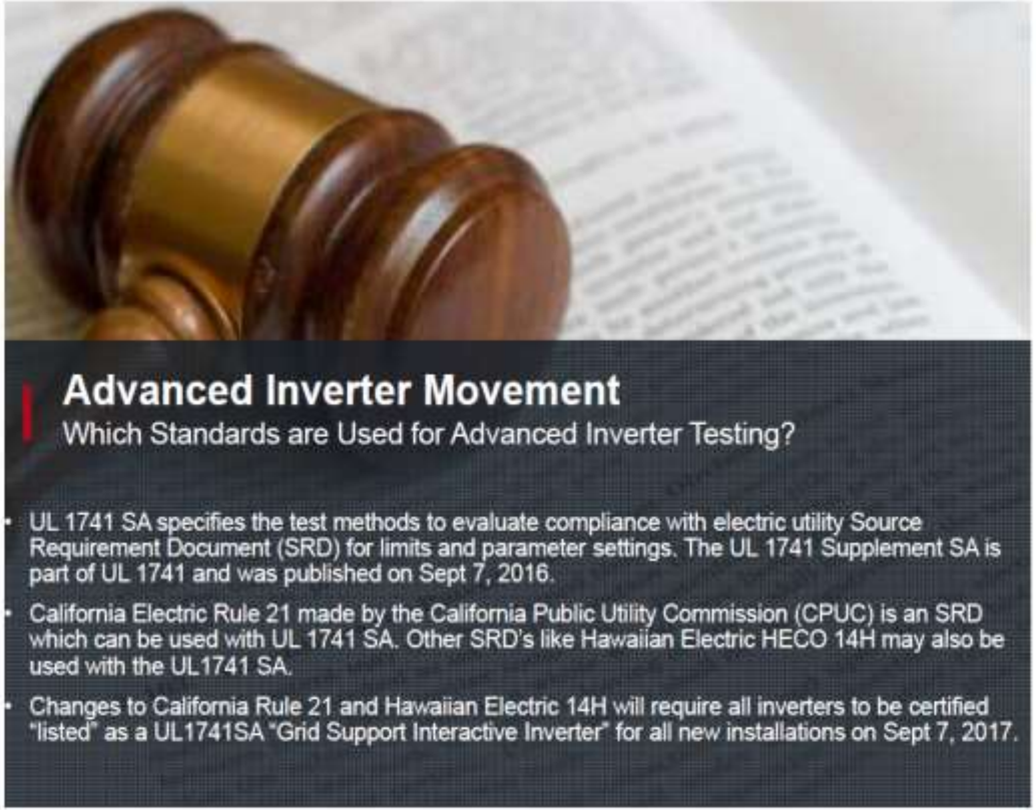
IEEE

Timeline for rollout of 1547.1 and UL 1741

Dates	Activities	Status
April 2018	**Milestone:** IEEE 1547-2018 published: New DER grid interconnection requirements established. In parallel: IEEE 1547.1 update in progress. (New test procedures to verify conformance to 1547-2018)	Complete
February 26-27, 2019	IEEE P1547.1 WG meeting – Draft 9.3 approved by Working Group	Complete
March 2019	Final pre-ballot edits to P1547.1	Complete
April 2019	**Milestone:** Final WG vote to send P1547.1 Draft 9.4 to IEEE-SA	Complete
April 2019	P1547.1 D9.4 sent to IEEE-SA for ballot invitation and MEC review	Complete
Q2-Q4 2019	IEEE-SA balloting and ballot resolution of P1547.1 (iterative)	In progress
Q4 2019 / Q1 2020	UL 1741 begin revision draft to incorporate new 1547.1 and 1547	
Q4 2019	**Milestone:** IEEE-SA ballot approval of P1547.1	
Q1 2020	IEEE RevCom review of P1547.1 In parallel: Finalize UL 1741 ballot document to incorporate new 1547.1.	
Q1/Q2 2020	**Milestone:** 1547.1 finalization and publication	
Q1/Q2 2020	UL Standards Technical Panel review and ballot updated UL 1741	
Q2/Q3 2020	**Milestone:** UL 1741 update published	
Q3 2020 – Q4 2021	Inverter manufacturers update and recertify products to UL 1741	
Q4 2020 – Q4 2021	UL 1741 / 1547-2018 compliant inverters expected to be available on market	

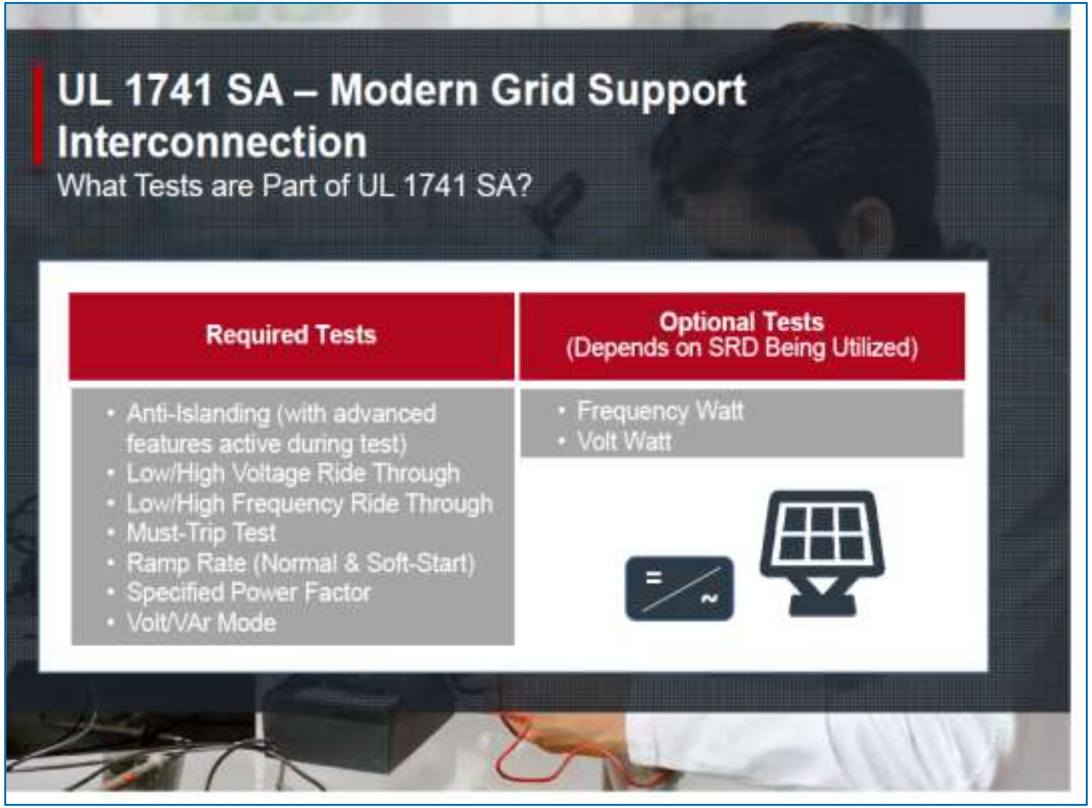
Update from P1547.1 WG Chair, Nov. 2019

UL-1741-SA, an interim solution



Source, UL Presentation, T. Zgonena, 11/1/2017

UL-1741-SA, an interim solution



Source, UL Presentation, T. Zgonena, 11/1/2017

UL-1741-SA, an interim solution

Use of UL1741 SA with IEEE 1547, 2nd Ed. Until IEEE 1547.1 2nd Ed. Publication

- There is some utility interest to make use of IEEE 1547 2nd edition ASAP.
- It is difficult to implement 1547 edition 2 without a test protocol.
- Even with using UL1741 SA as a seed document and fast track task group efforts 1547.1 edition 2 is still ~1.5yrs away from publication.
- There is growing support / agreement to use the published 1547 edition 2 to develop a Source Requirements Document (SRD) such that we can use the existing published UL1741 SA standard and test protocols to provide a certification that addresses a majority of the 2nd edition 1547 requirements.
- This hybrid certification will quickly address a majority of our needs ASAP!

- Once both the 2nd editions of 1547 and 1547.1 are published UL1741 will be revised to replace the Supplement SA with the 2nd edition references and… All will be right with the world.

☺

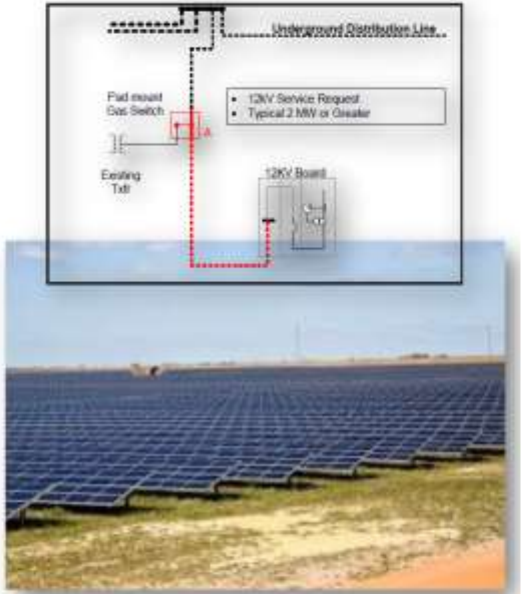
Source, UL Presentation, T. Zgonena, 11/1/2017

CA Rule 21

Generation Tariffs In California

Rule 21 – Export Generation Projects
Wholesale Distribution Access Tariff (WDAT)

- **Rule 21** and **WDAT**, Procedurally are handle different, Engineering is the same
  - Rule 21 is a CA PUC approved tariff
  - WDAT is a FERC approved tariff
- Interconnected for purposes of selling the energy
  - Rule 21
    - Export (NEM interconnection, PPA sell to Local Utility)
    - Non-export (Local customer)
  - WDAT
    - Export (Sell Energy to Utility or other entity)
- Example of California Procurement Programs
  - Solar PV Program (SPVP) - 500MW of PV
  - Renewable – Market Adjusting Tariff - Re-MAT – 220 MW of PV
  - Utility Distribution Upgrade Deferrals



Energy for What's Ahead℠

Source, SCE Presentation, R. Salas, 9/14/2018

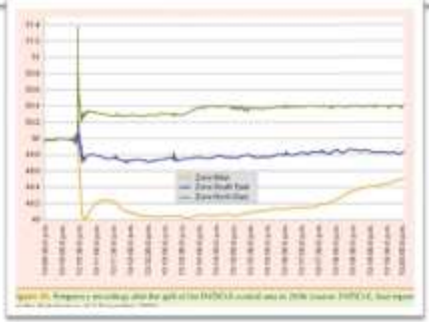
CA Rule 21

Need For Advanced Inverter Functionality

Germany Experience

- Reverse power flows caused issues on distribution system because they were not originally designed for reverse power flow
- Grid stabilities issues with inverters not being able to respond to frequency deviations
- Having to retrofit approximately 315,000 installed inverters
  - German standards updated to support the high levels of PV in distribution systems, with new technical requirements, communication and control strategies

Overview of German Grid Issues and Retrofit of Photovoltaic Power Plants in Germany for the Prevention of Frequency Stability Problems in Abnormal System Conditions of the ENTSO-E Region Continental Europe



Hawaiian Experience

- High level of penetration causing disruption to the interconnection of DERs
- Need for more advanced function to mitigate issues on their highly penetrated systems

Energy for What's Ahead™

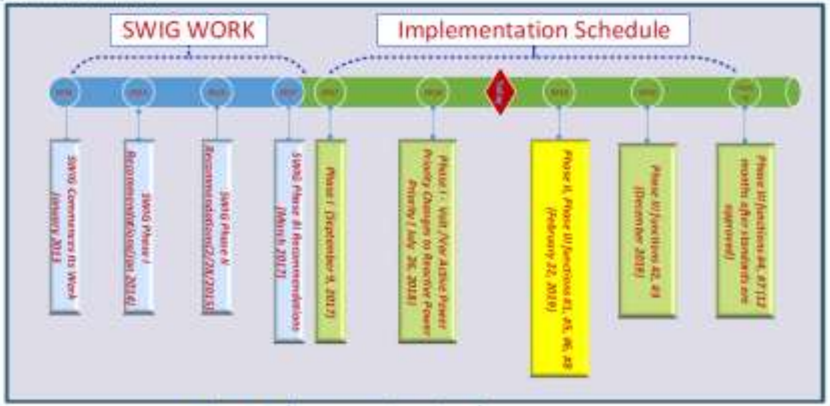
Source, SCE Presentation, R. Salas, 9/14/2018

CA Rule 21

SOUTHERN CALIFORNIA EDISON

Energy for What's Ahead℠

California Smart Inverter Implementation Plan



Phase I (Autonomous Functions)

Function 1: Low/High Voltage Ride-through
Function 2: Low/High Frequency Ride-through
Function 3: Dynamic Volt/Var
Function 4: New Fixed Power Factor Requirements
Function 5: Reconnect By Soft Start Requirements
Function 6: Ramp Control Requirements

Phase II (Communications)

- Establishes communication capabilities requirements between Generating Facilities and Utility
- February 22, 2019, new IR must meet one of three methods available to communicate to Smart Inverters
  - Direct to inverter
  - Through GF-EMS
  - Through Aggregator
- Default Protocol is the IEEE2030.5 Other may be used
- End Device (Inverter, GFEMS, Aggregator) must be certified under SunSpect Alliance Test

Phase III (Advanced Functions)

Function 1: Monitor Key DER data
Function 2: DER Disconnect and Reconnect Commands
Function 3: Limit Maximum Active Power Mode
Function 4: Set Active Power Mode
Function 5: Frequency Watt Mode
Function 6: Volt Watt Mode
Function 7: Dynamic Reactive Support
Function 8: Scheduling Power Values and Modes

Energy for What's Ahead℠

Source, SCE Presentation, R. Salas, 9/14/2018

HI Rule 14

What is Rule 14H ?

- **Rule 14H is the Interconnection Rule in Hawaii**
  - Defines the technical and functional requirements for DER interconnected on the grids operated by the Hawaiian Electric Inc. companies. HECO, HELCO, MECO
    - https://www.hawaiianelectric.com/billing-and-payment/rates-and-regulations/hawaiian-electric-rules
- **Rule 14H is embodied in Tariff language. Related Rules & Tariffs include:**
  - Rule No. 22 - Customer Self-Supply
  - Rule No. 23 - Customer Grid-Supply
  - Rule No. 24 - Customer Grid-Supply Plus
  - Rule No. 25 - Smart Export
  - Rule No. 26 - Community-Based Renewable Energy Program
- **SRD V 1.1 outlines the specific requirements for Grid Support Inverters**
  - https://www.hawaiianelectric.com/Documents/clean_energy_hawaii/producing_clean_energy/SRD_UL1741_SA_V1.1_20170922_final.pdf

5 |

ENPHASE.

Source, Enphase presentation, J. Berdner, 9/14/2018

HI Rule 14

Rule 14H Functions Matrix

Function Set	Advanced Functions Capability	Interconnection Standards: IEEE 1547-2003	Interconnection Standards: IEEE 1547a-2014	Interconnection Standards: IEEE 1547-2018	Rule 14H: 2015	Rule 14H: 2018 SRD V1.1	Listing/ Certification: UL 1741	Listing/ Certification: UL 1741(SA) 2016	Listing/ Certification: IEEE 1547.1-2017*
All	Adjustability in Ranges of Allowable Settings		√	‡					Δ
Monitoring & Control	Ramp Rate Control			‡ ?	‡	‡ ?		Δ	Δ ?
	Communication Interface			‡		‡			Δ
	Disable Permit Service (Remote Shut-Off)			‡					Δ
	Limit Active Power			‡		‡ CSS,NEM+			Δ
	Monitor Key DER Data			‡					Δ
Scheduling	Set Active Power								
	Scheduling Power Values and Models					‡ CGS+, smart CSS			
Reactive Power & Voltage Support	Constant Power Factor	√	√	‡	‡	‡	√	Δ	Δ
	Voltage-Reactive Power (Volt-Var)	X	√	‡		‡		Δ	Δ
	Autonomously Adjustable Voltage Reference			‡					Δ
	Active Power-Reactive Power (Watt-Var)	X		‡					Δ
	Constant Reactive Power	√	√	‡	‡	‡	√		Δ
	Voltage-Active Power (Volt-Watt)	X	√	‡		‡ Opt		Δ	Δ
	Dynamic Voltage Support during VRT			√					
Bulk System Reliability & Frequency Support	Frequency Ride-Through (FRT)			‡	‡	‡		Δ	Δ
	Rate-of-Change-of-Freq. Ride-Through			‡					Δ
	Voltage Ride-Through (VRT)			‡	‡	‡		Δ	Δ
	Voltage Phase Angle Jump Ride-Through			‡					Δ
	Frequency-Watt	X	√	‡		‡		Δ	Δ

Legend: X Prohibited, √ Allowed by Mutual Agreement, ‡ Capability Required, Δ Test and Verification Defined
[...] Subject to clarification of the technical requirements and use cases, !!! Important Gap

Source: EPRI.

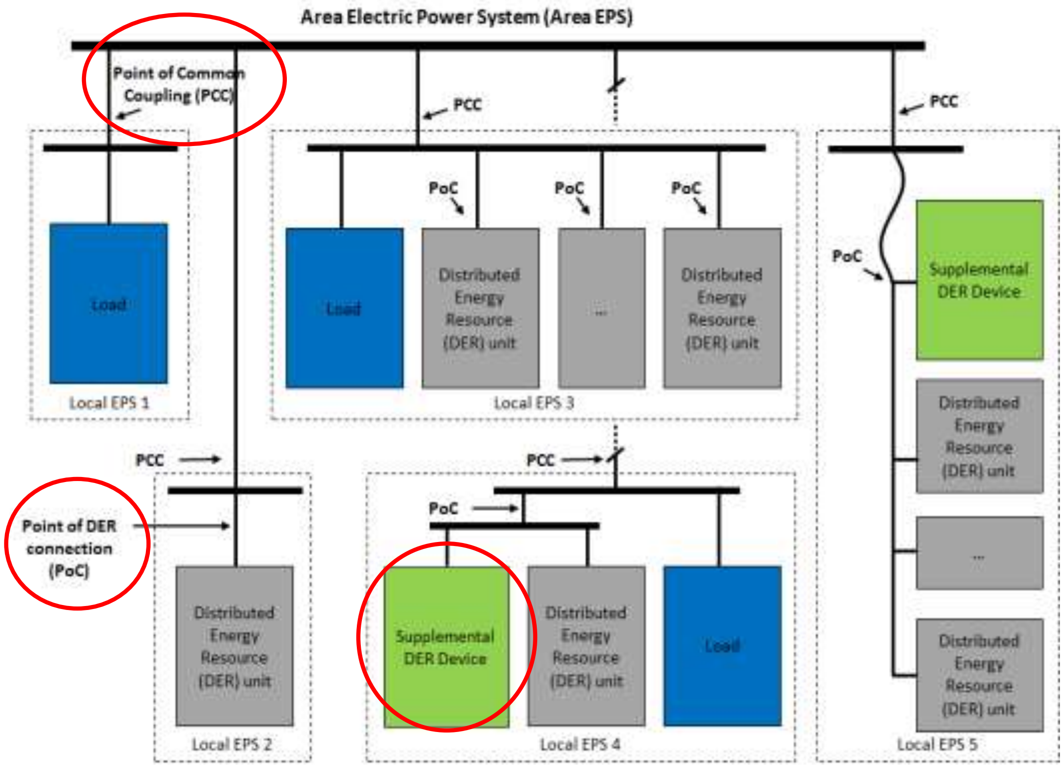
ENPHASE

Questions?

Charlie.Vartanian@pnnl.gov

Backup Slides

Reference Point of Applicability

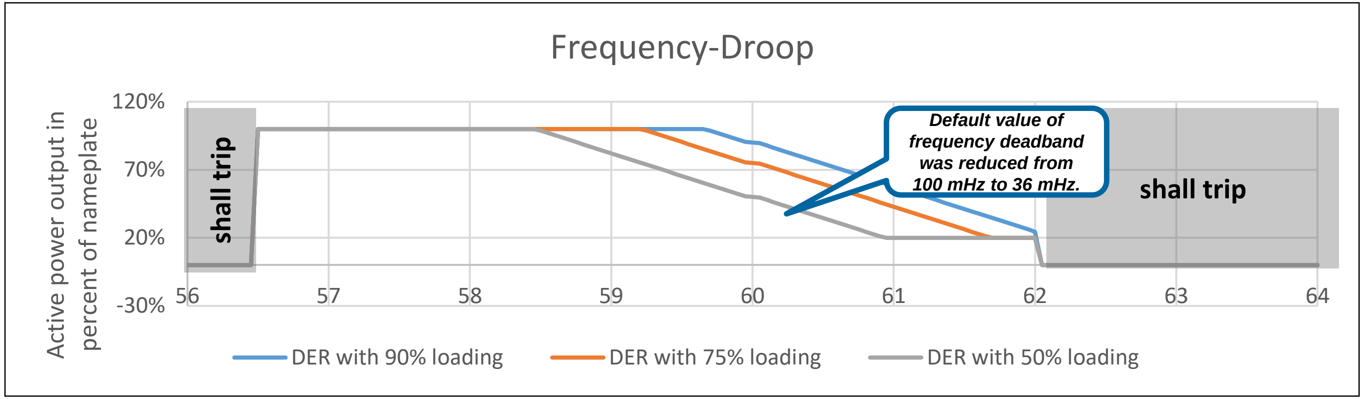


- **RPA is where performance requirements apply**
- IEEE 1547 specifies RPA depending on three criteria:
  - Aggregate DER rating
  - Average load demand
  - Zero sequence continuity
- Generally:
  - PoC (DER terminals) for small and load-immersed DER
  - PCC for large exporting installations

Enter Service criteria

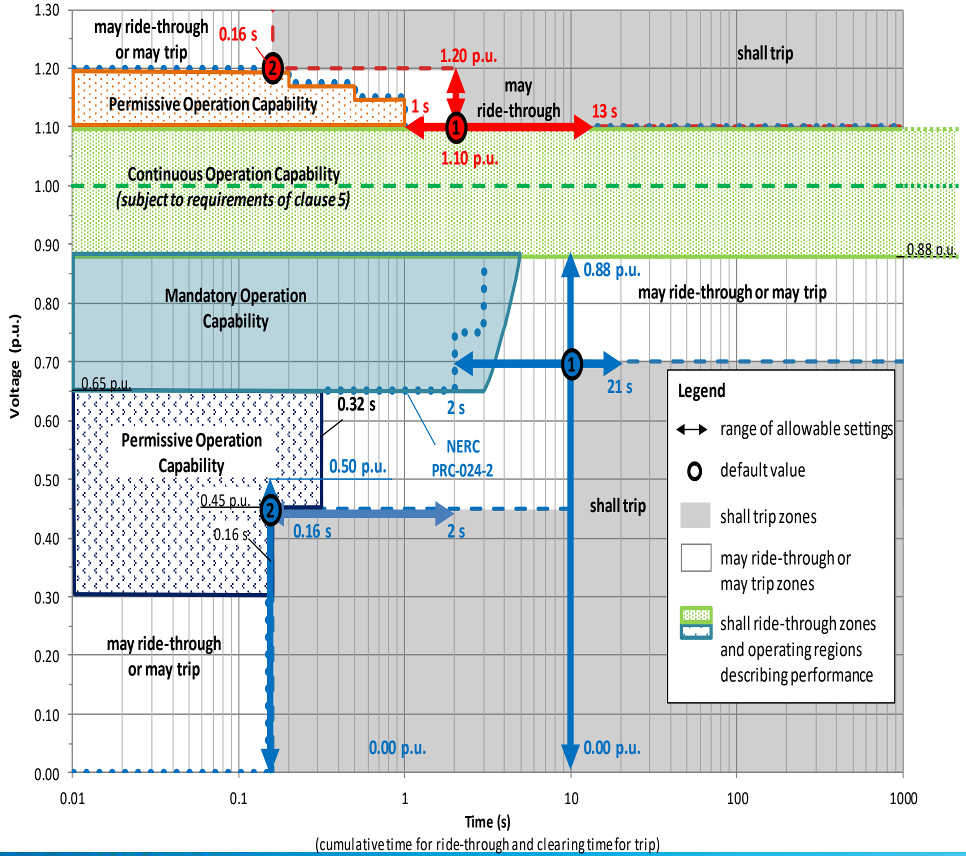
- Prior to *Enter Service* or *Return to Service* after a trip, power system's voltage must be within specified voltage magnitude and frequency range continuously for a defined period
- *Permit Service* flag must be set to *Enabled*
- Power system voltage and frequency limits, and DER delay period are all adjustable within a defined range
- The DER must be capable of ramping up its power either continuously or in small steps (<20%) after entering service
  - Exception: Smaller DER installations (<500 kVA) can alternatively return to service in one step after a randomized additional delay

Frequency Support



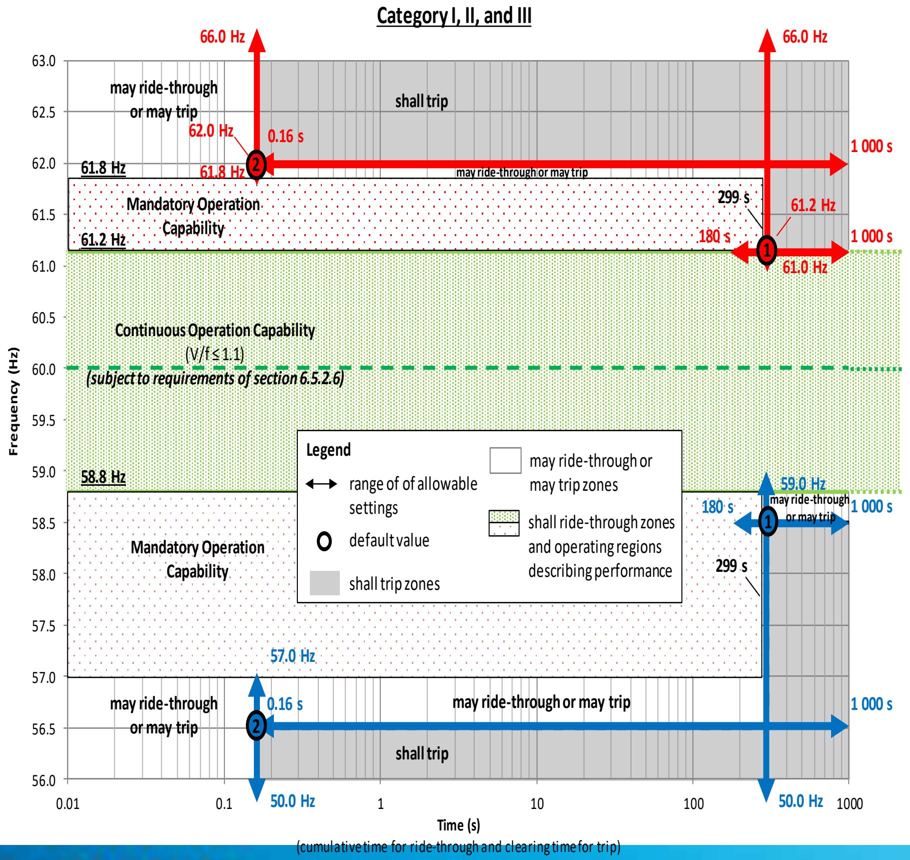
- Overfrequency: all DERs required to provide droop response
- Underfrequency: Cat II and III DERs required to provide droop response *if power is available*
- Only a functional capability requirement
  - Utilization remains outside the scope of IEEE 1547-2018
- Adjustable dead bands and droop
- Response time requirements (not "as fast as technically possible")

IEEE Std 1547-2018 Voltage Ride Through, Category II



- **Mandatory operation:**
  - Continuance of active current and reactive current exchange
- **Momentary cessation**:
  - Temporarily cease to energize the utility's distribution system
  - Capability of immediately restoring output of operation
- **Permissive operation**:
  - Either mandatory operation or momentary cessation.

IEEE Std 1547-2018 Frequency Ride-Through and Trip



- **Continuous operation:**
  - Exchange of current between the DER and EPS within prescribed behavior while connected to the Area EPS and
  - while the *applicable voltage* and the system frequency is within specified parameters.
- **Mandatory operation:**
  - Continuance of active current and reactive current exchange

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

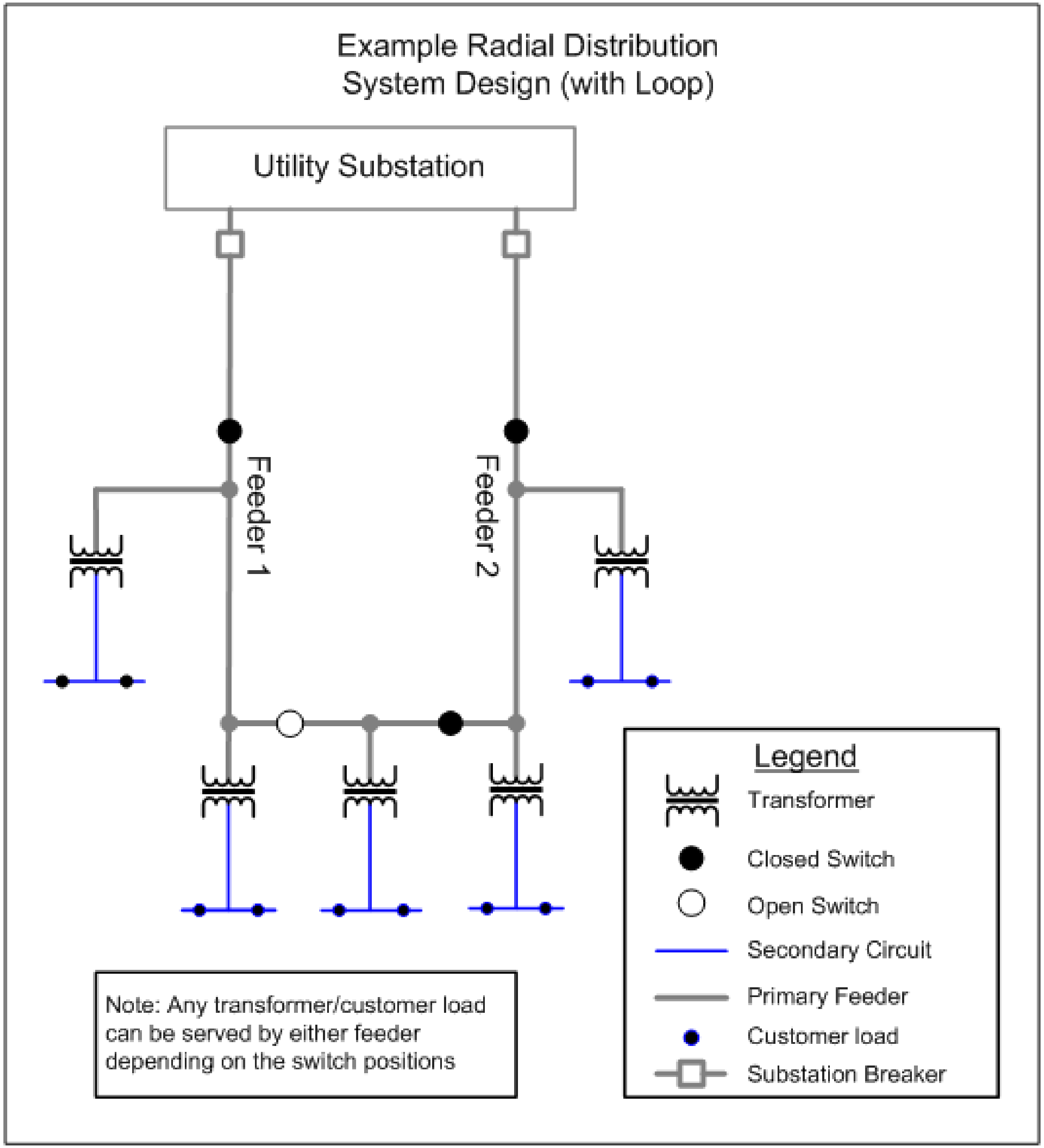
Overview of Secondary Networks - DERs and BESS Considerations

Michael Coddington

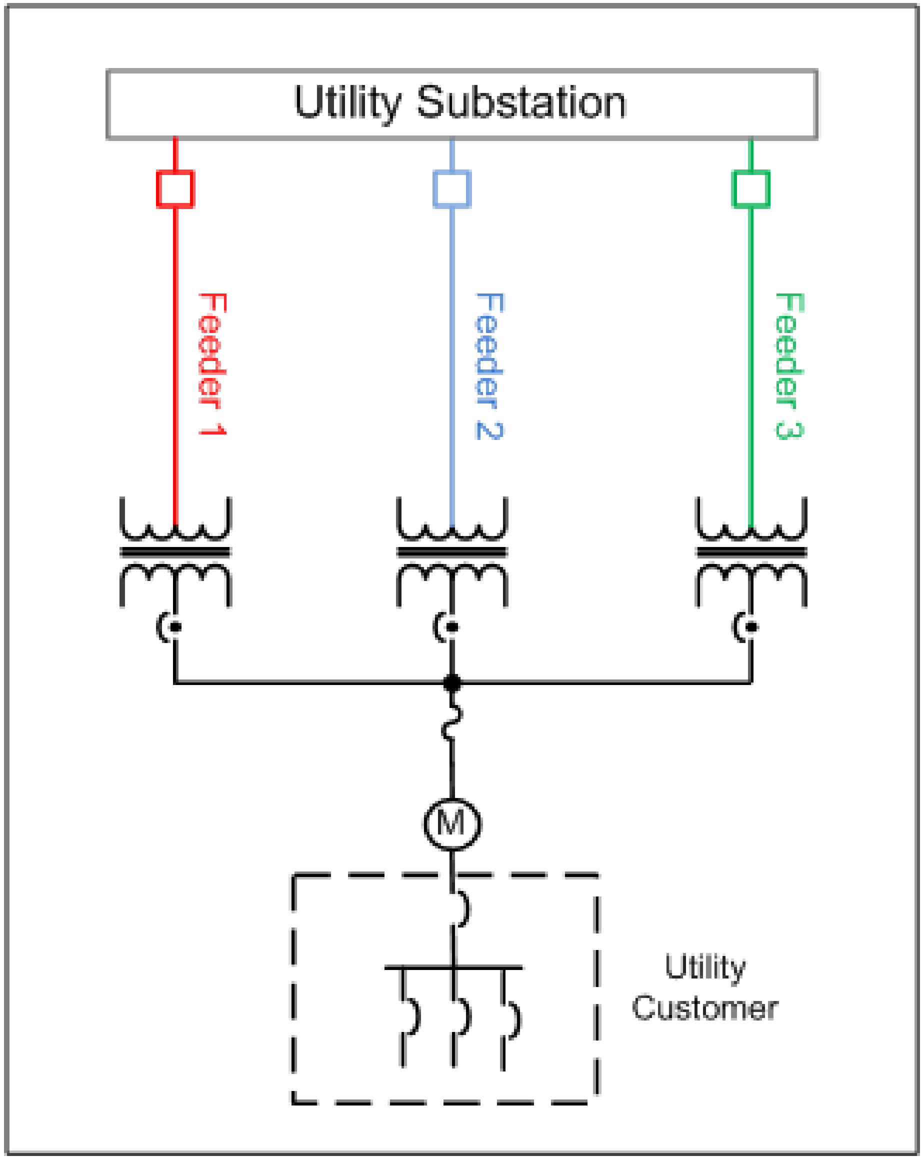
IEEE P1547.9 Meetings

October 31, 2019

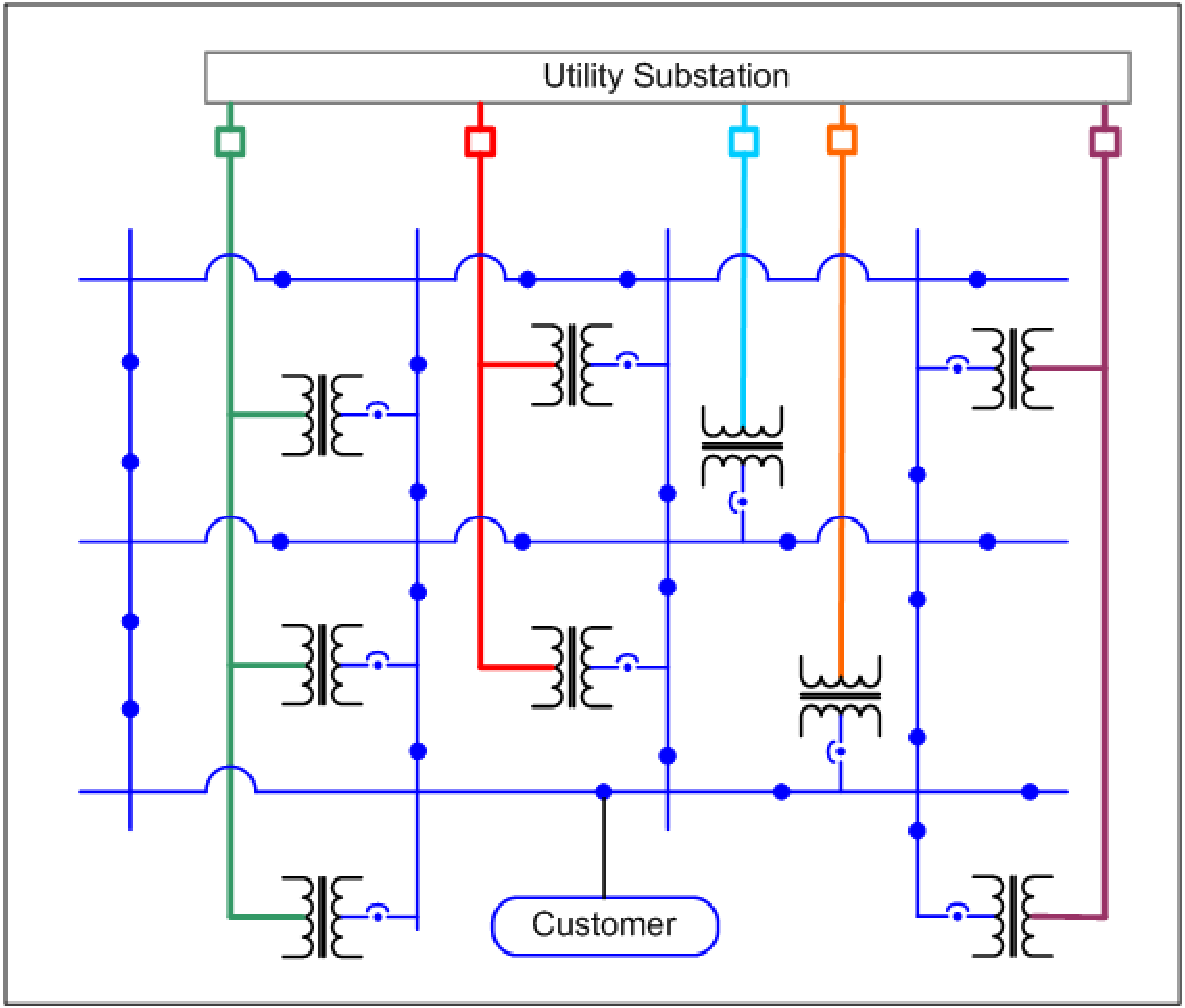
Radial Distribution System



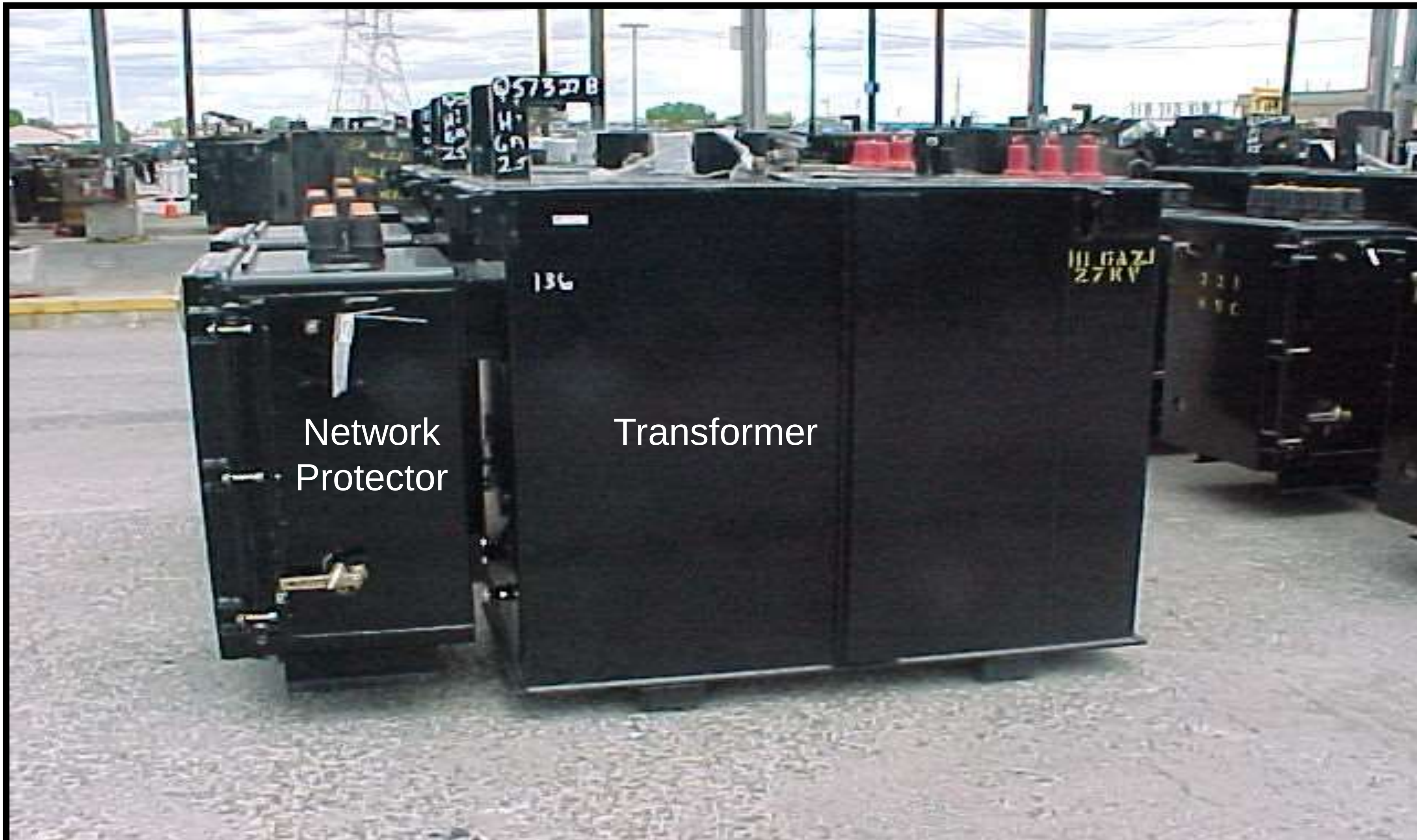
Example Spot Network



Area Network Example



Network Transformer & Network Protector



Network Protectors

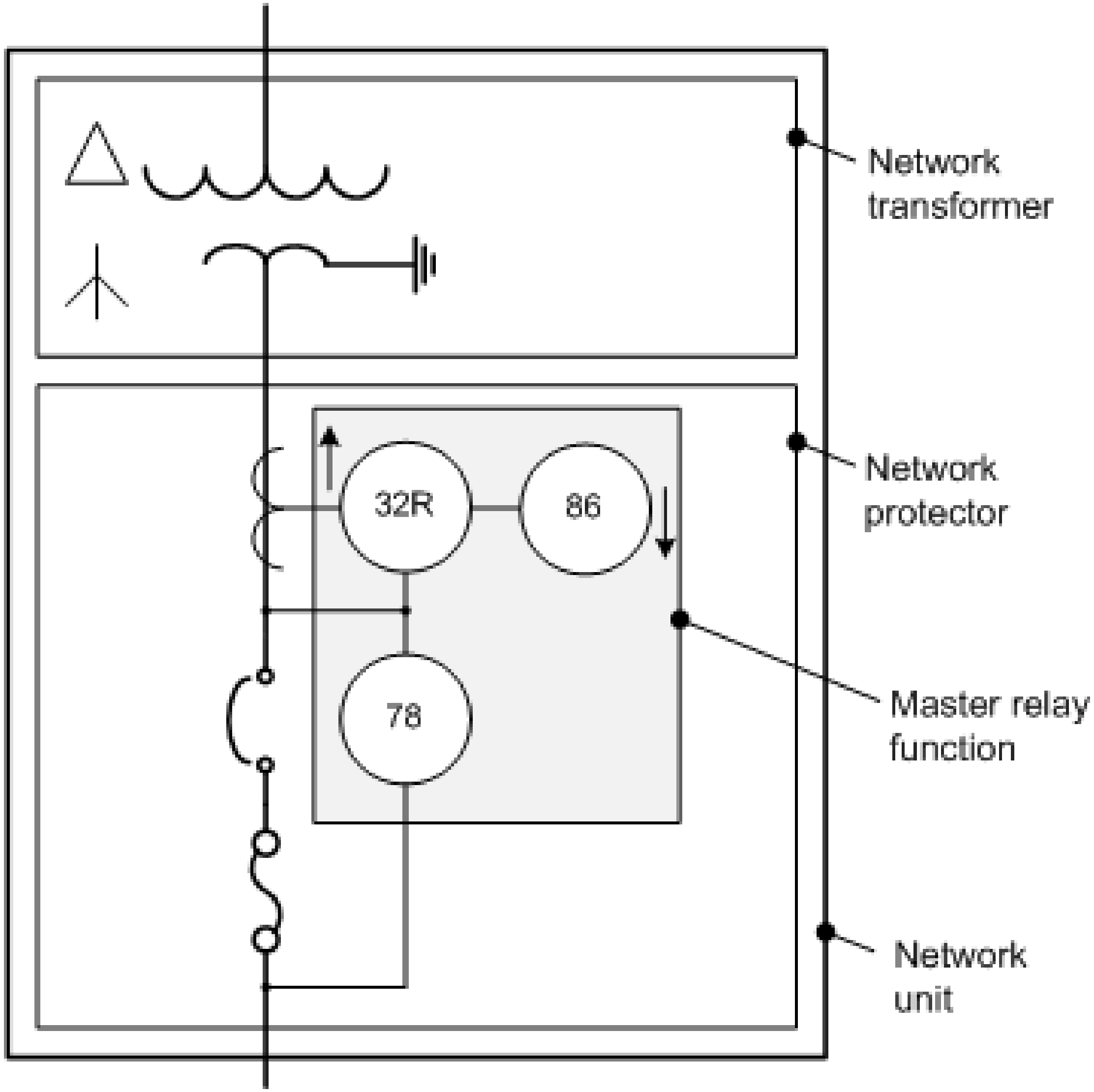
Primary purposes:

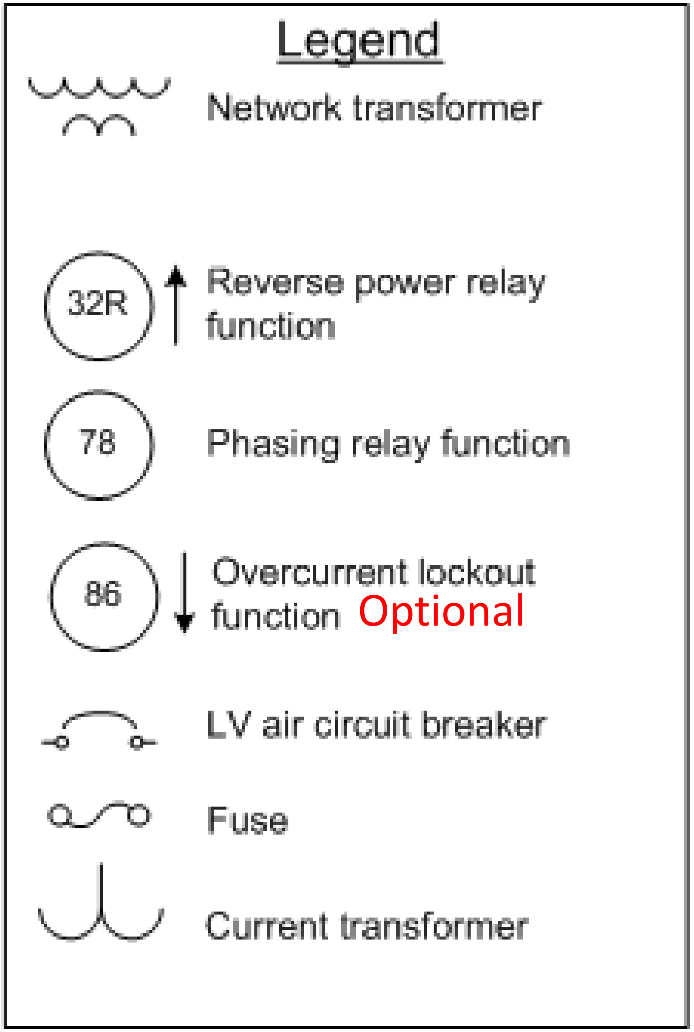
- Trip open the protector when there is power flow from the network to the primary (reverse power)
- Insure automatic closure of the protector when there is a potential for a forward flow of power into the secondary network

Three types of network protector relays

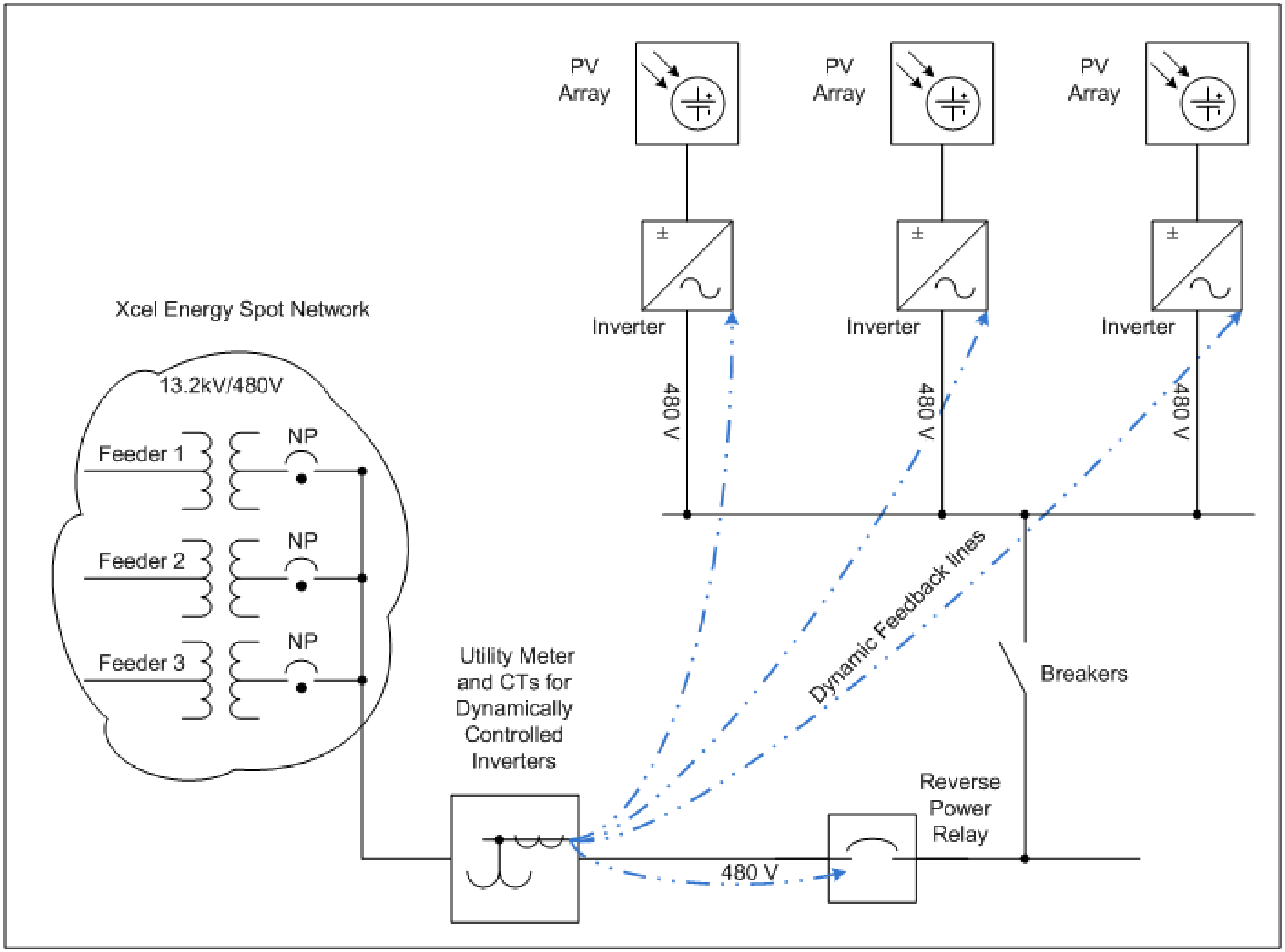
- Electromechanical (oldest)
- Solid-state
- Microprocessor (newest)

Network Unit / Network Protector

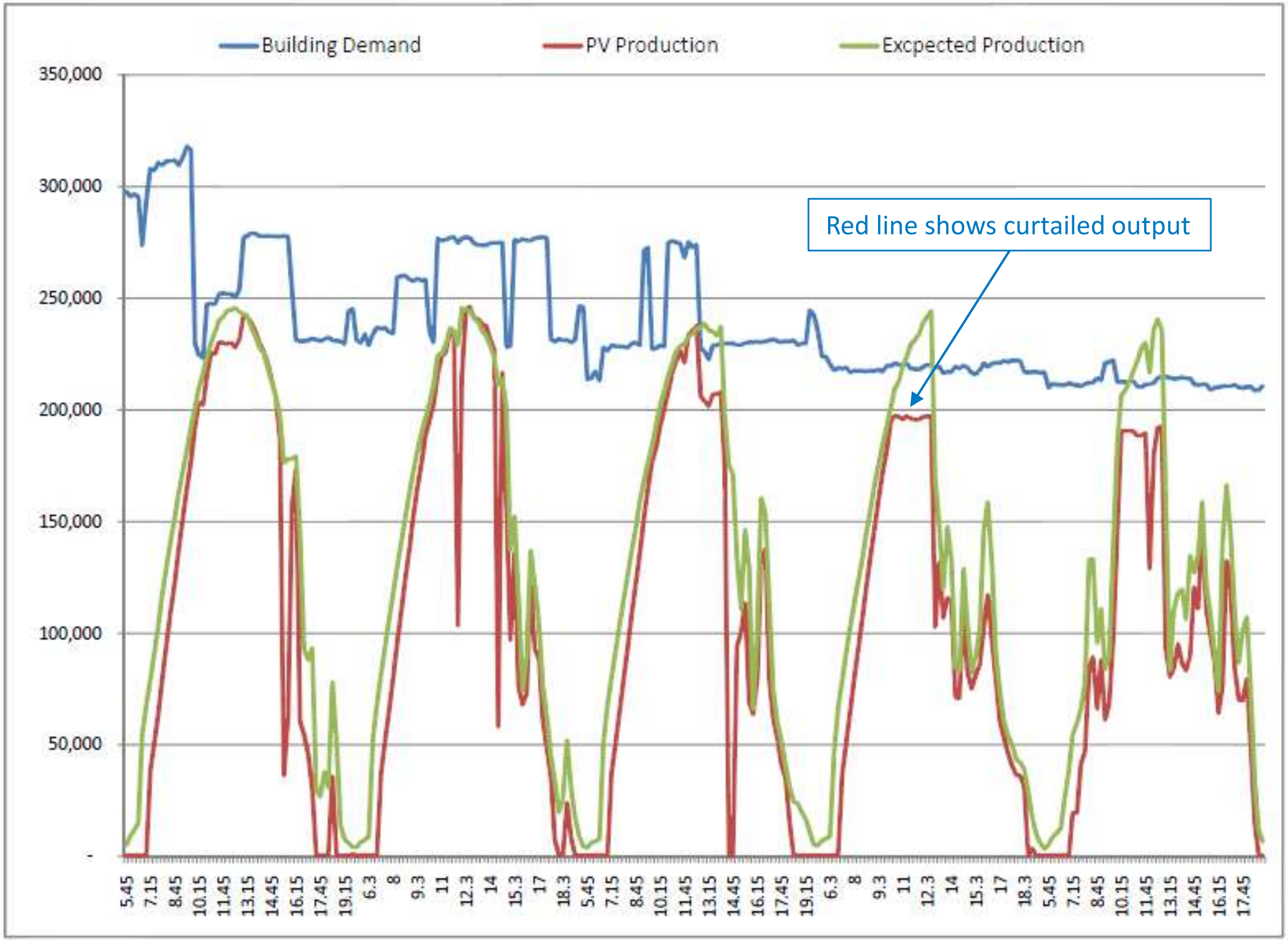




Colorado Convention Center One Line Diagram

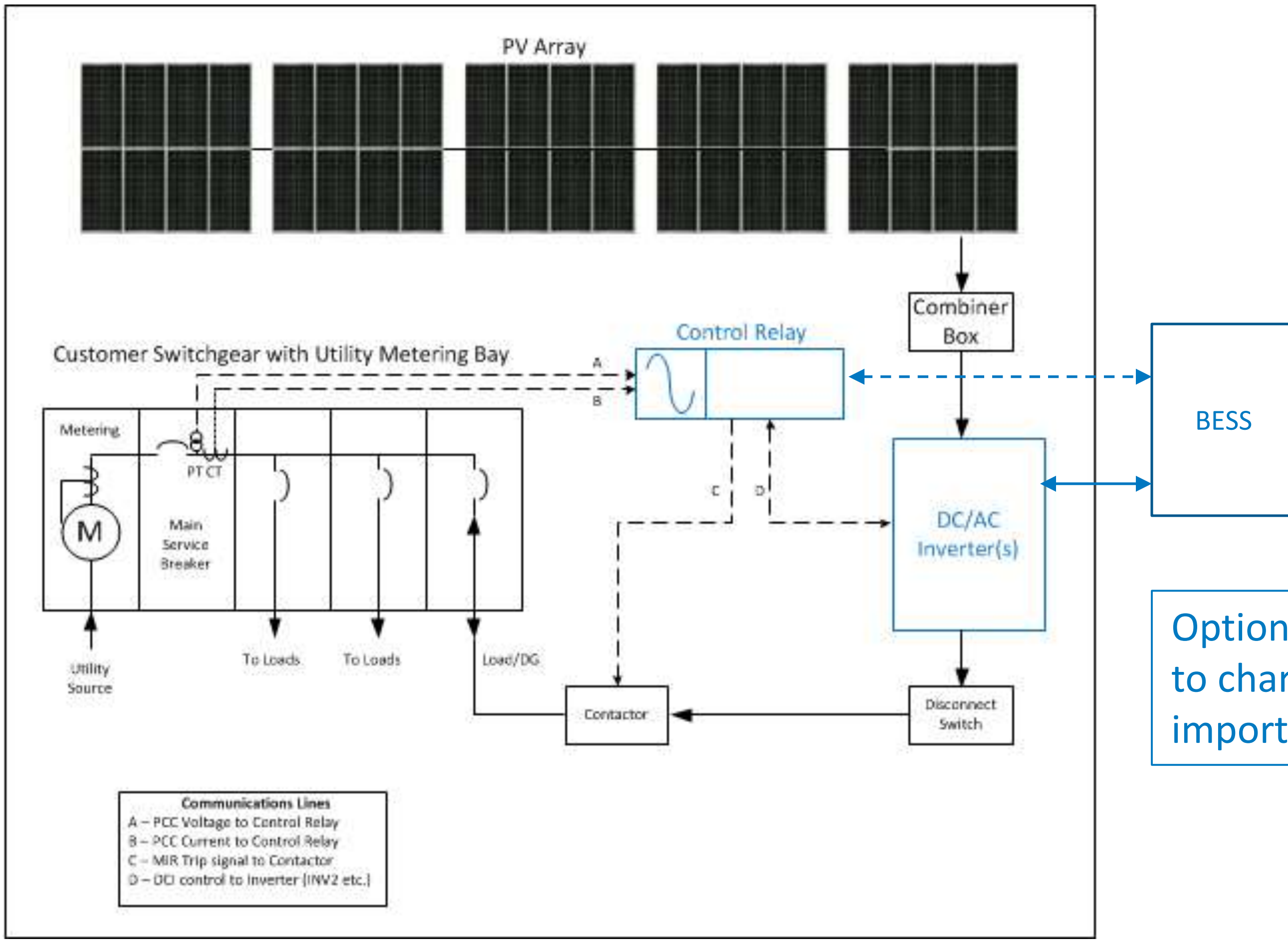


Dynamically-Controlled Inverter Results



Energy loss from PV System at times due to lower consumption at site

PV on Network with BESS, Control Relays



Optional Battery system used to charge during minimum import times.

Thank You