

# Smart Inverter Fundamentals

*a presentation for MDVSEIA members and D.C. stakeholders*



Center for  
Renewables  
Integration

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# Today's Presentation

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



# Center for Renewables Integration

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**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”

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“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.

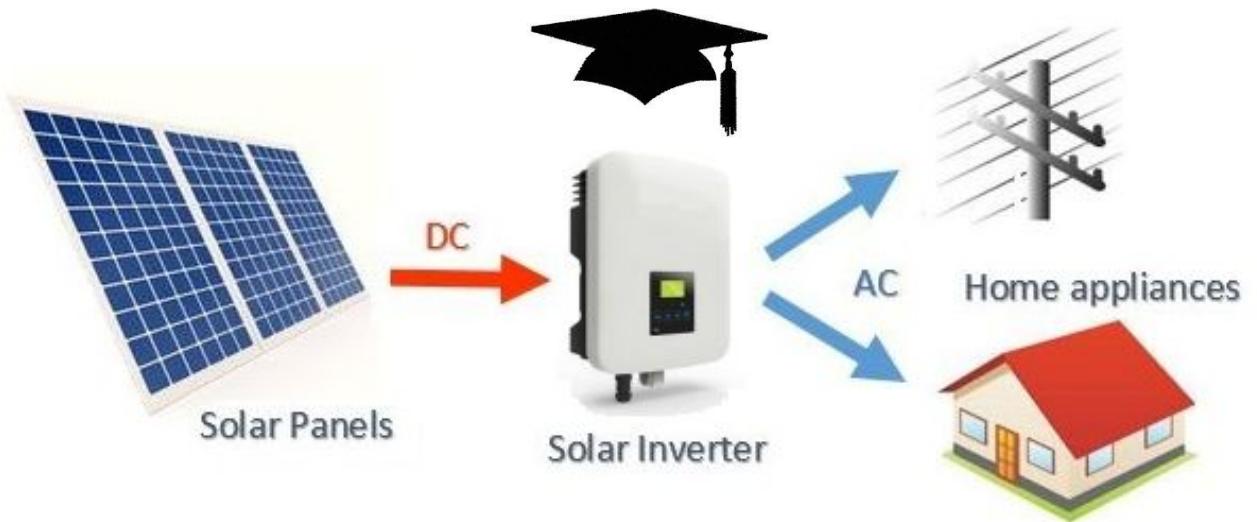


Illustration – Clean Energy Reviews



# Standards Development and Applications

TBD

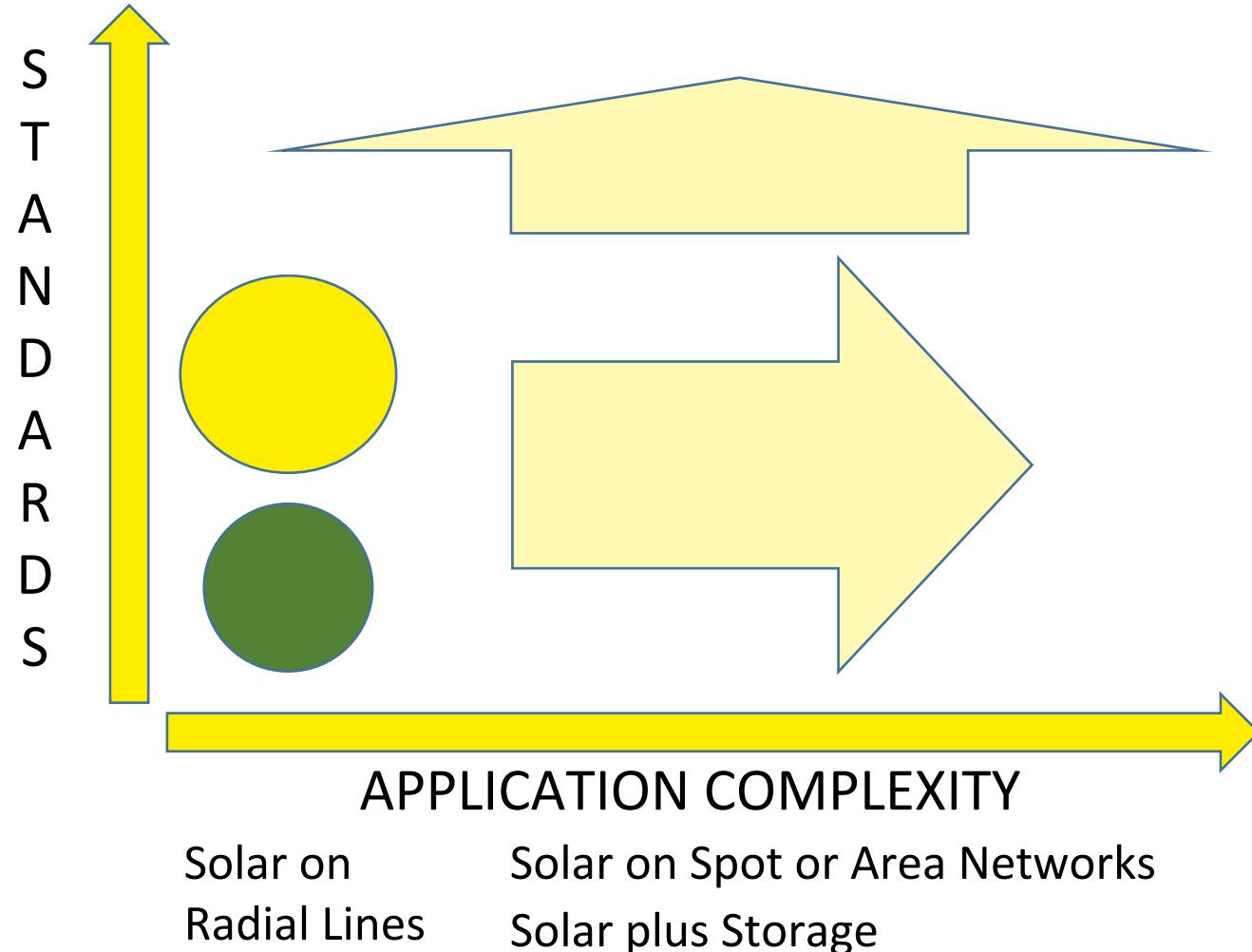
Communications to support grid services and external inverter control.

2022

IEEE 1547-2018 compliant  
"Smart Inverters" Available

TODAY

Advanced inverter features compliant with interim standards



# 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 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-through 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

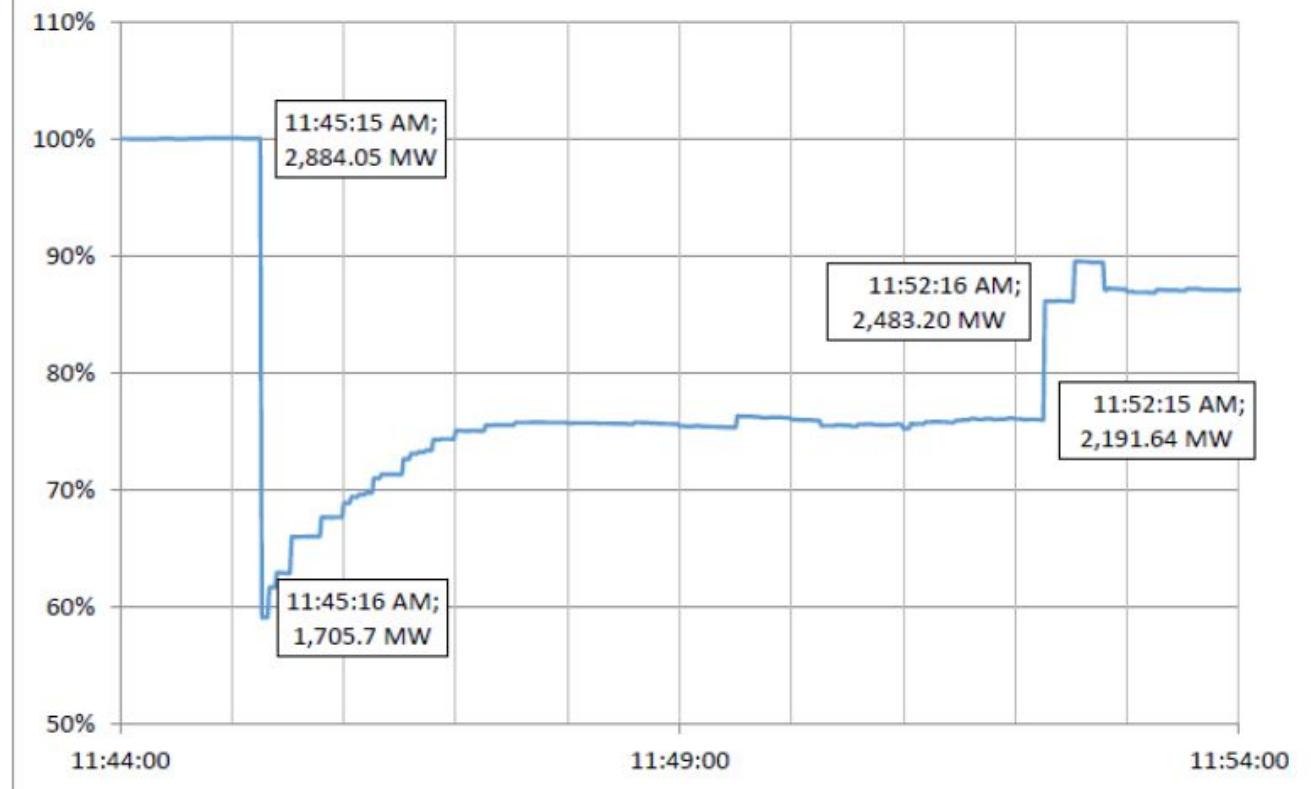


Figure - NERC



# 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.

**Problem Statement**

**Issue Charge**

**Stakeholder Group Assignment**

**Key Work Activities**

**Expected Deliverables**

**PJM © 2018**

**1 | Page**

**pjm**

**"Inverter-based DER Ride Through"**

*Inverter-based DER Ride Through and Trip Settings and IEEE standard 1547-2018*

**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 at Electric System (BES)<sup>[1][2]</sup>. For BES reliability, the key performance requirements for ride through. Ride through requires resources to stay connected to the system for a event of a wide area disturbance, rather than trip offline and potentially exacerbate all

Failures of inverter-based resources to properly ride through contingencies have caused California<sup>[3][4]</sup>, Texas<sup>[5]</sup>, and Europe<sup>[6]</sup>. In Australia, such a failure to ride through contributed to mitigate these concerns, ride through requirements for DER have been implemented, such as California, Hawaii, Germany, and Australia.

A recently revised version of the DER interconnection standard IEEE 1547 now specifies that may meet the reliability needs of the Bulk Electric System. The Institute of Electrical and Electronics Engineers (IEEE) is an international industry organization that, among other things, produces standards for interested parties. The IEEE standard 1547, first developed in 2003, has been widely used and in distribution utility requirements. The 1547 standard is also cited in PJM requirements for DER that fall under FERC jurisdiction<sup>[7]</sup>.

The former edition of the IEEE 1547 standard specified a single (albeit adjustable) trip through requirement. The revised standard, IEEE 1547-2018, offers three different categories of voltage ride through and trip settings that the authority governing interconnection (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 implementation of the new standard, new engineering judgements must be made among distribution, transmission, and other entities, and which performance category (together with optional adjustments) should apply.

PJM recognizes that, in implementation of ride through requirements, a key engineering concern is the risk of arc flashes while performing hot work on primary distribution lines. In order to facilitate a smooth transition to the new standard, and to ensure all DER are reliable in a predictable way during wide area abnormal conditions, PJM and stakeholders are coordinating the implementation of ride through and trip settings for DER interconnecting under FERC jurisdiction.

There is an opportunity to use the outcome of this technical coordination effort to serve interconnect under FERC jurisdiction<sup>[8]</sup>, as well as, and perhaps more importantly, a local utility and state can use in their implementation of the ride through and trip requirements.



# 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
<b>Voltage regulation by reactive power control</b>		
Constant power factor mode	Mandatory	Mandatory
Voltage—reactive power mode <sup>a</sup>	Mandatory	Mandatory
Active power—reactive power mode <sup>b</sup>	Not required	Mandatory
Constant reactive power mode	Mandatory	Mandatory
<b>Voltage and active power control</b>		
Voltage—active power (volt-watt) mode	Not required	Mandatory

<sup>a</sup>Voltage-reactive power mode may also be commonly referred to as “volt-var” mode.

<sup>b</sup>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
$P_1$			$P_2 + 0.1 P_{\text{rated}}$	$P_{\text{rated}}$
$P_2$	0.5 $P_{\text{rated}}$		0.4 $P_{\text{rated}}$	0.8 $P_{\text{rated}}$
$P_3$	The greater of 0.2 $P_{\text{rated}}$ and $P_{\text{min}}$		$P_{\text{min}}$	$P_3 - 0.1 P_{\text{rated}}$
$P_4$	The lesser of 0.2 $\times P_{\text{rated}}$ and $P_{\text{min}}$		$P_2 - 0.1 P_{\text{rated}}$	$P_{\text{min}}$
$P_5$	0.5 $P_{\text{rated}}$		0.8 $P_{\text{rated}}$	0.4 $P_{\text{rated}}$
$P_6$	$P_{\text{rated}}$		$P_{\text{rated}}$	$P_2 + 0.1 P_{\text{rated}}$
$Q_1$	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	0		
$Q_3$	0	0		
$Q_4$	0	44% of nameplate apparent power rating injection		
$Q_5$				

NOTE— $P_{\text{rated}}$  is the nameplate active power rating of the DER.

$P_{\text{rated}}$  is the maximum active power that the DER can absorb.

$P_{\text{min}}$  is the minimum active power output of the DER.

$P_{\text{min}}$  is the minimum, in amplitude, active power that the DER can absorb.

$P$  parameters are negative in value.

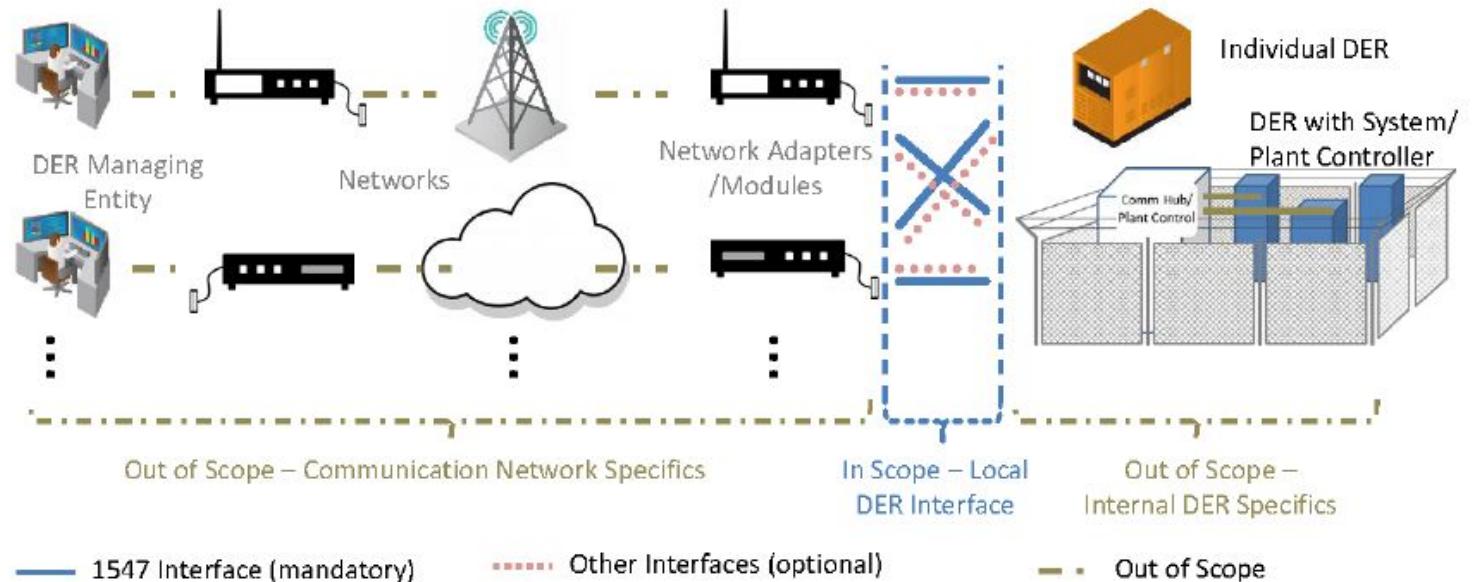


# Communications

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.**

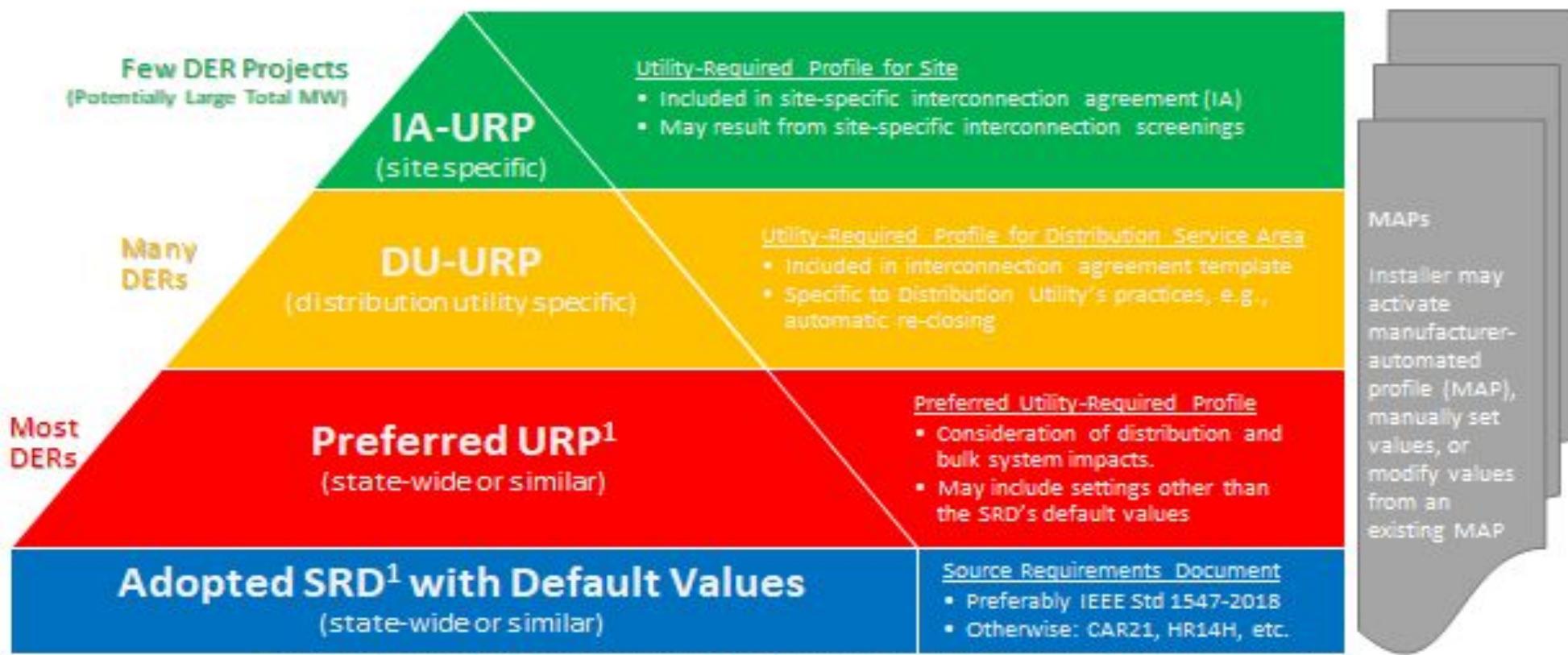
**Net System Capacity:** The nameplate capacity of a small generator facility, or the total of the nameplate capacities of the units comprising a small generator facility, as designated by the manufacturer(s) of the unit(s) minus the consumption of: electrical power of the unit(s), and if applicable, 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

## Hierarchy of DER Interconnection Requirements & Settings



<sup>1</sup> Based on decision by Authority Governing Interconnection Requirements (AGIR), may be a public utilities commission or similar



# Adoption of Smart Inverter Standards in Local Jurisdictions

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## 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

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## 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

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## 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

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## 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

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## 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 URP<sup>71</sup> 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

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## **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

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## 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

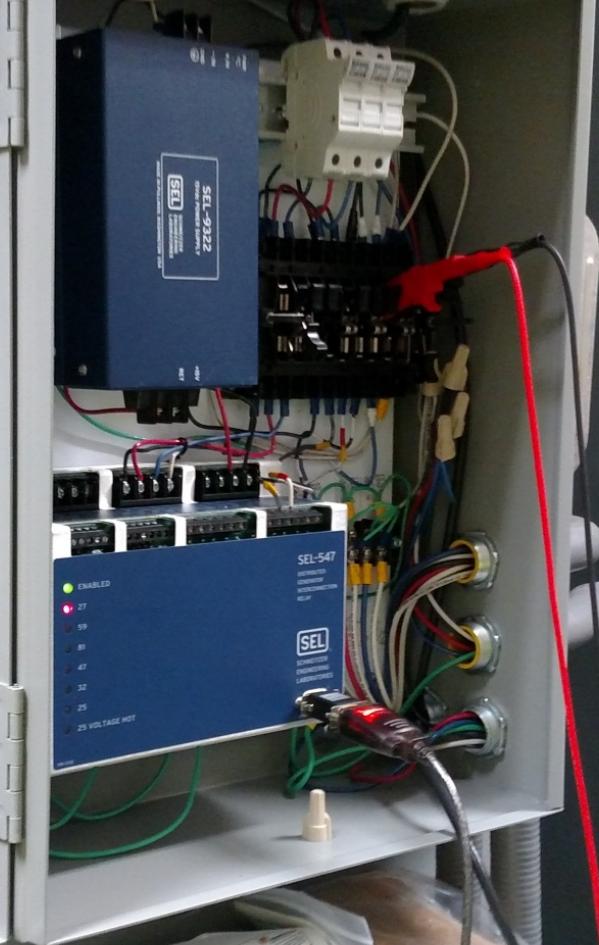
Jorge Camacho, P.E.

IEEE Std 1547 Conformity Assessment Steering Committee

j.a.camacho@ieee.org

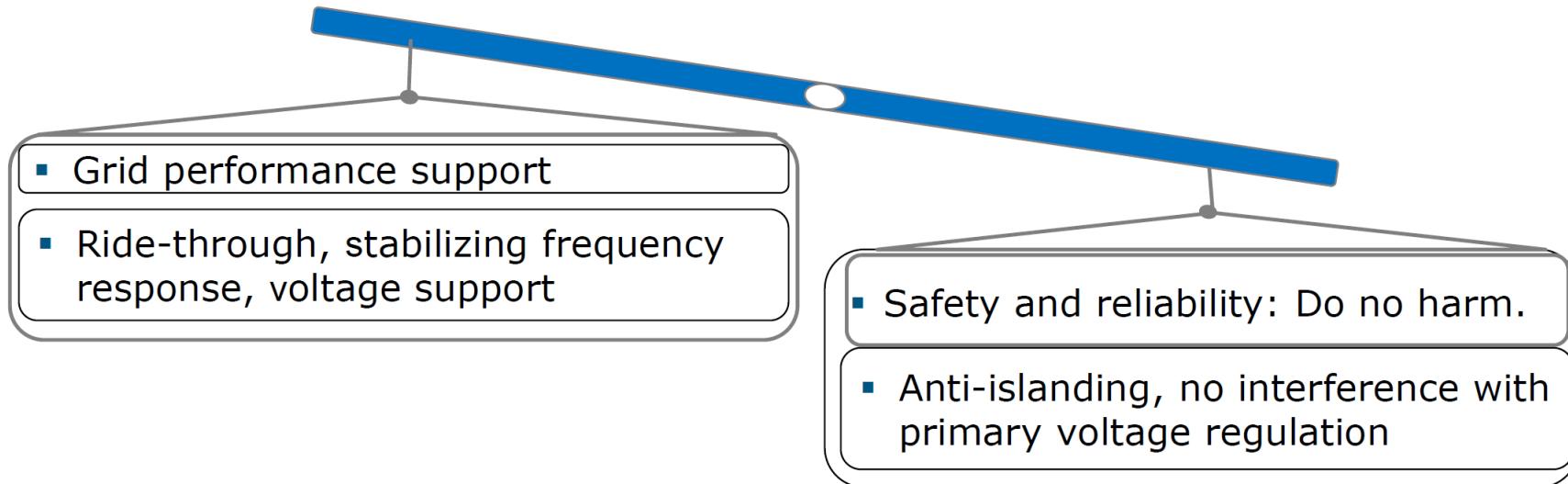






# Grid Planning and Operation Challenges

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



**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.**

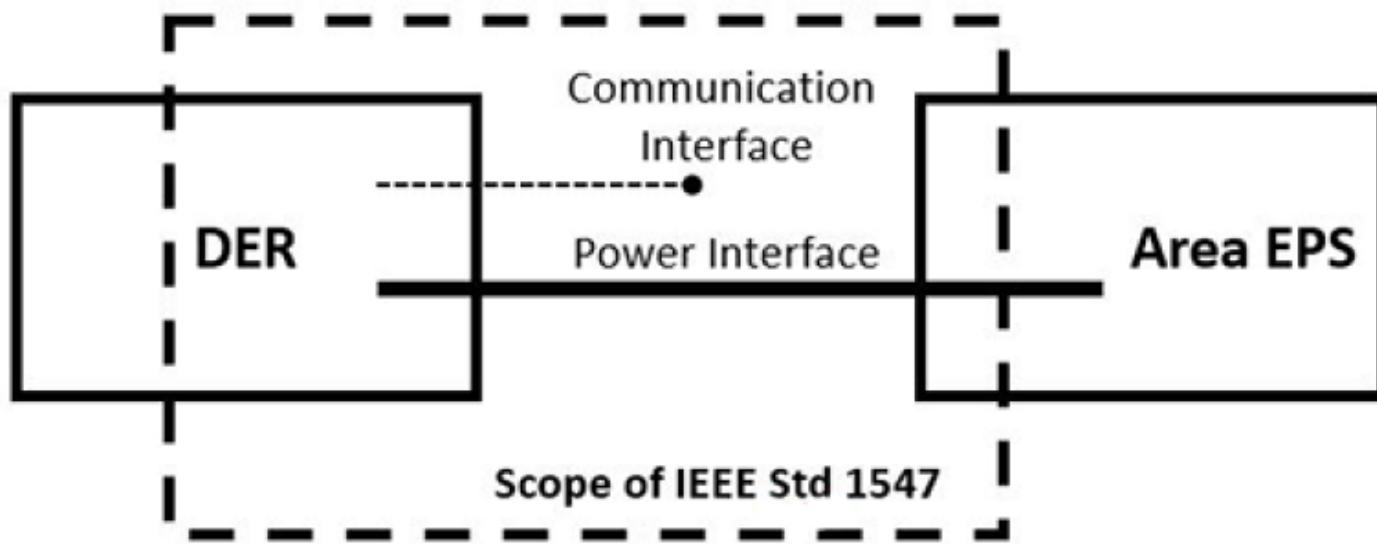
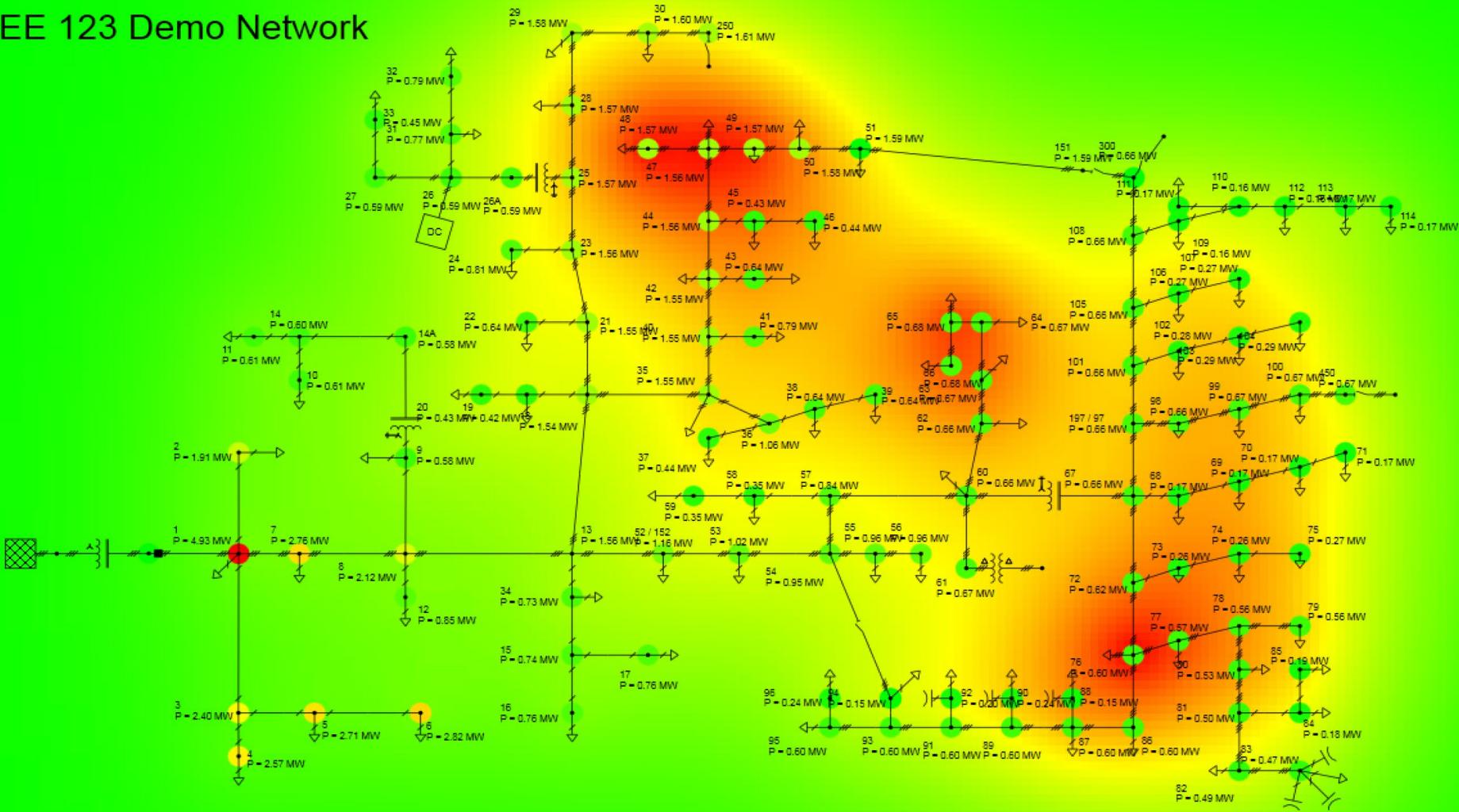


Figure 1 – IEEE STD 1547-2018

IEEE 123 Demo Network

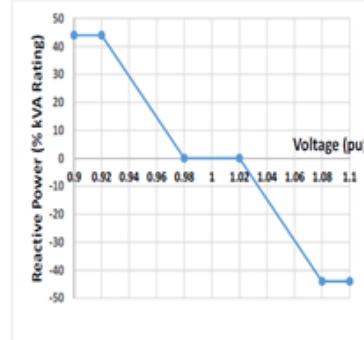
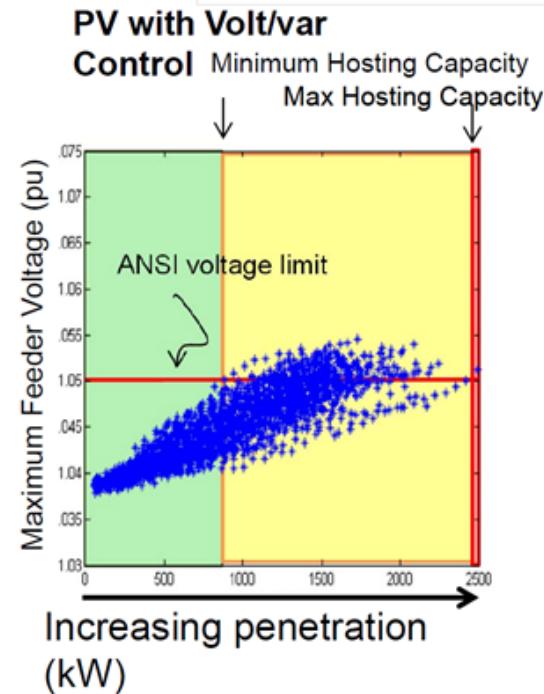
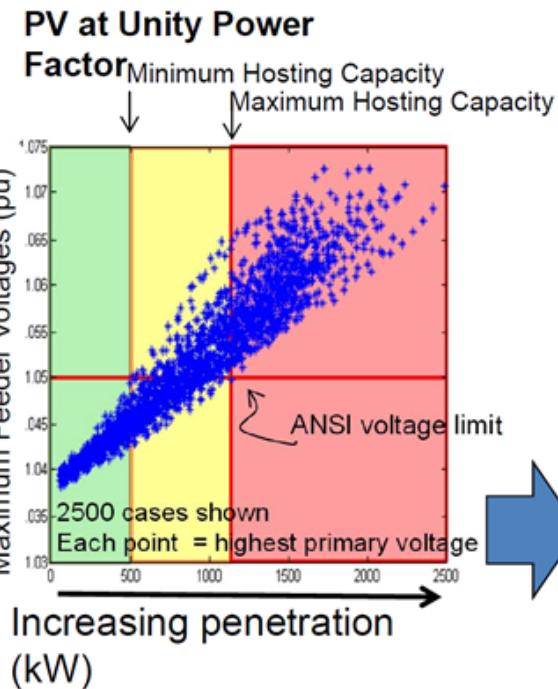
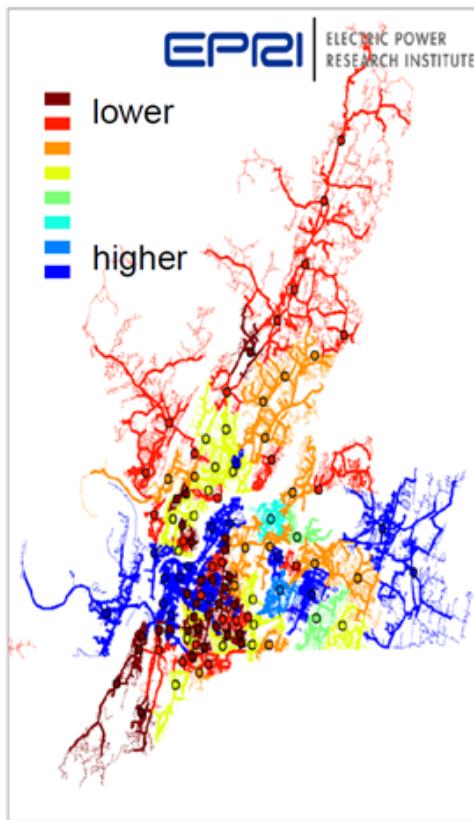


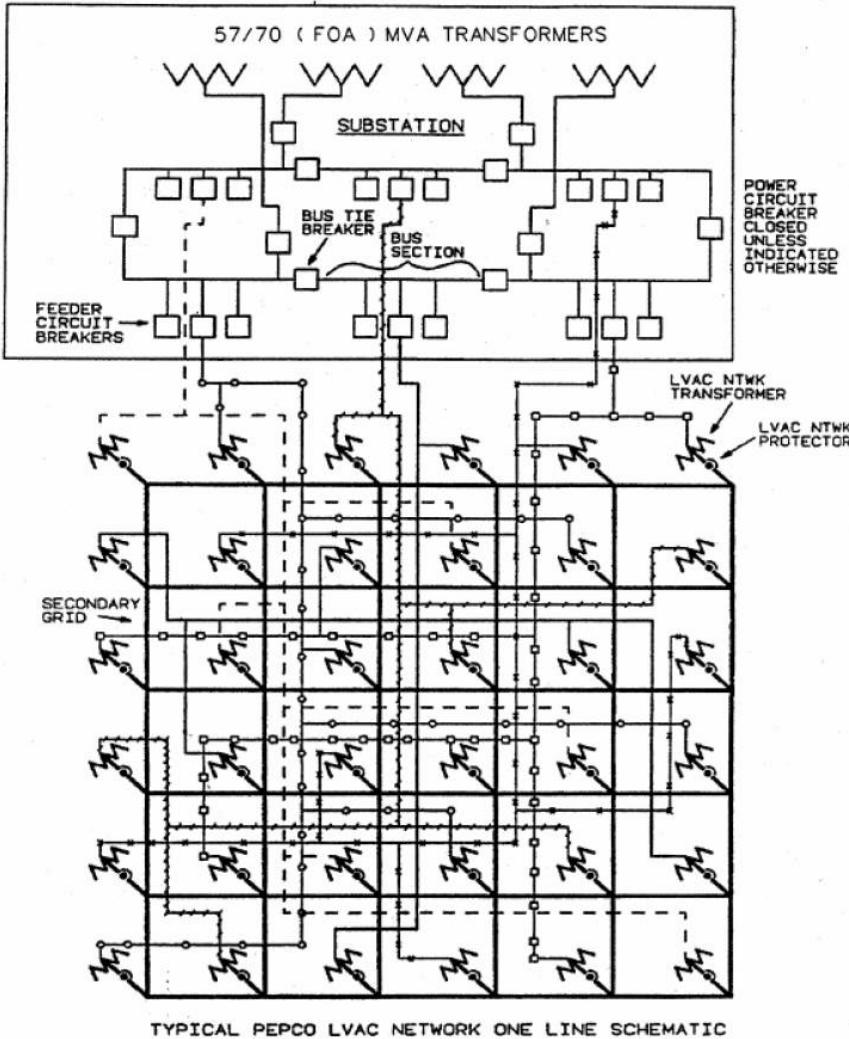
# Solar - Radial Distribution Feeder Hosting Capacity PHI

Pepco Holdings GIS Team



# Hosting Capacity





## 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



# Conformity Assessment

## IEEE 1547

**Interconnection and Interoperability of Distributed Energy Resources (DERs) with Associated Electric Power Systems (EPSs) Interfaces**

**IEEE 1547 Commissioning Conformity Assessment Steering Committee (CASC)**



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

# Independent, Transparent, and Technical Sound DER Integration Process

## IEEE Conformity Assessment Program (ICAP)

- IEEE approved Commissioning Agent (CA)

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Published: 2019

1547-2019 - IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces  
IEEE Std 1547-2018 (Revision of IEEE Std 1547-2003)  
Published: 2018

[View More](https://ieeexplore.ieee.org/document/8786948)

**Abstract**  
Scope:  
This document is a tool to assess conformance of a Distributed Energy Resource (DER) Interconnection during the commissioning phase of a DER Interconnection to the IEEE 1547 as may be specified in the governing Interconnection Agreement executed between the Area Electric Power System (EPS) Operator and DER Owner. Commissioning agents and DER owners that participate in The Institute of Electrical and Electronics Engineers Conformity Assessment Program (ICAP) 1547 Certification Program must comply with this conformance assessment document and requirements in this document. Conformance with this document is assessed as part of the ICAP certification program.

**Metrics**

**Versions**

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Electronic ISBN: 978-1-5044-6046-0  
More »](https://ieeexplore.ieee.org/serlet/opac?punumber=8786946)

Publisher: IEEE

<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

- 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

- 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

- 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

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)**

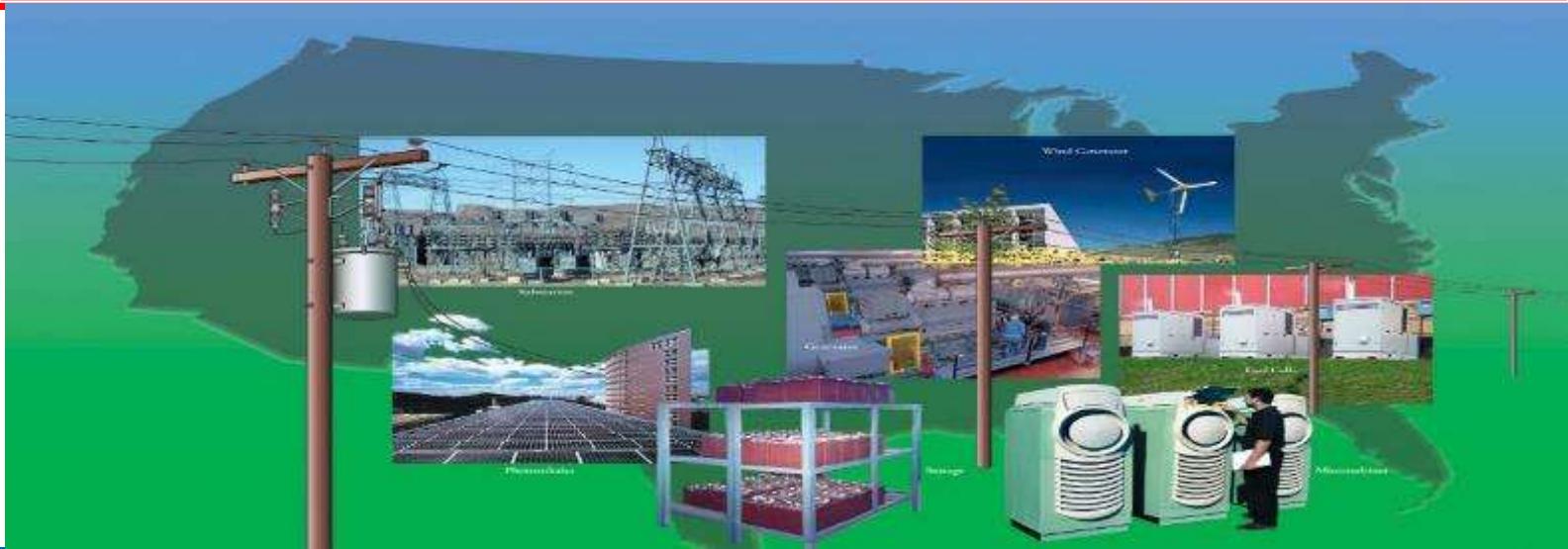
5. **IEEE 1547-2018 Adoption**, and early movers, CA Rule 21, IAP Rule 14, and UL-1741-SA

Adopting the New Hardware Standards That Should Guide the Selection of Key Considerations Under the new Standards? What Would be the Reasons for not Going for Maximum Capacity of New Inverter Functionalities  
Based On Other Jurisdictions' Experience  
(e.g., California and Hawaii's standards that predate IEEE 1547-2018) and Autonomous Inverter Features,  
Maximizing Use of Intern Standards Available Now

# **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

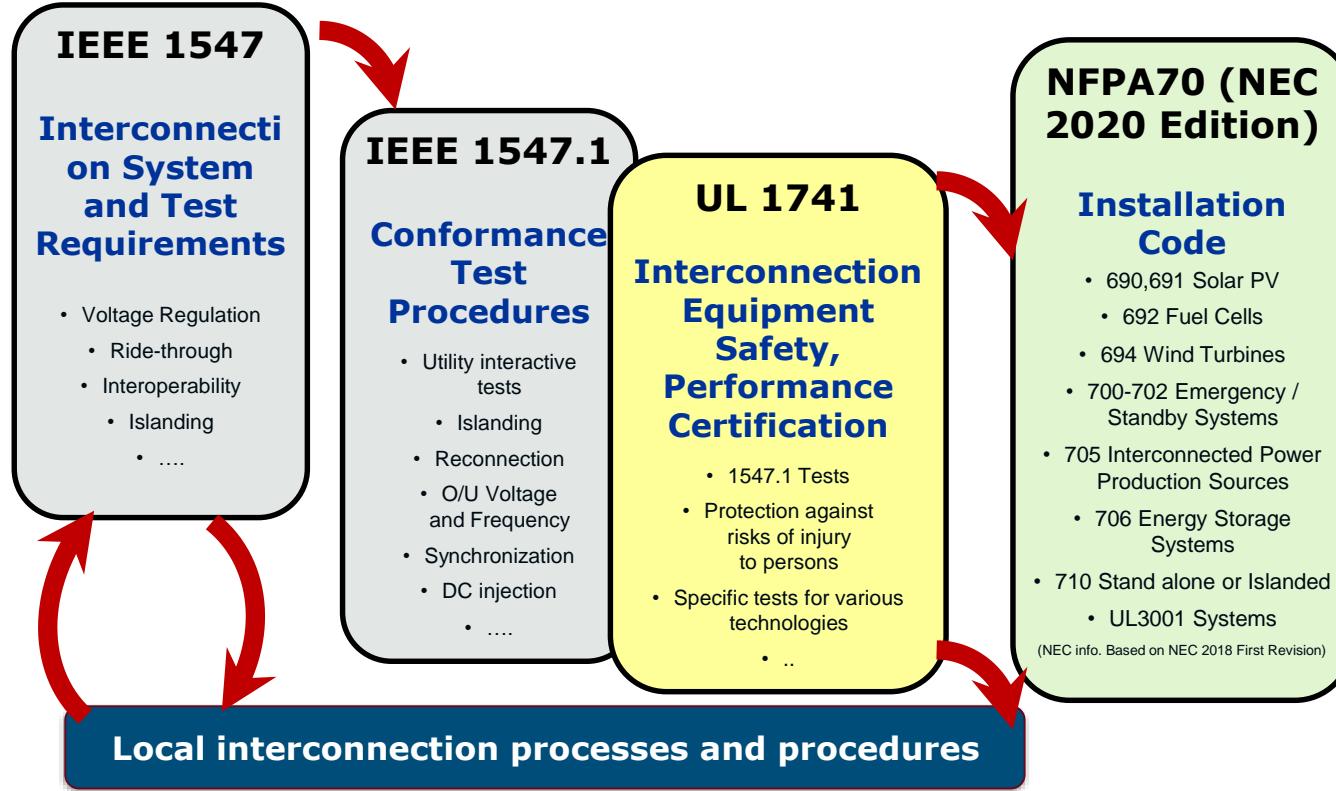
**Title:** Standard for Interconnection *and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces*

**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](#).<sup>60</sup>

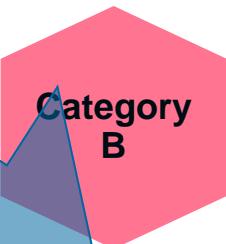
**Table 7—Minimum reactive power injection and absorption capability**

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



- 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



- 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 capability – implementation 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**

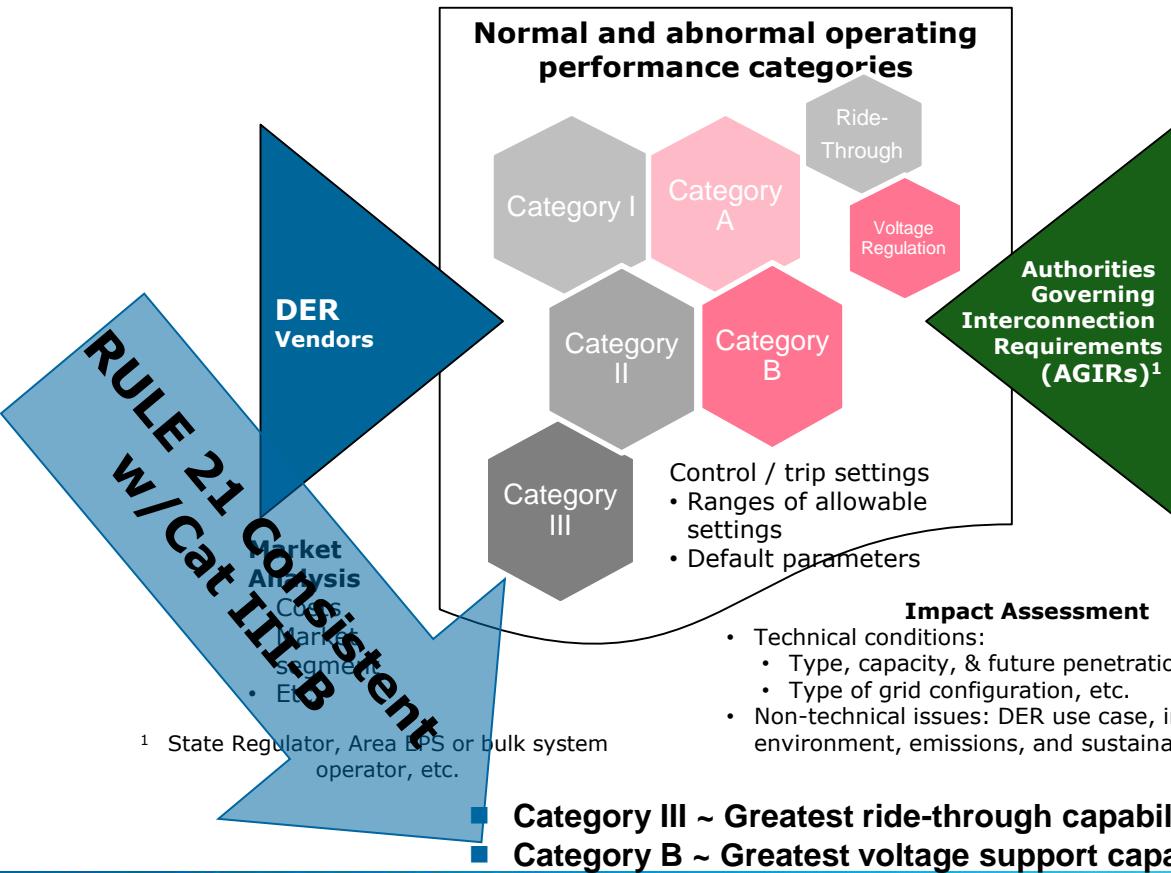
Active power-reactive power mode (“watt-var”)

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

# **Response to abnormal conditions**

*Clause 6*

# Assignment of new IEEE 1547-2018 Performance Categories



## Stakeholder Engagement

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

# 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

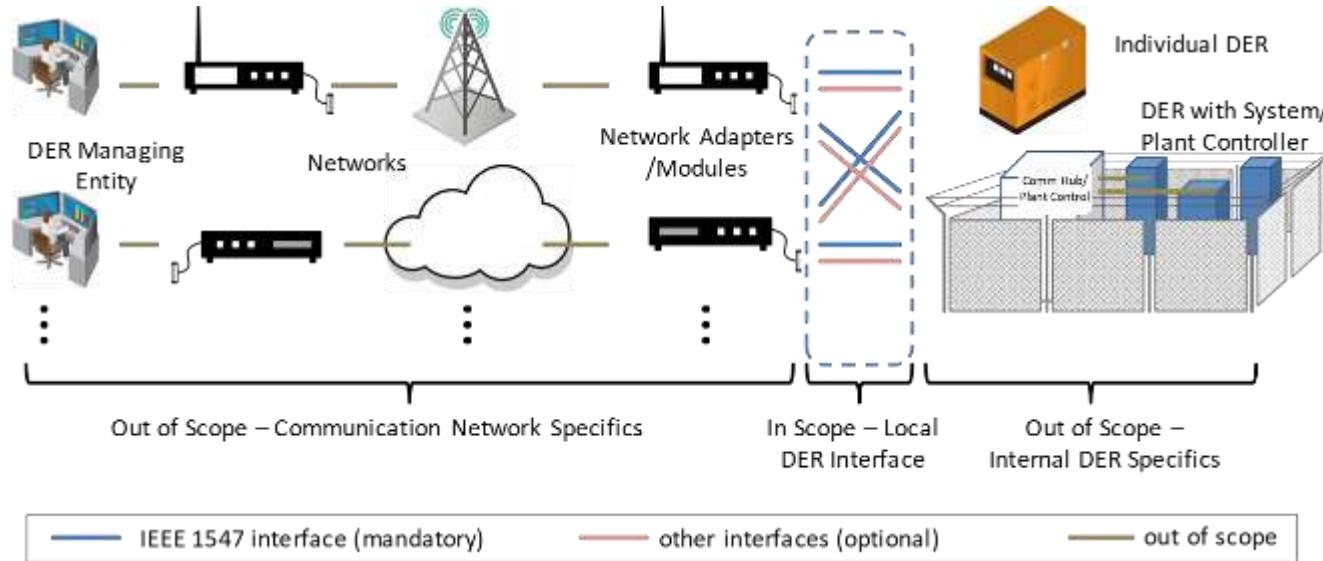
Category	Objective	Foundation
I	Essential bulk system needs and reasonably achievable by all current state-of-art DER technologies	German grid code for synchronous generator DER
II	Full coordination with bulk power system needs	Based on NERC PRC-024, adjusted for distribution voltage differences (delayed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

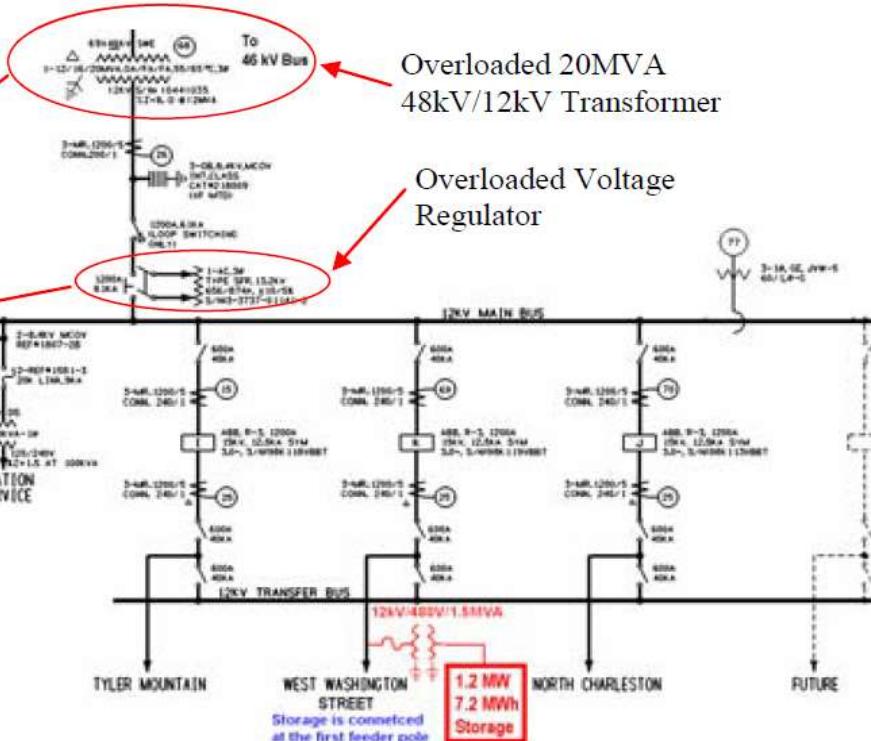
Source, AEP

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



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

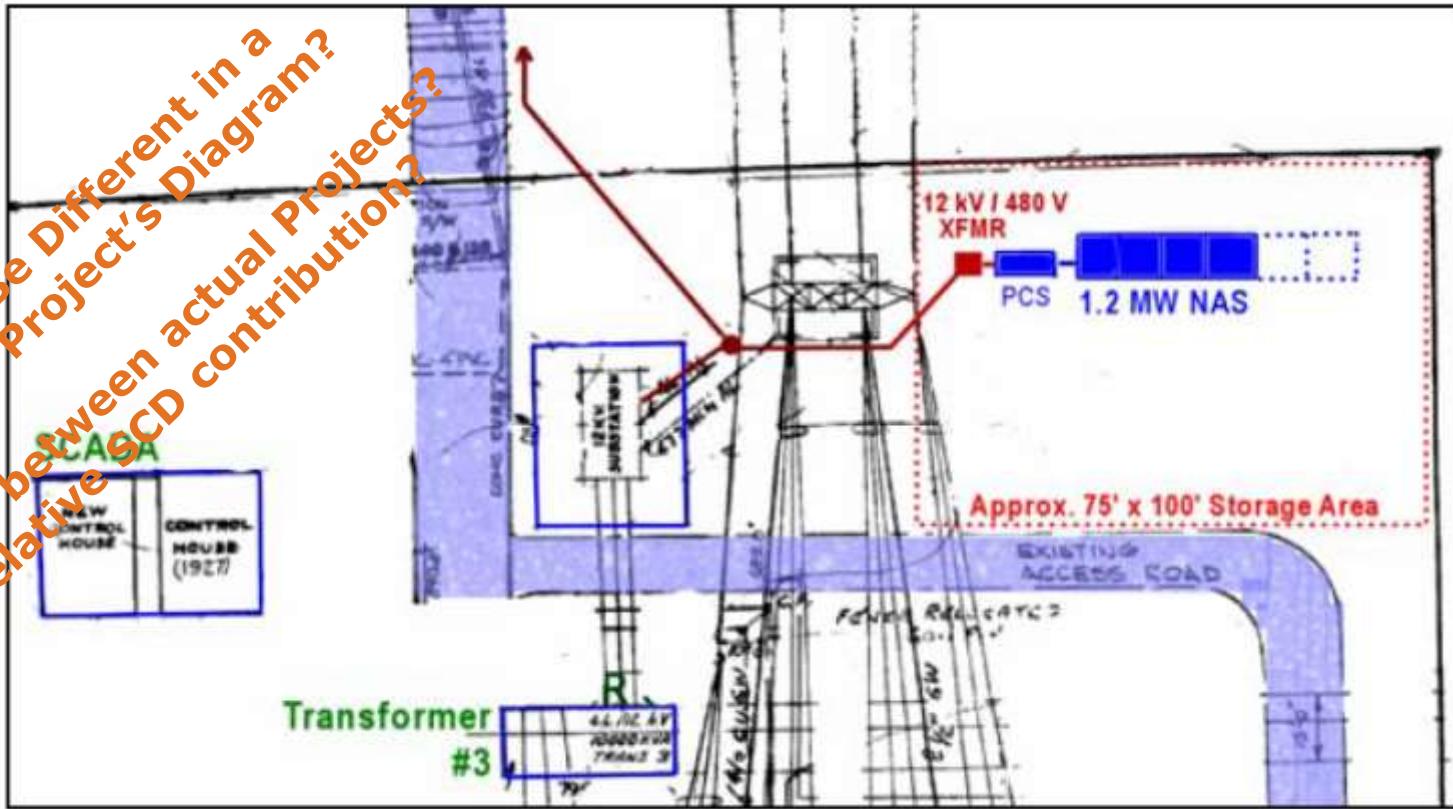


Source, AEP

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

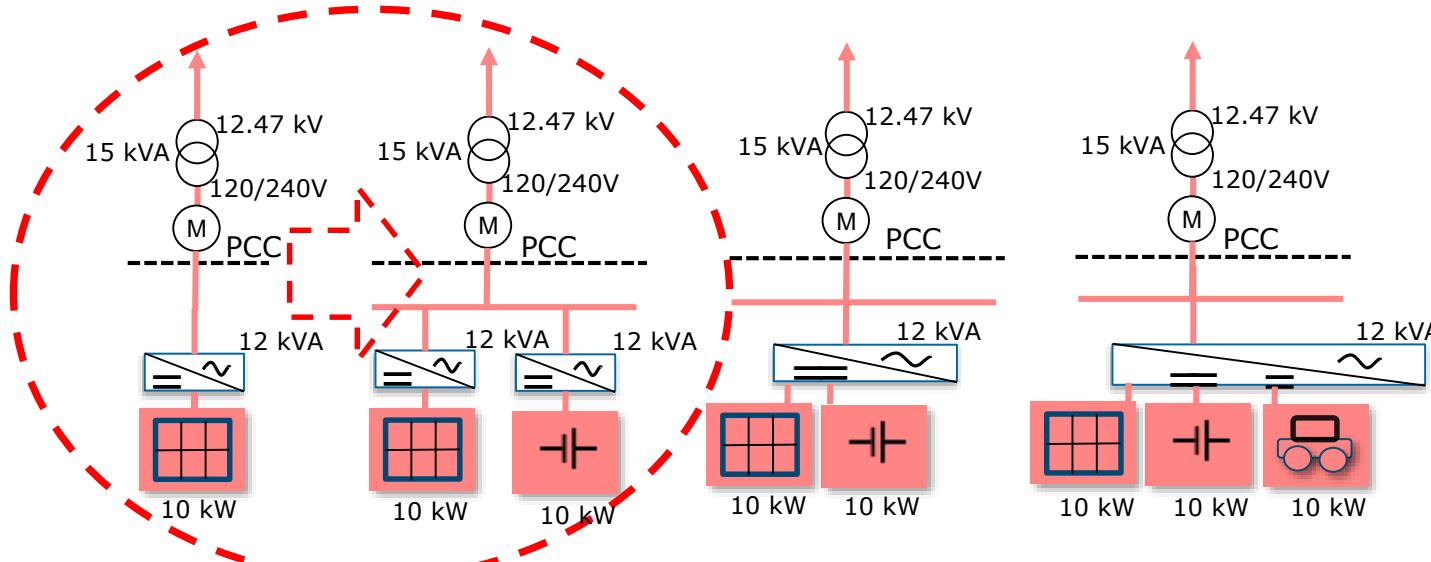
What Would Be Different in a  
PV or PV+ES Project's Diagram?  
Differences between actual Projects?  
e.g. relative SCD contribution?



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	<ul style="list-style-type: none"><li>Frequency regulation</li><li>Spin/non-spin/replacement reserves</li><li>Ramp</li><li>Black start</li><li>Real time energy balancing</li><li>Energy price arbitrage</li><li>Resource adequacy</li></ul> <p>1547-2003 vs. new CA 21 &amp; 1547Revision</p>
VER Generation	<ul style="list-style-type: none"><li>Intermittent resource integration: wind (ramp/voltage support)</li><li>Intermittent resource integration: photovoltaic (time shift, voltage sag, rapid demand support)</li><li>Supply firming</li></ul>
Transmission/Distribution	<ul style="list-style-type: none"><li>Peak shaving: off-to-on peak energy shifting (operational)</li><li>Transmission peak capacity support (upgrade deferral)</li><li>Transmission operation (short duration performance, inertia, system reliability)</li><li>Transmission congestion relief</li><li>Distribution peak capacity support (upgrade deferral)</li><li>Distribution operation (Voltage Support/VAR support)</li><li>Outage mitigation: micro-grid</li></ul>
Customer	<ul style="list-style-type: none"><li>Time-of-use /demand charge billing management (load shift)</li><li>Power quality</li><li>Peak shaving (demand response), Back-up power</li></ul>

Which "End Uses" Require a Dispatchable Resource?



# **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***



# Timeline for rollout of 1547.1 and UL 1741

Dates	Activities	Status
April 2018	<b>Milestone:</b> 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	<b>Milestone:</b> 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	<b>Milestone:</b> 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	<b>Milestone:</b> 1547.1 finalization and publication	
Q1/Q2 2020	UL Standards Technical Panel review and ballot updated UL 1741	
Q2/Q3 2020	<b>Milestone:</b> 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



**Advanced Inverter Movement**

Which Standards are Used for Advanced Inverter Testing?

- UL 1741 SA specifies the test methods to evaluate compliance with electric utility Source Requirement Document (SRD) for limits and parameter settings. The UL 1741 Supplement SA is part of UL 1741 and was published on Sept 7, 2016.
- California Electric Rule 21 made by the California Public Utility Commission (CPUC) is an SRD which can be used with UL 1741 SA. Other SRD's like Hawaiian Electric HECO 14H may also be used with the UL1741 SA.
- Changes to California Rule 21 and Hawaiian Electric 14H will require all inverters to be certified "listed" as a UL1741SA "Grid Support Interactive Inverter" for all new installations on Sept 7, 2017.

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

# UL-1741-SA, an interim solution

UL 1741 SA – Modern Grid Support Interconnection

What Tests are Part of UL 1741 SA?

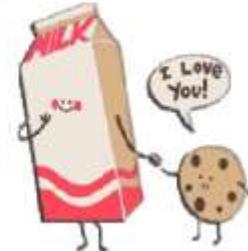
Required Tests	Optional Tests (Depends on SRD Being Utilized)
<ul style="list-style-type: none"><li>Anti-Islanding (with advanced features active during test)</li><li>Low/High Voltage Ride Through</li><li>Low/High Frequency Ride Through</li><li>Must-Trip Test</li><li>Ramp Rate (Normal &amp; Soft-Start)</li><li>Specified Power Factor</li><li>Volt/VAr Mode</li></ul>	<ul style="list-style-type: none"><li>Frequency Watt</li><li>Volt Watt</li></ul> 

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

# UL-1741-SA, an interim solution

## Use of UL1741 SA with IEEE 1547, 2<sup>nd</sup> Ed. Until IEEE 1547.1 2<sup>nd</sup> Ed. Publication

- There is some utility interest to make use of IEEE 1547 2<sup>nd</sup> 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.



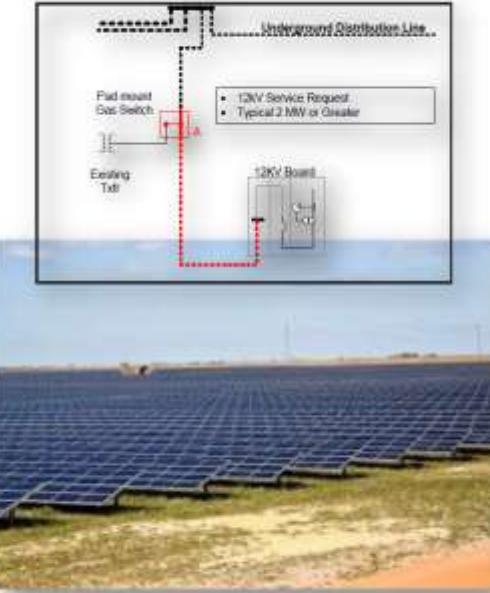
Source, UL Presentation, T. Zgonena, 11/1/2017

# 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



# CA Rule 21

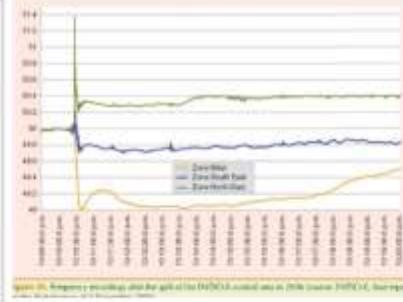
## Need For Advanced Inverter Functionality

### Germany Experience

- Reverse power flows caused issues on distribution system because they were not originally designed for reverse power flow
- Grid stability 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



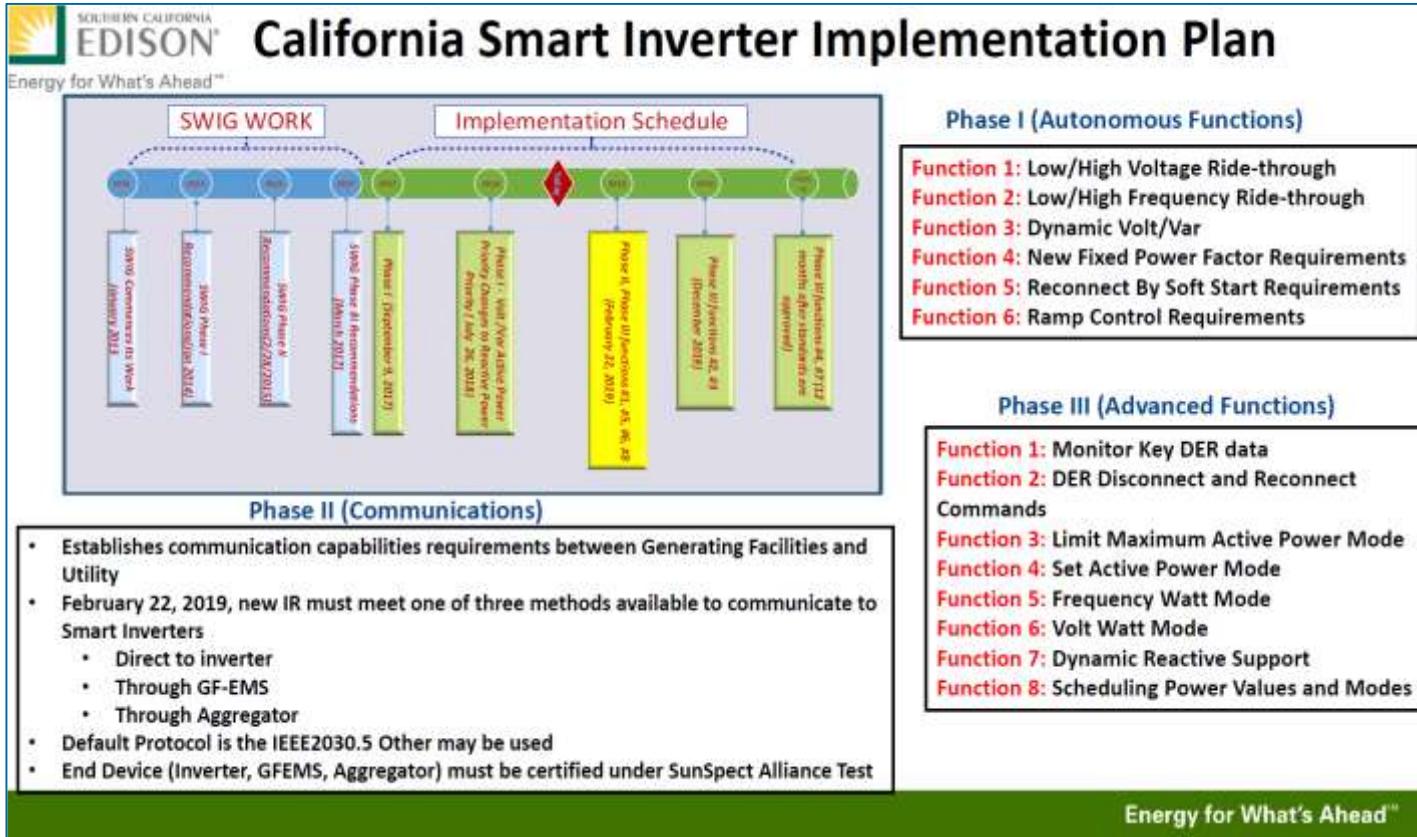
### Hawaiian Experience

- 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



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](https://www.hawaiianelectric.com/Documents/clean_energy_hawaii/producing_clean_energy/SRD_UL1741_SA_V1.1_20170922_final.pdf)

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

# HI Rule 14

## Rule 14H Functions Matrix

Function Set	Advanced Functions Capability	Interconnection Standards			Rule 14H		Listing/Certification		
		IEEE 1547-2003	IEEE 1547a-2014	IEEE 1547-2018	2015	2018 SRD V1.1	UL 1741	UL 1741(SA) 2016	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	Δ
	Voltage-Active Power (Volt-Watt)	X	✓	‡		‡ Opt		Δ	Δ
Bulk System Reliability & Frequency Support	Dynamic Voltage Support during VRT		✓						
	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.



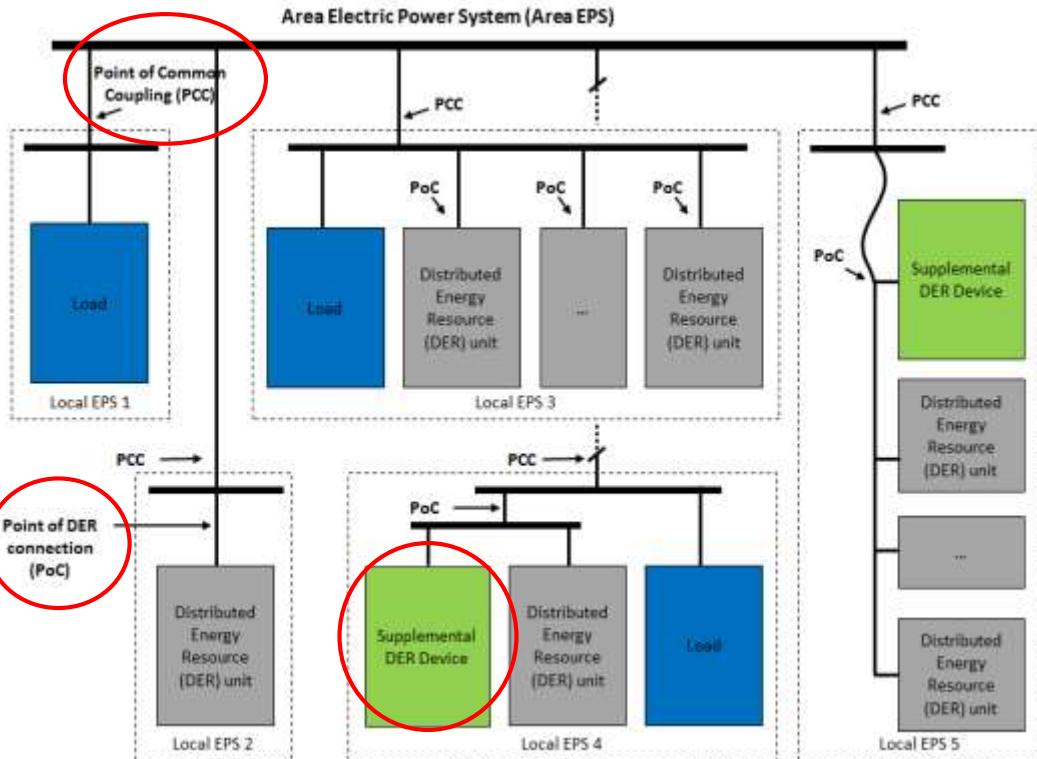
# Questions?

*Charlie.Vartanian@pnnl.gov*



# Backup Slides

# Reference Point of Applicability

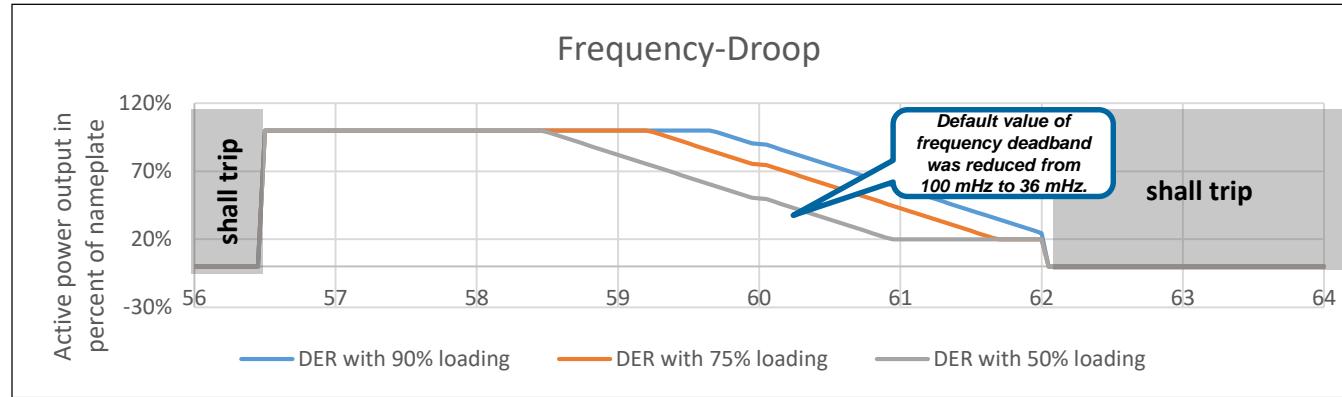


- **RPA is where performance requirements apply**
- IEEE 1547 specifies RPA depending on three criteria:
  - Aggregate DER rating
  - Average load demand
  - Zero sequence continuity
- Generally:
  - PoC (DER terminals) for small and load-immersed DER
  - PCC for large exporting installations

# Enter Service criteria

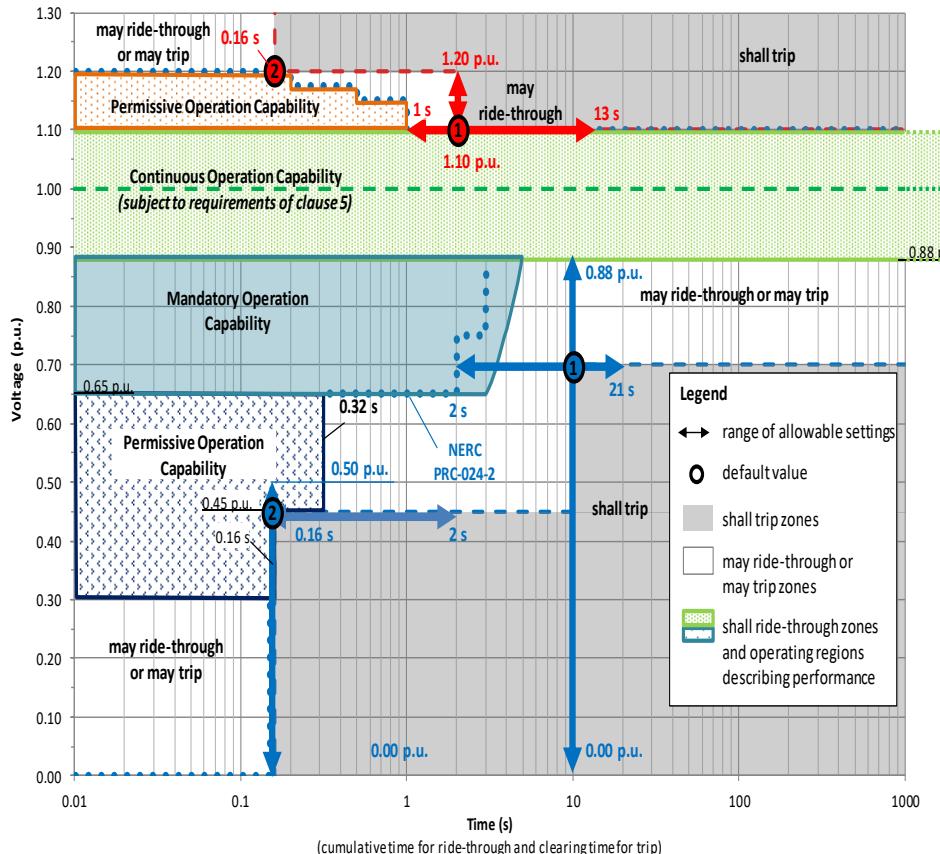
- Prior to *Enter Service* or *Return to Service* after a trip, power system's voltage must be within specified voltage magnitude and frequency range continuously for a defined period
- *Permit Service* flag must be set to *Enabled*
- Power system voltage and frequency limits, and DER delay period are 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

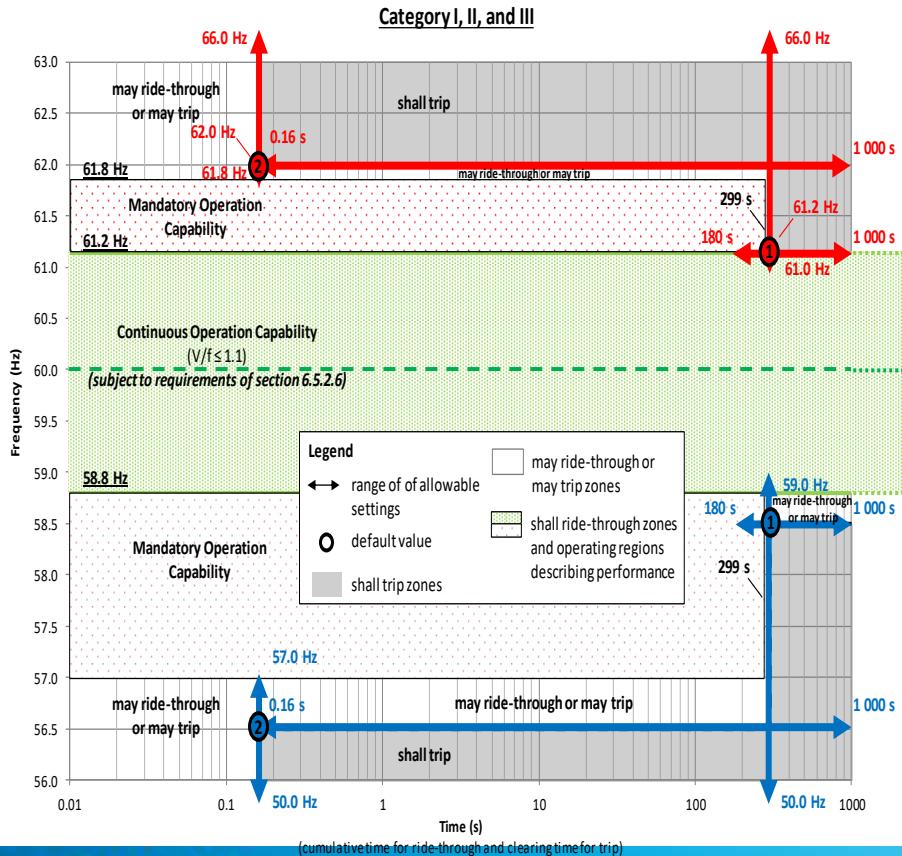
## ■ **Momentary cessation:**

- 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

# Overview of Secondary Networks - DERs and BESS Considerations



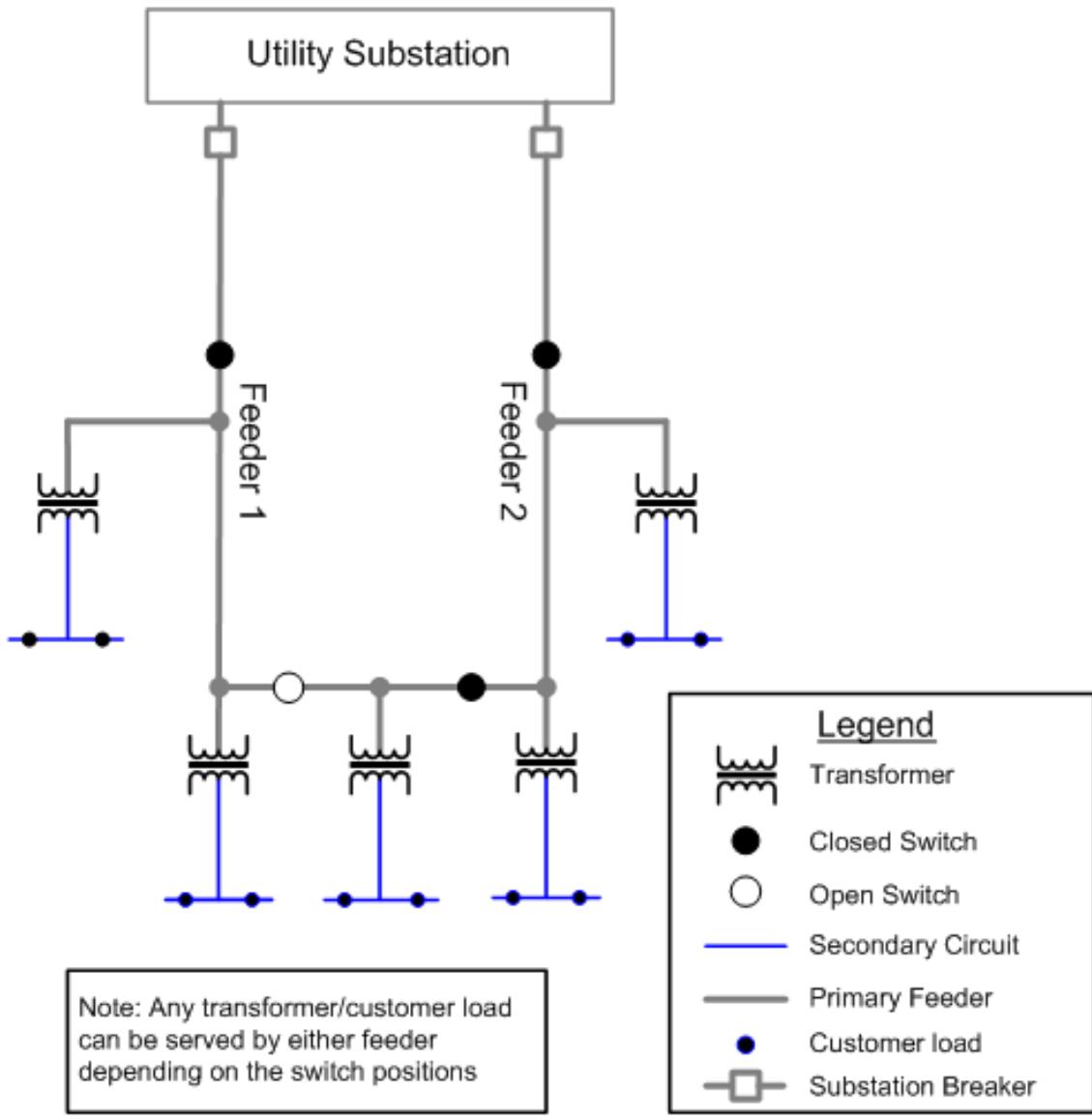
Michael Coddington

IEEE P1547.9 Meetings

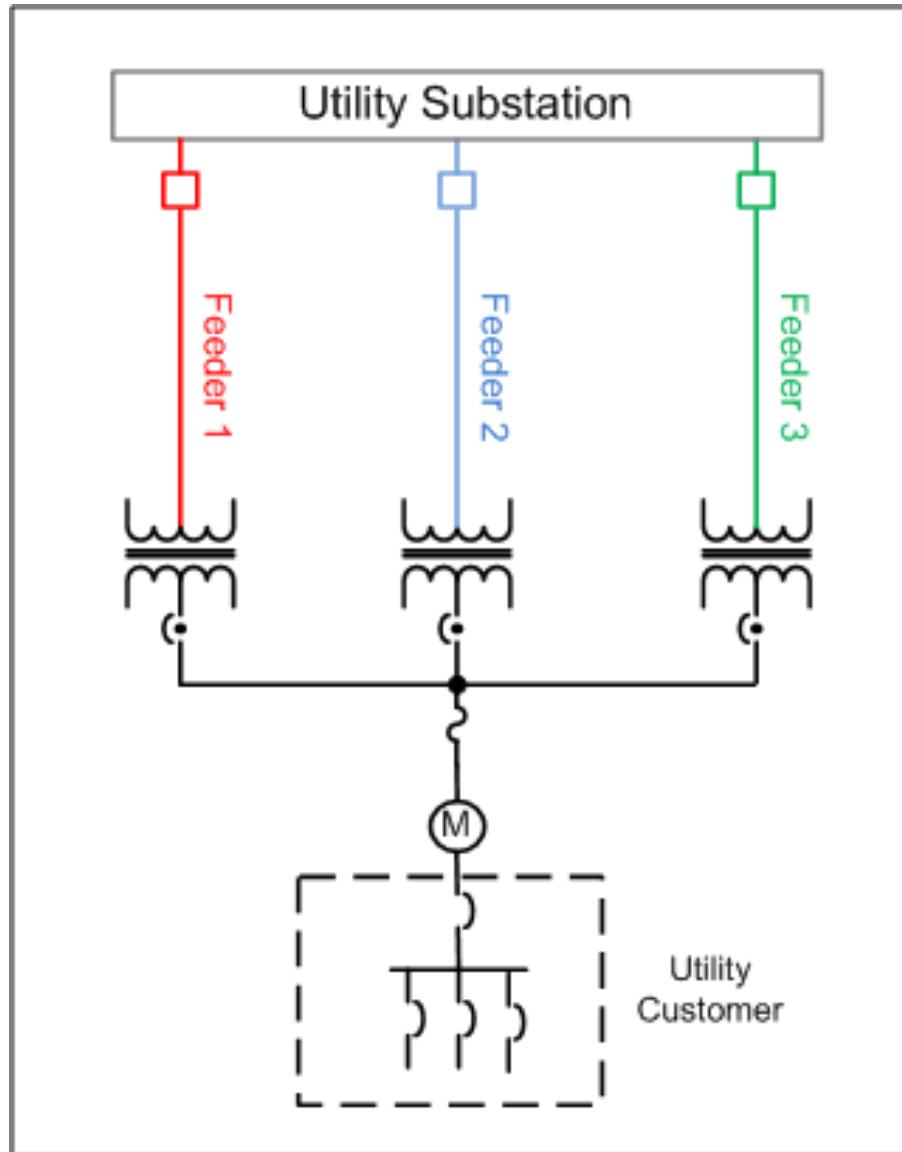
October 31, 2019

# Radial Distribution System

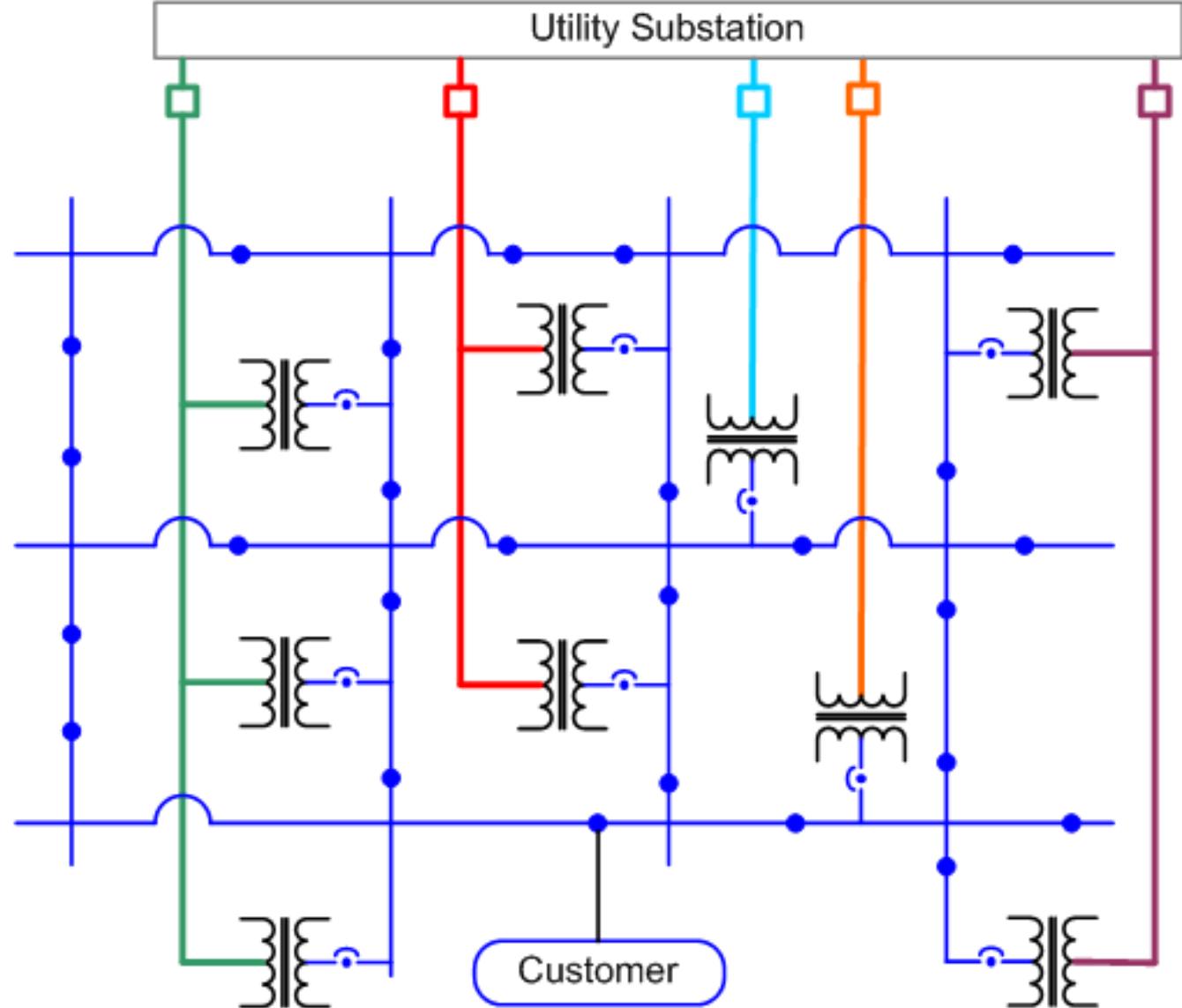
Example Radial Distribution System Design (with Loop)



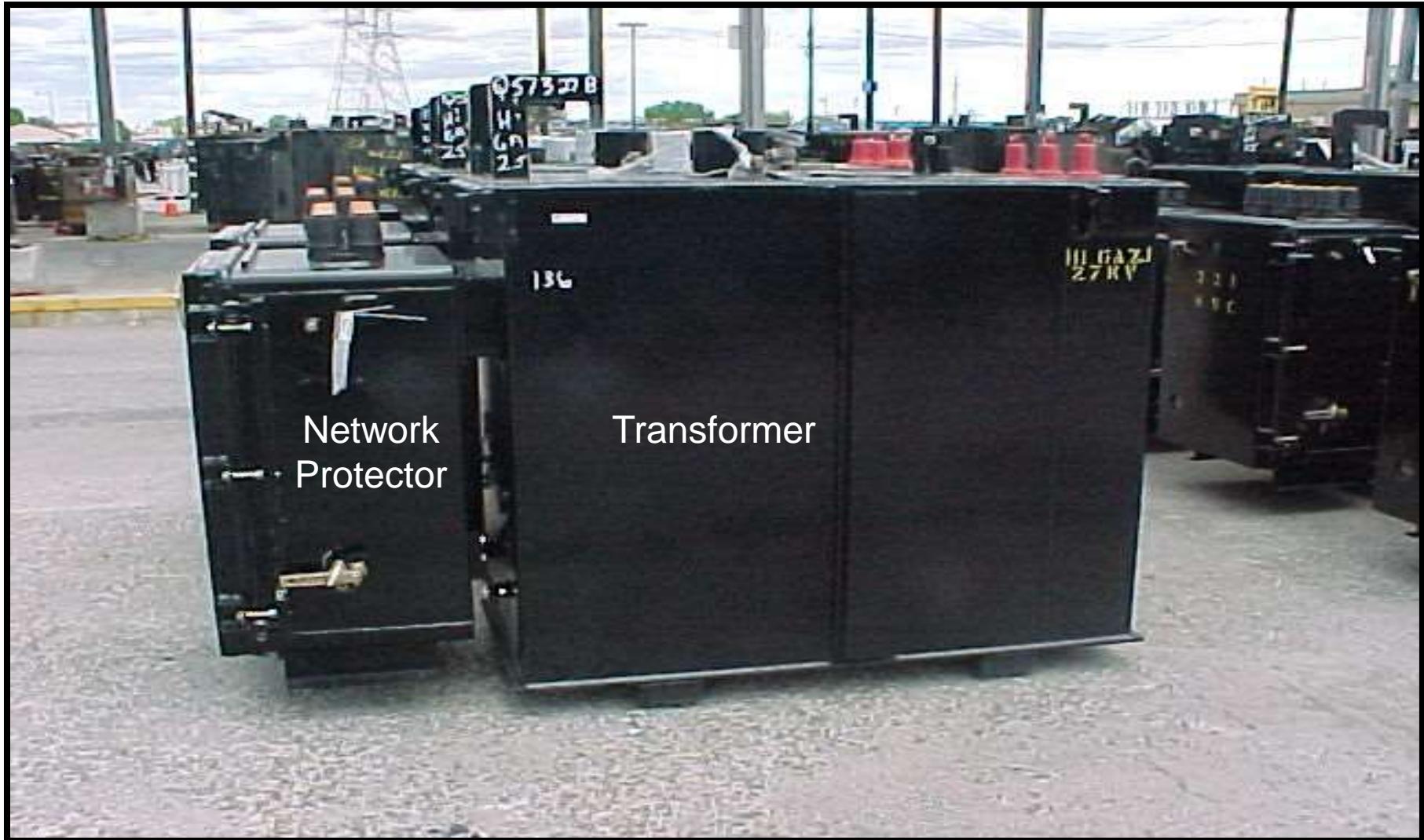
# Example Spot Network



# Area Network Example



# Network Transformer & Network Protector



# Network Protectors

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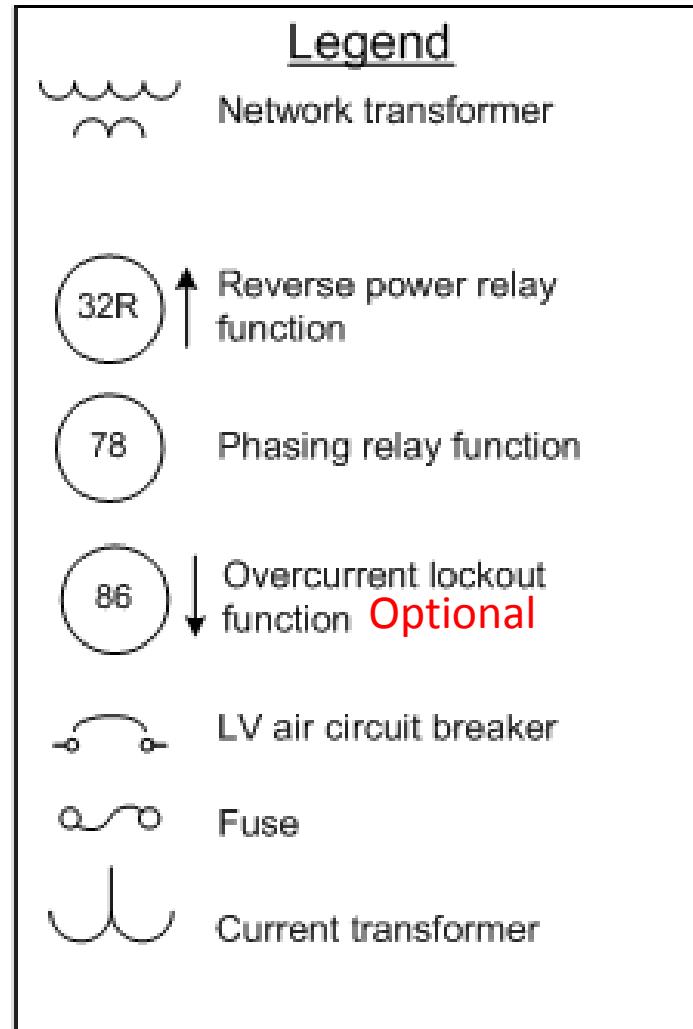
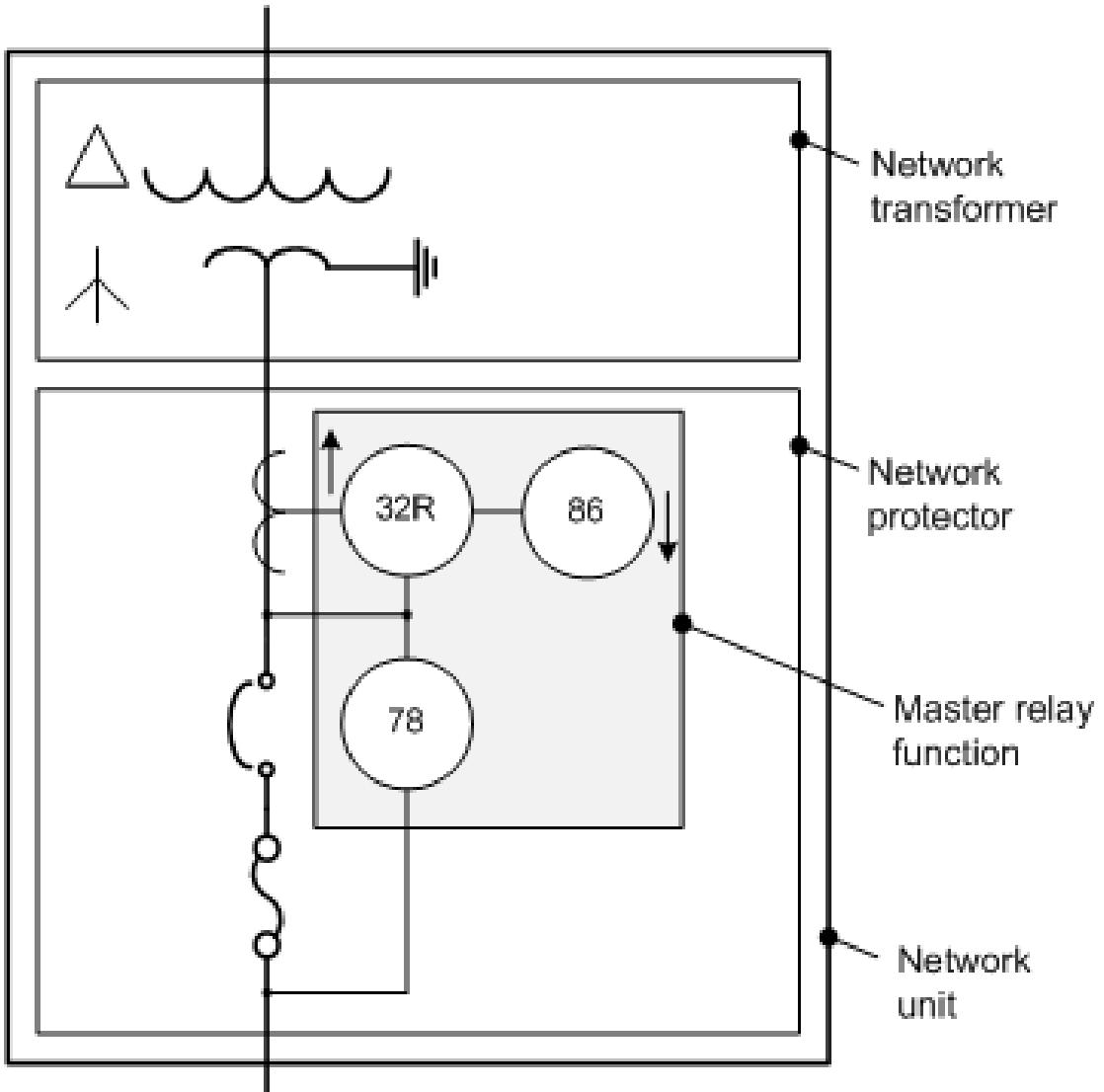
## Primary purposes:

- 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

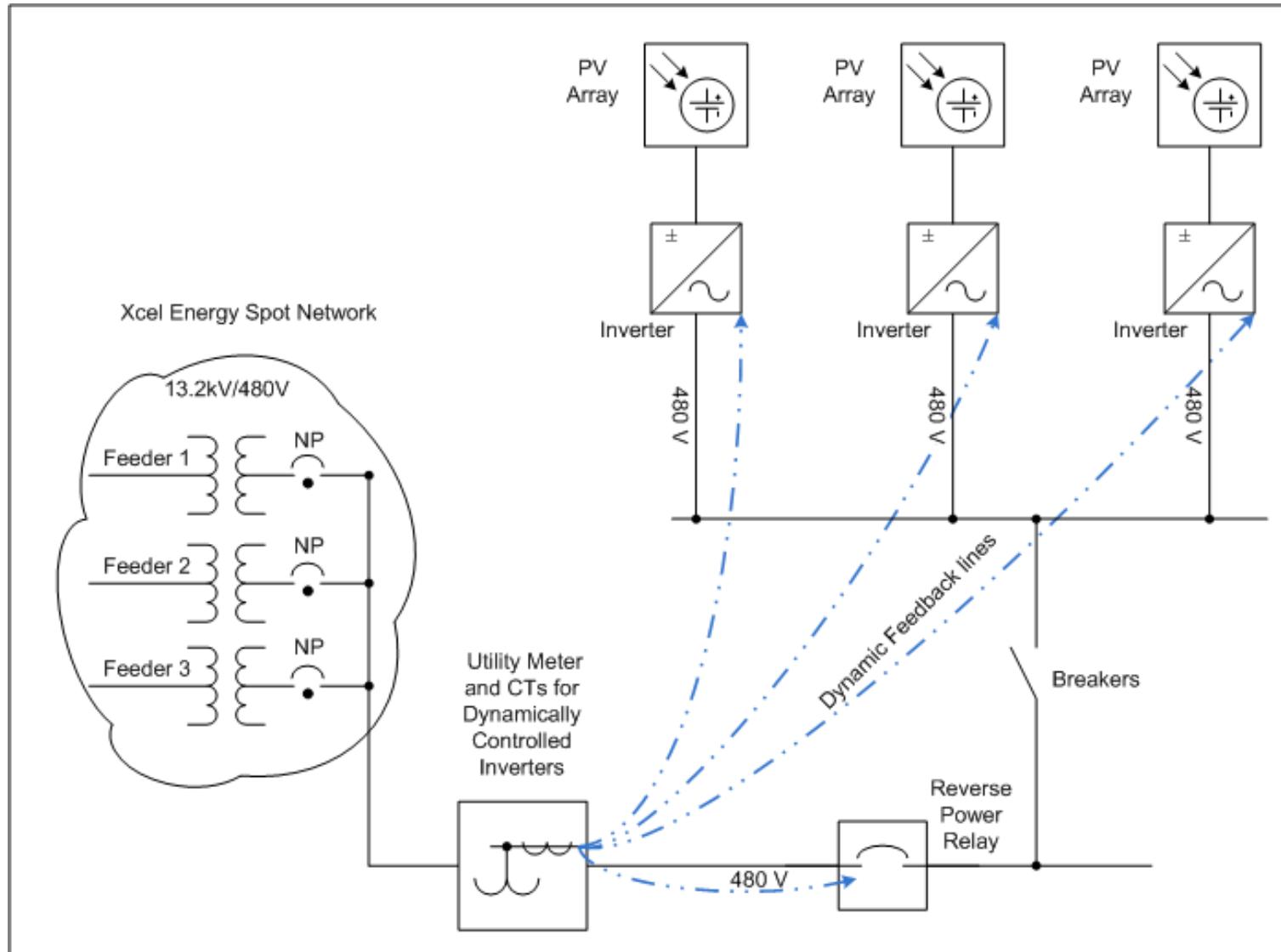
## Three types of network protector relays

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

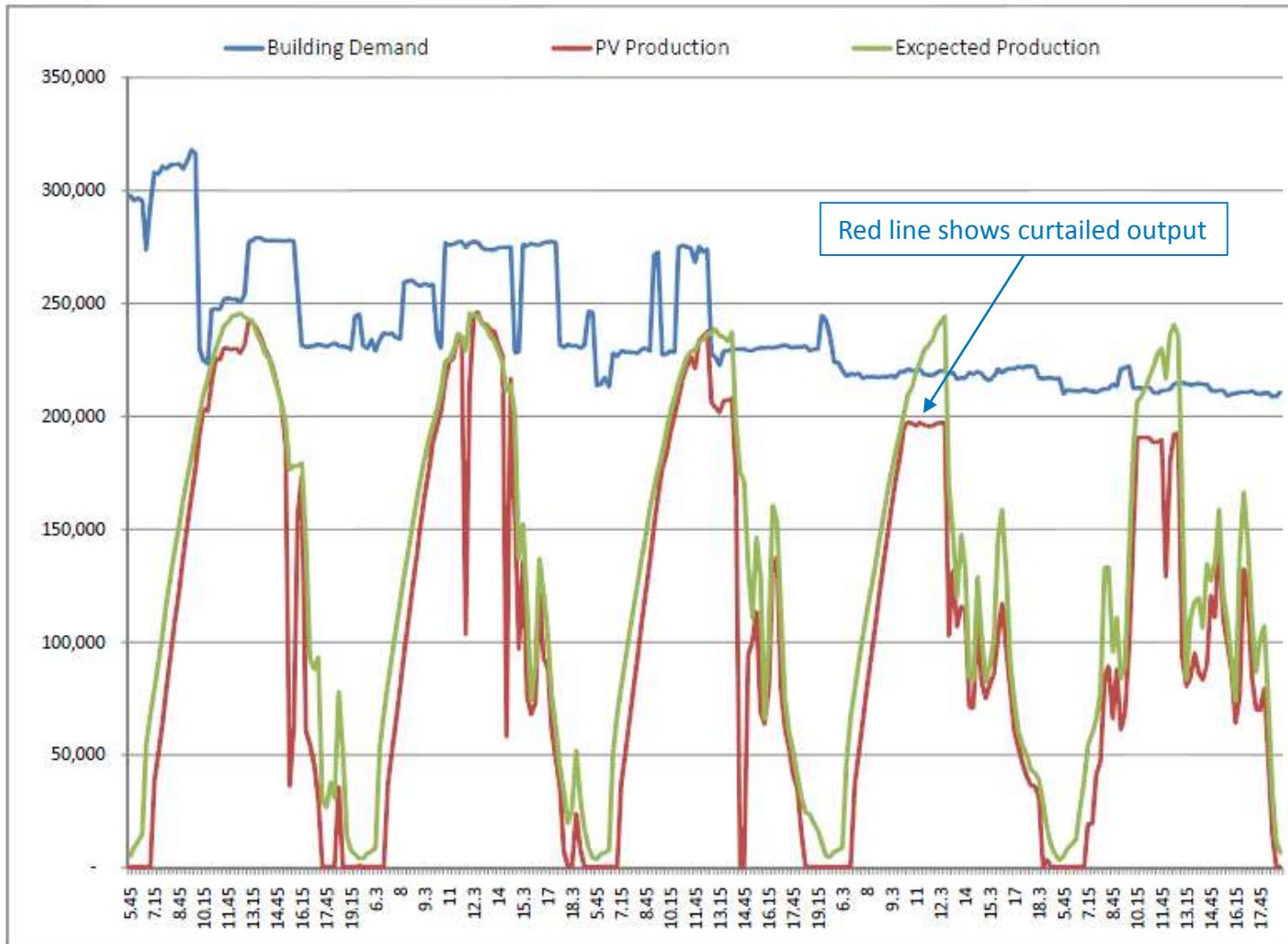
# Network Unit / Network Protector



# Colorado Convention Center One Line Diagram

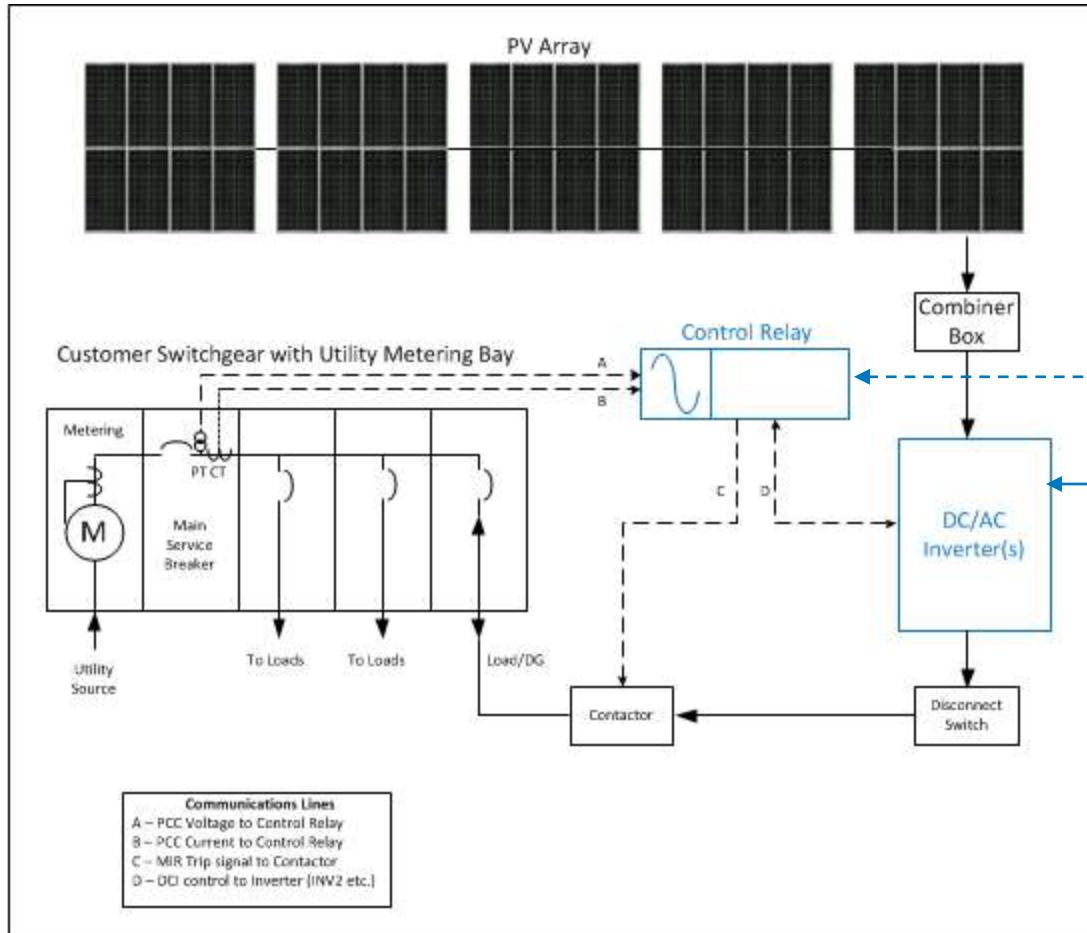


# Dynamically-Controlled Inverter Results



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

