IEEE Standards Development
October 4, 2022

Mark Siira – IEEE
IEEE Standards Committee 21 Chair

Introductions

Presentation Outline

Introduction

- History of the Electric Power System and importance of standards

Interconnection

- IEEE 1547 Series
  - Basic Requirements
- IEEE P2800 Series
  - Transmission-Connected Inverter Based Resources
- IEEE Energy Storage Standards
  - IEEE 1547.9 Guide for interconnection of Energy Storage
  - IEEE P2688 Energy Storage Management Systems

Microgrid – Related Standards

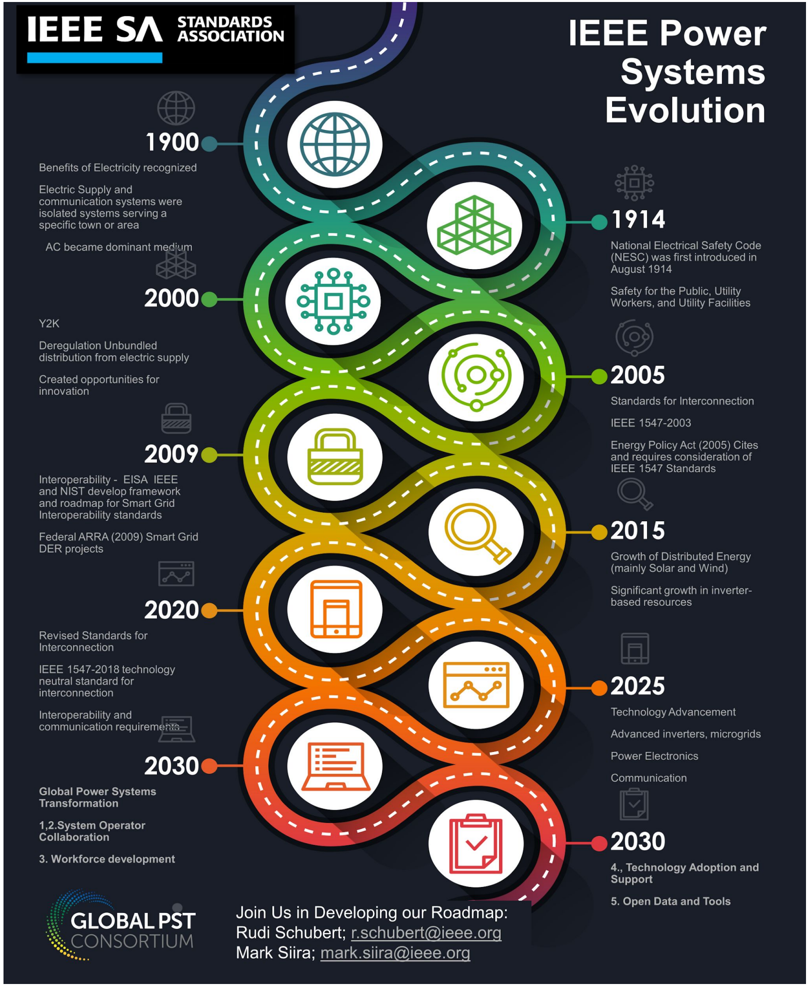
- IEEE 2030 Interoperability Standards
  - Smart Grid Interoperability Reference Model
  - NIST Framework 4.0
- IEEE 2030.7 and 2030.8 – Microgrids
- IEEE 2030.10 and 2030.10.1 – DC Systems
- IEEE 2030.11 – DERMS (Aggregation of DER)
- IEEE 2030.12 – Microgrid Protection

Upcoming Changes and New Standards

- IEEE 1547 and IEEE 1547.10
- IEEE 2030.13 Vehicle to Grid
- IEEE P1547.4 Islanded Systems – Grid Forming Inverters

History of Electric Power System

Electric Power System Evolution



- Interconnection Rules became known in 2003 with the adoption of IEEE 1547-2003
- This unleashed a rapid growth of Distributed Energy – Increasing Penetration of Inverters caused update to standard in 2018
- IEEE Efforts to work the entire range of stakeholders through the Global Power Systems Transformation
  - System Operator Collaboration
  - Workforce Development
  - Standards
  - Open Data and Tools

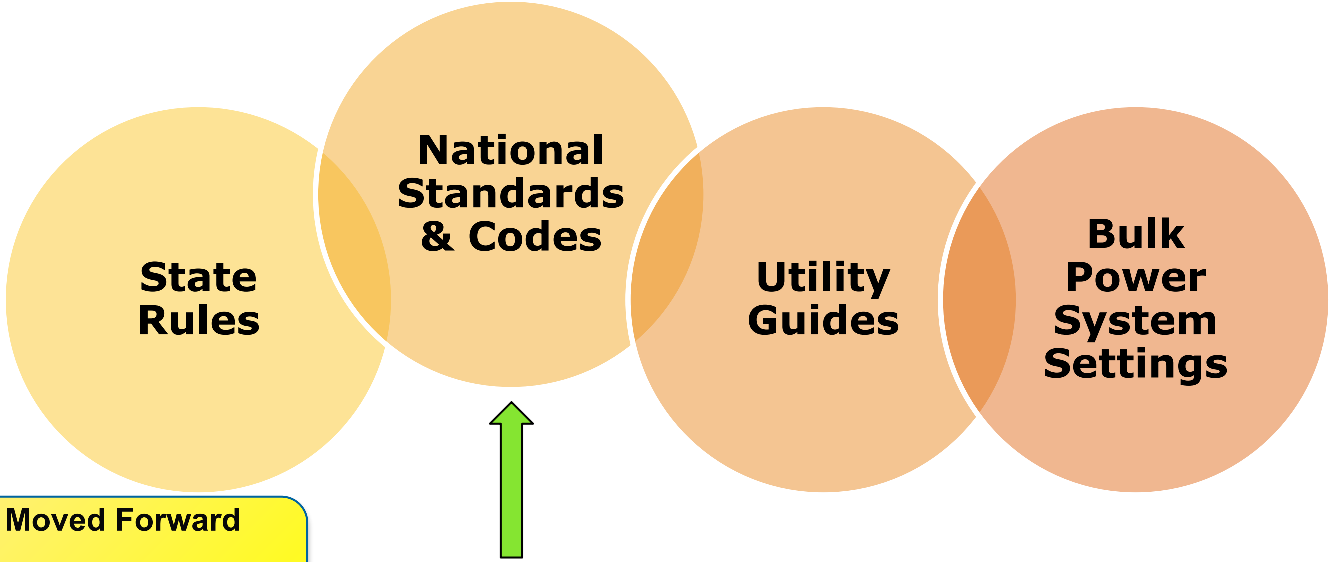
Why Standards Are Important

- Standards provide a consensus view of requirements or guidelines based on an industry technical area or need.
- Standards establish common terminology and frameworks that ensure clarity in specifications and requirements
- Standards lead to modularity.
- Standards develop the framework from which design rules emerge
- System designs become more robust over time through iteration and improvement of designs

References:

- *IEEE Std 610.12-1990 IEEE Standard Glossary of Software Engineering Terminology*
- *Managing in an Age of Modularity* - Harvard Business Review; Carliss Y. Baldwin and Kim B. Clark
- *"Make Megaprojects More Modular- Repeatable design and quick iterations can reduce costs and risks and get to revenues faster". - Harvard Business Review; Bent Flyvbjerg; November, 2021*

Standards, Codes, Rules and Requirements



Many States Have Moved Forward
- Detail at: http://sites.ieee.org/sagroups-scc21/standards/

IEEE 1547-2018

Most states will need to update their interconnection rules, guides, settings, etc., and harmonize with the bulk power system

Interconnection Standards

IEEE 1547-2018 Interconnection Standard

IEEE

Definition of Distributed Energy Resource

In the context of IEEE 1547:

"A source of electric power that is not directly connected to a bulk power system."

- Includes distributed generators.
- Includes distributed energy storage technologies.
- Does not include controllable loads used for demand response.

IEEE 1547 evolution of grid support functions

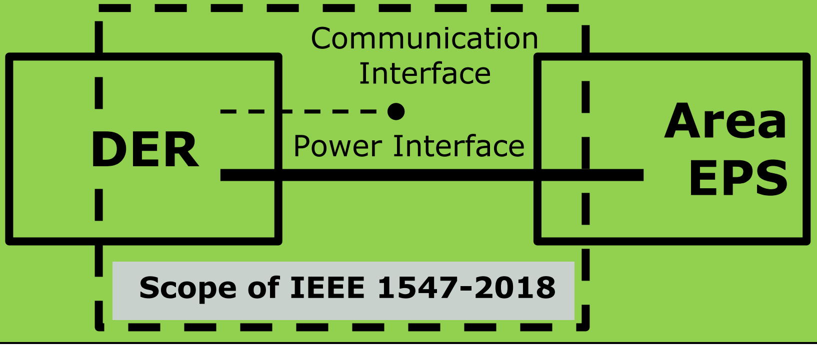
IEEE 1547-2003

- **Shall NOT** actively regulate voltage
- **Shall** trip on abnormal voltage/frequency

IEEE 1547-2018

- **Shall be capable of** actively regulating voltage
- **Shall** ride through abnormal voltage/frequency
- **Shall be capable of** frequency response

IEEE 1547 Scope

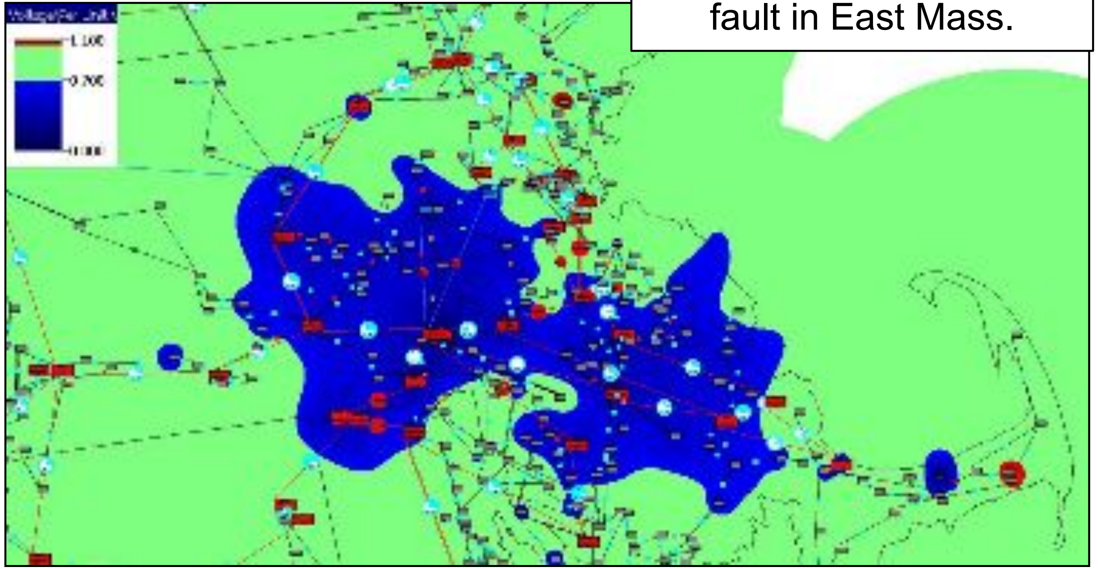


IEEE P1547

- Focused on distribution and bulk system
- Specifications encompass the whole DER
- Equipment listing as well as plant-level verification.
- Includes both electrical as well as interoperability/communications requirements.

Driver for new Requirements IEEE 1547

Voltage profile for 345 kV fault in East Mass.



Source: ISO-New England

IEEE 1547-2018 mandates BOTH:

- Tripping requirements, and
- Ride-through requirements

Ride-through is not a "setting", it is a capability of the DER

- i.e., it is the DER's robustness

Tripping points are adjustable over an allowable range

- Range does not allow DER tripping to seriously compromise BPS security
- Tripping points specified by the Area EPS Operator (utility) within constraints of the regional reliability coordinator

Categories of grid support – 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: 0.25 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”)

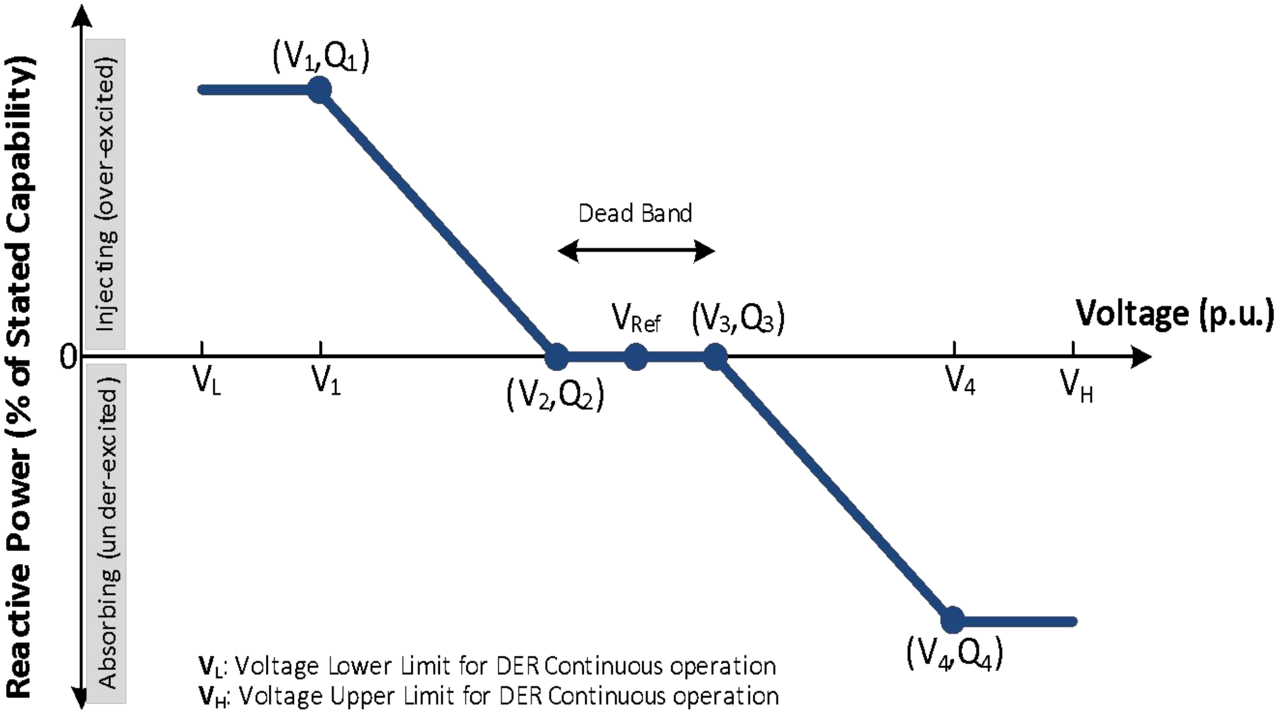
“State-of the art” DER – Cat B

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

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

.

Voltage-Reactive Power mode



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

- Full coordination with all bulk system power system stability/ reliability needs
- Coordinated with existing reliability standards to avoid tripping for a wider range of disturbances (more robust than Category I)

Category III

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

Categories of abnormal performance requirements

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

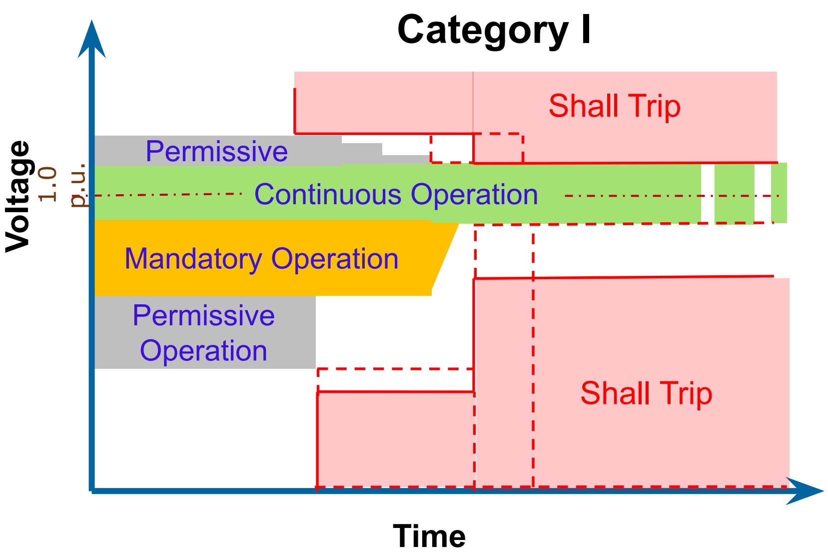
Category II and III are sufficient for bulk system reliability.

Specific performance terminology

- **Trip** – cessation of output without immediate return to service; not necessarily disconnection
- **Cease to energize** – no active power delivery, limitations to reactive power exchange; Does not necessarily mean physical disconnection. Can be either a *momentary cessation* or a *trip*
- **Permissive operation** – DER may either continue operation or may cease to energize, at its discretion
- **Mandatory operation** – required active and reactive current exchange
- **Momentary cessation** – cessation of energization for the duration of a disturbance with rapid recovery when voltage or frequency return to defined range
- **Return to service** – re-entry of DER to service following a trip
- **Restore output** – DER recovery to normal output following a disturbance that does not cause a ***trip***.

Red Text Indicates New Terms for IEEE 1547-2018

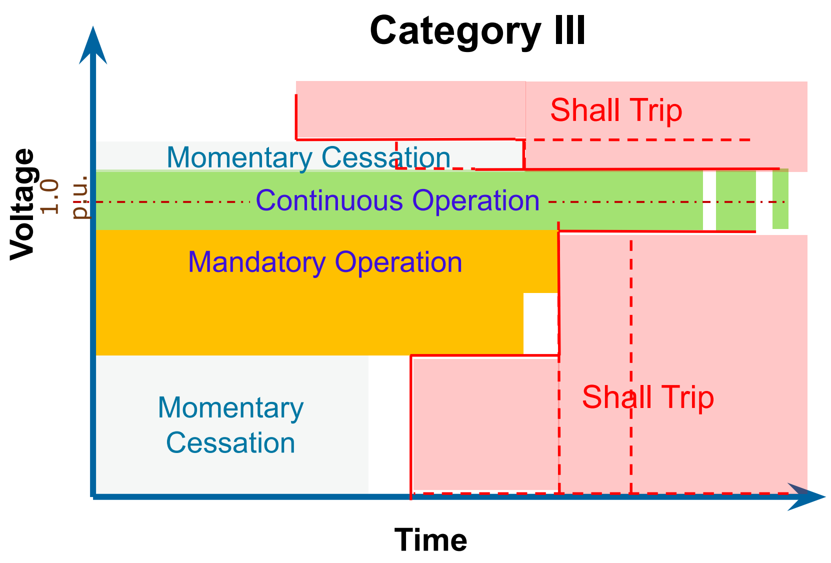
Structure of voltage ride-through and tripping – Categories I and II



Dashed lines indicate permissible range of trip adjustment

Structure of voltage ride-through and tripping – Category III

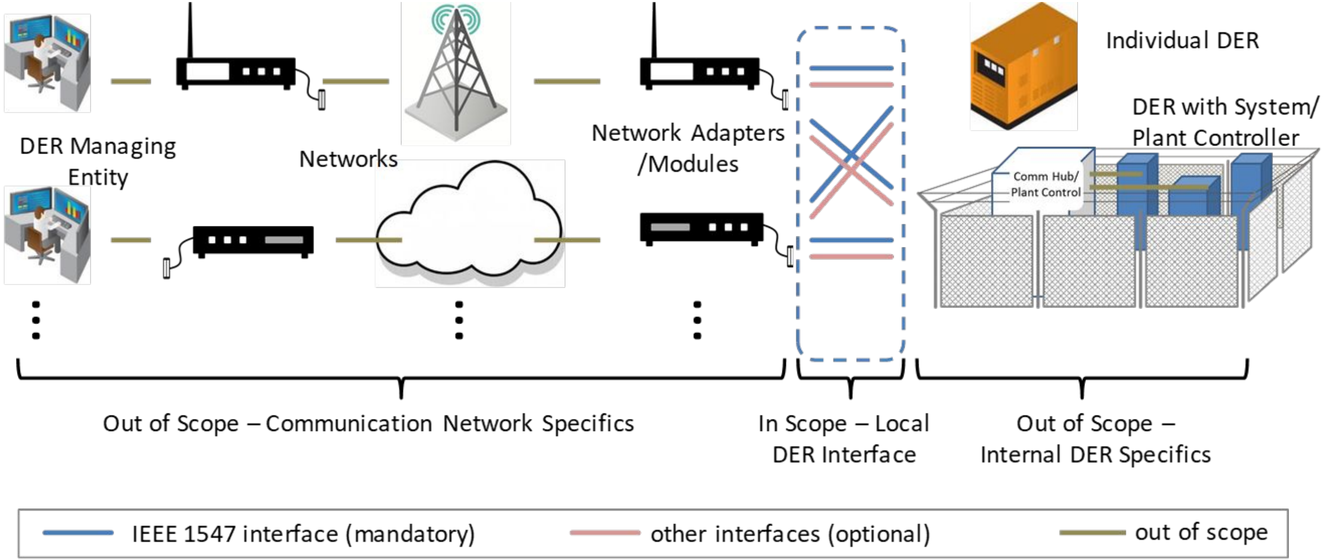
- Category III introduces *momentary cessation* requirement
- Requires a relatively long zero voltage ride-through requirement (in *momentary cessation* mode)
- If feeder is faulted then tripped, DER in *momentary cessation* mode will not energize the islanded feeder
  - Voltage will remain zero and DER will eventually trip off



DER islands in 1547-2018 (Clause 8.2)

- Island: Condition in which a portion of an Area EPS is energized solely by one or more DER – i.e., utility source is disconnected
- Unintentional island: one that is not planned
  - DER must detect, trip, and clear within 2 seconds –same as IEEE 1547-2003
  - Area EPS Operator (utility) can extend this to 5 seconds
  - Ride through requirements do not nullify this requirement
  - False detection of an island does not justify non-compliance with ride-through
- Intentional island: one that is planned such that DER can carry a specific load (e.g., microgrid, emergency/standby power supply)
  - 1547-2018 now addresses intentional islands
  - For *Local EPS Islands* (facility islands), standard only covers conditions of connection and disconnection
  - For Area EPS Islands (includes utility system assets), connection, disconnection, and changes to DER settings required during islanding condition

Interoperability Requirements of IEEE 1547



IEEE 1547-2018 defines communication interface

Categories of information to be exchanged

- Nameplate Data – As-built characteristics of the DER, e.g.:
  - Manufacturer/model
  - Active and reactive power rating, etc.
- Configuration Information – alternative nameplate ratings
- Monitoring Information –Measured values of:
  - Active and reactive power
  - Voltage, etc.
- Management information
  - Update functional and mode settings

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

High-Level Test and Verification Process

Maintenance	Periodic	In-service confirmation on recurring schedule
Post-installation review	Commissioning Tests	Confirm DER functionality and interoperability on site
	As-Built Installation Evaluation	Confirm DER is installed as designed
Interconnection review	Design Evaluation	Desk study prior to installation
Equipment conformance testing	Production Tests	Test of every unit, usually in factory
	Type Tests	Test in laboratory or factory of a representative DER unit

Interconnection Standards

IEEE 2800-2020 Interconnection Standard for Transmission Connected Inverter-Based DER

IEEE 2800 Standard

Scope

This standard establishes the required interconnection capability and performance criteria for inverter-based resources interconnected with transmission and sub-transmission systems. , , Included in this standard are performance requirements for reliable integration of inverter-based resources into the bulk power system, including, but not limited to: **voltage and frequency ride-through, active power control, reactive power control, dynamic active power support under abnormal frequency conditions, dynamic voltage support under abnormal voltage conditions, power quality, negative sequence current injection, and system protection.**

Applicable to IBRs like wind, solar & energy storage, and any IBR connected via VSC-HVDC.

- "Type 3" wind turbines (doubly-fed induction generators) are in scope
- HVDC-VSC connected resources, e.g., onshore connection point of a VSC-HVDC tie-line interconnecting an offshore resource is also in scope.

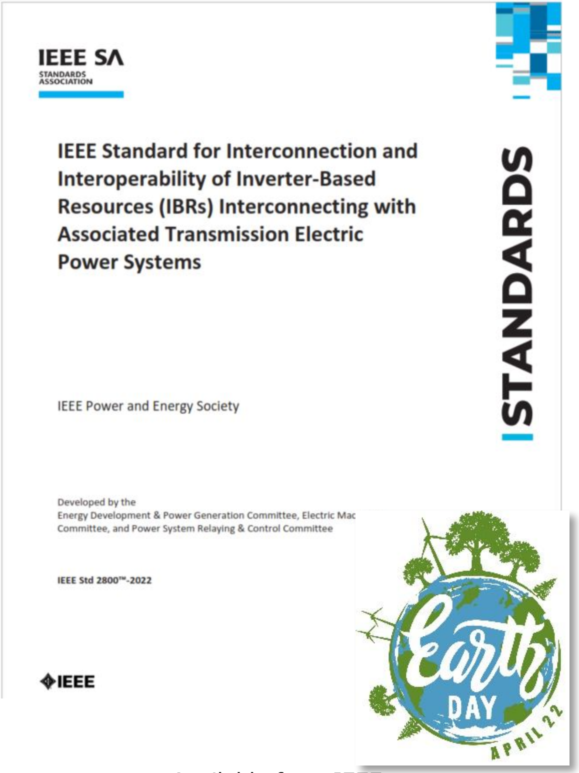
Summary of IEEE 2800 Standard

- The standard **harmonizes** Interconnection Requirements for Large Solar, Wind and Storage Plants

- It is a **consensus-based** standard developed by over ~175 Working Group participants from utilities, system operators, transmission planners, & OEMs over 2 years

- It has successfully passed the IEEE SA ballot among 466 balloters **(>94% approval**, >90% response rate)

- **Published on April 22, 2022 (Earth Day)**



More Info at https://sagroups.ieee.org/2800/

Available from IEEE at https://standards.ieee.org/project/2800.html and via IEEExplore: https://ieeexplore.ieee.org/document/9762253/

Complementing North American Reliability Standards

		Performance	Test & Verification & Model Validation
FERC / NERC?	**Transmission**	*IEEE 2800-2022* • FERC Orders • NERC Reliability Standards & Guidelines	• NERC compliance monitoring & enforcement *IEEE P2800.2*
NARUC / State PUCs?	**Sub-Transmission**	• Not available	• Not available
	Distribution (for DER)	• IEEE Std 1547-2018 • IEEE Std 1547a-2020 ✔	• IEEE 1547.1-2020 • UL 1741 (SB) • IEEE ICAP ✔

DER: Distributed Energy Resources

Source: EPRI, 2021

Only when adopted by the appropriate authorities, IEEE standards become mandatory

IRENA Report: Key Messages

*“Power system transformation towards decentralization, digitalisation and electrification calls for **evolving grid codes**”*

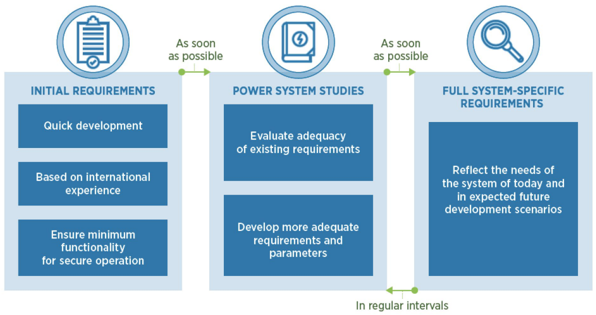
- **[Inverter-based resources, IBR] impact** the way power systems are operated
- The role of grid codes in **building trust** between different actors
- An **imperfect grid code** is, in many cases, better than no grid code at all
- Grid codes should be **technology-neutral** and should **evolve** to meet system needs
- Grid codes should **enable innovations** to connect safely to the grid
- Ensuring **compliance** with the code is key
- International **standardization** and regional grid codes facilitate sharing of flexibility and increased economy of scale for equipment manufacturers

Figure ii **Categories of grid codes in Europe, functionality and main actors**

	MARKET CODES	OPERATION CODES	CONNECTION CODES
FUNCTIONALITY	• Electricity Balancing • Capacity Allocation • Congestion Management	• System Operation • Electricity Emergency and Restoration	• Requirements for Generators • Loads Connection • HVDC Connection
MAIN ACTORS	• Transmission System Operators • Market Operator	• Transmission System Operators • Energy Suppliers	• Transmission System Operators • Distribution System Operators • Investors • Project Developers • Technology Providers • Energy Suppliers • Consumers

Note: HVDC = high voltage direct current.

Figure iii **Grid code parameter development and revision process**

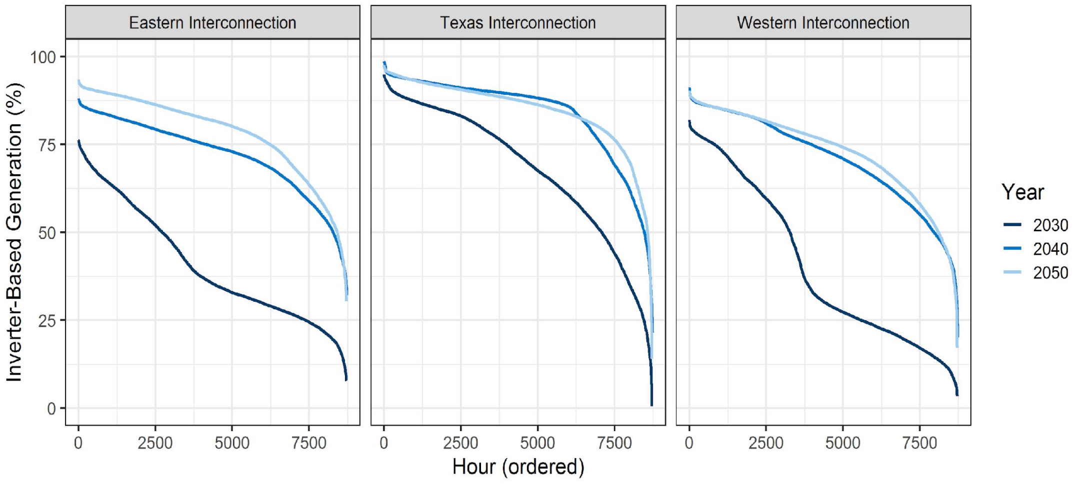


© IRENA (2022), *Grid codes for renewable powered systems*, International Renewable Energy Agency, Abu Dhabi. [Online]

Pace of IBR Interconnections

All major U.S. interconnections are expected to reach peak **instantaneous IBR levels of 75-98%** within the lifetime of IBRs being connected today.

- These plants will need to not just remain online, but contribute to system recovery and reliability.
- IEEE 2800 addresses minimum technical requirements deemed needed from IBRs.



Data from 2021 DOE/NREL Solar Futures Study:
https://www.nrel.gov/analysis/solar-futures.html

IBR: inverter-based resources like wind, solar, storage

Insufficient Solar, Wind & Storage Interconnection Requirements

- Diverse & different requirements across various jurisdictions

  …requires more effort and time to address

- Inverter-based resources (IBR) are different from synchronous generators

  …higher (and sometimes lower) capability

- Requirements may not be balanced

  …some too stringent & not taking advantage of new capability

Source: https://www.natf.net/

Recurring Reliability Issues with IBRs

- Unexpected tripping, cessation of active power, oscillations, etc.
- Mis-application of IEEE 1547 standard for Transmission connected resources
- Analysis found **opportunity for standardization** of IBR performance to maintain grid reliability

Source: NERC, 2017-2022

Contextualization within IBR Interconnection Process

Challenges and Opportunities for North America

Existing Step 1: Interconnection Request — Plant-Specific Interconnection Request

- **Insufficient**, diverse, or vague RTO/ISO/TP's technical interconnection requirements (**TIRs**)
- Submission of **any available models,** often **inappropriately configured**
- **Vague model 'acceptance criteria'**

Existing Step 2: Feasibility Study — Plant-Specific Interconnection Screening / Preliminary Review

Limited screening for:

- Grid strength metrics (neither conventional nor advanced)

that could help determine **what type of models and system impact studies** would be needed to reliably connect the IBR.

Existing Step 3: System Impact Study — Plant-Specific Grid Integration & Reliability Impact

- System impact studies often use **insufficient models** that may **not** be **site-specific** and **may be configured with generic** parameters
- May **not represent** IBR units, supplemental IBR devices, and **the IBR plant design** ultimately commissioned in the field

Existing Step 4: Facility Study — IBR Plant Cost Estimation and Determination of Transmission Grid Upgrades

- **No common assessment of IBR plant-level conformity** with regard to RTO/ISO/TP's technical interconnection requirements (TIRs)
- Detailed **IBR plant design may change** after Interconnection Agreement (IA) is executed

IBR Plant Construction — Installation and Building of all Equipment and Structures

- What is built in the field does often not match what had been previously studied/modeled
- **No "as-built" plant-level evaluation**

Existing Step 5: Interconnection Commissioning — Plant-Specific Commissioning & Model Validation/ Verification

- Only a (limited) set of field tests are performed to validate/verify IBR plant model.
  - Limited to small-signal disturbances.
  - Often **no verification of** large-signal disturbances such as **ride-through**

- **Limited collection of field data** to validate/verify IBR plant model.
  - Often not for large-signal disturbances.

Source: EPRI, 2021-2022

IEEE 2800-2022
IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems

&

P2800.2
Recommended Practice for Test and Verification Procedures for Inverter-based Resources (IBRs) Interconnecting with Bulk Power Systems
Active PAR

IEEE SA: https://standards.ieee.org/ieee/2800.2/10616/
P2800.2 WG: https://sagroups.ieee.org/2800-2/

What to expect from IEEE 2800-2022?

- **Provides Value**
  - widely-accepted, unified technical minimum requirements for IBRs
  - simplifies and speeds-up technical interconnection negotiations
  - flexibility for IBR developers & OEMs ☐ not an equipment design standard
- **Specifies**
  - performance and functional capabilities *and not* utilization & services
  - functional default settings and ranges of available settings
  - performance monitoring and model validation
  - type of tests, plant-level evaluations, and other verifications means, but not detailed procedures (☐ *IEEE P2800.2)*
- **Scope**
  - Limited to all transmission and sub-transmission connected, large-scale wind, solar, energy storage and HVDC-VSC

What *not* to expect from IEEE 2800?

- **No exhaustive requirements for evolving IBR technology solutions**
  - IEEE 2800 applies to all IBRs (including grid-forming ones), but was designed with conventional grid-following IBRs in mind
  - Considers synchronous condensers as ”supplemental IBR devices” but allows for exceptions when used in IBR plants
- **No definition of an interconnection process**
  - This is up to transmission system owners and their stakeholders and regulators
  - IEEE 2800 may be used as *part* of such a process
- **No procedures to verify that IBRs comply with requirements**
  - **Procedures are currently being developed in IEEE P2800.2:**

P2800.2

Recommended Practice for Test and Verification Procedures for Inverter-based Resources (IBRs) Interconnecting with Bulk Power Systems

Active PAR

IEEE SA: https://standards.ieee.org/ieee/2800.2/10616/
P2800.2 WG: https://sagroups.ieee.org/2800-2/

Capability versus Utilization

Capability:

"Ability to Perform"

- Functions
- Ranges of available settings
- mance specifications

Examples

- Frequency Response
  - Frequency Droop Response
  - Ramp rate limitations
- Ride-Through
  - Voltage ride-through
  - Current injection during ride-through
  - Consecutive voltage ride-through
  - Frequency ride-through
  - ROCOF ride-through
  - Phase angle jump ride-through

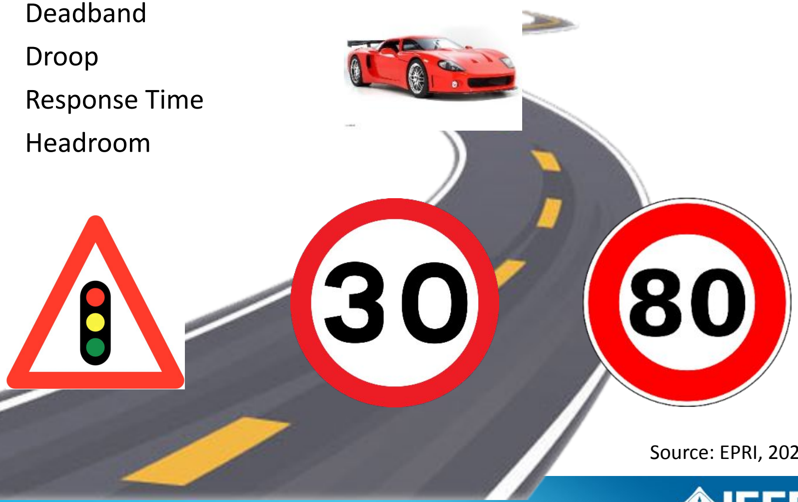
Utilization of Capability:

"Delivery of Performance"

- Enable/disable functions
- Functional settings / configured parameters
- Operate accordingly (e.g., maintain headroom, if applicable)

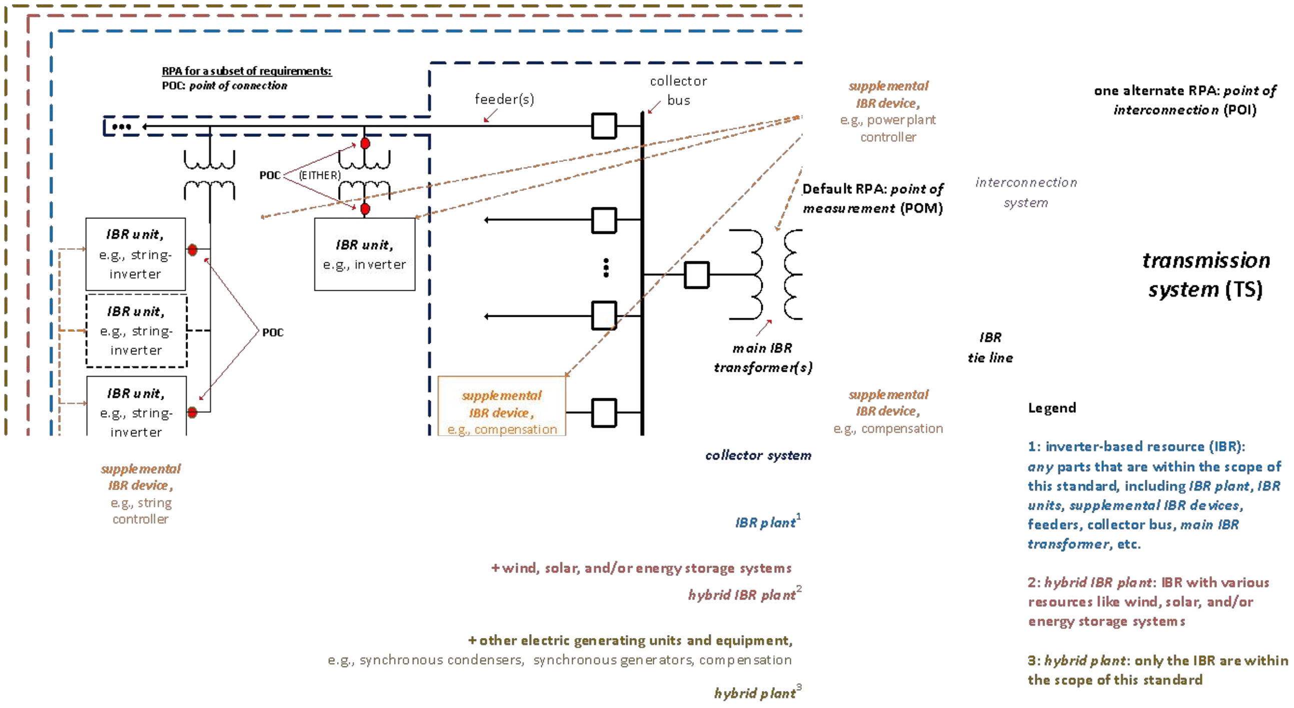
Examples

- Deadband
- Droop
- Response Time
- Headroom

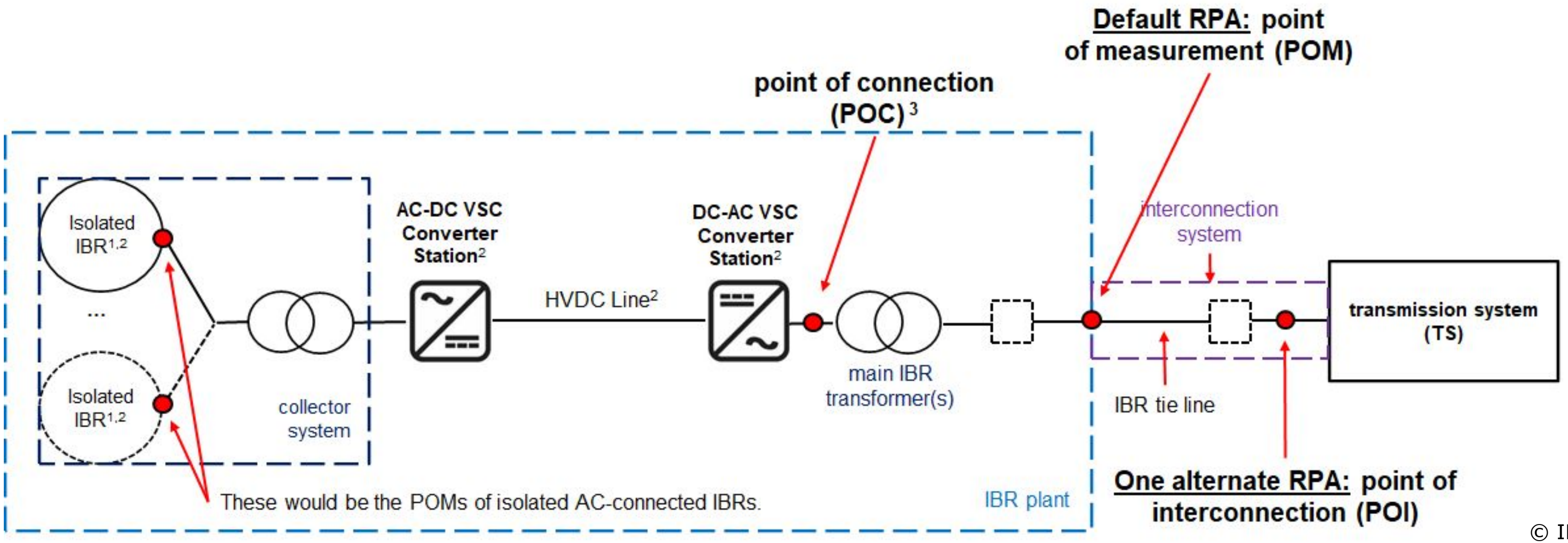


Source: EPRI, 2021

Reference Point of Applicability – Example 1



Reference Point of Applicability – Example 2

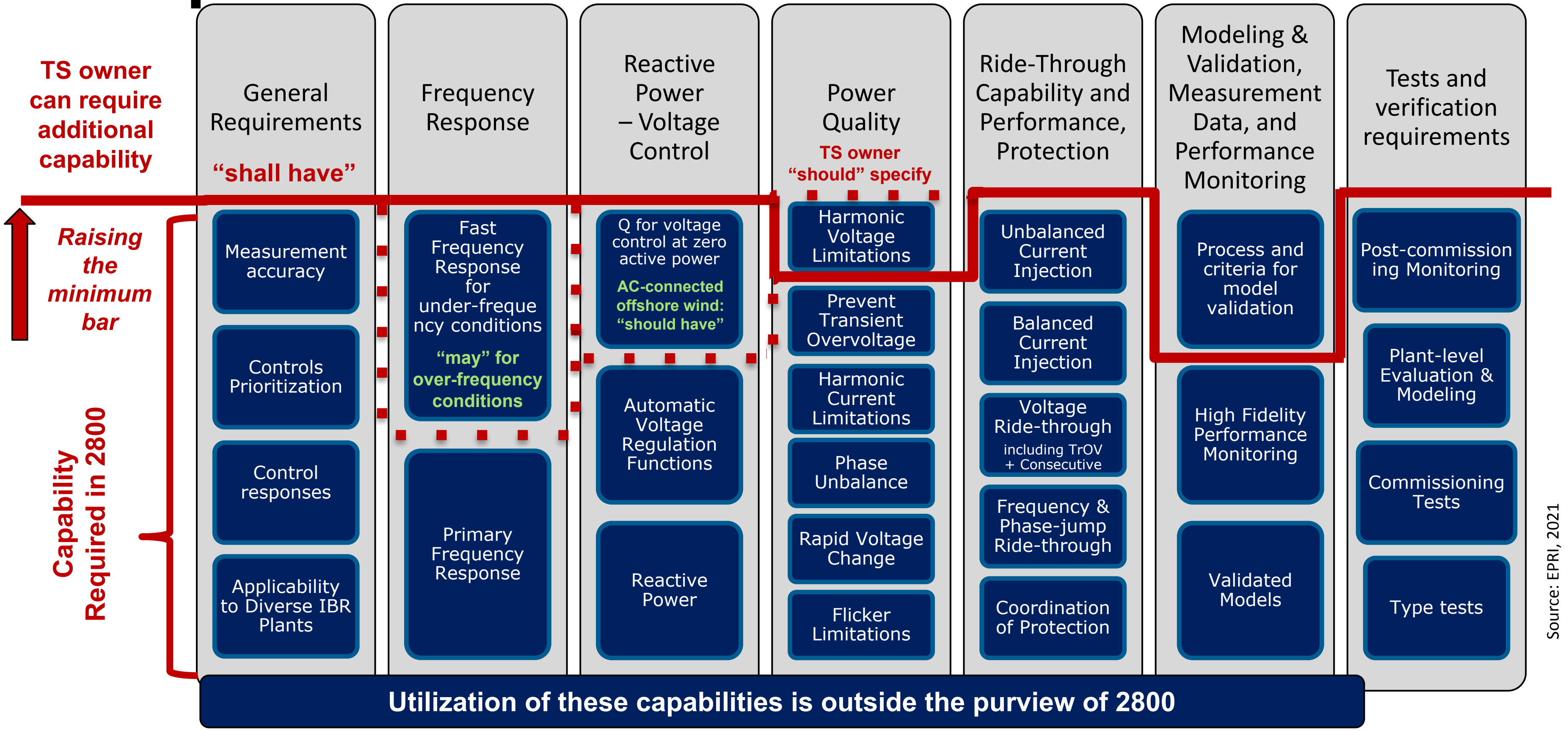


[1] Includes IBR units like type IV wind turbine generators

[2] May serve as a supplemental IBR device that is necessary for the IBR plant with VSC-HVDC to meet the requirements of this standard at the RPA

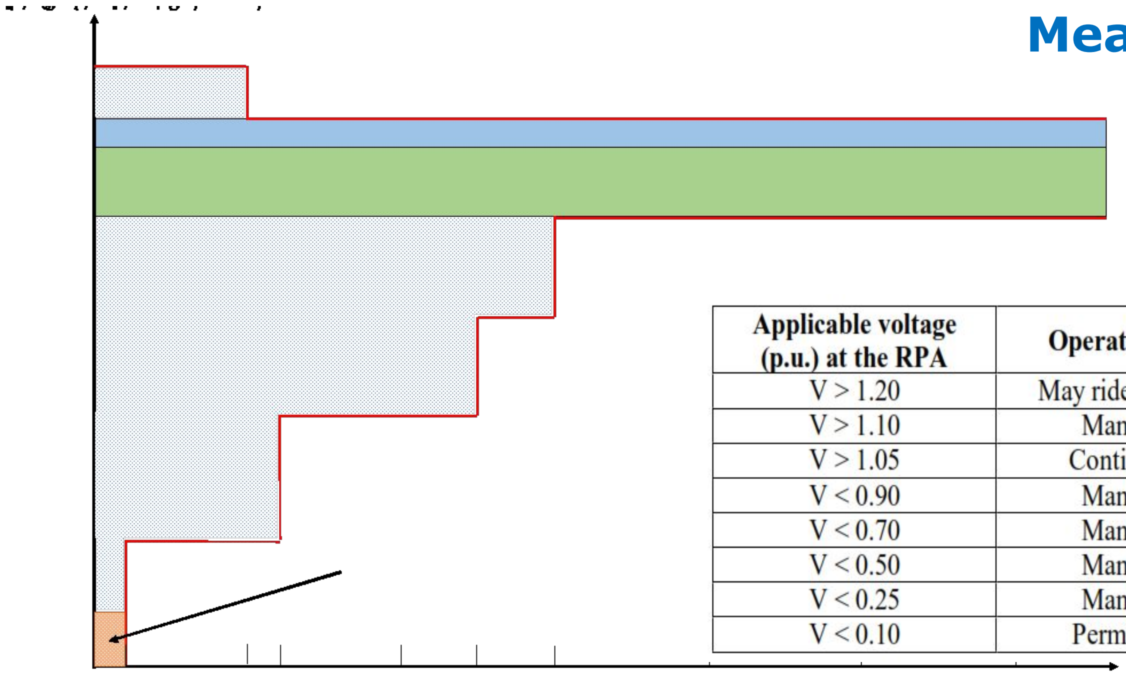
[3] Depending on design, the POC may be on the TS side of the main IBR transformer.

IEEE 2800-2022 Technical Minimum Capability Requirements



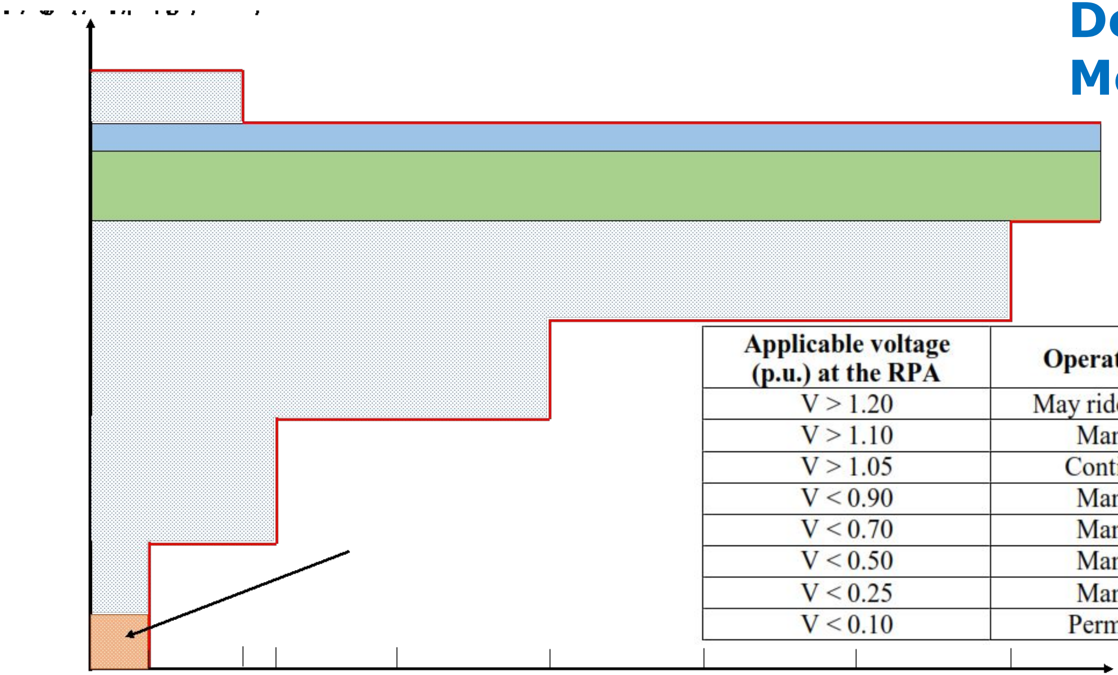
Voltage Ride-Through Capability – Plants with Aux. Load limitations, i.e., Wind Plant

Default RPA: Point of Measurement



Applicable voltage (p.u.) at the RPA	Operating mode/response	Minimum ride-through time (s) (design criteria)
V > 1.20	May ride-through or may trip	NA
V > 1.10	Mandatory operation	1.0
V > 1.05	Continuous operation[90]	1800
V < 0.90	Mandatory operation	3.00
V < 0.70	Mandatory operation	2.50
V < 0.50	Mandatory operation	1.20
V < 0.25	Mandatory operation	0.16
V < 0.10	Permissive operation[91]	0.16

Voltage Ride-Through Capability – Plants without Aux. Load limitations, i.e., Solar Plant



Default RPA: Point of Measurement

Applicable voltage (p.u.) at the RPA	Operating mode/response	Minimum ride-through time (s) (design criteria)
V > 1.20	May ride-through or may trip	NA
V > 1.10	Mandatory operation	1.0
V > 1.05	Continuous operation[90]	1800
V < 0.90	Mandatory operation	6.00
V < 0.70	Mandatory operation	3.00
V < 0.50	Mandatory operation	1.20
V < 0.25	Mandatory operation	0.32
V < 0.10	Permissive operation[91]	0.32

Clarification of Voltage Ride-Through Capability Req.

Three possible understanding:

- Voltage versus Time curve: For a given voltage, IBR plant shall not trip until the duration at this voltage exceeds ride-through curve capability.
  - ✔ Correct understanding

- Voltage Deviation *times* Time *Area*: Area between a nominal voltage (100%) and either a low or high voltage ride-through boundary.

- Voltage versus Time Envelope: Ride-through curves define an envelope to lay as a template over a voltage versus time trajectory.

Modeling Data

- Some specified requirements **cannot** be verified based on tests (type, commissioning etc.)
- Verification of such requirements is **done using models and simulations**
- IBR owner is **required** to provide **verified models** to TS owner/operator

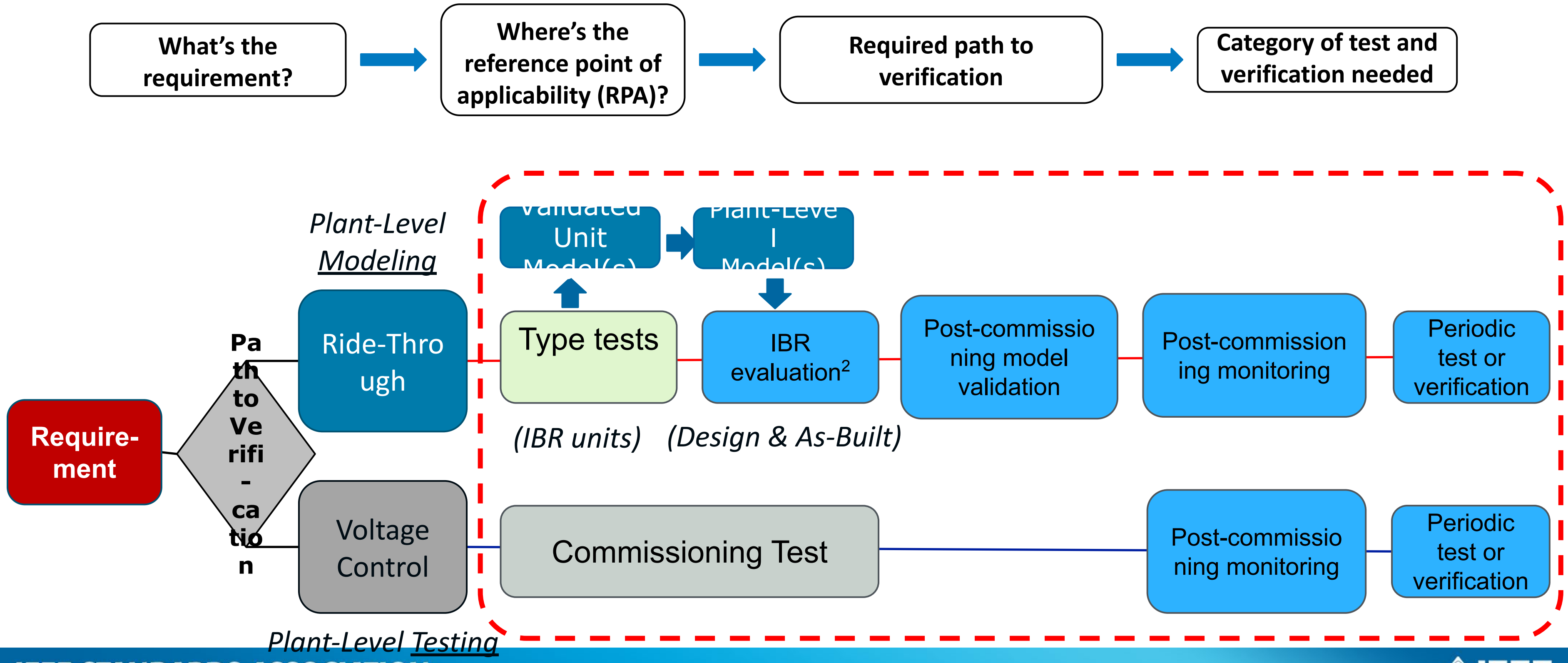
  such as, power flow, stability dynamic model, short-circuit, EMT, harmonics etc
- Development of verified models is outside the scope of this standard; however, some guidance is provided.
- **Annex G of IEEE 2800-2022** provides recommended practice for modeling data

Measurements for Performance Monitoring/Model Validation

IBR plant is required to take measurements at specified points throughout the resource, from individual IBR units to the POM, using various technologies

Data Type	Data Points	Recording Rate	Retention	Duration
Plant SCADA Data	Voltage, frequency, P, Q, etc.	One record per second	One year	One year
Plant Equipment Status Log	Breakers, shunt devices, LTCs, collector system, IBR units, etc.	Static, as changed	One year	NA
Sequence of Event Recordings	Date/Time stamp, type of event, sequence number etc.	Static, as changed	One year	NA
Digital Fault Recordings	Each L-G voltage, phase & neutral currents, etc.	>128 samples/cycle, triggered	90 days	5 second data
Dynamic Disturbance Recordings	Voltage, current, frequency, calculated P and Q	Input: ≥ 960 samples/second Output: ≥ 60 times/second; continuous	One year	NA
IBR Unit Data	Fault & alarm codes, PLL loss of synchronism, dc/ac voltage and current etc.	Many kHz, triggered	90 days	5 second data

IEEE 2800 Test and Verification Framework



Energy Storage Standards

Stand-alone Solar PV and IEEE 1547.9-2022

Energy Storage Standards

Photovoltaic Standards (Stand-Alone or Remote Systems)

- **IEEE 937-2019**; IEEE Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic (PV) Systems
- **IEEE 1013-2019;** IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stand-Alone Photovoltaic (PV) Systems
- **IEEE 1361-2014;** IEEE Guide for Selection, Charging, Test and Evaluation of Lead-Acid Batteries Used in Stand-Alone Photovoltaic (PV) Systems
- **IEEE 1526- 2020;** Recommended Practice For Testing the Performance of Stand Alone Photovoltaic Systems
- **IEEE 1561-2019;** Guide for Optimizing the Performance and Life of Lead-Acid Batteries in Remote Hybrid Power Systems
- **IEEE 1562-2019;** Guide for Array and Battery Sizing in Stand-Alone Photovoltaic (PV) Systems.
- **IEEE 1661-2019;** Guide for Test and Evaluation of Lead-Acid Batteries Used in Photovoltaic (PV) Hybrid Power Systems

IEEE P2688: Recommended practice for Energy Storage Management Systems in energy storage applications

Scope:

- This recommended practice covers the development and deployment of ESMS in energy storage applications.
- ESMS is an umbrella term that includes a range of systems that generally fall into one of several categories:
  - Power management systems (PMS)
  - Power plant controllers (PPC)
  - Energy management systems (EMS)
- For each category, ESMS includes software functions and hardware capabilities addressing the requirements to operate ESSs in supply-side and demand-side applications.

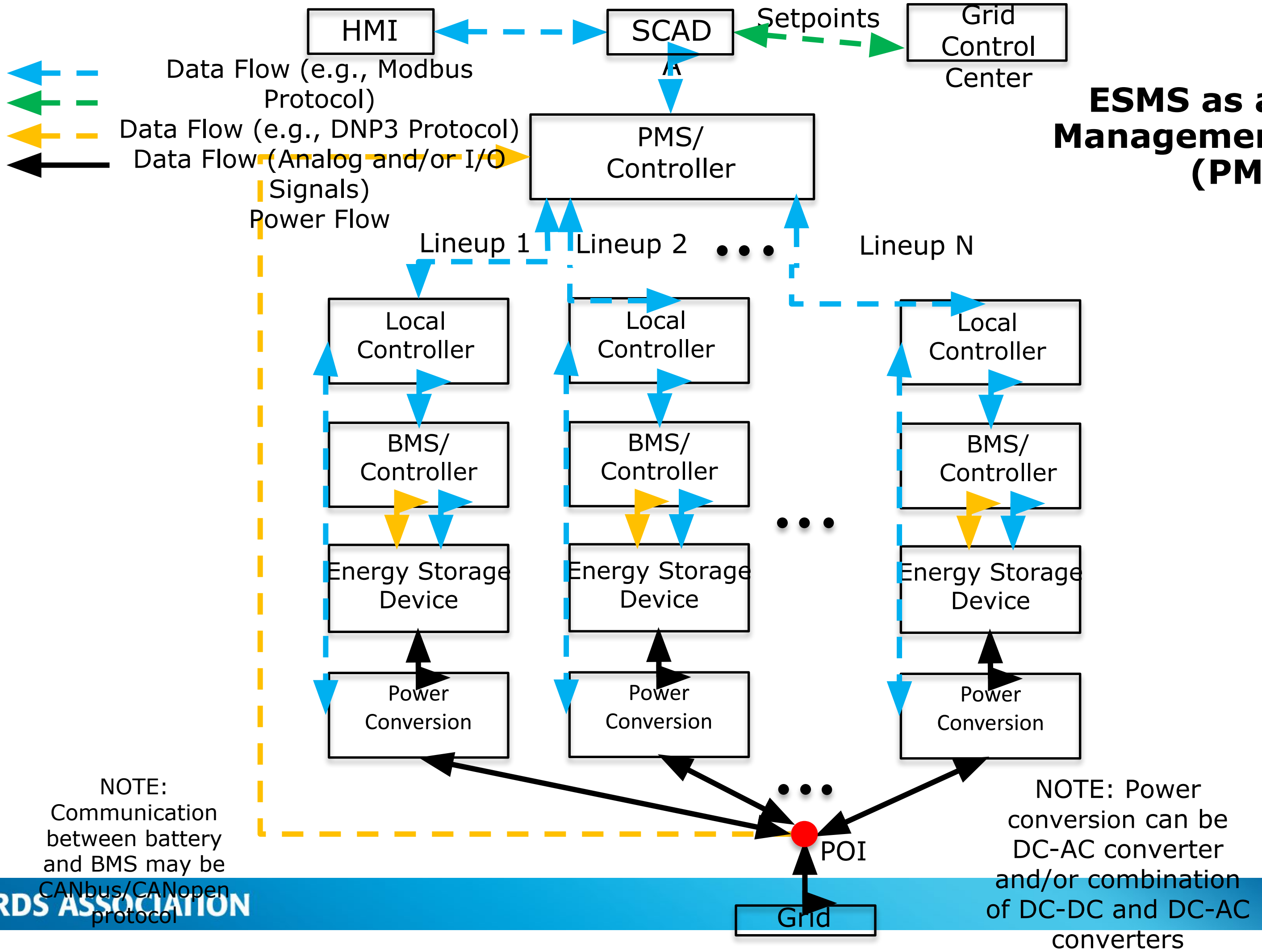
Energy Storage management system purpose and functions

- The **purpose** of the ESMS is to dispatch single and aggregated ESSs, and coordinate their operation together with other distributed energy resources (DERs) in grid applications.

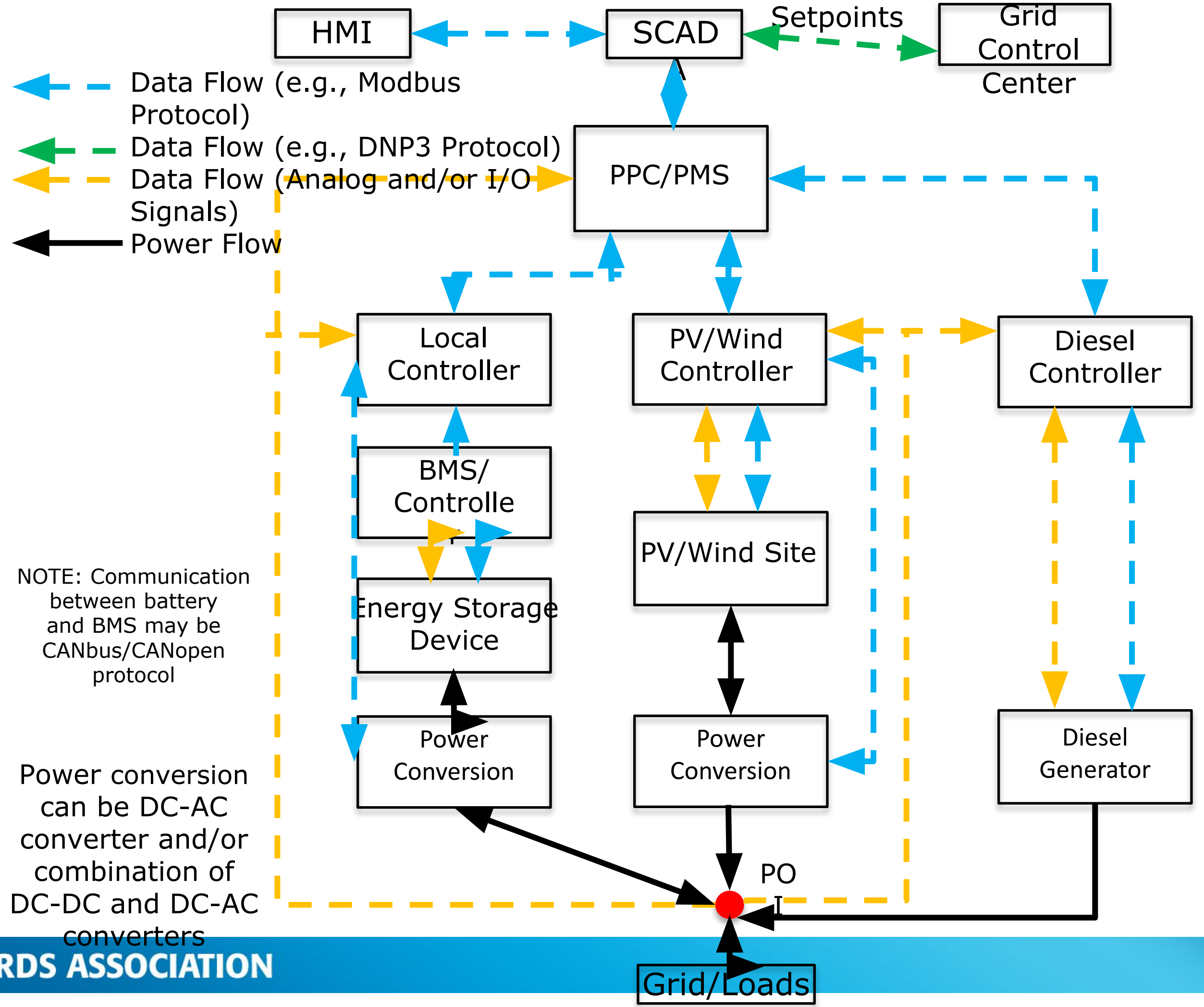
- Core **functions** of an ESMS include: dispatch of real and reactive power of single or multiple ESSs to provide grid services; monitoring, estimation, and visualization of system states, including safety sub-system alarms. Hardware capabilities include: sensing, control, and communication.

IEEE

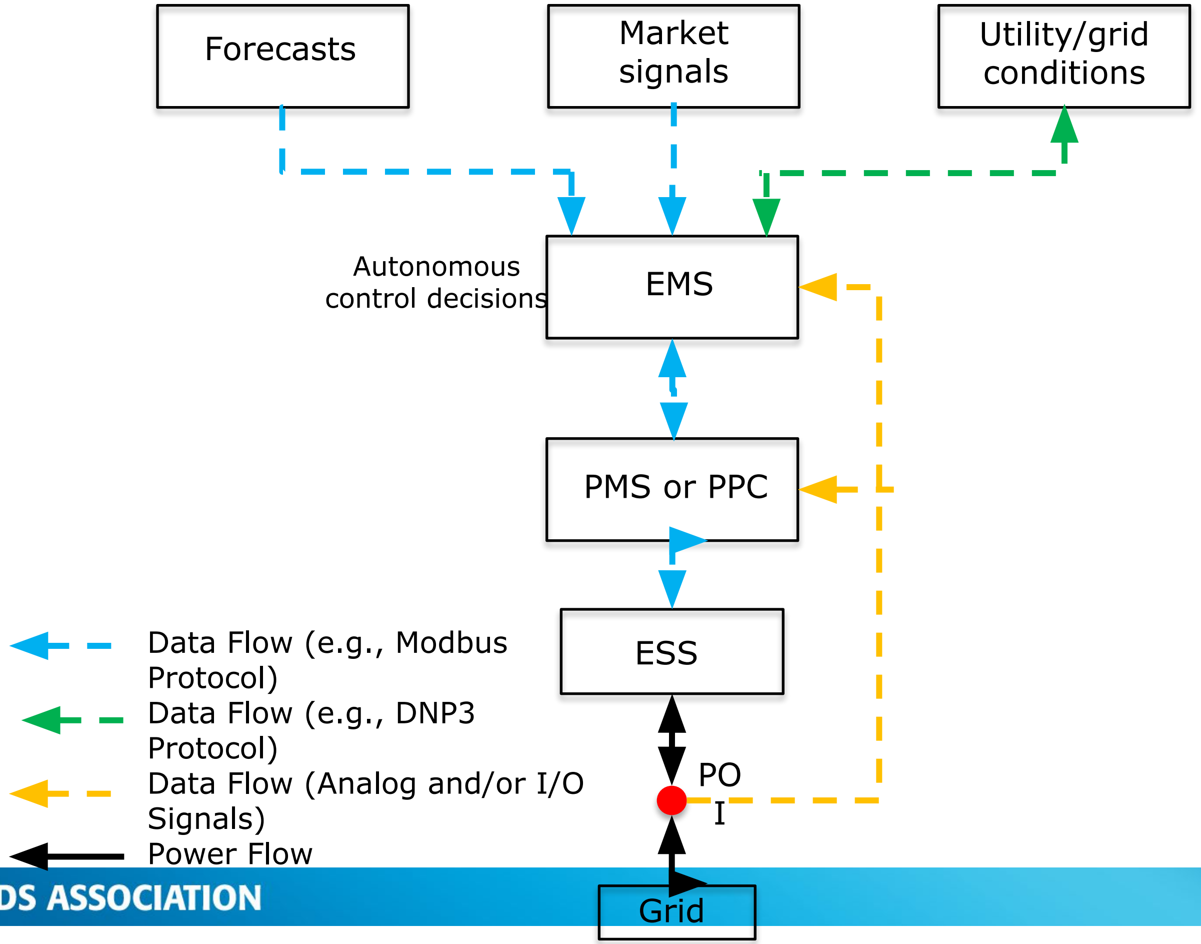
ESMS as a Power Management System (PMS)



ESMS as a Power Plant Controller (PPC)



ESMS as an Energy Management System (ESMS)



IEEE P1547.9 - Guide to Using IEEE Std 1547(TM) for Interconnection of Energy Storage Distributed Energy Resources with Electric Power Systems

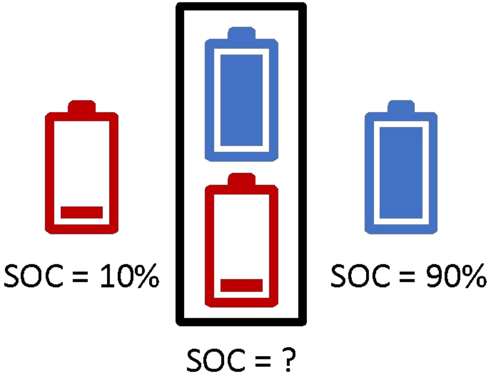
- Guidance for application of IEEE 1547-2018 for battery and other storage technologies.
- During the drafting of IEEE Std 1547-2018, there was an effort to create a subclause dealing with interconnection aspects that were specific to energy storage.
- Ultimately that subclause was not included in the final document, but IEEE SA and 1547 leadership agreed that the conversation pointed to the need for an ES-specific Application Guide. 1547.9-2022 is that Guide.

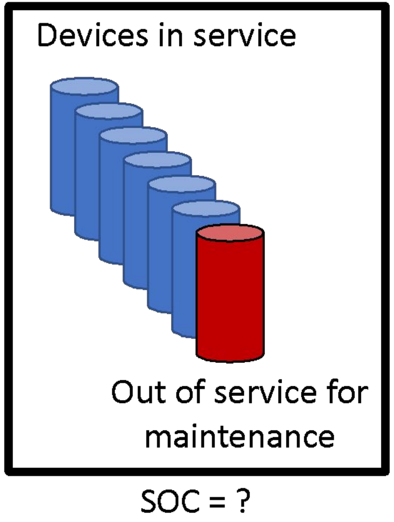
IEEE 1547.9 focuses on applying 1547 to energy storage. Examples:

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

IEEE 1547.9 - What IS “operational state of charge”?

- **<u>operational state of charge:</u>** the usable energy stored as a proportion of the operational capacity, expressed as a percentage.
- **<u>operational capacity:</u>** the estimated energy that an energy storage system can provide on discharge, subject to operational constraints. Examples of factors influencing operational capacity include rated energy, state of health, discharge rate, temperature, and usable state-of-charge range.





IEEE 1547.9 - Operational models

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

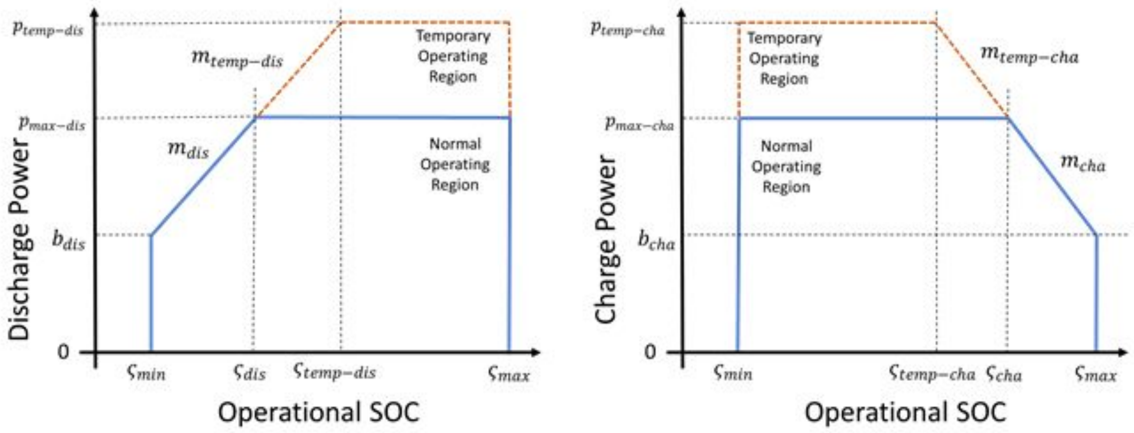


Figure 3—Discharge power (left) and charge power (right) operating regions defined by the operational model constraints

IEEE 1547.9 - Participation in black start/system restoration

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

IEEE 1547.9 - Clarifying volt-var support modes while charging

It is recommended that ES DER comply with Normal Operating Performance Category B. In Clause 5, 1547.9 clarifies how these extend into the charging region.

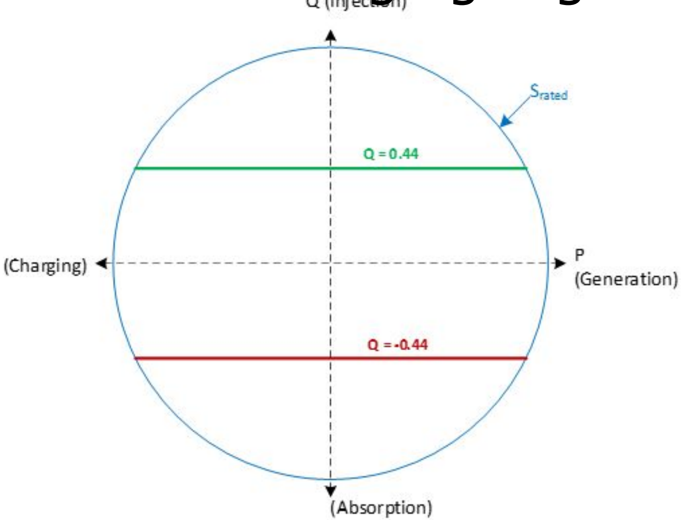


Figure 4—Reactive power capability of ESS

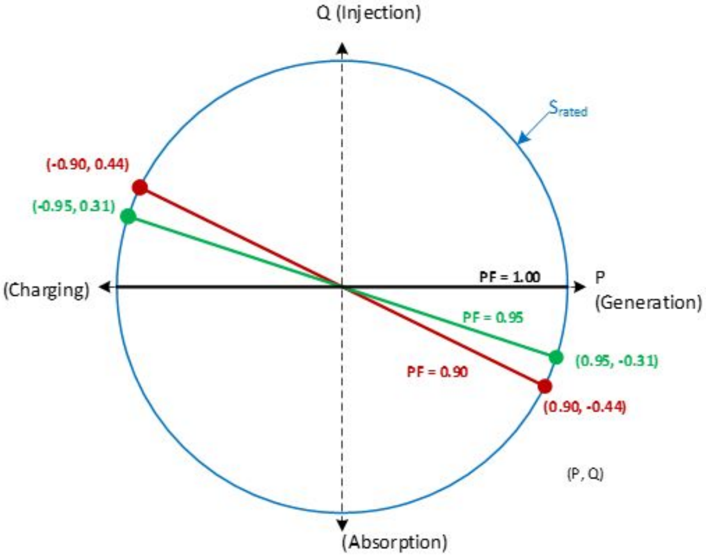


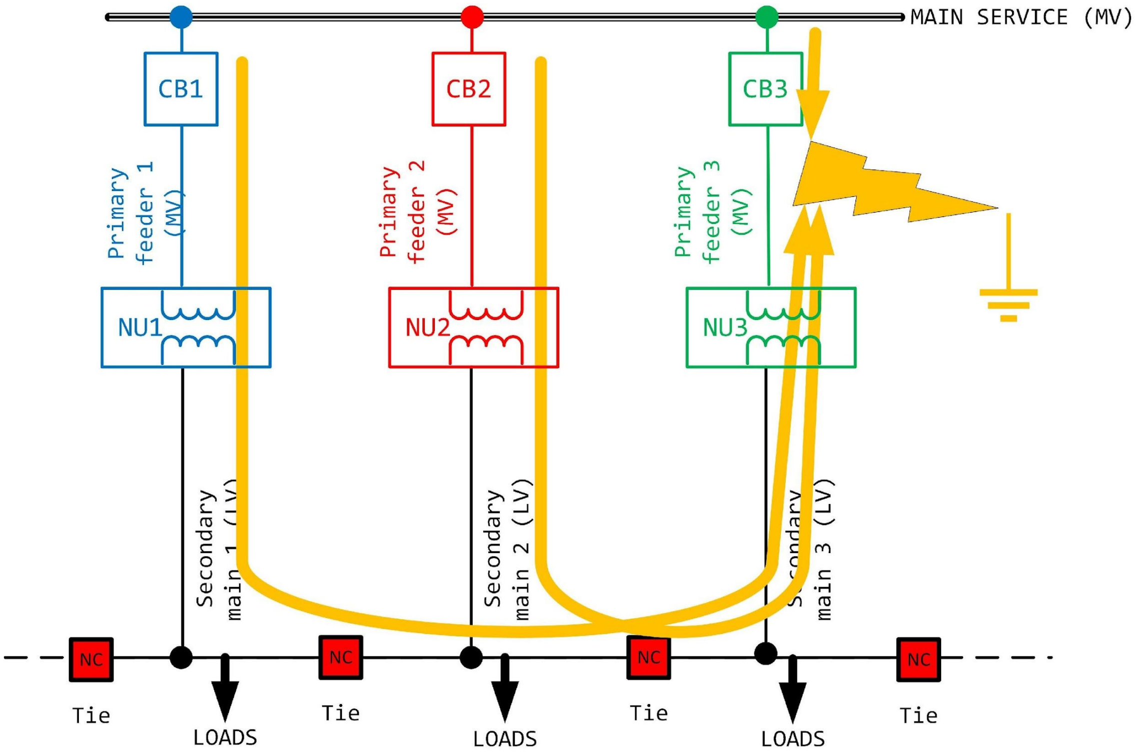
Figure 5—Constant power factor operation of ESS

IEEE 1547.9 - The “take your load with you” clause

- In 1547-2018 clauses 6.4.2 and 6.5.2, there is an exemption from voltage and frequency ride-through requirements for DERs that “take their load with them”. This applies if the Local EPS:
  - Is controlled so that export is never greater than 10% of the aggregate of all DERs in the Local EPS; ***or***
  - An amount of load equivalent to at least 90% of the pre-disturbance Local EPS output is shed simultaneously.
- These put limits on *export*, but not *import*.
- If ES DERs are engaged in non-active-export services, such as var support, then the ES DER and Area EPS operators should work out when and how these exceptions might apply.

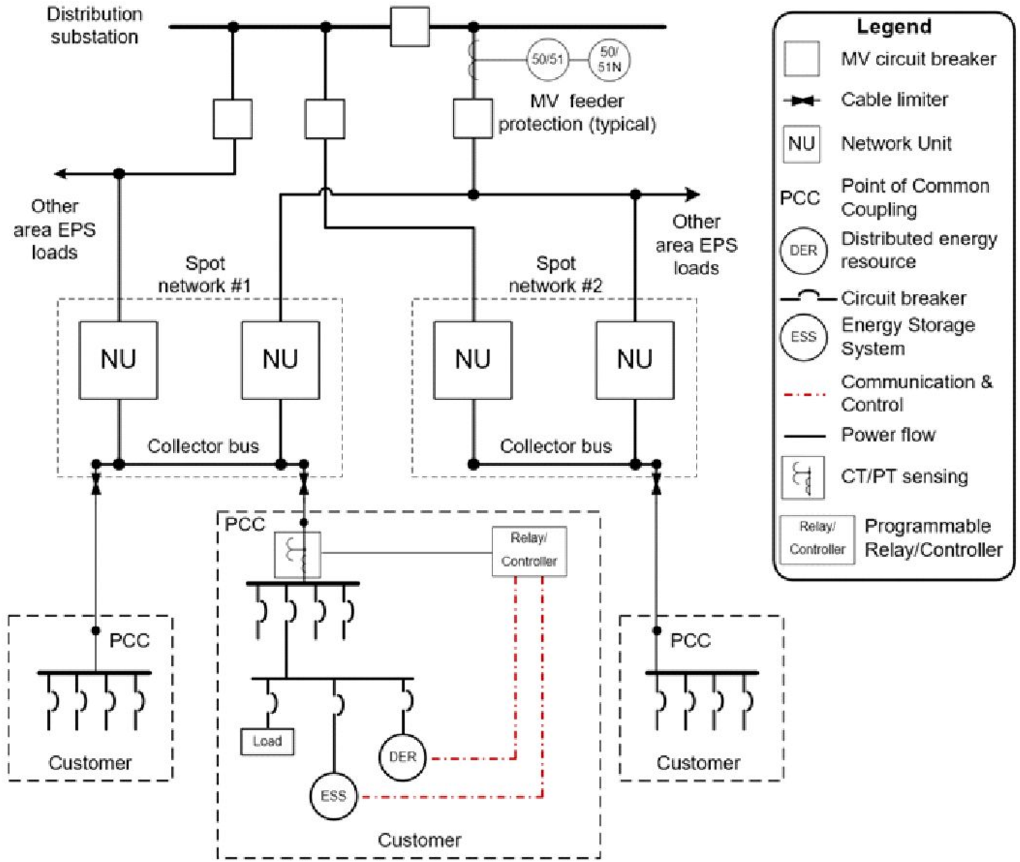
IEEE 1547.9 - ES DERs in secondary networks

Key challenge: DERs on secondary networks aren't allowed to discharge in such a way that reverse power flow through network units might occur.



IEEE 1547.9 - ES DERs in secondary networks

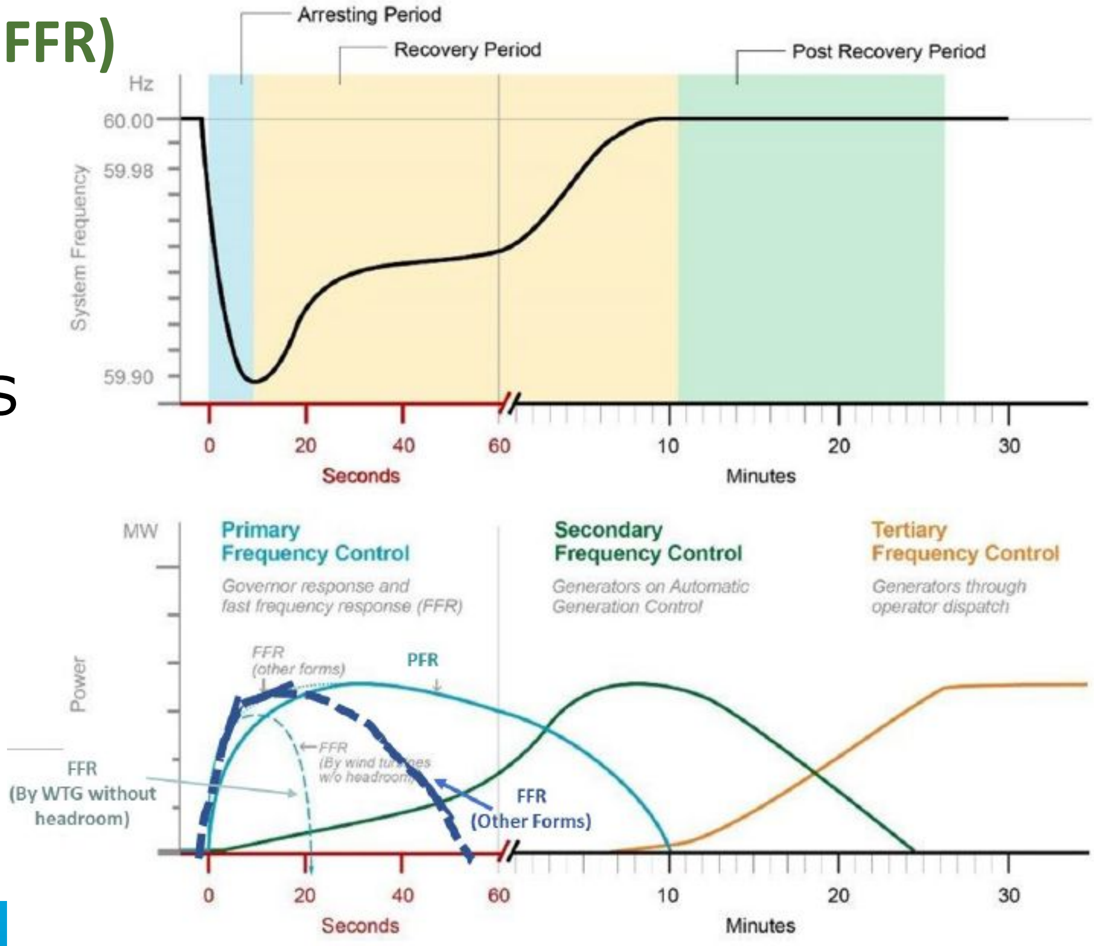
- ES DER may be used to absorb the output of other DERs in the secondary network
  - Will allow higher deployment levels without reverse power flow.
- However, careful coordination is critical.



Fast Frequency Response (FFR)

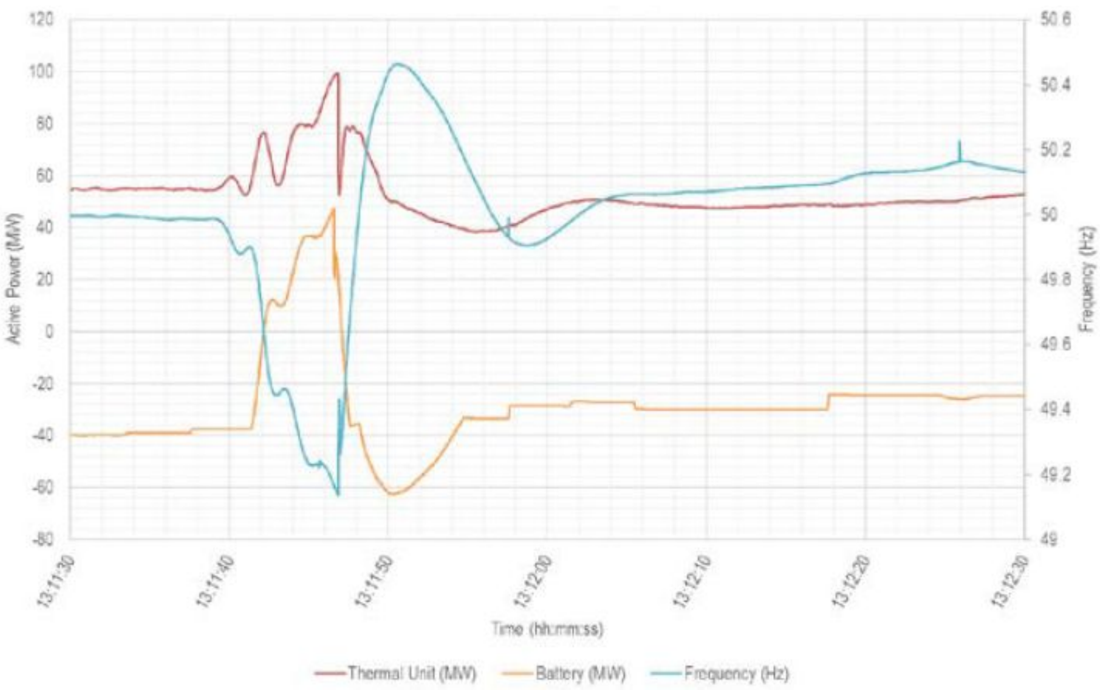
The graphic at right illustrates various levels/time scales of frequency response to an underfrequency event. ES DERs can also respond to overfrequency events by charging/importing active power.

(This figure is from IEEE 2800-2022.)



Fast Frequency Response (FFR)

- 1547-2018 permits, but does not require or further describe, fast frequency response (FFR). FFR comes in different forms such as synthetic inertial response deployed in many ES DERs.
- 1547.9 discusses inertial response and its deploymer in ES DERs. ***(Note: IEEE 2800-2022 does require FFR capability and goes into detail on FFRs for transmission-connected ESSs.)***



IEEE 1547.9 - Interoperability, information exchange, information models and protocols

- Clause 10 of 1547.9 discusses energy storage-specific changes in the interoperability requirements laid down in the base standard.
- *Most* of the examples are cases of ES-specific parameters that need to be added to the reporting requirements.
- One example is shown at right (ESS-specific additions to Table 29 in 1547-2018).

Table 29—Monitoring information [1547]

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

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

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

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

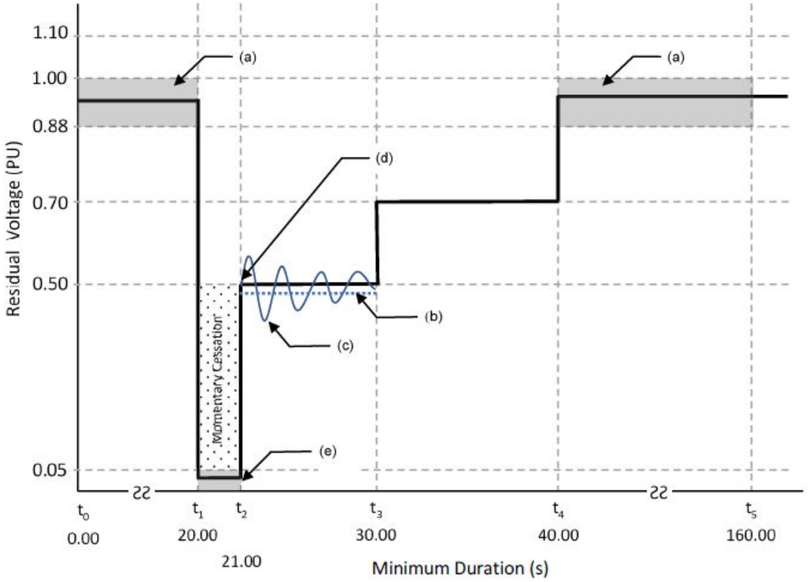
Parameter	Description
Smoke Detection	Smoke has been detected indicating fire
Flame Detection	Flame has been detected indicating fire
Off-Gas Detection	Hydrogen has been detected
Fire Protection System Detection	The fire protection system has activated

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

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

IEEE 1547.9 - ES DER-specific testing requirements

- In 1547-2018 clause 11 and 1547.1-2020, there are a few places where the application to the charging mode wasn't 100% clear. 1547.9 seeks to clarify those.
  - Example: at the right is the Category III LVRT test signal specified in 1547.1-2020. This test is to be conducted at two output power levels, one above 90% and one between 25% and 50%.
  - 1547.9 recommends that for ES DER these tests be conducted at four power levels: >90% exporting, > 90% importing, and 25-50% exporting and 25-50% importing.



NOTES—

(a) Any voltage between 1.00 p.u. and 0.88 p.u. is permitted.
(b) Average of the rms voltage over duration of excursion.
(c) Example of positively damped voltage oscillations allowed during testing.
(d) DER shall restore output within 0.400 seconds following momentary cessation, i.e., following time t_2.
(e) Any voltage less than 0.05 p.u. is permitted.

Figure 3—Category III LVRT test signal

IEEE 1547.9 - Safety

- This clause has no direct parallel in 1547-2018.
- Safety is a crucial topic when dealing with ES DERs. Thus, although ***safety considerations are outside of the scope of 1547***, the 1547.9 working group thought it of value to collect examples of existing safety codes and standards and to provide some examples of safety-related topics and subsystems. Clause 12 contains this information.

IEEE 1547.9 - V2G

- SAE International produces consensus standards governing vehicle systems and components.
- IEEE produces consensus standards governing interconnexion with power grids.
- Here, the two jurisdictions overlap.

In scope of

Charger location	V1G	V2G
Onboard	No	Yes, via SAE J3072
Offboard	No	Yes

Interoperability

IEEE 2030-2011

IEEE P2030 Revision

IEEE P2030.4

IEEE

Definitions

- Smart Grid

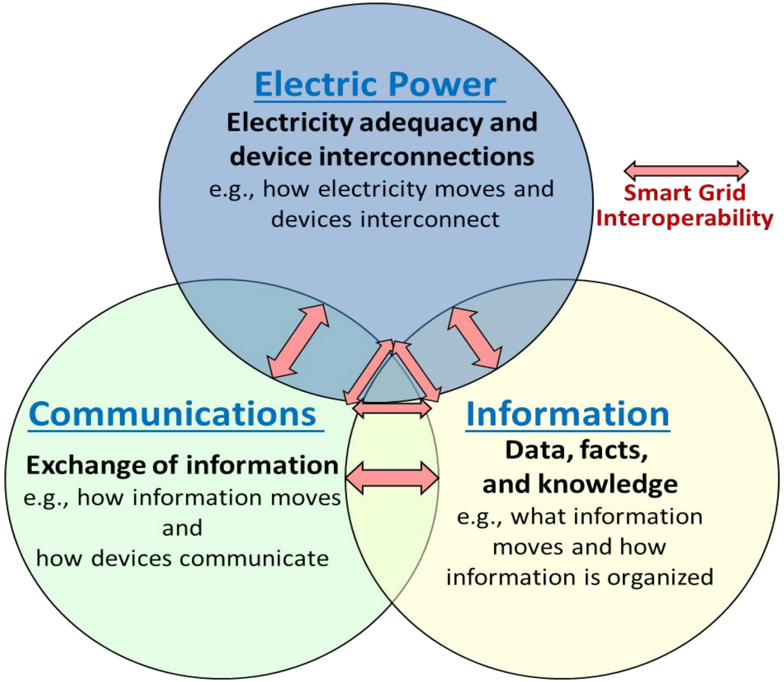
  Evolution of the electric power infrastructure that encompasses the **integration of**

  - **power,**
  - **communications, and**
  - **information technologies**

  for an improved infrastructure serving loads while providing for an ongoing evolution of end-use applications.

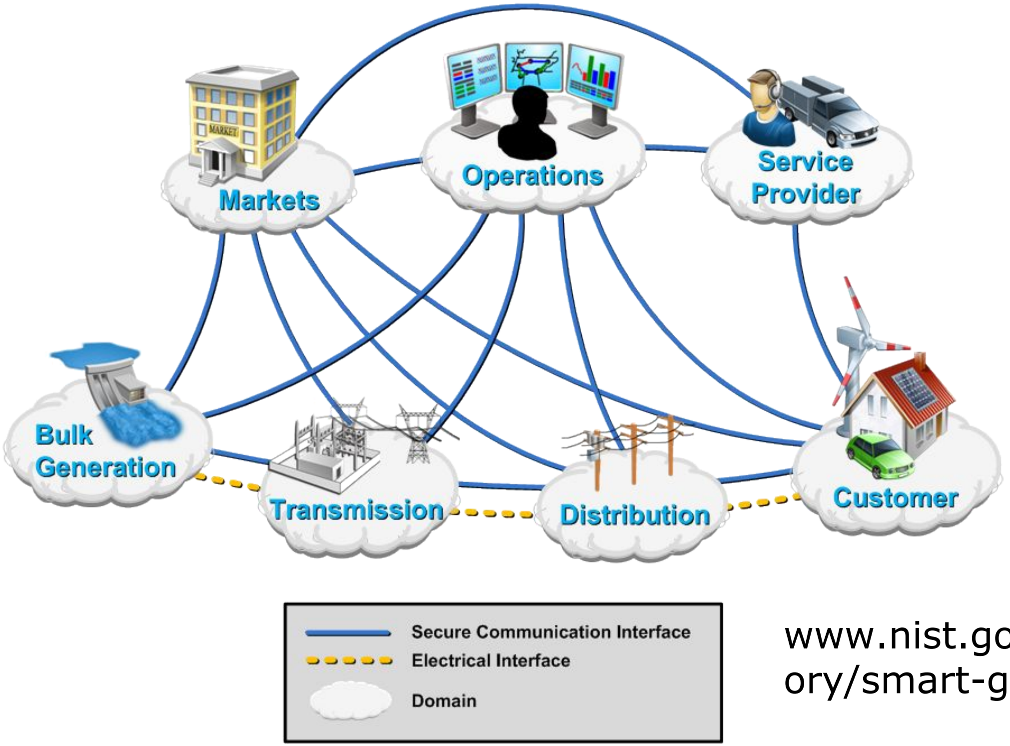
Smart Grid Interoperability

Smart Grid: the integration of power, communications, and information technologies for an improved electric power infrastructure serving loads while providing for an ongoing evolution of end-use applications. (Std 2030)



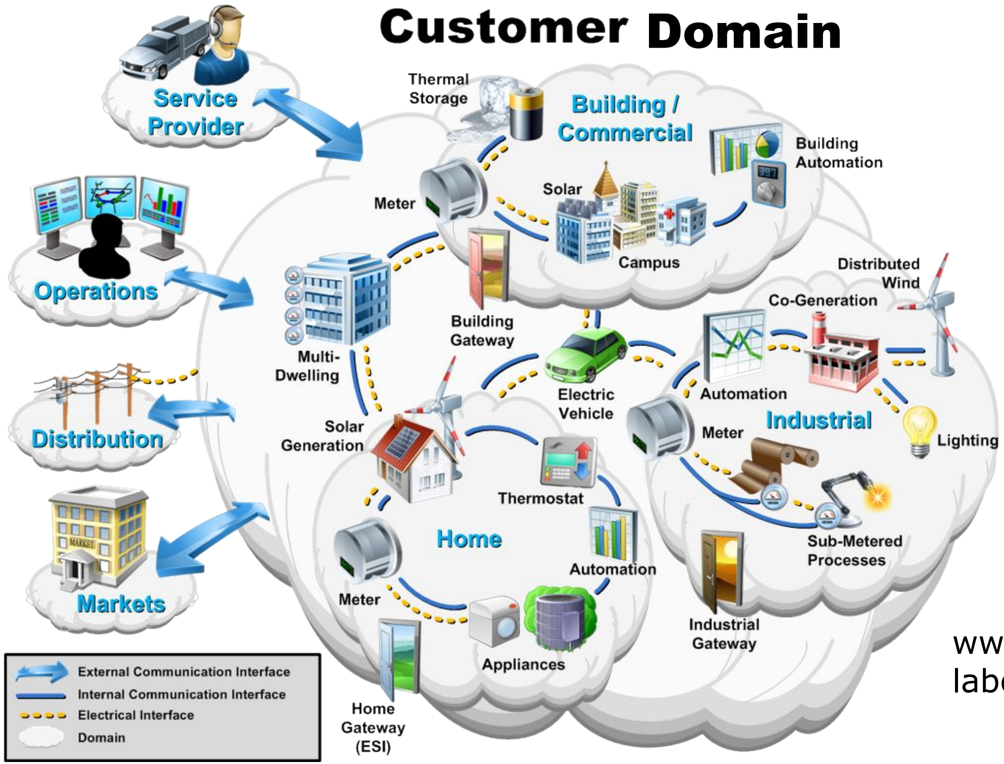
Interoperability: the capability of two or more networks, systems, devices, applications, or components to **externally exchange and readily use information securely & effectively**. (Std 2030)

Smart Grid Conceptual Model v.1.0



www.nist.gov/engineering-laboratory/smart-grid/

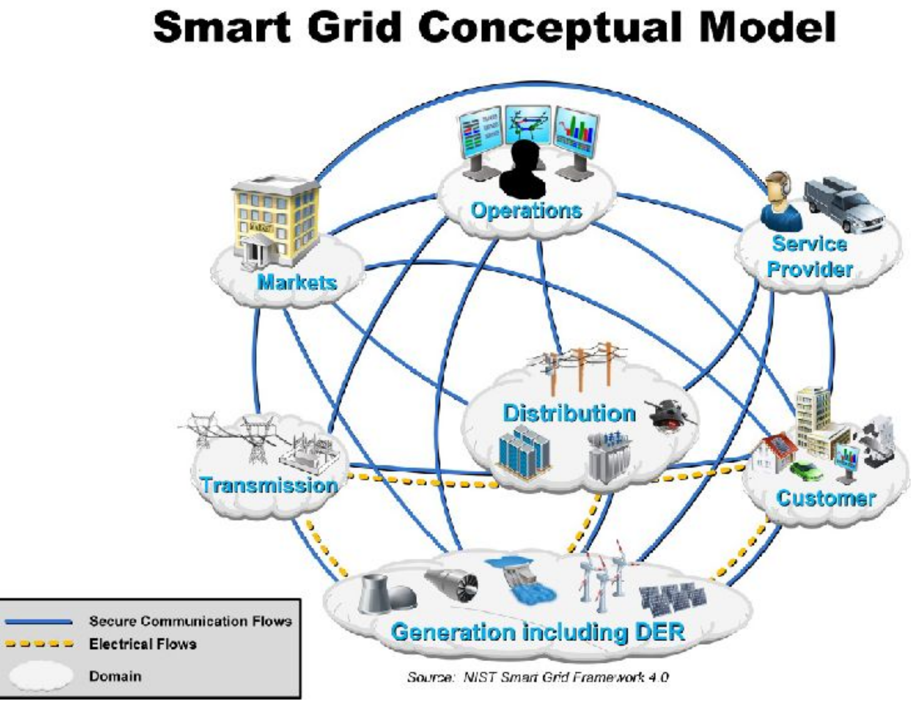
Smart Grid Conceptual Model

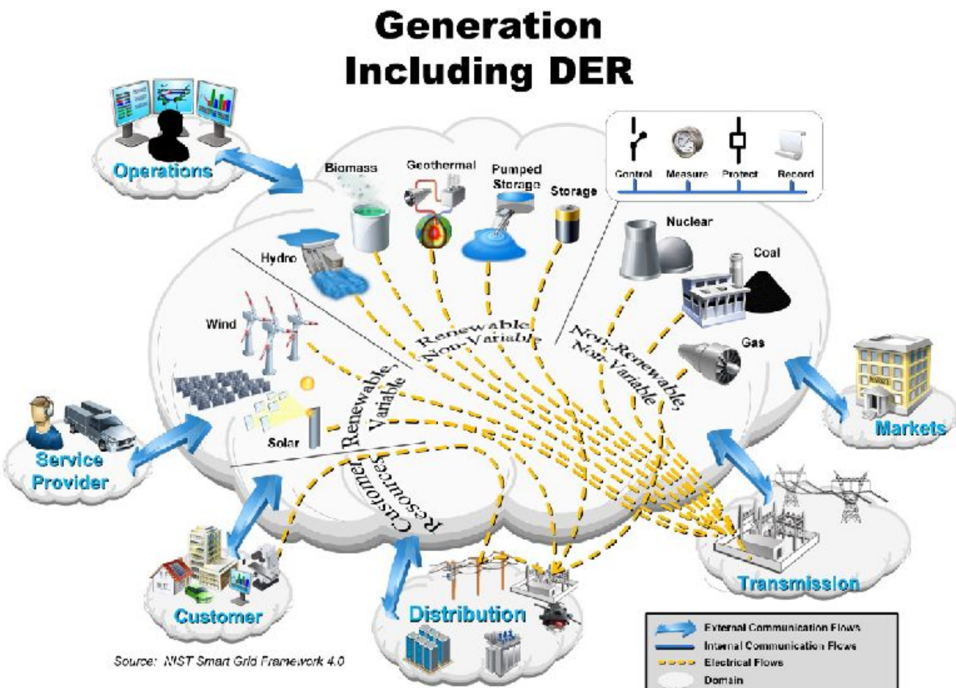


www.nist.gov/engineering-laboratory/smart-grid/

IEEE P2030 Revision

- Basis is NIST Interoperability Roadmap 4.0 (Current NIST Model April 2022)



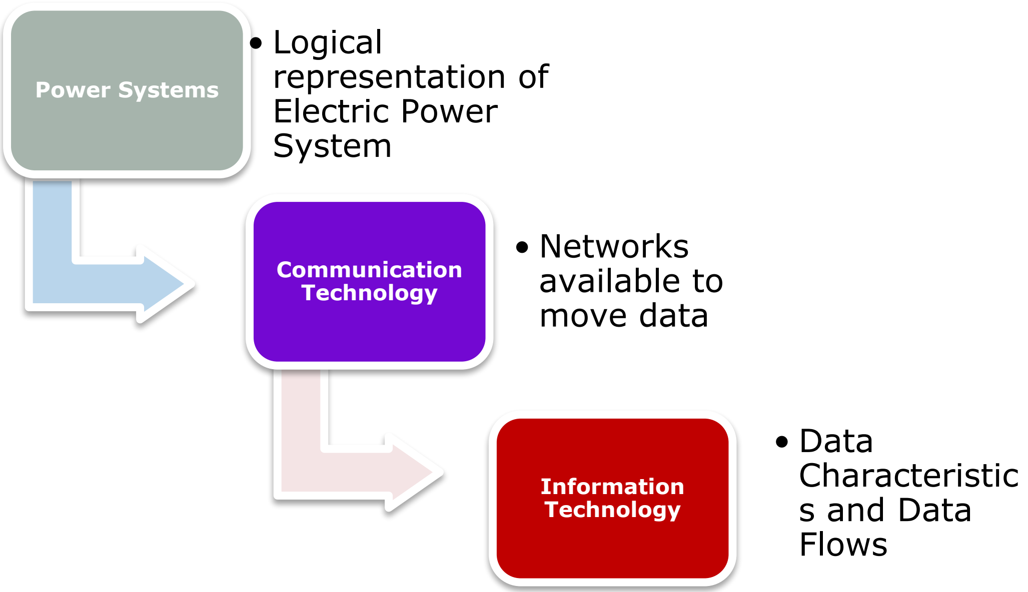


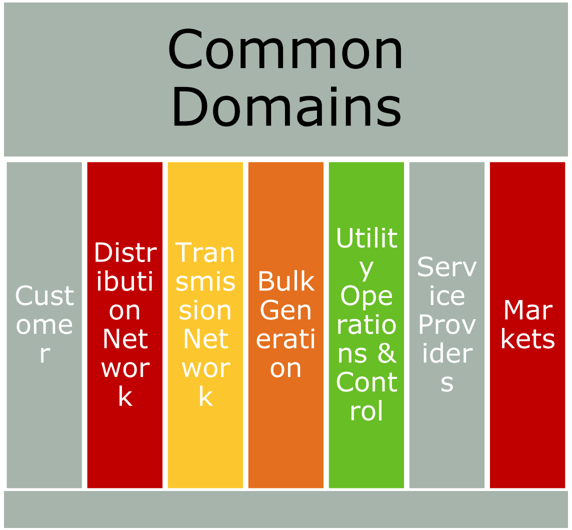
IEEE 2030-2011 Smart Grid Interoperability

- Provides a knowledge base of terminology, characteristics, and smart grid functional performance
- Establishes the Smart Grid Interoperability Reference Model (SGIRM)
- SGIRM defines three Integrated Architectural Perspectives (IAP's) :
  PS-IAP: power systems;
  CT-IAP: communications technology, and
  IT-IAP: information technology.
- SGIRM emphasizes **functional interfaces;**
  logical connections (PS and CT); and data flows (IT).

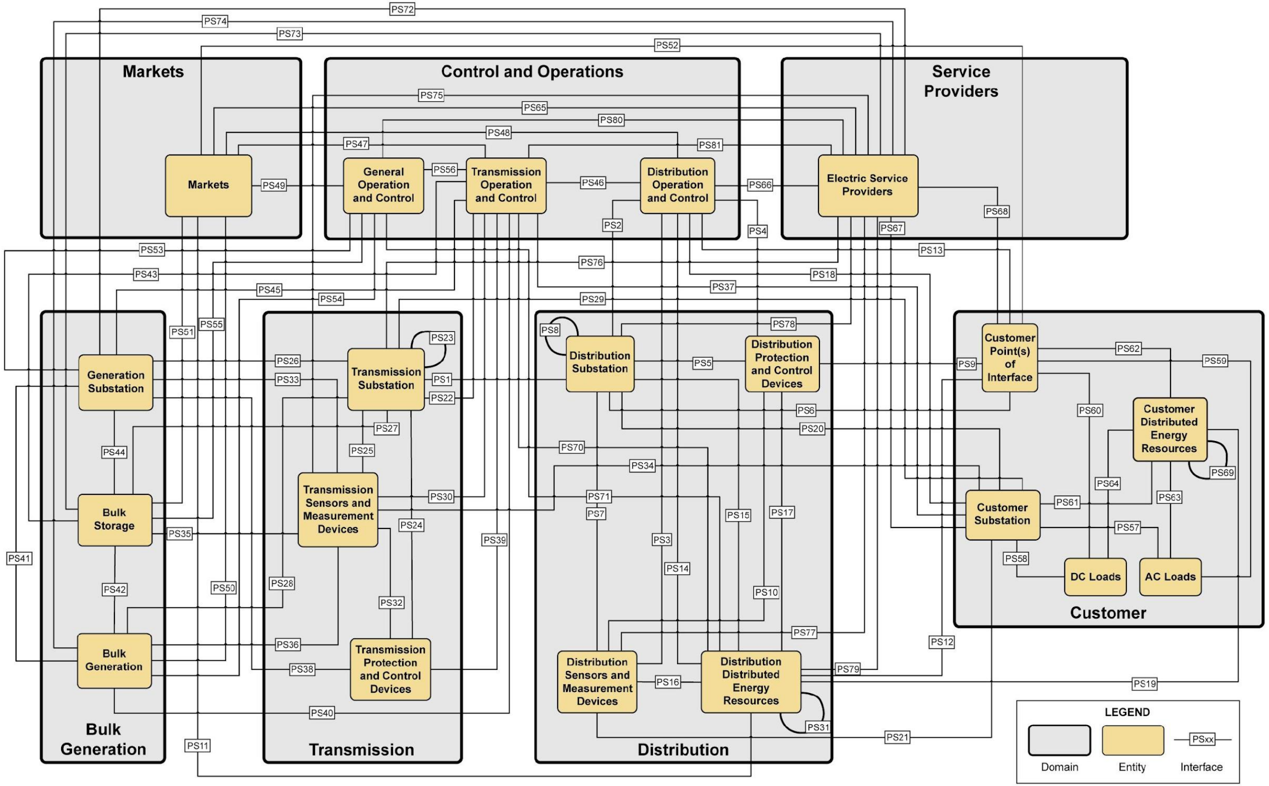
Smart Grid Interoperability of DR with EPS

- **IEEE 2030-2011 - Guide for Smart Grid Interoperability**
  - More commonality and completeness in communications and information technology requirements

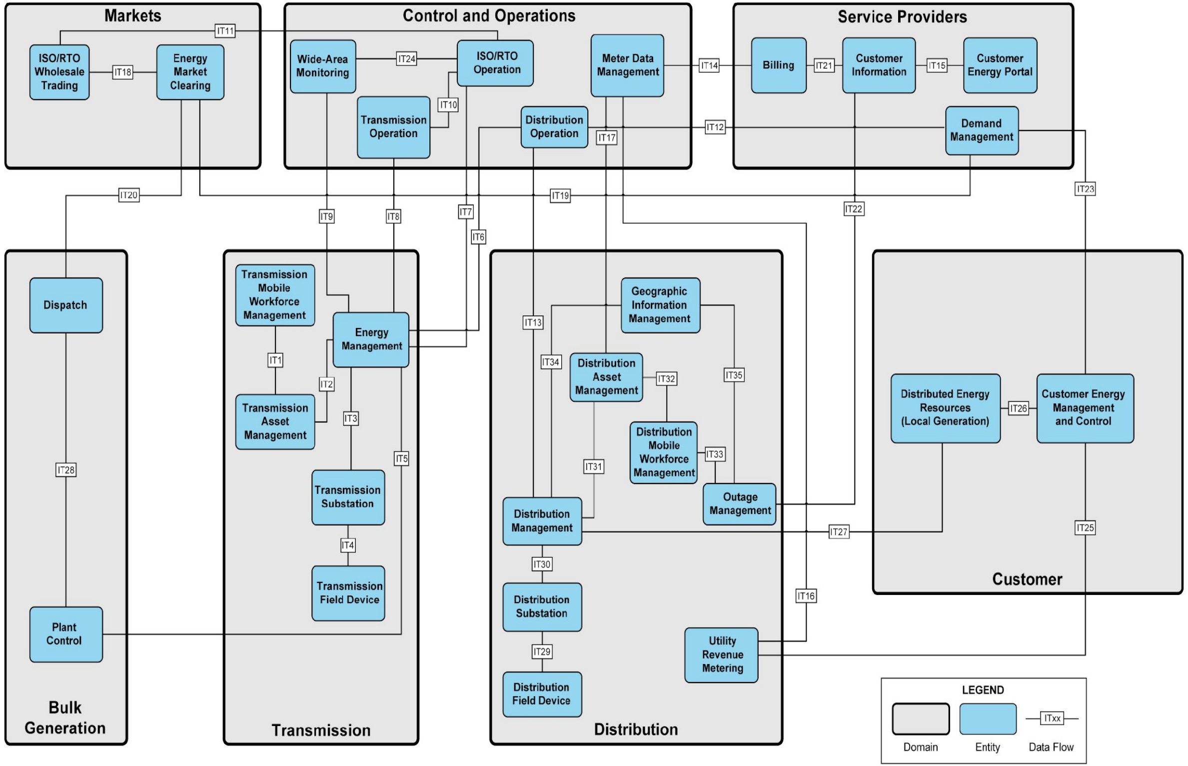




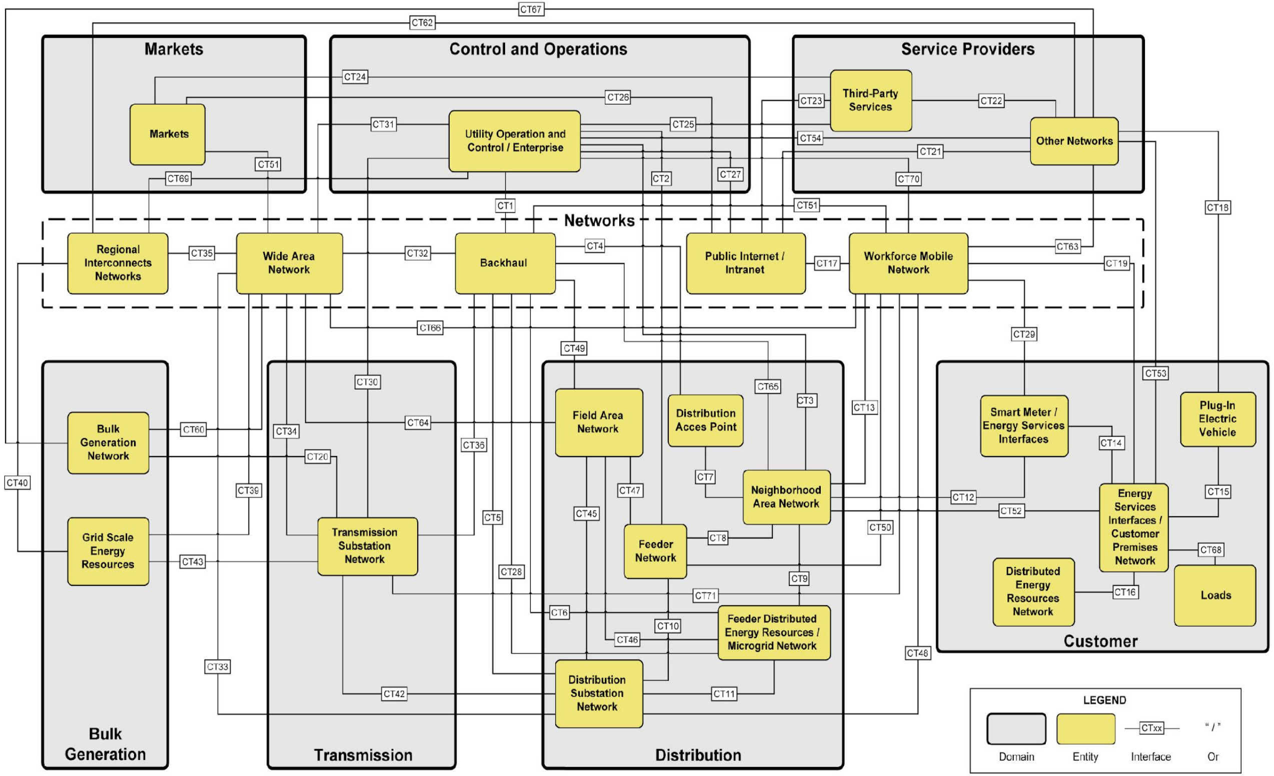
IEEE STD 2030: POWER SYSTEM – INTEGRATED ARCHITECTURAL PERSPECTIVE (PS-IAP) – *LOGICAL CONNECTIONS*



IEEE STD 2030: INFORMATION TECHNOLOGY – INTEGRATED ARCHITECTURAL PERSPECTIVE (IT-IAP) -- "DATA FLOWS"



IEEE Std 2030: Communication Technology – Integrated Architectural Perspective (CT-IAP) "LOGICAL CONNECTIONS"



SGIRM Data Classification Reference Table

- Comprehensive and consistent set of attributes that can be applied to all interfaces and data flows

Data characteristic	Classification/Value range			
Data use category	*To be determined by the user of the table based on the intended use of the data (i.e., control data, protection data, and/or monitoring data)*			
Reach	*meters (feet)*		*kilometers (miles)*	
Information transfer time	*<3 ms*	*Between 3 ms and 10 s*	*Between 10 s and minutes*	*hours*
Data occurrence interval	*milliseconds*	*seconds*	*minutes*	*hours*
Method of broadcast	*Unicast*	*Multicast*	*Broadcast*	*All*
Priority	*Low*	*Medium*	*High*	
Latency	*Low-low (<3 ms)*	*Low (<16 ms)*	*Medium (<160 ms)*	*High (≥160 ms)*
Synchronicity	*Yes*		*No*	
Information reliability	*Informative*	*Important*	*Critical*	
Availability (information reliability)	*Low (limited impact)*	*Medium (serious impact)*	*High (severe or catastrophic impact)*	
Level of assurance	*Low*	*Medium*	*High*	
HEMP, IEMI	*Hardened, yes*		*Hardened, no*	
Data volume	*bytes*	*kilobytes*	*megabytes*	*gigabytes*
Security	*Low (limited impact)*	*Medium (serious impact)*	*High (severe or catastrophic impact)*	
Confidentiality	*Low (limited impact)*	*Medium (serious impact)*	*High (severe or catastrophic impact)*	
Integrity	*Low (limited impact)*	*Medium (serious impact)*	*High (severe or catastrophic impact)*	
Availability (security)	*Low (limited impact)*	*Medium (serious impact)*	*High (severe or catastrophic impact)*	

SGIRM: Example of PS-IAP Interface

- End result of using SGIRM:
  - Comprehensive and complete description of the interfaces and requirements

Power systems				*Data characteristics*																	*Communications*		*IT*	
Power system data path	Entity (from) and number of Points	Entity (to) and number of points	Data type	Reach	Information transfer time	Data occurrence interval	Method of broadcast	Priority	Latency	Synchronicity	Information reliability	Availability (reliability)	Level of assurance	HEMP, IEMI	Data volume	Security	Confidentiality	Integrity	Availability (security)	Power systems description	Communications path(s)	Communications description	IT data paths	IT description
PS13	Distribution Operation and Control (1 Point)	Point(s) of Interface (thousands to millions of points)	Operations	Up to 75 miles	10 sec to minutes	hours	ALL	High	High >160 ms	No	Important	Medium	High	No	Bytes	Medium	Low	Medium	Medium	Provides information exchange and control of customer equipment by Distribution Operations and Control. Logical connections include those for control, monitoring.	CT3 then CT52 or CT12	Utility Control/Operation/ Enterprise LAN to Smart Meter or Customer Access Point via NAN	IT13 to IT27, IT26 (to EMS)	Monitoring/ Control by Distribution Operations
			Reporting		Hours	hours	Multicast	Low	High >160 ms	No	Important	Medium	Medium	No	kB	Low	Medium	Low	Low				IT16 (to IT25 in some cases)	Smart meter or Energy Management System interface
PS6	Distribution Substation (tens to hundreds of points)	Customer Point of Interface (thousands to millions of points)	Nameplate	Up to 5 miles	Hours	hours	Multicast	Low	High >160 ms	No	Important	Low	Medium	No	kB	Low	Low	Low	Low	Provides for protection coordination and customer information that is desired at the substation. Logical connections include those for protection, control, and monitoring	CT5 to CT65 then CT12 or CT52	Distribution Substation Network to Backhaul/ WAN to NAN to Smart Meter or Customer Access Point	IT27 and IT26 (to EMS)	Distribution System Management
			Operations		<3 ms to 10 seconds	milliseconds to seconds	Multicast	High	<3 ms to <160 ms	Yes in some cases	Critical	Medium	High	No	kB	Medium	Low	Medium	Medium					
			Reporting		Hours	hours	Multicast	Low	High >160 ms	No	Important	Medium	Medium	No	kB	Low	Medium	Low	Low					
			Protection and Control		<3 ms to 10 seconds	milliseconds to seconds	Multicast	High	<3 ms to <160 ms	Yes in some cases	Critical	High	High	No	kB	Medium	Medium	Medium	Medium					

How to Apply SGIRM to Your SG Project

1. Identify Power System **PS Interfaces**
- 2030-2011 Annex C.2; Fig 6-1 PS-IAP.
- Only Relevant PS
  - Domains,
  - Entities and
  - Interfaces
- are identified.

2. Derive **Data Requirements**
- Use 2030-2011 Table 5-1.
- SGIRM Data Classification Ref Table.

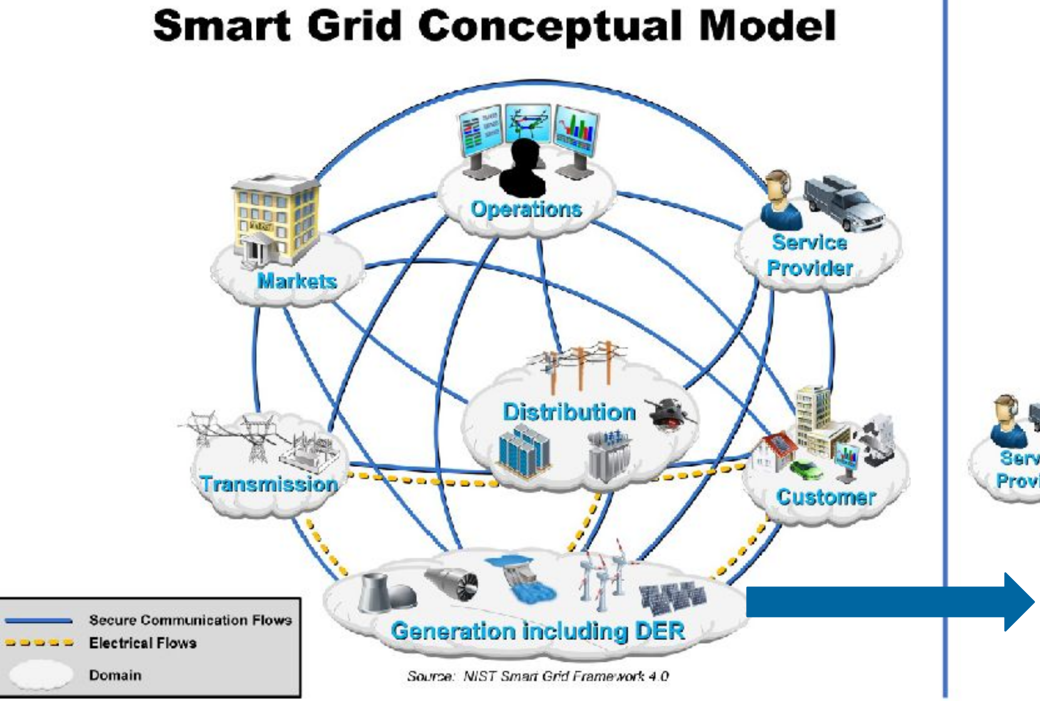
3. **Map PS Interfaces to IT Interfaces**
- Use 2030-2011 Fig 8-1 IT-IAP.
- Decide which
  - Data Flows are needed.

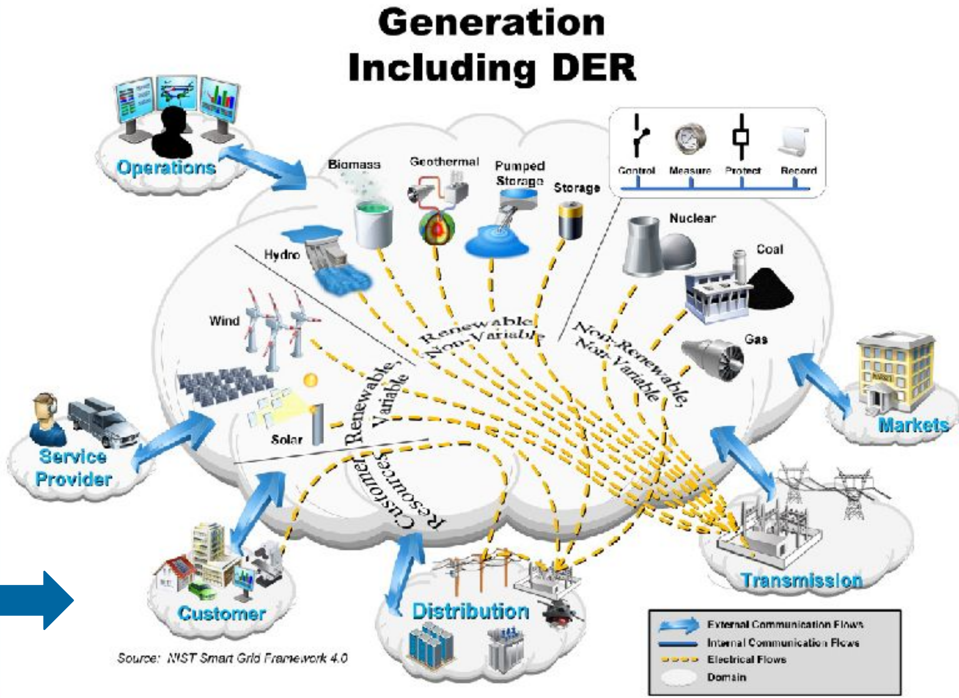
4. **Map PS & IT Interfaces to CT Interfaces**
- Use 2030-2011 Fig 7-3 CT-IAP.
  - Pick & choose CT-interfaces.

5. **Aggregate**
- all PS, CT & IT Interfaces
- Data Flows
- Communications descriptions
- to form a System of Systems conforming to SGIRM.
- Document the design.

IEEE P2030 Revision

- Being Updated for NIST Interoperability Roadmap 4.0 (April 2021)





IEEE P2030 – Revision of IEEE 2030-2011

- Currently an Active Project – Assigned Sub Groups:
  - Overall Document
  - Standards and Interoperability
  - Cyber –Physical Systems
  - Privacy and Security
  - Smart Grid Interoperability Reference Model
  - Smart Grid Protocols
  - Use Cases

Interoperability

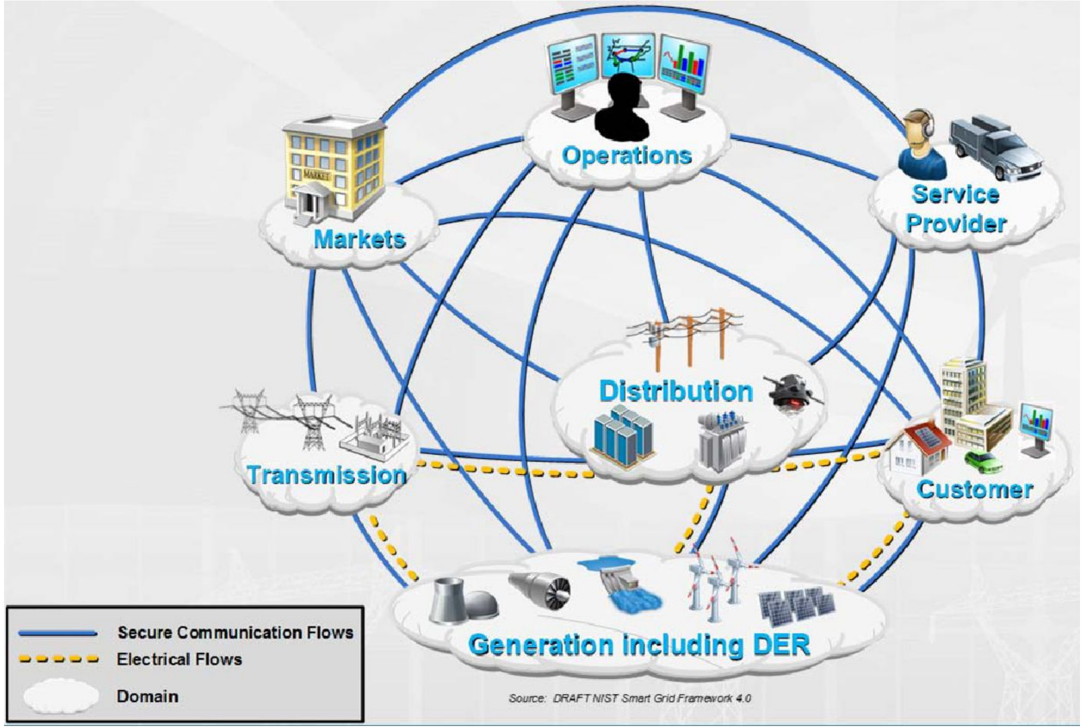
IEEE P2030.4 –Guide for Interoperability of Distributed Energy Resource (DER) Systems with the Electric Power System and End-Use Applications

IEEE

IEEE P2030.4 – SGIRM application guide

- Guide to users of IEEE Std 2030-2011 in applying SGIRM
- Defining requirements for control and automation components, using a common open architecture, the SGRIM
- Scope of Guide
  - Guiding principles for application of the SGIRM
  - Expanding the SGIRM to include new smart grid operating approaches
  - Defining requirements for DER aggregation, DERMS and microgrids
  - *Note: work follows up on the use of SGIRM for DERMS (IEEE Std 2030.11-2021)*

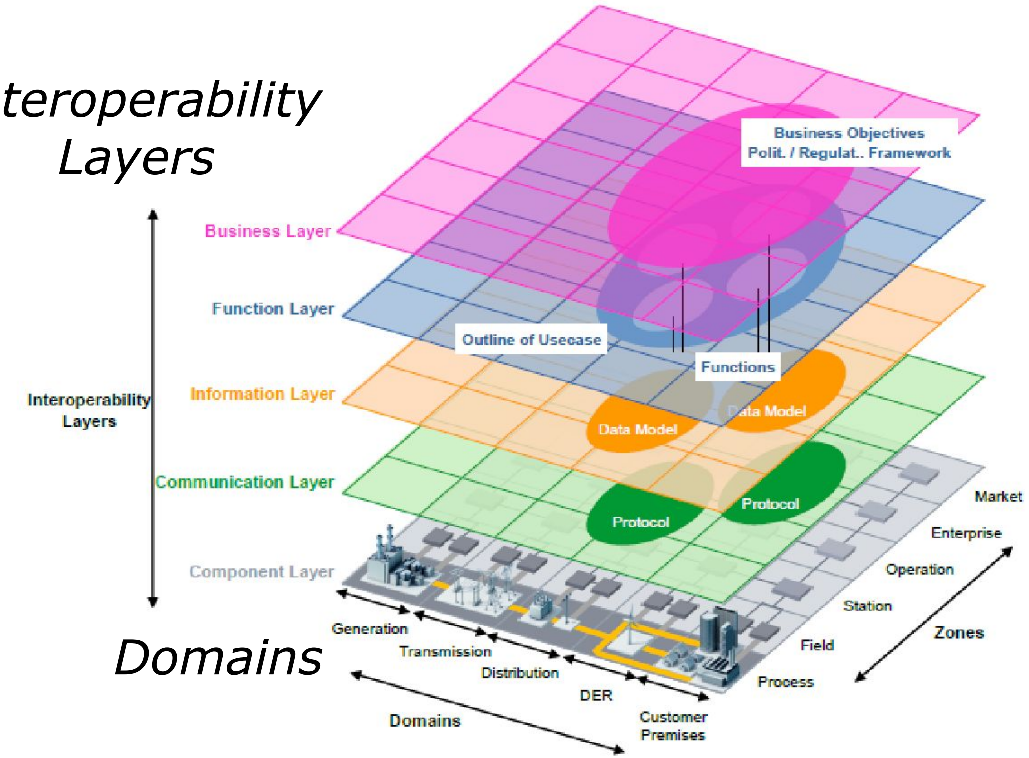
SG domain models – NIST-2021 – latest



NIST Framework and Roadmap for SG interoperability, Release 4.0, 2021

Smart Grid Architectural Model (SGAM) – 2012 – Revised in 2022

Interoperability Layers

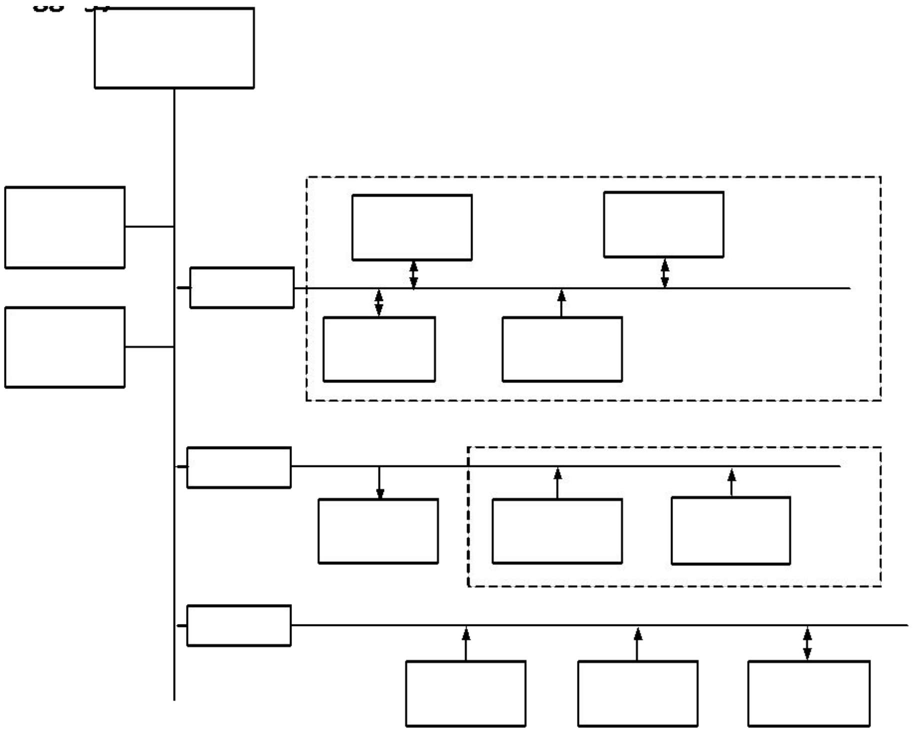


Domains

Zones

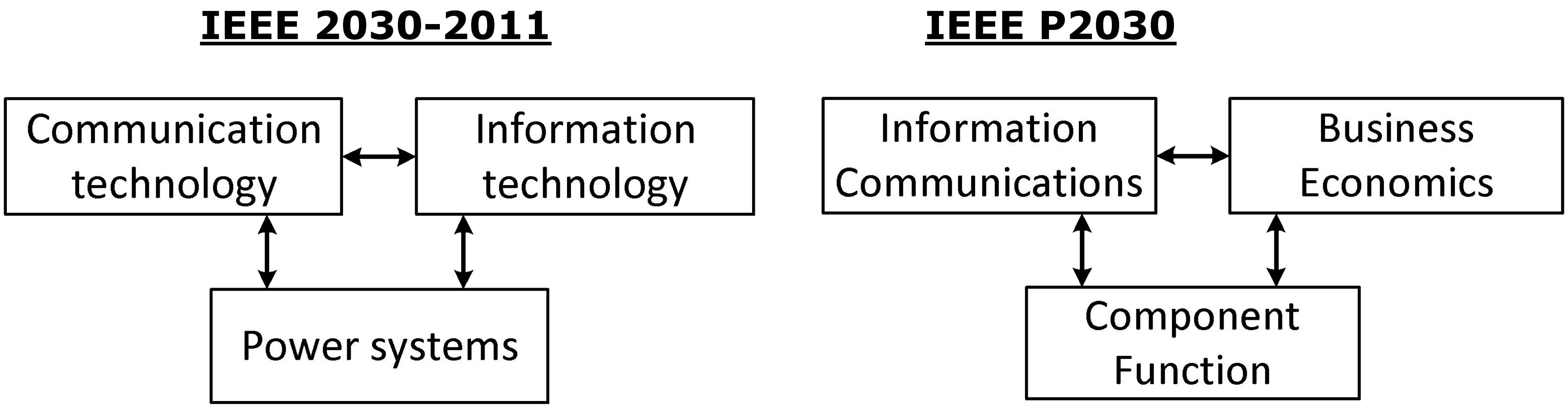
Adapted from the NIST SG interoperability framework, Release 1, 2009

Role of DER in D & T grids – new SG context



DERMS applications

SGIRM IAPs – 2030-2011 vs P2030.4



Note: IAP = Interoperability Architectural Perspective

SGIRM IAP (layer) descriptions – P2030.4

Common domains/zones – 2030-2011 vs P2030.4

- Bulk generation
- Transmission
- Distribution
- Service providers
- Markets
- Control/operations
- Customers/end users

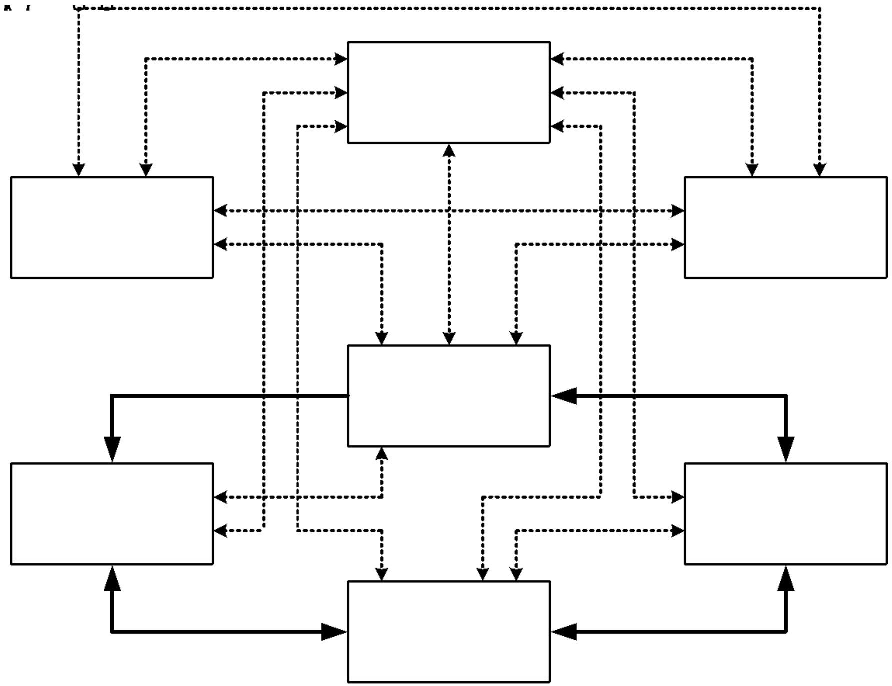
Domains

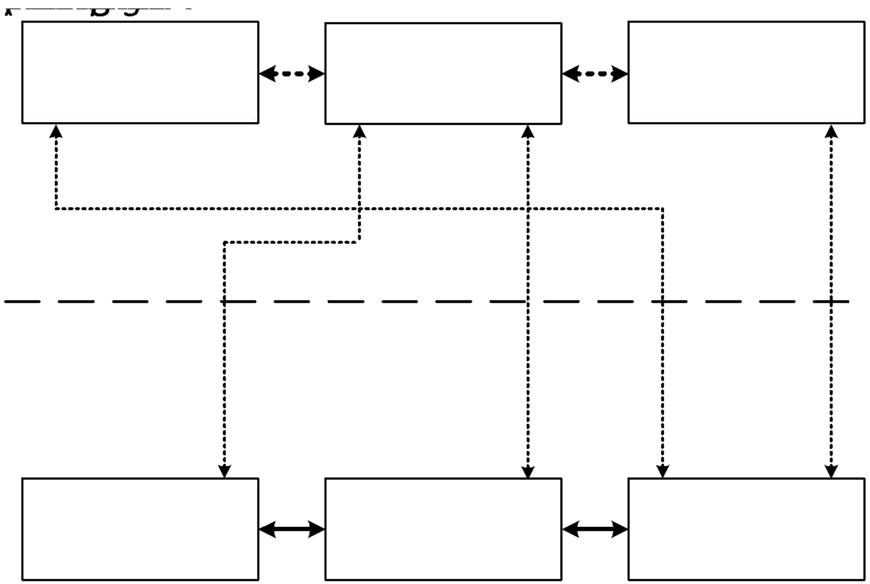
- Generation and storage
- Transmission and distribution
- End use (load)

Zones

- Grid edge
- Field and substation
- Cloud and enterprise

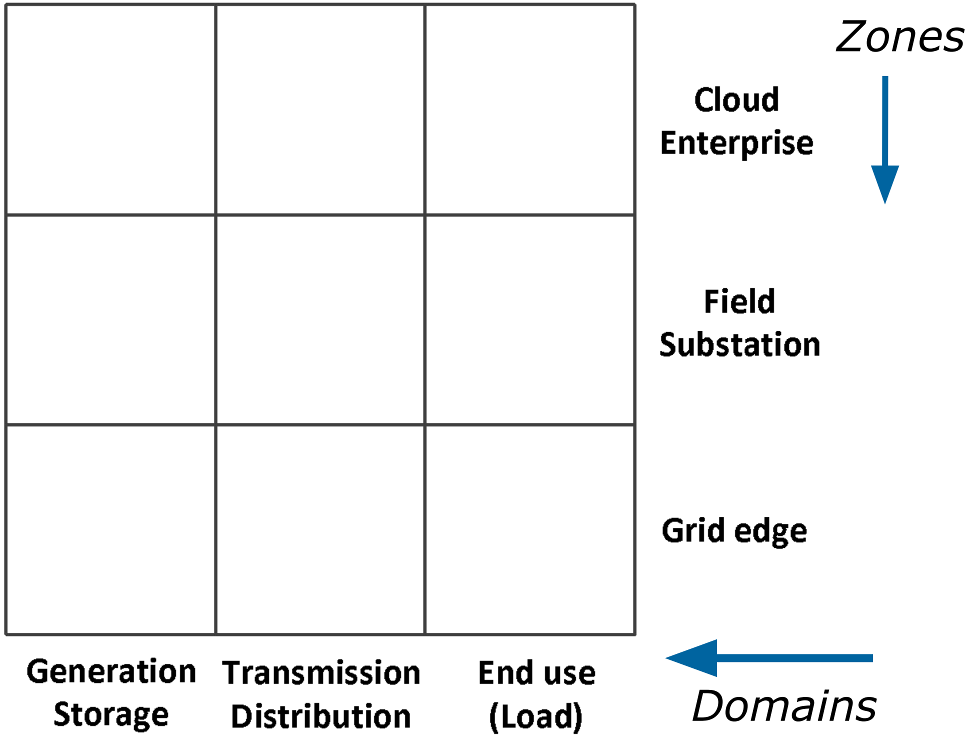
SGIRM domain view – 2030-2011 P2030.4





Note: domains/zones are common to all SGRIM IAPs

SGIRM domain/zone structure – P2030.4



Note 1: these domains/zones may exist for all IAPs (or layers) as required

Note 2: the structure is better represented as a 3-D plot (similar to the SGAM)

SGIRM reformulation – defining IAP, domain, zone

- **IAPs** (layers): (*1*) component/function, (*2*) information/ communication, (*3*) business/economics
  - Obtained from combinations for (*2*) and adding (*3*)
- **Domains**: (*1*) generation/storage, (*2*) transmission/ distribution, (3) end use/load
  - Combining generation, DER and storage in (*1*) and T & D in (*2*)
- **Zones** (taken and adapted from Domains in 2030-2011, for a 3-D figure): (*1*) grid edge, (*2*) field/substation, (*3*) cloud/enterprise
  - Combining functions under (*2*) and locations under (*3*)

Microgrid – Related Standards

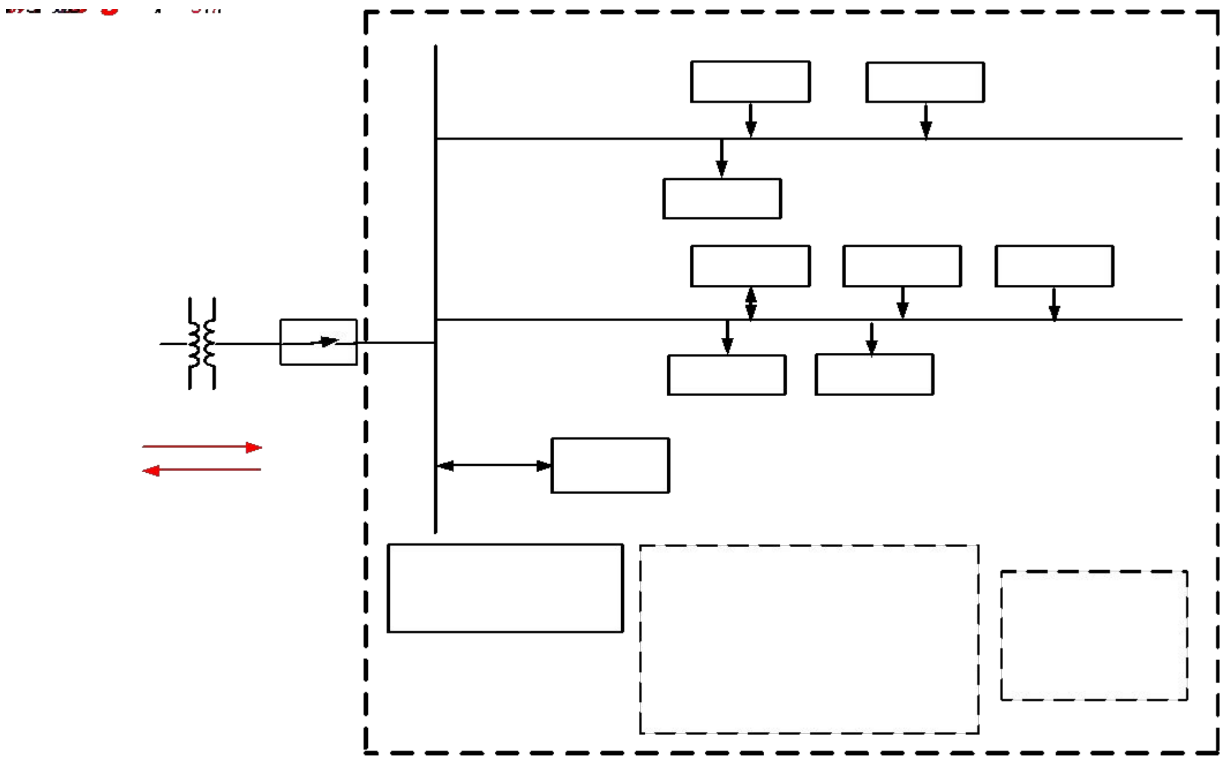
IEEE 2030.7 and 2030.8 – Microgrids
IEEE 2030.10 and 2030.10.1 – DC Systems
IEEE 2030.11 – DERMS (Aggregation of DER)
IEEE 2030.12 – Microgrid Protection

IEEE P2030.4 –Guide for Interoperability of Distributed Energy Resource (DER) Systems with the Electric Power System and End-Use Applications

IEEE 2030 smart grid series
Selected Standards Related to Microgrids

- IEEE Std P2030 – general smart grid interoperability guide
- IEEE Std 2030.2/3 – battery energy storage – in force
- IEEE Std 2030.7/8 – microgrid controllers – in force
- IEEE P2030.4 – Interoperability of Distributed Energy Resource (DER) Systems
- IEEE Std 2030.11- Distributed Energy Management Systems (DERMS) – on-going work
- IEEE P2030.12 – Guide for Protection of Microgrids

IEEE Std 2030.7/8 – microgrid operation



Microgrid benefits

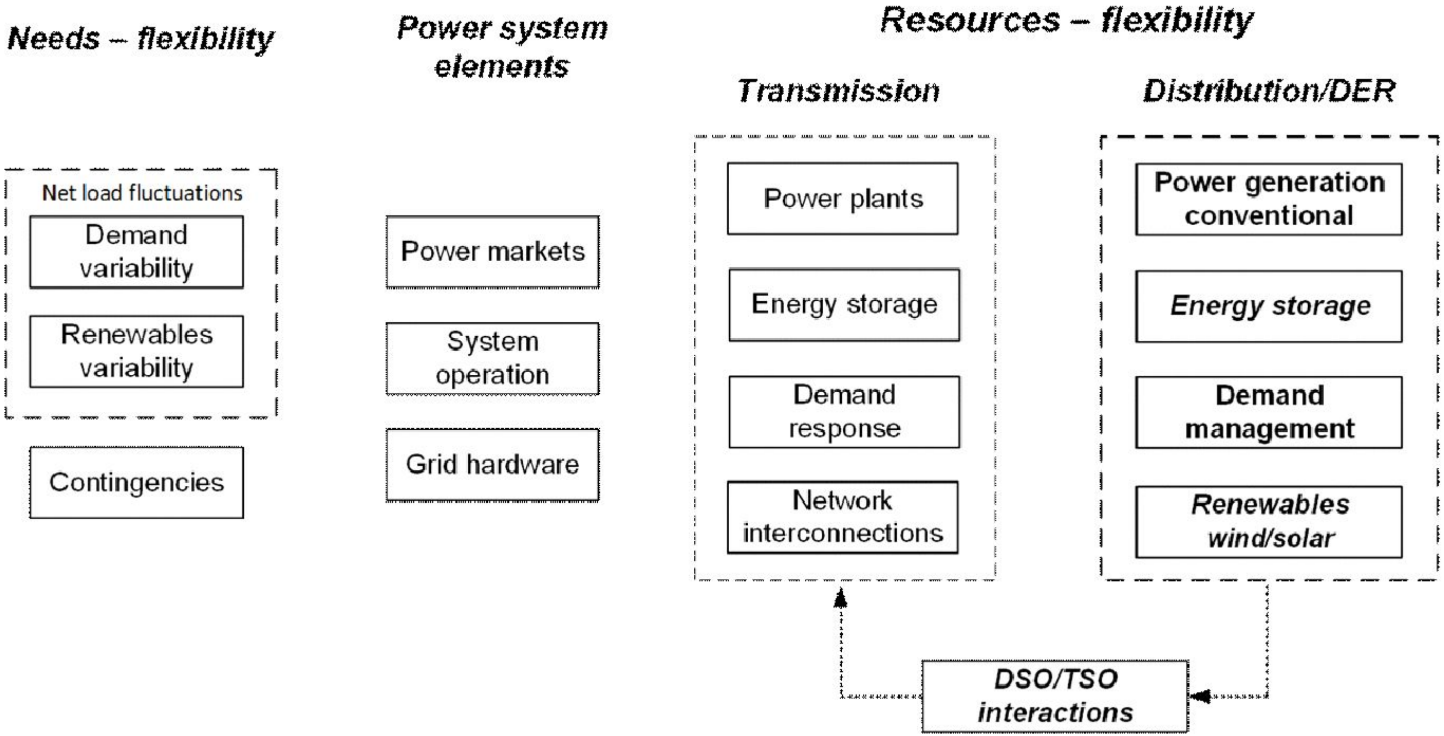
- Microgrids – an enabling technology at the distribution level for
  - Reconfiguring existing distribution systems
  - Developing distribution systems in new regions – developing world
  - Integrating local Distributed Energy Resources (DER) – renewables
  - Enabling market participation of DERs within microgrids
  - Customer and end-user empowerment
- Quantifiable benefits (distribution) – making a business case for
  - Enhancing grid **resilience**
  - Enhancing grid **reliability** and stability
  - Enhancing energy security using local energy resources
  - Matching power quality to the end-user requirements
  - Providing ancillary services to the grid, voltage/frequency
  - Lowering the environmental impact (carbon footprint, infrastructures)

IEEE Std 2030.7 – microgrid functions

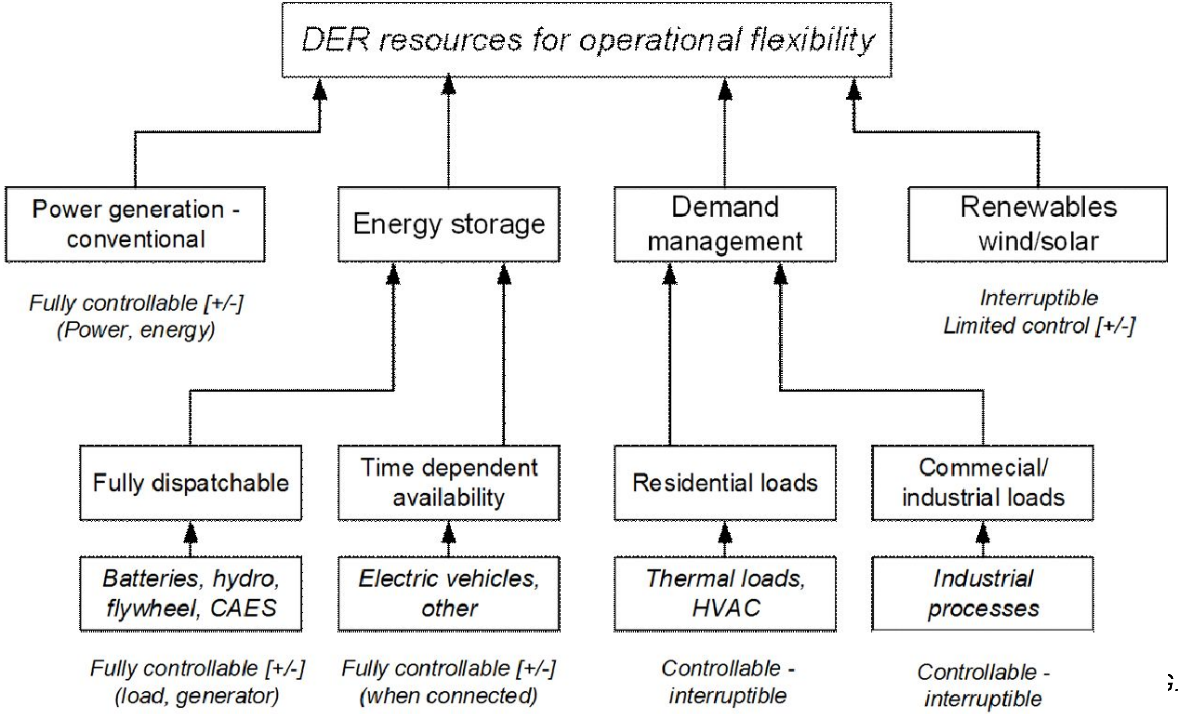
IEEE P2030.11 – DERMS deployment guide

- Distributed Energy Resources Management Systems (DERMS) Functional Specification
  - Purpose of DERMS – aggregation of DER for services to DSO/TSO
- DERMS – link between DER and DMS (DSO), EMS (TSO)
- Scope of Guide
  - Functional requirements and core functions of aggregation software
  - Services to DSO and TSO (including others) – energy, capacity, reserve, frequency/voltage support, power quality

IEEE P2030.11 – Flexibility services/resources



DERMS – DER as flexibility service provider



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IEEE P2030.11 – DERMS core functions

G.J.

Advanced Inverter Study Group

Grid-forming Inverters

1547.4 Study Group

Original PAR – Migrated to White Paper

Scope :

- This document provides alternative approaches and good practices for the design, operation, and integration of distributed resource (DR) island systems with electric power systems (EPS). This includes the ability to separate from and reconnect to part of the area EPS while providing power to the islanded local EPSs. This guide includes the distributed resources, interconnection systems, and participating electric power systems.

Purpose:

- This guide is intended to be used by EPS designers, operators, system integrators, and equipment manufacturers. The document is intended to provide an introduction, overview and address engineering concerns of DR island systems. It is relevant to the design, operation, and integration of DR island systems. Implementation of this guide will expand the benefits of using DR by targeting improved electric power system reliability and build upon the interconnection requirements of IEEE 1547.
- General Modes of Operation
  - Normal Parallel mode
  - Transition to Island Mode
  - Island Mode
  - Reconnection Mode

IEEE P1547.4 Revision Study Group

- Potential Revision of IEEE 1547.4-2011 - Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems
- General update of 1547.4 to re-coordinate with 1547-2018, in particular clause 8.2.
- Increased detail and updates in some areas. These could include:
  - Guidelines for power quality while in islanded mode, which might include
    - Maximum allowed Voltage Unbalance Factor from grid-forming assets
    - Updated discussions of harmonic requirements
  - Grounding of intentional island systems
  - Inverter-based versus rotating-machine-based intentional island systems
  - Intentional island systems with no single dominant source bus (i.e., nothing that even approximates a slack bus)
- Control of grid-forming inverters (coordinating as appropriate with the UNIFI consortium and P2988 for Virtual Synchronous Machines).
- System performance requirements during transitions between on-grid and off-grid modes (coordinating as appropriate with IEEE Std 2030.7-2017 and IEEE Std 2030.8-2018).
- Handling of mixtures of grid-forming and grid-following or legacy assets.
- Microgrid planning issues (coordinating as appropriate with IEEE 2030.9-2019), such as
- Identify any appropriate coordination with 2030.10-2021, which is on DC microgrids.

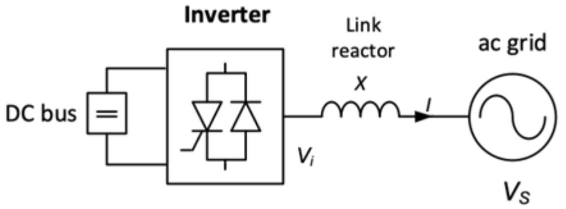
SCC21 Study Group on Advanced Inverters

Purpose and scope

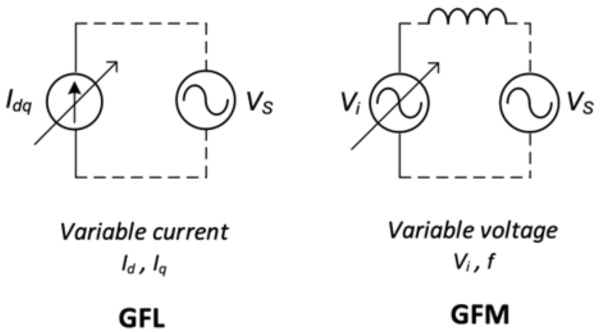
- Purpose – describing various inverter operating modes and the functionality of modern inverters
- Focus – comparison between grid-following (GFL) and grid-forming (GFM) inverters
- Context – a increasing penetration of inverter-based resources (IBR) and the resulting displacement of conventional generation based on rotating generators
- Intent – drawing a parallel with synchronous generator (SG) operation and the operation of the existing power grid dominated by SG
- Historical perspective/background and future grids – GFM technology, an established approach for standalone/remote applications, including uninterruptible power supplies (UPS) and islanded microgrids, being considered for deployment in interconnected grids

Inverter Control

- Operating Modes
  - Current or power control – Current and power are related since the grid voltage is regulated close to the rated value under steady conditions.
    - This mode of operation allows independent control of active and reactive current/power, or P-Q control, as found in grid-following (GFL) inverters.
  - Voltage amplitude and angle/frequency control – This mode allows V-f control, as found in grid-forming (GFM) inverters.
    - This mode of operation requires an internal control system to set the frequency of inverter voltage and control of the amplitude of the inverter voltage. **This operation is similar that of a standalone synchronous generator (SG) and is used in UPS.**



Inverter control options



Inverter Control

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Note: The terms grid-following inverter and grid-forming inverter have been coined recently but are not new technologies

Inverter (Static) Power Conversion - Advantages

- Reduced losses and increased efficiency
  - Rotating machines, in addition to electrical losses associated with winding conductors, also have magnetic, stray, and mechanical (rotational) losses. The total losses are higher than that of static power conversion systems, where losses are mostly associated with power switch conduction and switching losses.
- Reduced size and weight
  - Rotating machines are bulky, as they rely on magnetic circuits to do the power conversion. Static power converters consist mainly of power electronic switches and a number of associated passive components (capacitors and inductors), used as current and voltage source interface elements.
- Reduced acoustic noise
  - Acoustic noise in rotating machines is associated with rotating masses and ventilation (cooling) requirements. Static power converters can be operated at lower noise levels, particularly if liquid cooling is used, or forced ventilation is kept to a minimum.
- Reduced cost
  - The cost of power electronic switches has been continually decreasing ever since the first switch was introduced in the 1970s, and the downward trend is expected to continue
- Fast dynamic response
  - The inverter response can be made as fast as allowed by the electronic power and control devices and the power sources

Inverter (Static) Power Conversion - Disadvantages

- Absence of inertia associated with rotating masses
  - Static power converters are fed from a dc voltage source to which power is provided by a solar PV generator, wind turbine generator, and BESS, among others. The physical inertia present in some IBR, such wind turbine generators, interacts indirectly with the electric grid through the inverter.
- Harmonic voltage and current generation
  - Harmonics are associated with the chopping of the dc bus voltage to synthesize sinusoidal ac voltages with a desired fundamental component. The inverter voltage is associated with harmonics at the switching frequency and multiples. Extracting the fundamental component of current requires the use of harmonic filters to reduce current waveform distortion on the ac side.
- Electromagnetic interference (EMI)
  - EMI is also associated with the chopping of the dc bus voltage and is related to the fast rate of change of voltage. EMI emissions are regulated. EMI mitigation requires high-frequency filters.
- Low short-circuit capabilities
  - Static power converters have limited short- and medium-term overload capabilities, due the current limitations of power electronic switches.

Study Group – Conclusions (White Paper)
Challenges of Low-carbon Grids
Key Challenges

- Evolution of electric grids – an increasing penetration of renewable energy resources has undesirable effects
  - Intermittency and variability of the energy produced, which is therefore not dispatchable.
  - Lack of inertia and inertial response capability to ride through generation-load unbalance.
  - Need for voltage and frequency reference sources for inverter synchronization
- Impact of large amounts of renewable generation – solutions to decreasing inertia
  - Keeping the generators in decommissioned steam turbine power plants running to provide inertia
  - Installing synchronous condensers, possibly with added flywheels for added inertia
  - Implementing fast frequency response in selected IBR, or IBR operating in GFM mode
- Existing inverter implementations – standards and guides
  - GFL IBR implementations – integration of solar and wind energy, and battery energy storage
  - GFM requirements for STATCOMs
- Possible grid evolution scenarios
  - Grids with the continued presence of large central power plants – GFL and some GFM inverters
  - Grids with a large dominance of RES – GFM inverters (larger IBR) and GFL inverters

Inverter Deployment and Standards

Possible activities

- Revision of existing standards
  - IEEE Std 1547
  - IEEE Std 2800
  - Integrating GFM features in other existing standards and guides incorporating the IBR technology
- New standards
  - GFM IBR
  - IBR implementation in future grids with GFL and GFM features
- Specific IBR deployment challenges
  - Managing inertia and rate of change of frequency (RoCof) in future grids
  - Transitioning from GFL to GFM operation
- Considerations
  - Industry Developed Standards
  - IEC Activity
  - Segmented development
    - Transmission
    - Distribution
    - Standalone

IEEE SCC21 Roadmap for P1547.x Standards (Draft Update 09-15-22)

	Topic	Expires (10 yrs.)	2018	2019	2020	2021	2022	2023	2024	2025	2026
1547-2018	Base Std	2028	Revised		Amended	PAR: Std					
						Study Group		Revision			
1547.1-2020	Test Std	2030			Revised				Revision		
P1547.2	Application Guide	2018	PAR: AG				Expected Revision				
P1547.3	Cyber Security	2018 – parts in 1547-2018		PAR: AG			Expected Revision		PAR: RP		Revision?
1547.4	Intentional Islands	2021				Expires		Revision			
	Advanced Inverters					Study Group		PAR?			
P1547.5	DER > 10 MVA	Withdrawn–now partly	in P2800								
P1547.6	Secondary Networks	now in 1547-2018									
1547.7-2013	Impact Studies	2023						Expires			
P1547.8	Recommended Practice	Inactive (Included in Revised 1547)									
1547.9-2022	Storage + V2G	New Std		PAR: AG		Expected Revision		PAR: RP		Revision?	
P1547.10	Network Gateway						PAR: Std				

Project types: Std – Standard; RP – Recommended Practice; AG – Application Guide

KEY To Roadmap

KEY

Working Group

PAR Development

Future Working Group

Study Group

IEEE SCC21 Roadmap for P2030.x Standards (Draft Update 09-15-22)

	Topic	Expires (10 yrs.)	2018	2019	2020	2021	2022	2023	2024	2025	2026
P2030	Base Std	2021			PAR: Guide		Revision				
P2030.1	Guide for EV supply equipment	Inactive				PAR: Guide					
P2030.2	Guide for ES Interoperability	2025					PAR: Guide				
P2030.4	Guide for Control and Automation Syst										
2030.5	Std Smart Energy Profile		Revision			Revision					
2030.7 2030.8	Microgrid Controllers										
P2030.11	Guide for DERMS				Revision						PP
2030.12	Protection of Microgrid										
P2030.13	Fast Charging										

KEY: Working Group | PAR Development | Future Working Group

Standards Under development:

Interconnection
Interoperability
Microgrid

Standards Under Development

- Interconnection
  - IEEE P1547.2 - Application Guide for IEEE Std 1547(TM), IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems
    - Guidance for application of IEEE 1547-2018 for all DER technologies. Covers details for a wide variety of applications and technologies.
  - IEEE P1547.3 - Guide for Cybersecurity of Distributed Energy Resources Interconnected with Electric Power Systems
    - Guidance for cybersecurity of DER and associated communications systems.
  - IEEE P2800.2—IEEE Interconnection Standard for Large-Scale Solar, Wind, and Energy Storage Plants (Inverter Based Resources)
    - Harmonizes Interconnection Requirements for Large Plants connected at High Voltage
    - Performance and functional settings, Reference Point of Measurement
    - EEE P2800.1&2 type of tests, plant-level evaluations, and other verifications means
  - IEEE P1547.4 -- C

Standards Under Development

- Interoperability
  - IEEE P2030 – Revision of IEEE 2030-2011
  - IEEE 2030.5™-2018 - a protocol that has been instrumental in integrating interoperability into California regulations, and is critical to establishing vehicle-to-grid energy-transfer protocols. Currently Under Revision
  - IEEE P2030.4; Guide for Control and Automation Installations Applied to the Electric Power Infrastructure
  - IEEE 2030.2-2015 Guide for the Interoperability of Energy Storage Systems
  - IEEE P2030.11 Guide for DERMS (Aggregation of DER)
- Microgrid
  - IEEE 2030.7-2017; Standard for the Specification of Microgrid Controllers
  - IEEE 2030.8-2018; Standard for the Testing of Microgrid Controllers
  - IEEE 2030.9-2019 Recommended Practice for the Planning and Design of the Microgrid
  - IEEE P2030.10 IEEE standard for DC Microgrids

New Activities

Revision to IEEE Std. 1547 - 2018

- Revision may start in late 2022 or early 2023, subject to WG guidance
  - Incoming Chair focusing on completion of Ballot for P1547.2 as an officer, subgroup lead.
  - Kick-off meeting to gather stakeholders input is suggested for early 2023.
- Leadership Team Formation ongoing
  - Most of the team assembled (i.e., Chair, Secretary, Treasurer, Vice Chairs).
  - Addition of more team members expected ☐ **call for nominations by joint sponsors**
- Work done by Study Group for Revision of IEEE Std. 1547 will help establish foundation of the Revision to IEEE Std. 1547-2018
  - SCC21 will be joined by several sponsors for the revision effort. Sponsors were active participants of the Study Group
  - Study Group successfully provided guidance on important considerations that will need to be addressed during the next revision life cycle.

IEEE SCC21 Roadmap for P1547.x Standards

	Topic	Expires (10 yrs)	2018	2019	2020	2021	2022	2023	2024	2025	2026
P1547	Base Std	2028	Revised		Amended	PAR: Std		Revision?			
P1547.1	Test Std	2030			Revised		AR: Std		Revision?		
P1547.2	Application Guide	2018	PAR: G			Expect Revision		PAR: RP		Revision?	
P1547.3	Cyber Security	2018 – parts in 1547-2018		PAR: G			Expected Revision		PAR: RP		Revision?
P1547.4	Intentional Islands	2021				Expires					
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P1547.8	Recommended Practice	Inactive (Included in Revised 1547)									
P1547.9	Storage + V2G	New Std		PAR: G		Expected Revision		PAR: RP		Revision?	

Legend: Active Working Group; PAR Development; Future Working Group

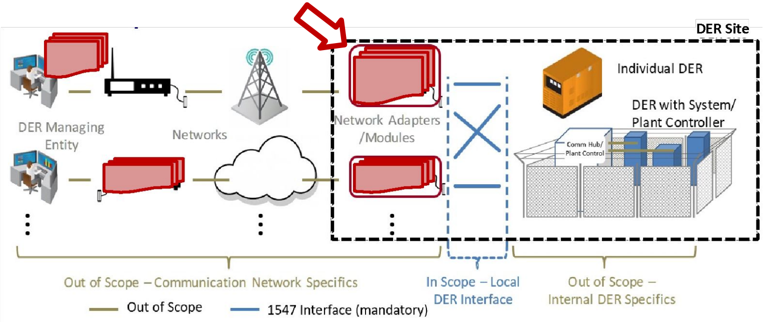
Project types: Std – Standard; RP – Recommended Practice; G – Guide

https://sagroups.ieee.org/scc21/standards/

- Summary of Activities to date
  - Study Group sunset with SCC21 backing on 6/3/2022
  - **1547 Revision sponsor and joint sponsors: SCC21 jointly with PE/T&D, COM/PLC, PE/EDPG, PE/EM, PE/PSCC, PE/PSRCC, PEL/SC**

New Activities

Approved PAR for P1547.10 (Recommended Practice for DER Gateway Platforms)



Potential Architectural Benefits of DER Gateways

- Flexibility for utilities to choose any network type
- DER manufacturers can ship a common product not prescriptive of a utility/region
- Companies (DER and network providers) can focus on their core competencies
- Replace/Update communication systems without obsoleting end device

- ***PAR was approved on May 13, 2022 (link)***

SCC21 (Main Sponsor and Coordination Role)				
IEEE/PES/PSCC (Cyber and Coms)	IEEE/PES/T&D and, possibly, IEEE/PES/PSRC (Utility Perspective)			IEEE/PES/ED&PG (OEM Perspective)
Centralized Manageability	Scheduling (Coordination with next revision of IEEE 1547 and CA SIWG Phase 3)	Real Time "Status" Monitoring	Advanced Notification & Synchronized Actions	Smart Inverter Function Implementation for Legacy DER
Communication Network Performance Monitoring (Coordination with IEEE 1686-2013)	Availability at Night and During Outages	Event Logging & Retrieval	Buffering Monitored Interval Data During Network Outages	Multi-Master Scenarios and Command Prioritization (RBAC)
Communication Protocol Translation (Coordination with IEEE 1815.1-2015)	Transparent Smart Inverter Function Handling	Alarms Logging & Retrieval	Supervision for Voltage Sags	Report Unexpected DER Settings Change
Cybersecurity (Coordination with IEEE 1686-2013 and IEEE P1547.3)	DER Lost Energy Calculation	Logging & Retrieving Interval Data	Continuous Monitoring & Report by Exception	Loss of Master Detection and Reversion of Settings to Defaults

- Genesis of joint sponsorship:
  - Presented to IEEE/PES/T&D/DRI WG and IEEE/PES/EDPG in August 2021; both expressed interest
  - Presentations to PSCC P0, T&D AdCom, PSRC IBR Coordination WG and Main Committee at 2022 IEEE JTCM; all expressed interest for joint sponsorship
  - Approved by SC21 at February 25 meeting

Impactful Recent Developments

- Grid Forming Inverters
  - During a disturbance or outage on the grid, conventional inverters will shut off power to these energy sources and wait for a signal that it is safe to restart—
  - Conventional inverters are also known as “grid-following.”
  - Grid-forming inverters are an emerging technology that allows solar and other inverter-based energy sources to restart the grid independently.

Grid-Following		Grid Forming	
Pro	**Con**	**Pro**	**Con**
Well Established Technology	Cannot operate with Grid Down (No Emergency Power)	Provides Voltage Regulation	Not in widespread use
	Lacks inertia and can cause PQ Problems	Can simulate machine with Inertia	
		Black Start, Emergency Backup Capable	
		Compatible with Microgrid Architecture	

Takeaways

- There are many changes in standards underway that will impact the methods used for interconnection testing
  - IEEE P1547 Revision
  - IEEE 1547.2, 1547.3 and IEEE 1547.9
  - IEEE 2800-2022 and IEEE P2800.2 (Verification and Test Procedures)
- Technology Changes
  - Grid Forming Inverters
  - Interoperability Guides
  - Cyber-Security Guides
- All will have impact on the requirements for verification and testing of DER connected to the electric power System.
- You can get involved in IEEE Standards Development

Contact Information - Questions

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Backup Slides

IEEE 1547-2018

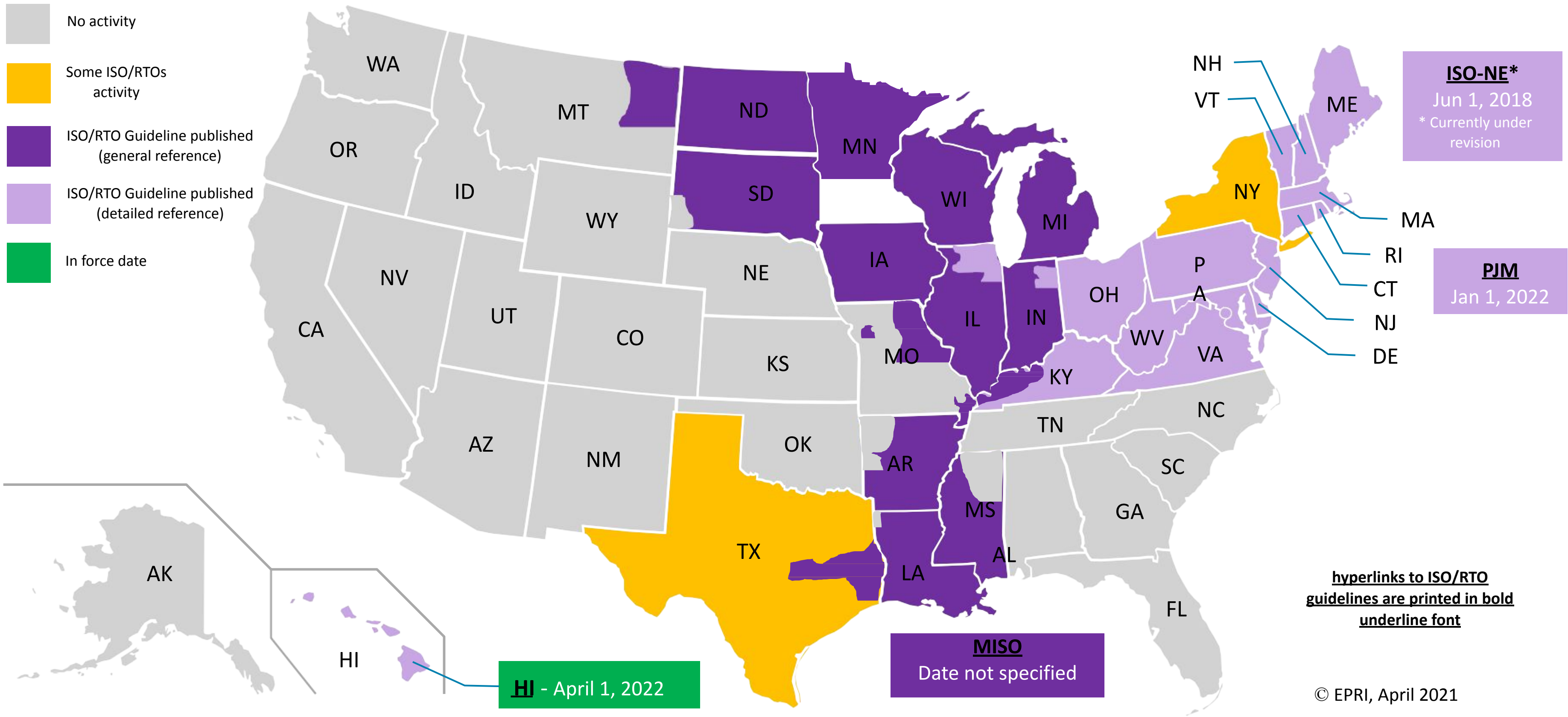
Status of Adoption across the U.S.
April 2021

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

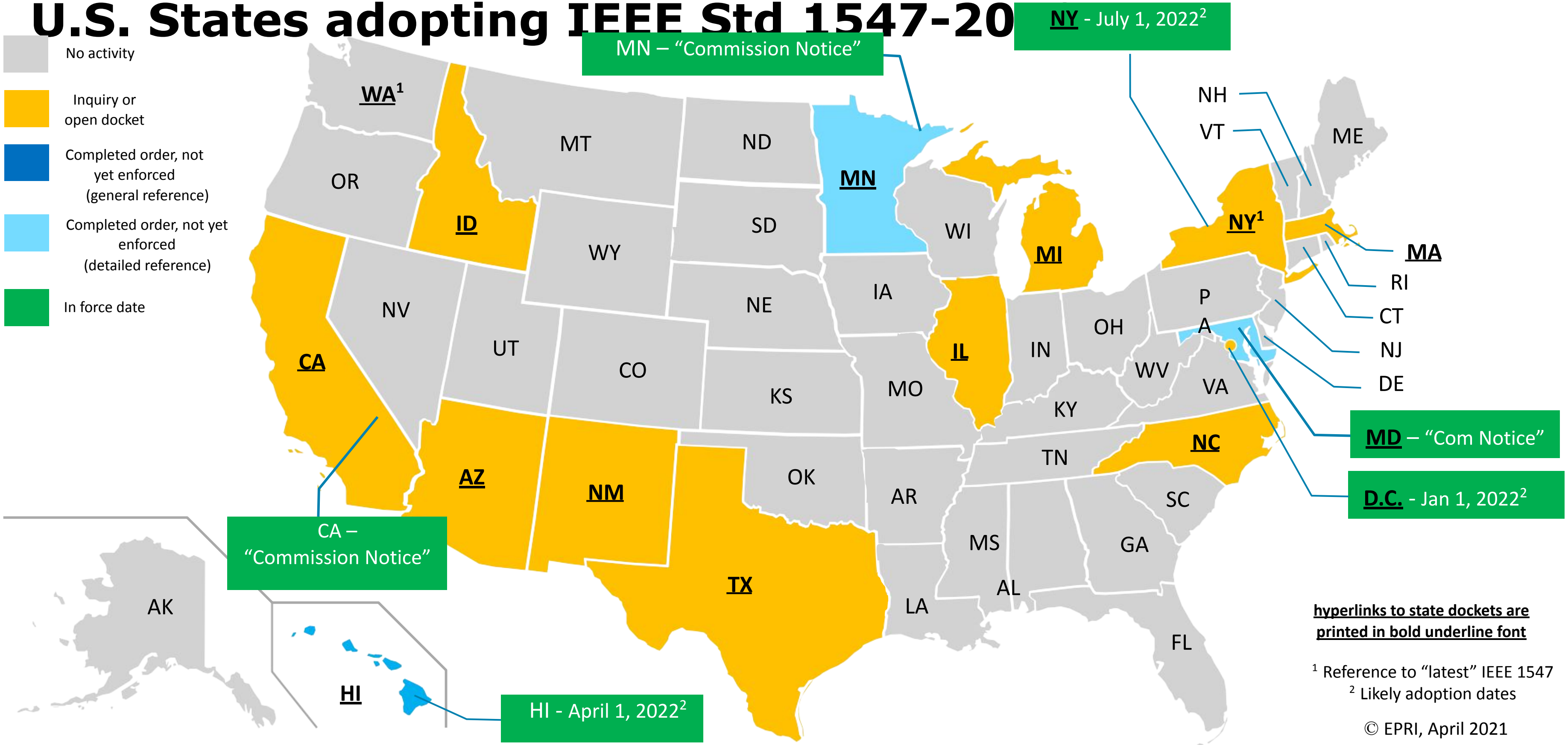
https://sagroups.ieee.org/scc21/standards/1547rev/

Courtesy of Electric Power Research Institute (EPRI)
https://www.epri.com/#/pages/product/000000003002012048/

Adoption guidelines from Reliability Coordinators for IEEE Std 1547-2018



U.S. States adopting IEEE Std 1547-20



hyperlinks to state dockets are printed in bold underline font

[1] Reference to "latest" IEEE 1547
[2] Likely adoption dates

Comparison of IEEE to IEC Standards

- EU Interconnection Standards – Analogous to IEEE 1547
  - EN- 50549-1: Requirements for generating plants to be connected in parallel with distribution networks - Connection to a **LV distribution network**. Generating plants up to and including Type B
  - EN-50549-2: Requirements for ..**MV distribution network** - Generating plants up to and including Type B
- Most Standards for Interconnection Have Requirements for:
  - Voltage Regulation
  - Voltage and Frequency Ride-Through during abnormal conditions
  - Power Quality
  - Islanding Protection
  - Reference Point is PCC
- IEEE 1547 has extensive discussion of Interoperability Requirements, and Verification and Testing Requirements
  - IEEE 1547 uses PCC and Point of Connection due to Inverter Grounding

References:

- *Microgrid and Distributed Energy Resources Standards and Guidelines Review: Grid Connection and Operation Technical Requirements*; David Rebollal et.al.; Department of Electrical Engineering, University Carlos III of Madrid

Collaboration in “Smart Energy” Standards

- IEEE SCC21 is collaborating with IEC SyC Smart Energy Committee –
  - IEEE P2030 Guide for Smart Grid Interoperability
  - IEEE P2030.4 – Guide for Automated Systems Interoperability
  - IEEE 1547.3 – Guide for Cyber Security
- IEC Documents:
  - IEC SRD 63200:2021 Definition of extended SGAM smart energy grid reference architecture model
  - IEC SRD 62913-1 ED2: Generic smart grid requirements - Part 1: Specific application of the Use Case methodology for defining generic smart grid requirements according to the IEC systems approach. (This is an update to the Ed 1 Use Case methodology document).
  - PWI TR SyC Smart Energy-1: Cyber Security and Resilience Guidelines for Cyber-Physical Power Systems (On hold, but may start up again, maybe due to review by IEC of the IEEE 1547.3 document.