Smart Inverters and Interconnection Evolution

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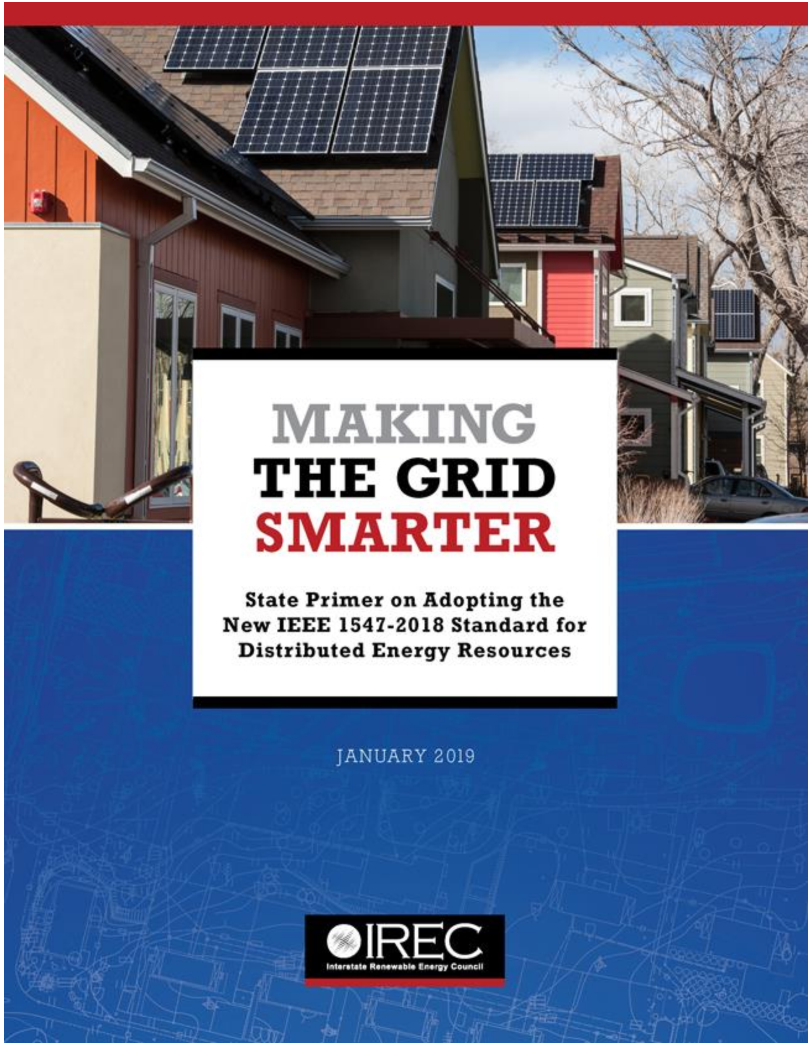
MAKING
THE GRID
SMARTER
State Primer on Adopting the
New IEEE 1547-2018 Standard for
Distributed Energy Resources
JANUARY 2019
IREC
Interstate Renewable Energy Council

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The California Special

Smart Inverters Today

- “Grid Support Utility Interactive” per UL 1741 SA
- Voltage and frequency ride-through (i.e., per CA Rule 21 and/or HECO 14H)
- Anti-islanding with grid support
- Ramp rates (soft start and normal)
- Set PF, volt-var
- Frequency-watt, volt-watt, permit service, limit max power

Also in IEEE 1547-2018

Volt-var autonomous Vref

Other voltage regulation modes

ROCOF and phase jump ride-through

Power Quality

Islanding (Microgrids)

Fault current characterization

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Bulk System Support (Ride-Through)

Abnormal Performance, Voltage – CAT I

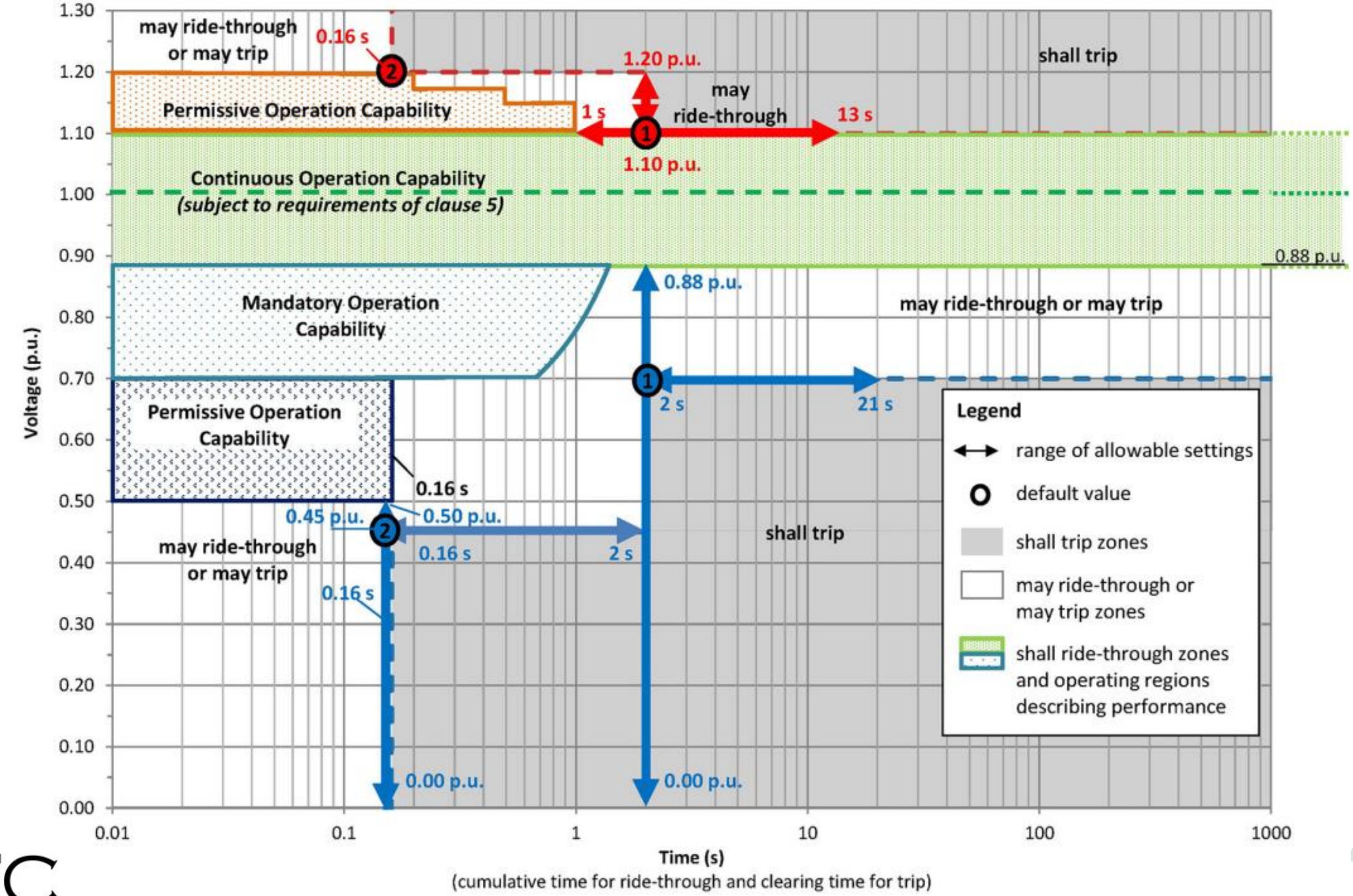

Figure H.7 of IEEE 1547-2018

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Abnormal Performance, Voltage – CAT II

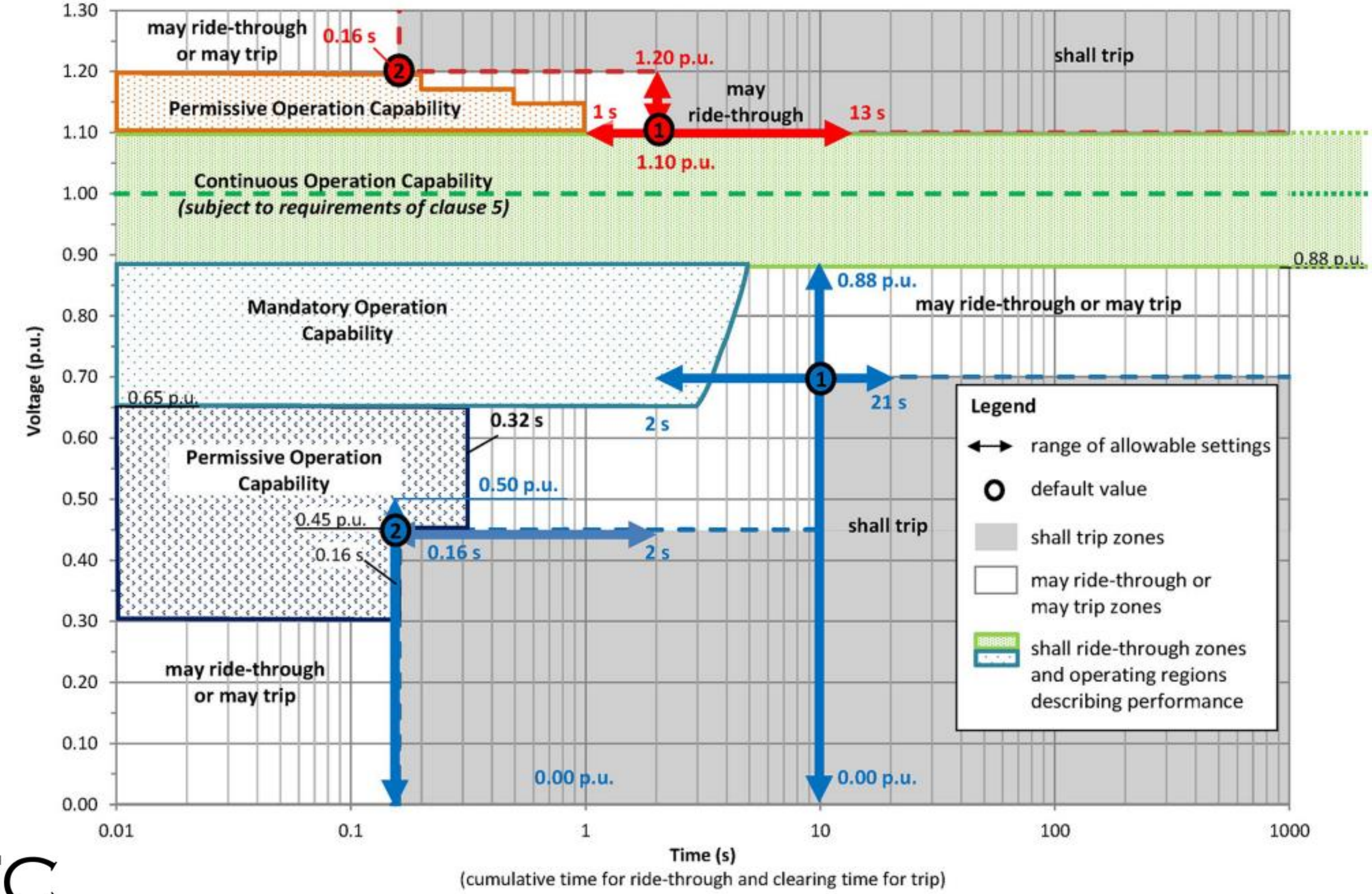

Figure H.8 of IEEE 1547-2018

Abnormal Performance, Voltage – CAT III

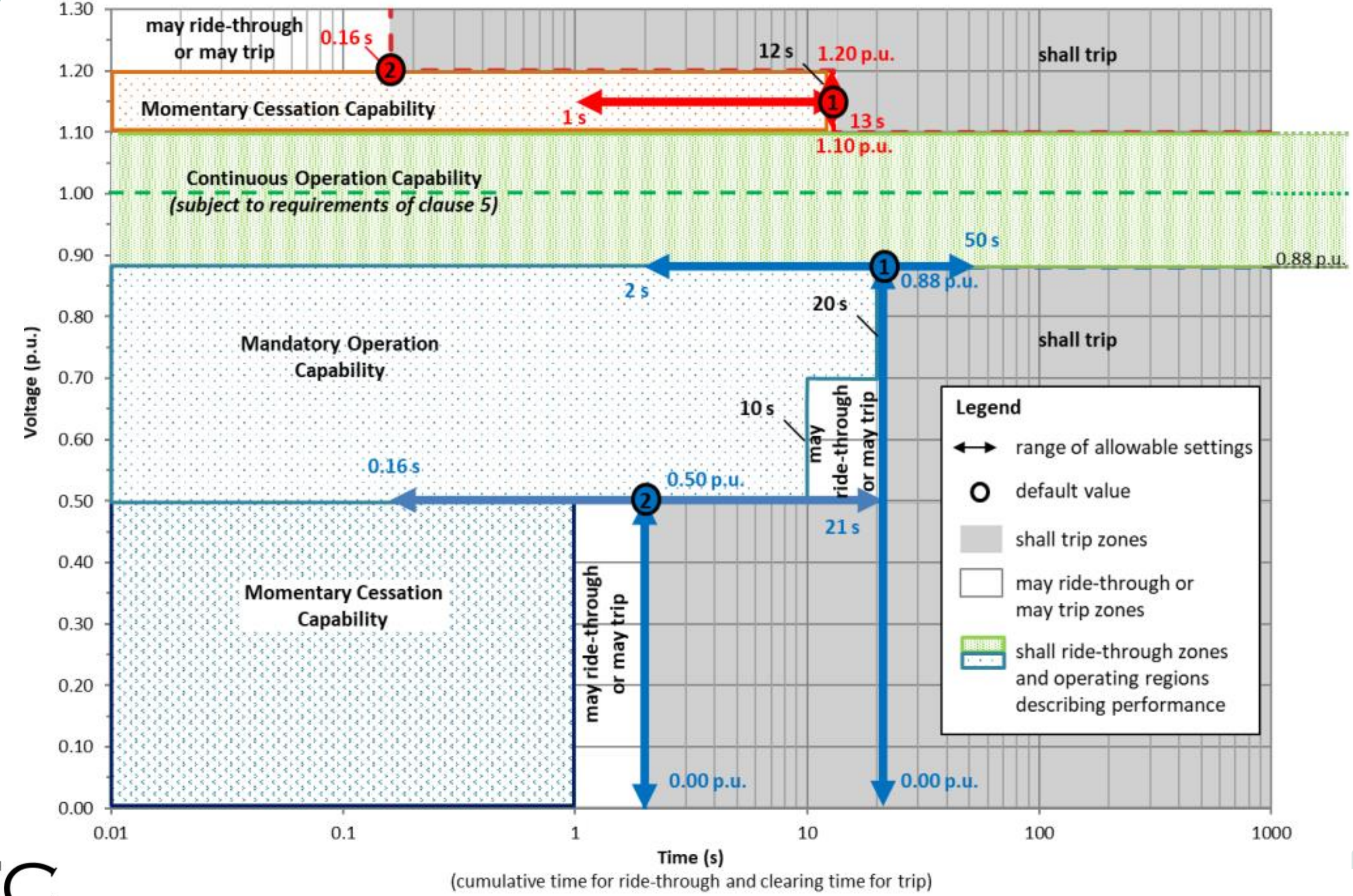

Figure H.1 of IEEE 1547a-2020 (replacing figure H.9 of IEEE 1547-2018)

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Abnormal Performance, Frequency – CAT I, II, III

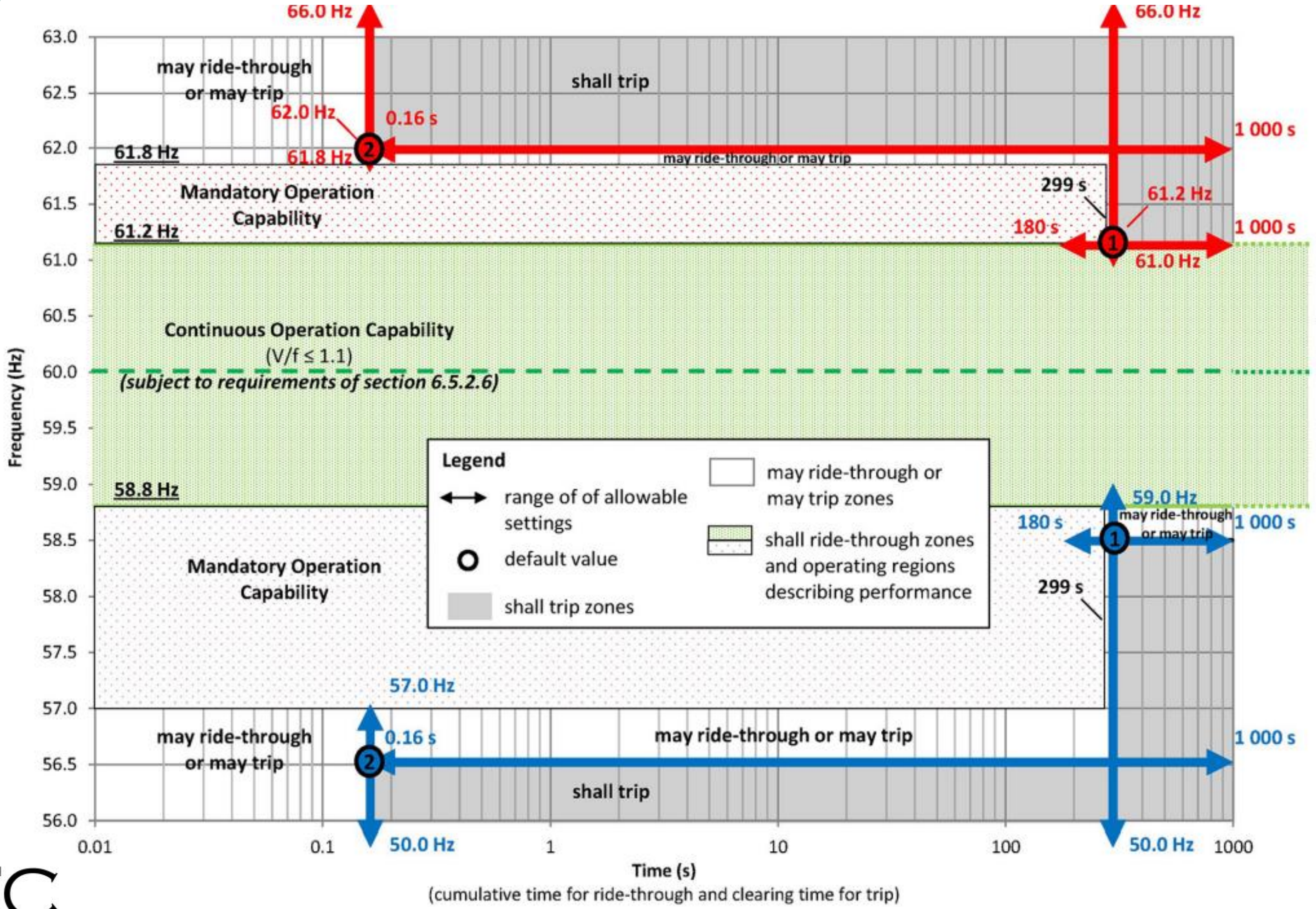

Figure H.10 of IEEE 1547-2018

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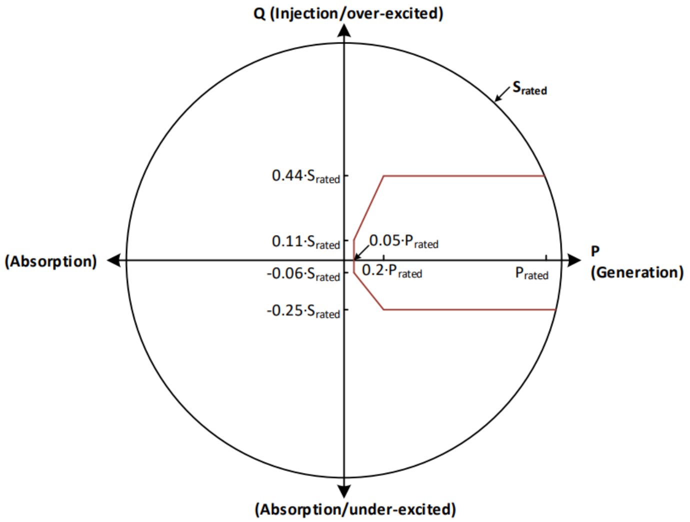
Voltage Regulation

Normal Performance Categories

Cat A



Cat B

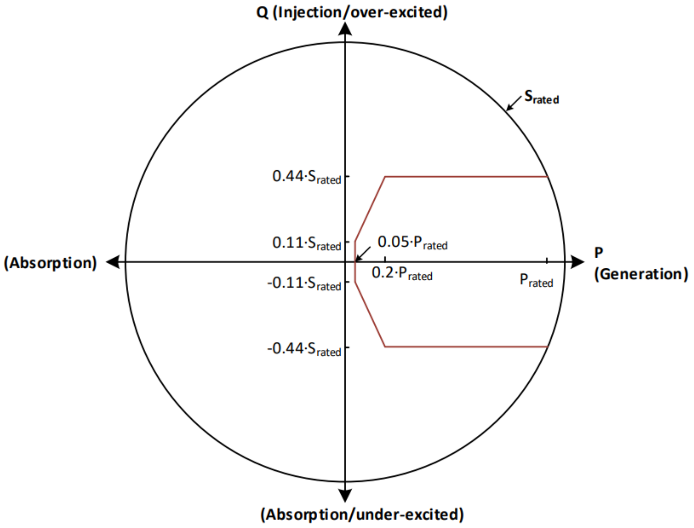


Figure H.3 of IEEE 1547-2018: Minimum reactive power capability of Cat A and B DER

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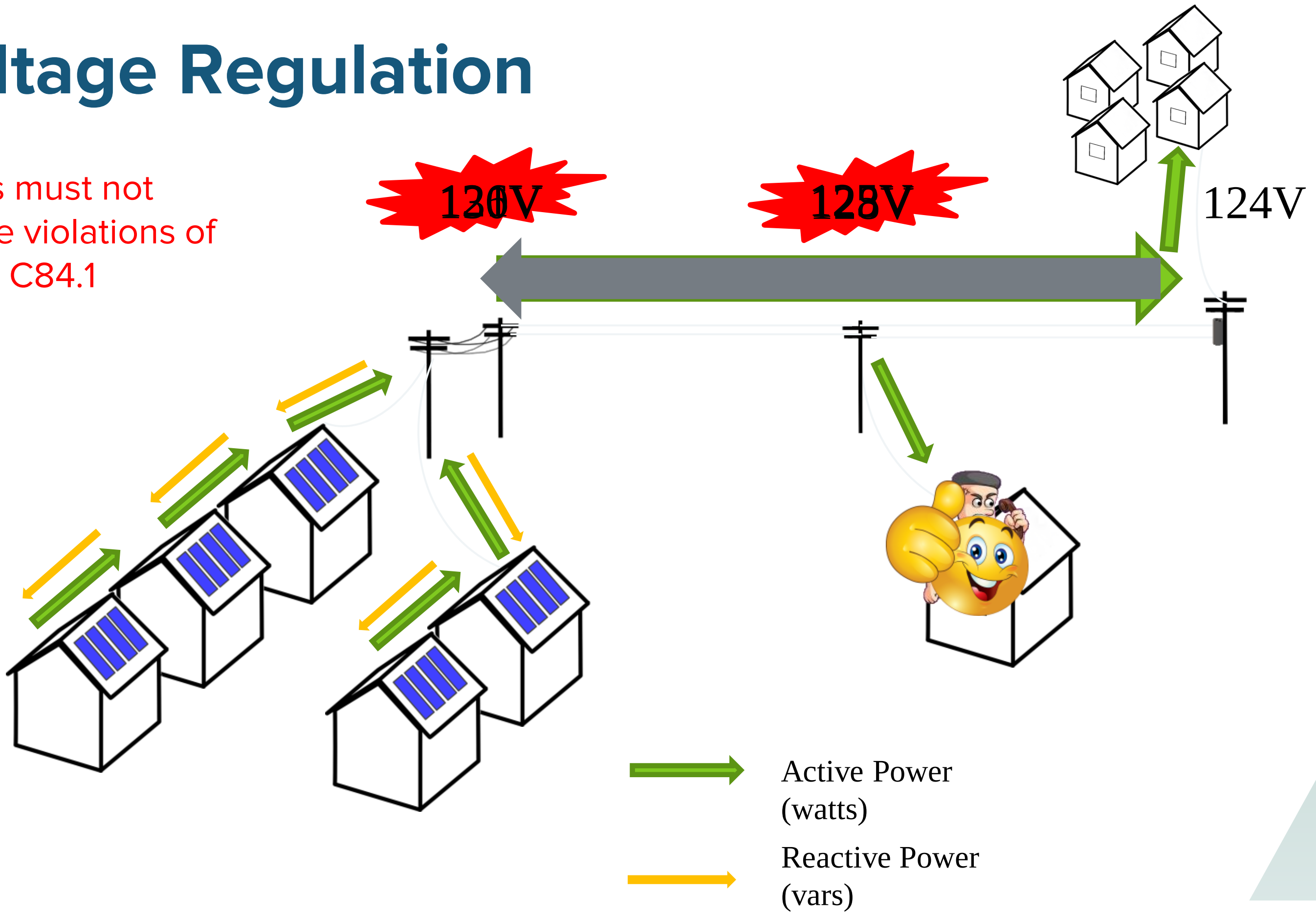
Voltage Regulation

DERs must not cause violations of ANSI C84.1



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Cat A/B sets the stage for voltage and reactive/active power control functions

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

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

Table 6 of IEEE 1547-2018

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Why early adoption of voltage regulation functions?

- Certain DERs can connect to the grid where once they couldn’t (w/o upgrades)
- Increase hosting capacity of a circuit
- Functions are optimized if all or most DER systems participate in voltage regulation
- Effectiveness dramatically reduced if adopted after higher DER penetration

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Voltage regulation considerations

- IEEE 1547-2018 default is the constant power factor mode with PF=1
  - i.e., **no reactive power = no voltage support**

- States/utilities to clarify which voltage regulation function DERs should use; adjust from Standard defaults accordingly (state-wide or case-by-case) - **states are diverging on this!**

- Potential for DER customer impacts

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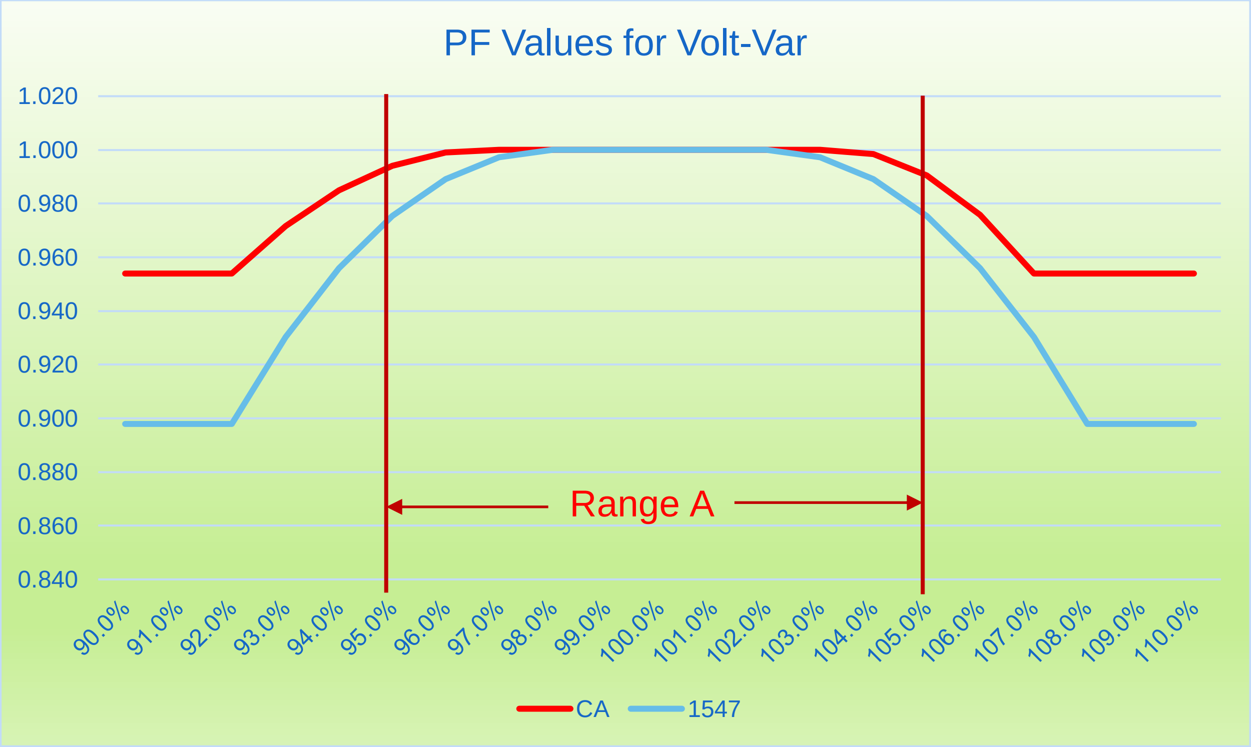
Why settings matter

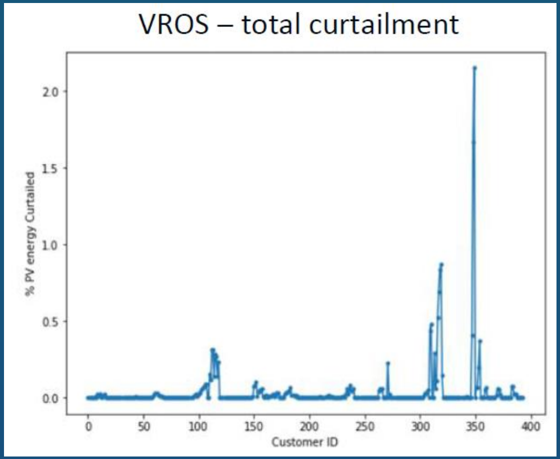


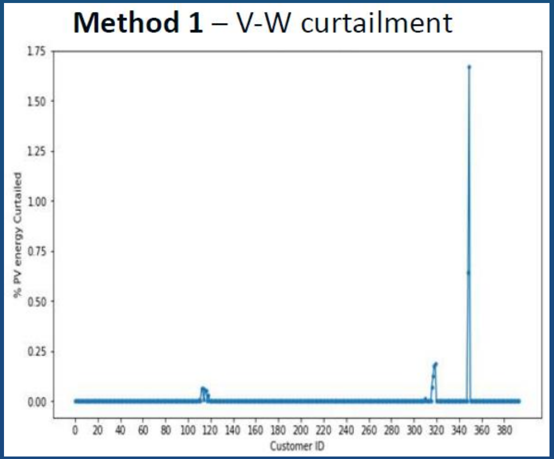
How will 1547 functions impact the customer?

- Curtailment
  - Headroom loss
    - reactive power functions (most likely de minimis)
  - Curtailment functions
  - **volt-watt**
  - frequency-watt (most likely de minimis)
  - control (max active power limitation)

Voltage complaints and reporting

- Ensure complaint process handles DER complaints appropriately
- Consider reporting on how many voltage-based curtailment issues arise
- Consider metric based on voltage data to determine potential for curtailment





Credit: NREL

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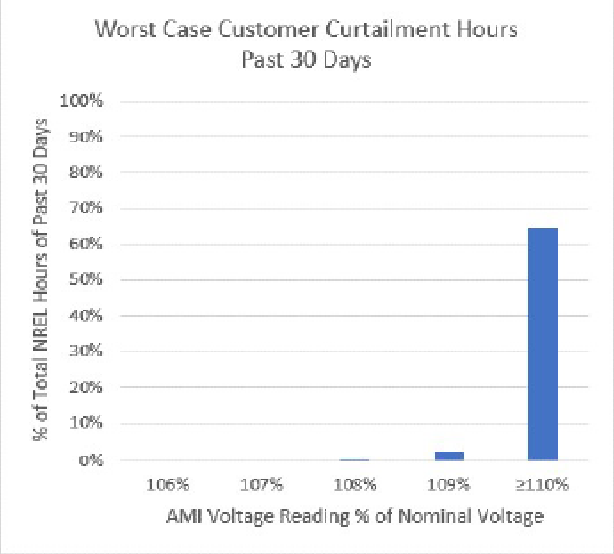
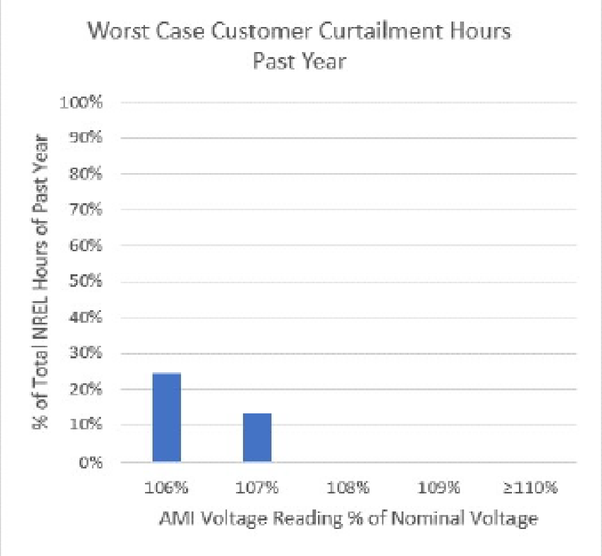
Summary Results for Utility (or Pending) Mitigations		
NREL Method 1 Estimation of Curtailment %	# of Customers with 1 year Curtailment %	# of Customers with 1 month Curtailment %
≤ 2%	15	10
> 2% ≤ 4%	0	1
>4%	4	8
Total	19	19

Summary Results for Customer Issues		
NREL Method 1 Estimation of Curtailment %	# of Customers with 1 year Curtailment %	# of Customers with 1 month Curtailment %
≤ 2%	16	15
> 2% ≤ 4%	2	0
>4%	0	3
Total	18	18

Worst Case Customer (>5% Curtailment) Voltage Histograms





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Volt-Watt Curtailment Reports

California Experience

- PG&E (largest IOU) reported only 9 customers with potential yearly curtailment >4%
- Worst yearly potential loss reported was 38.7% (failing distribution transformer)
- Next highest was 7.3%
- It appears true that volt-watt is unlikely to cause widespread curtailment, but individual customers can be highly impacted

Adopting and Implementing Smart Inverters

Adopting IEEE 1547-2018

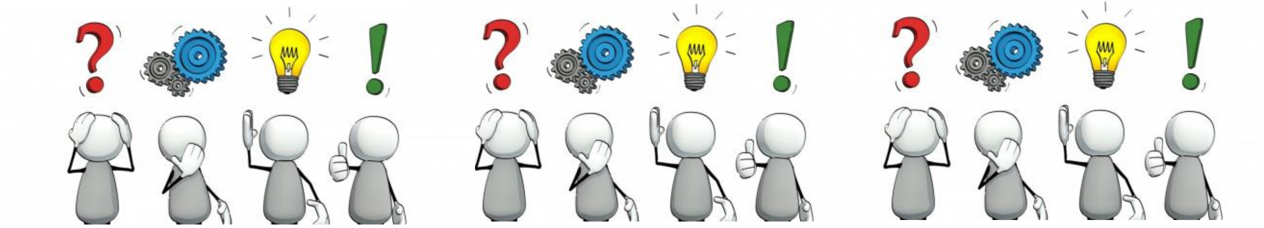
Where will the technical requirements reside?

Choose categories

Define default function states (or not)

Define default settings (or not)

Determine timeline for implementation



Adopting IEEE 1547-2018

Also:

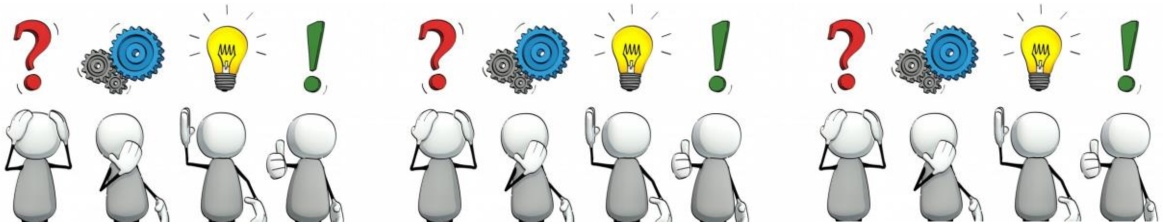
Communications (capability vs utilization, pathways, protocols)

Process updates (mitigations, settings changes/selection)

Interconnection Agreements

Applications

Related processes (e.g. voltage complaints for DER, HCA)



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IREC's Decision Options Matrix

https://irecusa.org/resources/decision-options-matrix-for-ieee-1547-2018-adoption-3/

Normal operating performance category	The selection of A or B will impact the use of voltage regulation controls. Some DER types cannot meet the full scale of reactive power support. Consider specifying category assignment based on technology type. [MTGS V.A]	**DO 3-1:** Inverter-based DERs must meet reactive power requirements of 1547-2018 Category B. Rotating DERs must meet Category A, and may meet Category B.	☐
		DO 3-2: All DER types (inverter-based and rotating) shall meet reactive power requirements of 1547-2018 Category A, and may meet Category B.	☐
Alternative performance category	If a technology that cannot meet the specified Abnormal or Normal Operating Performance Category, a defined process may be useful for determining if the technology can safely interconnect without unduly impacting grid support requirements.	**DO 4-1:** Define process for how exceptions to these category assignments are handled (e.g., for an inverter-based technology that cannot meet Category III capabilities).	☐
		DO 4-2: Leave process undefined for how exceptions to these category assignments are handled.	☐
Voltage trip settings and ranges	Consider local distribution utility protection practices and make sure appropriate trip settings are selected. As desired, select default settings or settings within the adjustable range. Trip settings should not hinder ride-through capability required at the transmission level.	**DO 5-1:** Align default settings with 1547.	☐
		DO 5-2: Select other default settings within 1547 ranges of adjustment.	☐
Frequency trip settings and ranges	Ensure that the under/overfrequency trip settings are coordinated between the utility and transmission operator. As desired, select default settings or settings within the adjustable range. Trip settings should not hinder ride-through capability required at the transmission level.	**DO 6-1:** Align default settings with 1547.	☐
		DO 6-2: Select other default settings within 1547 ranges of adjustment.	☐
Frequency droop[4] settings	This capability is required for all DERs (with some limitations on Category I types) during the under/overfrequency conditions. Consider using default settings or adjust within ranges of allowable settings. Consider input from transmission operators or regional reliability coordinator. [MTGS V.A]	**DO 7-1:** Align default settings with 1547.	☐
		DO 7-2: Select other default settings within 1547 ranges of adjustment.	☐
Voltage regulation modes by reactive power[5]	If desired, consider activating a non-unity power factor, volt-var, watt-var, or constant var function. See PNNL research on autonomously adjusting V_{ref}.[6] Also, consider statewide (or similar) default settings for such mode. [MTGS V.B, VI]	**DO 8a-1:** Adjustable constant power factor is activated.	☐
		DO 8a-2: Utilize volt-var without autonomously adjusting V_{ref}.	☐
		DO 8a-3: Utilize volt-var with autonomously adjusting V_{ref}.	☐
		DO 8a-4: Watt-var is activated.	☐
		DO 8a-5: Constant var[7] is activated.	☐
		DO 8b-1: Align default settings with 1547.	☐

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Timeline to compliance

- **April 2018** — IEEE publishes 1547-2018
- **May 2020** — IEEE publishes 1547.1-2020
- **August 2020** — UL updates 1741 allowing start of DER testing and certification
- NEW! **Sept 2021** — UL 1741 SB revised to fill in 1547.1 gaps
- **2022-2023** — Tested and certified 1547-2018-compliant DER available on market

MD: January 1, 2022 …extending (March 28, 2023 proposed)

HI: January 1, 2022 …extending (currently February 1, 2023)

MN: "such time the equipment is readily available"

CA: Proposed March 28, 2023

MA, NY: January 1, 2023

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Basic Components of Timeline

- Testing
- Issuance of Certificate (~1 -2 weeks)
- Qualified Equipment List (1 month ?)
- Shipping logistics (2-6 months, 3 typical)

Adoption Timeline

Weeks	Expected Accumulation
0	0.0%
12	1.9%
24	12.3%
36	47.1%
48	67.1%
60	80.6%
72	84.5%
144	100.0%

Chart shows cumulative certifications for each NRTL testing pathways over time. Vertical line represents one year

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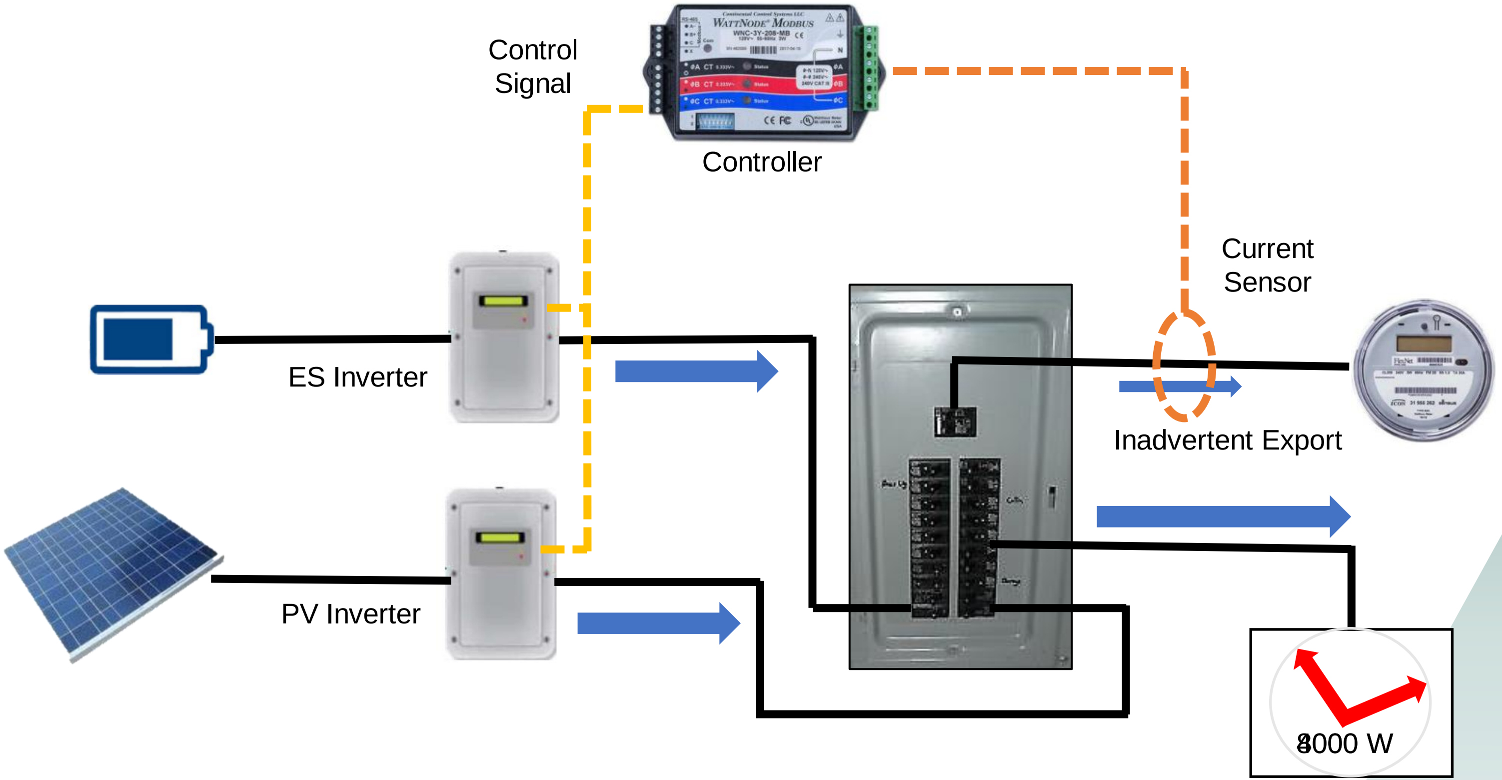
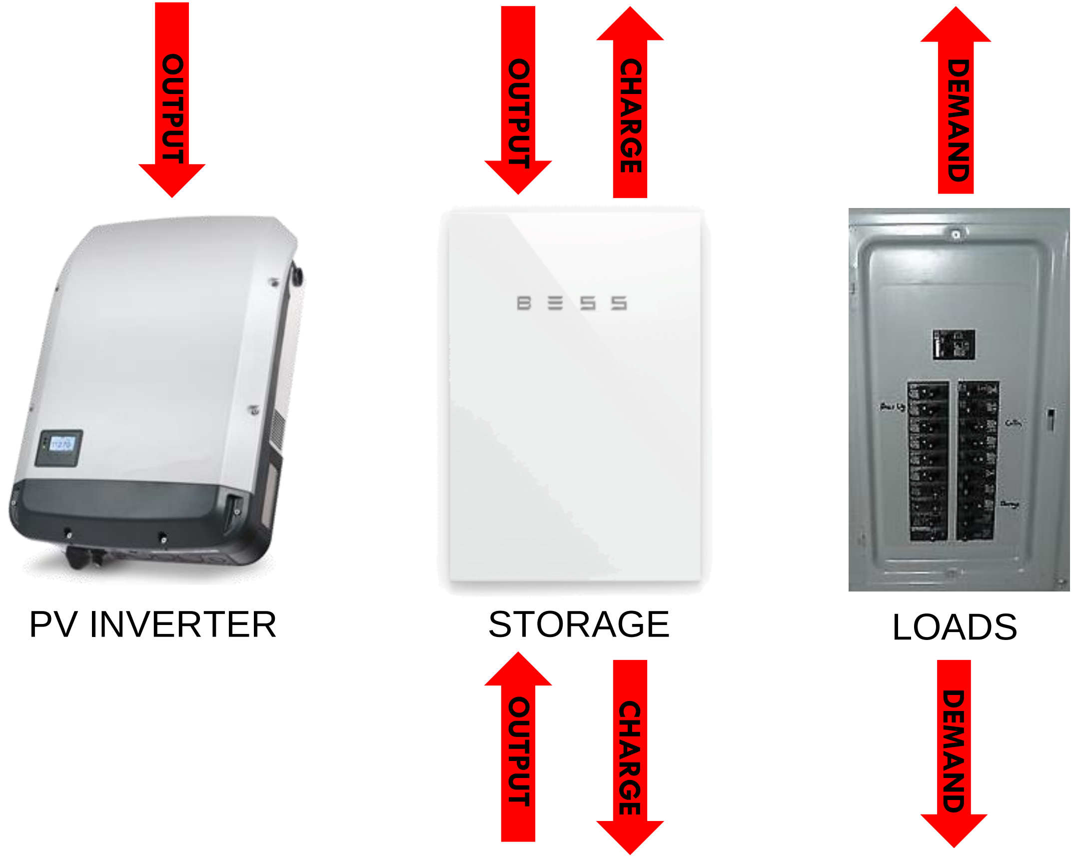
Export Limitation

How a PCS Works (Sample Configuration)



Export –Limiting Flexibility



Limited-Export Storage Basics

- Customers may want to design their storage systems to limit export to:
  - Avoid or reduce grid impacts and the need for costly infrastructure upgrades
  - To take advantage of time of use or other rate structures with differentiated pricing
  - To maximize on-site energy use

New and Requires More Refined Approach

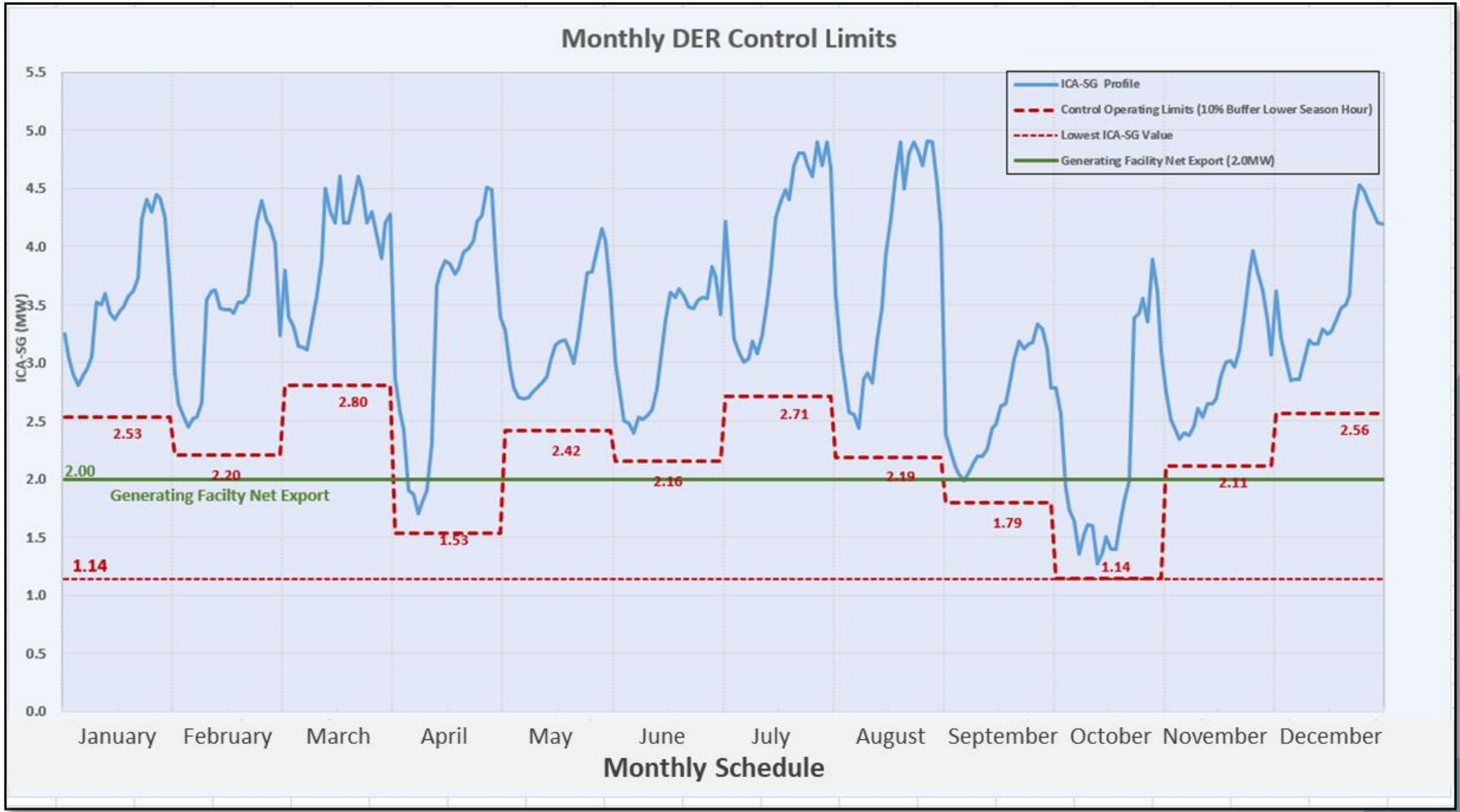
- The concept of limited export has challenged the existing frameworks for both all-export and non-export
- Puts the focus on refining the terminology for the “capacity” that will be evaluated for each technical criteria
- A handful of state rules now recognize limited export, but in most cases this is still limited to a static export value vs. one that is schedule or dynamic.

Screens Recommendations for FERC SGIP

Screen	Change	Nameplate	Export
2.1.1.1 Available service	none	n/a	n/a
2.1.1.2 ≤15% of peak rule	Use DER export		X
New Screen: Inadvertent export	**add ΔV <3%***	**X**	**X**
2.1.1.3 if network (spot/area)	Use DER nameplate	X	
2.1.1.4 ≤10% increase in fault current	Use DER nameplate	X	
2.1.1.5 <87.5% interrupting capability	Use DER nameplate	X	
2.1.1.6 Grounding compatibility	Consider inverter DER	n/a	n/a
2.1.1.7 Shared secondary <65% of trans. or <20kW	Use DER export		X
2.1.1.8 120/240 Unbalance <20% of trans. kVA	Use DER nameplate	X	
2.1.1.9 Shall not exceed 10 MW	Use DER nameplate	X	
2.4.4.1 Minimum load screen <100%	Use DER export		X
2.4.4.2 Voltage and PQ screen	Consider export control	X	X
2.4.4.3 Safety and reliability screen	Consider export control	X	X

*Use nameplate rating - export to determine if ΔV <3% as a RVC

Scheduled output



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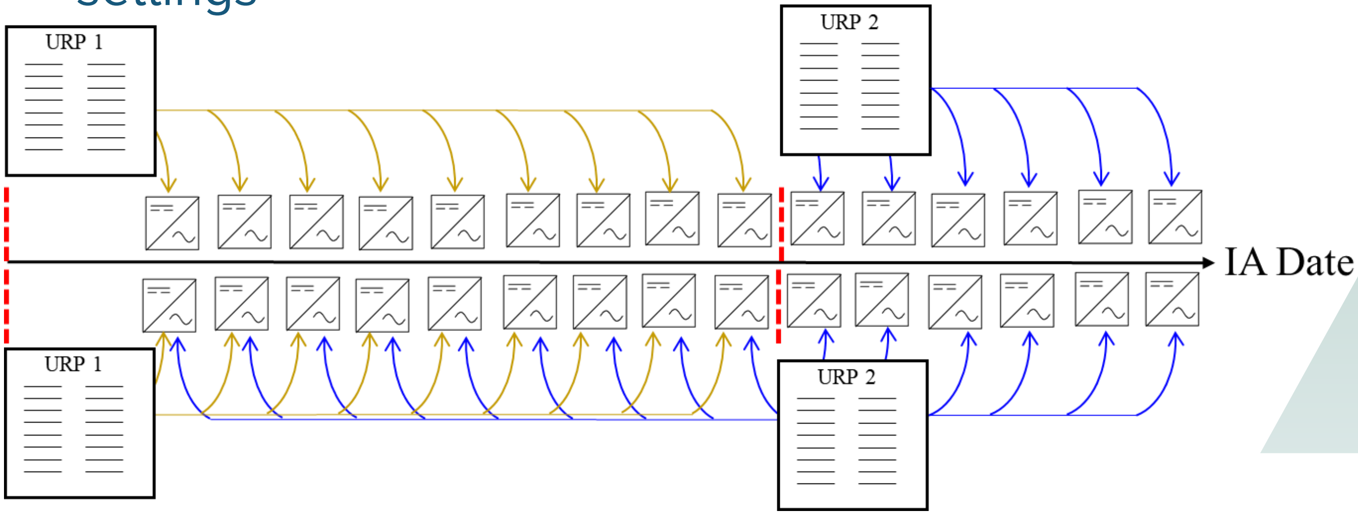
Other Interconnection Issues

Retro-active enablement

- CA found "natural turnover" to be preferred to requiring/stimulating smart inverter updates
- HI intends to only use communications to deploy new settings

Without comms:

With comms:



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Effective Grounding: Inverters vs. Rotating Machines

- Until IEEE C62.92.6, inverters were treated similarly to rotating machines to determine effect on GFOV
- C62.92.6 notes the physical differences, and how grounding does not play the same role
- Ground sources should be treated differently for inverter-based DER

Line Configuration Screen (LCS)

Primary Distribution Line Type	Type of Interconnection to Primary Distribution Line	Result/Criteria
Three-phase, three-wire	*~~3-phase or single-phase, phase-to-phase~~ If ungrounded on primary or any type on secondary*	*Pass screen*
Three-phase, four-wire	*~~Effectively-grounded 3 phase or Single-phase, line-to-neutral~~ Single-phase line-to-neutral*	*Pass screen*
Three-phase, four-wire (for any line that has sections or mixed three-wire and four-wire)	*All others*	*Pass screen for inverter-based generation if aggregate generation rating is ≤ 100% feeder* minimum load, or ≤ 30% feeder* peak load (if minimum load data isn't available)* *Pass screen for rotating generation if aggregate generation rating ≤ 33% of feeder* minimum load, or ≤ 10% of feeder* peak load (if minimum load data isn't available)* *(*or line section)*

Grounding Review Within Supplemental Review (SR)

- If project failed the Line Configuration, apply this SR Grounding screen
  - Projects with rotating machines
    - If effective grounding is maintained → The project passes
  - Projects with a three-phase inverter
    - If LN load >33% of peak load → The project passes
    - If using a Supplemental Grounding (SG) software tool → The tool determines if SG is or isn’t required to maintain effective grounding. The project passes if SG is not required
    - If using detailed HCA that incorporates evaluation of temporary overvoltage risk for inverter → The project passes if nameplate rating is below hosting capacity at POI

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Flicker

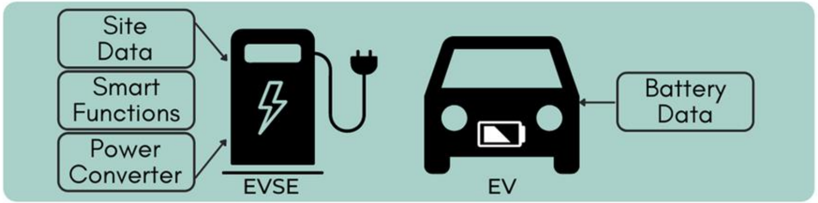
- Usually addressed in Supplemental Review and Detailed Study
- Per EPRI, PV doesn't generally introduce flicker
- Flicker screening is "behind the scenes" and assumptions may vary between utilities
- Assumptions are likely very conservative in general
- How should ESS be screened?

Voltage Headroom

- Utilities generally only allow DERs to push voltage to a max of ANSI Range A (105% nominal) at minimum load
- ANSI C84.1 allows for limited excursions into Range B and beyond (which do occur on the distribution system, regardless of DER)
- Utilities have different regulation strategies, resulting in differences in DER hosting capacity
- E.g., load drop compensation, Conservation Voltage Reduction
- Different modeling assumptions may come into play

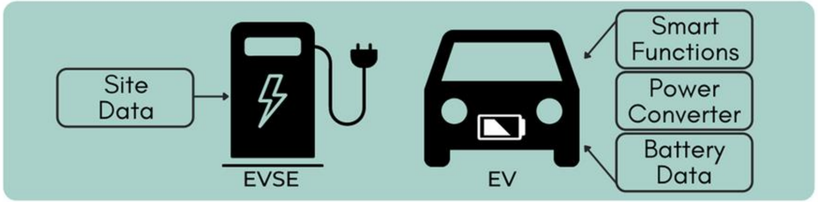
V2G Configurations

V2G-DC



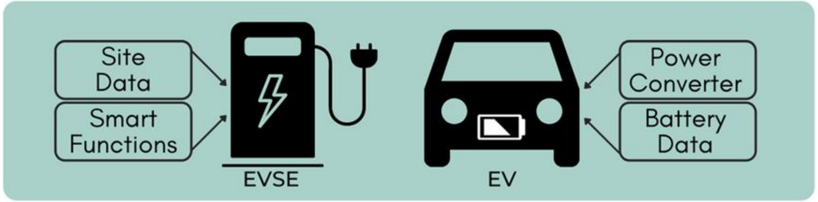
Expected Conformance:
EVSE is listed to UL 1741 (could include SA or SB).

V2G-AC



Expected Conformance:
EVSE is listed to UL 1741 SC.
EV is certified to SAE J3072.

V2G-SPLIT INVERTER



Expected Conformance:
Not clear yet, however, in practice, the EVSE and EV will need to be tested to IEEE 1547.1.

Create processes that allow review of this grid integration conformance.

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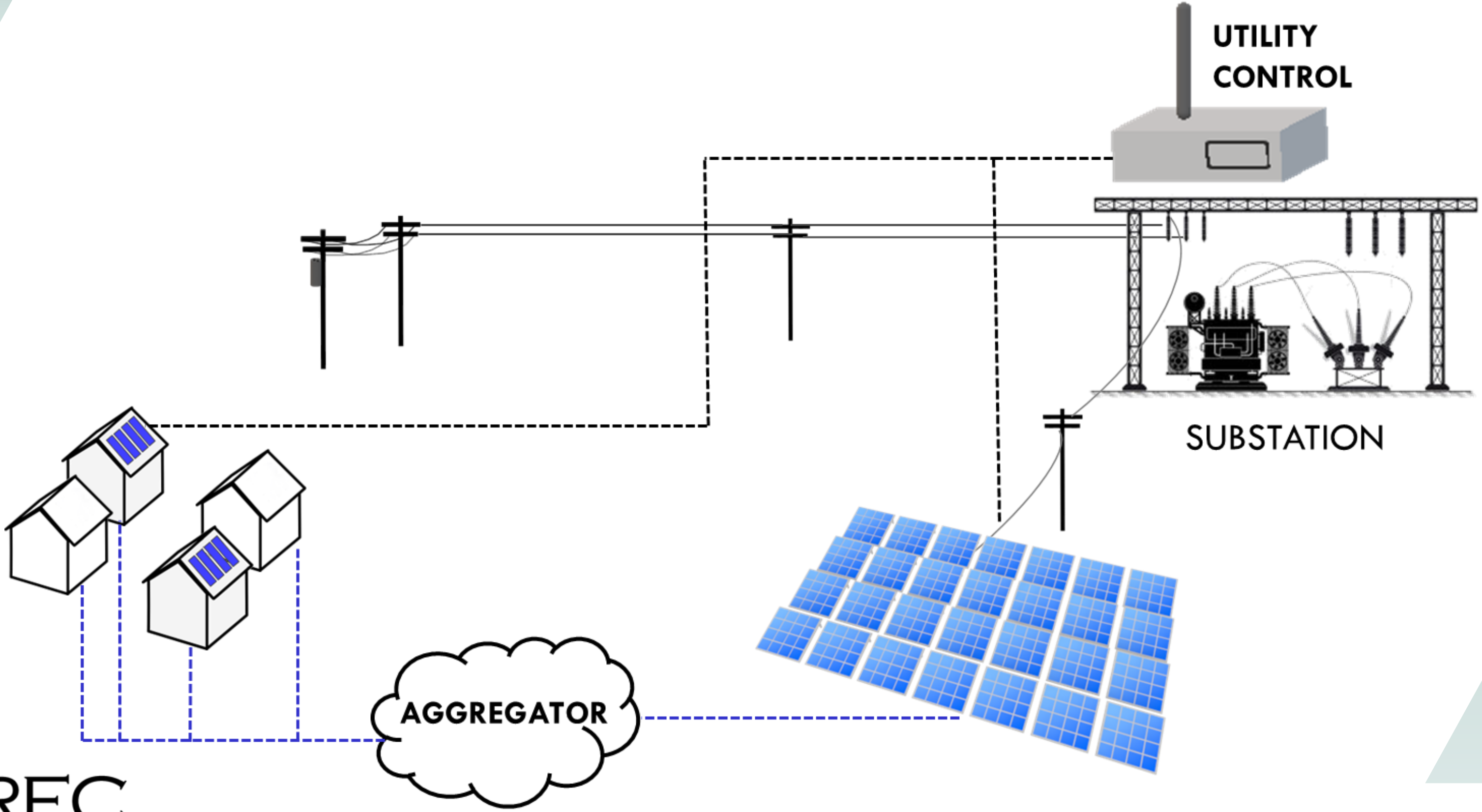
Control?



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Thank you!

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