

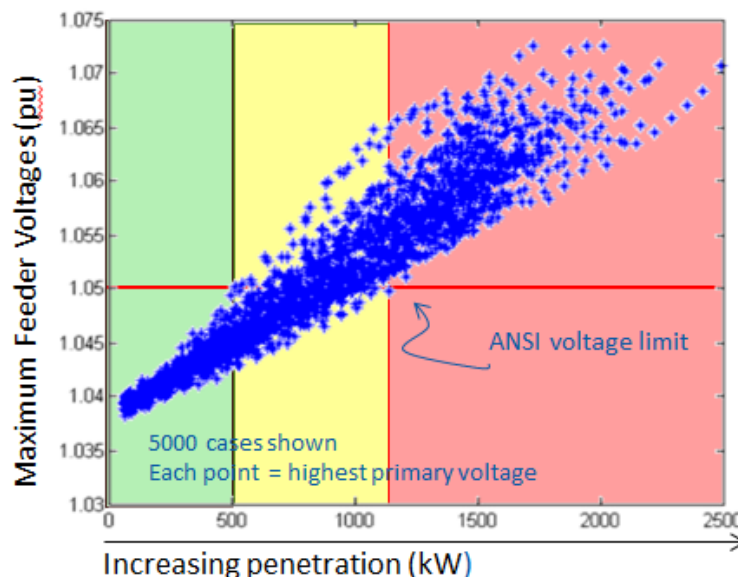
Advanced Inverter Functions and their Impact on Hosting Capacity

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First, a word on hosting capacity...

- Hosting capacity (HC) is typically a single number reflecting the amount of DER which can be interconnected *anywhere* on a distribution circuit *which would not require any circuit changes/upgrades*

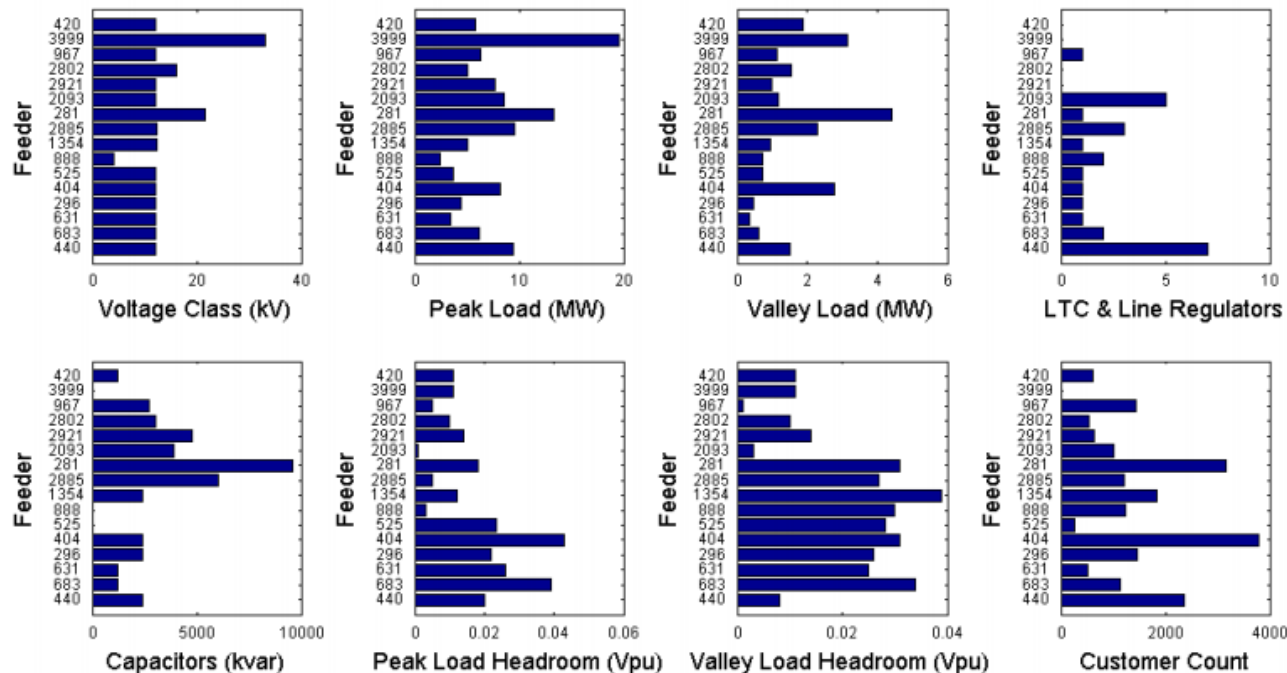


HC is also often used as an interconnection screen

See: J. Smith, M. Rylander, R. Broderick, M. Reno, B. Mather., "Alternatives of the 15% Rule." California Solar Initiative RD&D Report Dec. 2015 - http://www.calsolarresearch.ca.gov/images/stories/documents/Sol3_funded_proj_docs/EPRI/CSI-RDD_S3_EPRI_Final-Report_Dec2015.pdf.

Second, a word on generalizing...

- It should not be surprising that HC will depend on the characteristics a specific distribution circuit, making generalization difficult



See: J. Smith, M. Rylander, R. Broderick, M. Reno, B. Mather., "Alternatives of the 15% Rule." California Solar Initiative RD&D Report Dec. 2015 - http://www.calsolarresearch.ca.gov/images/stories/documents/Sol3_funded_proj_docs/EPRI/CSI-RDD_S3_EPRI_Final-Report_Dec2015.pdf.

Advanced Inverter Functions

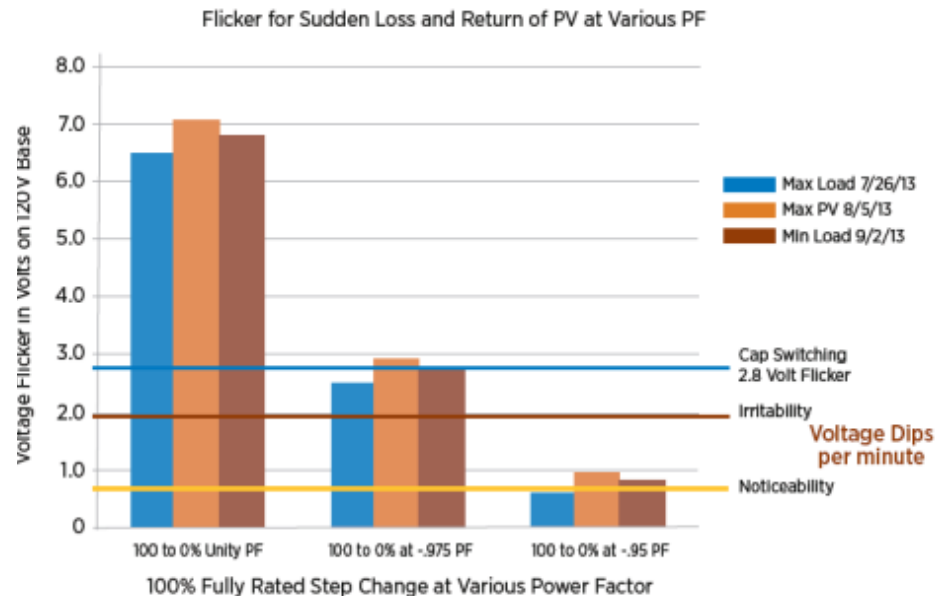
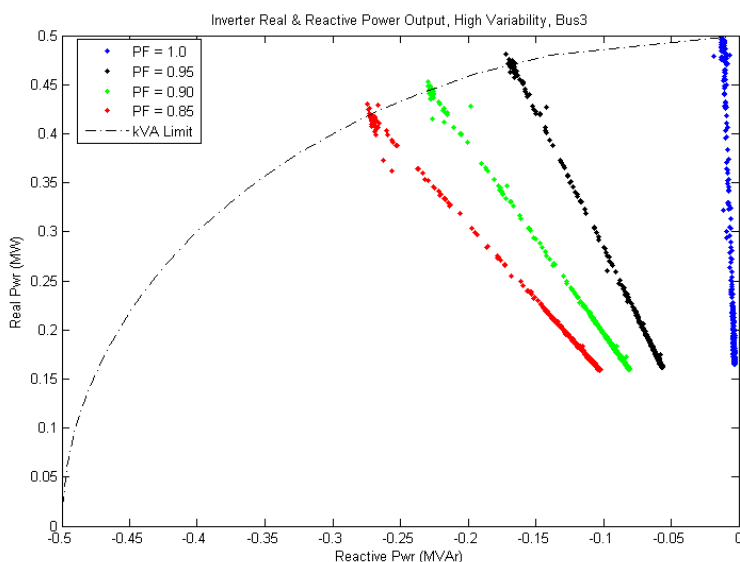
IEEE 1547-2018 Performance Categories (Grid support under normal grid conditions)		Mandatory Voltage Regulation Capabilities				
		Constant Power Factor Mode	Constant Reactive Power Mode ("reactive power priority")	Voltage-Reactive Power Mode ("volt-VAR")	Active Power-Reactive Power Mode ("watt-VAR")	Voltage-Active Power Mode ("volt-watt")
Category A	Meets minimum performance capabilities needed for area EPS voltage regulation Reasonably attainable by all state-of-the-art DER technologies	✓	✓	✓	Not required	Not required
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	✓	✓	✓	✓	✓

- With the standard updated, we have many “tools” to use to increase hosting capacity

Power Factor for Large PV Systems

- Specifically for mitigating voltage issues, constant PF likely increases HC by:

3x-10x

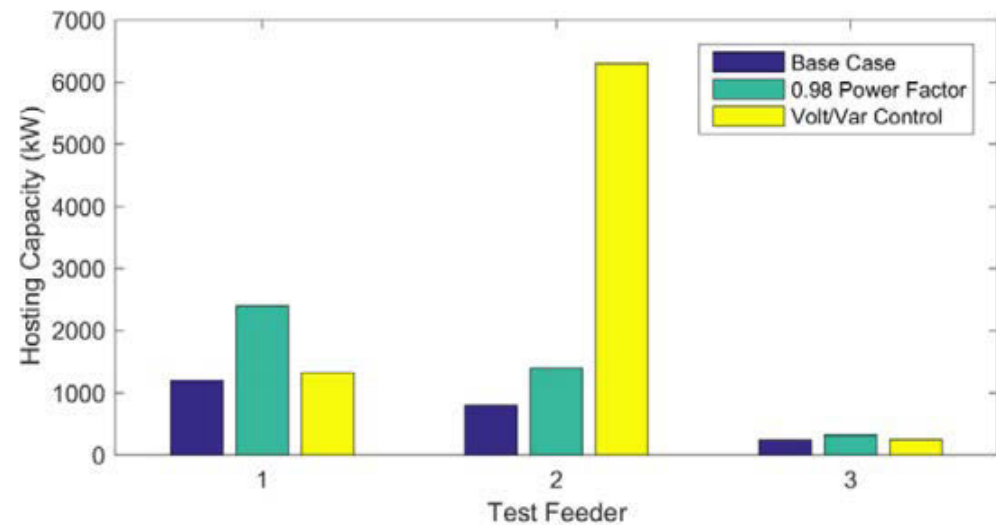
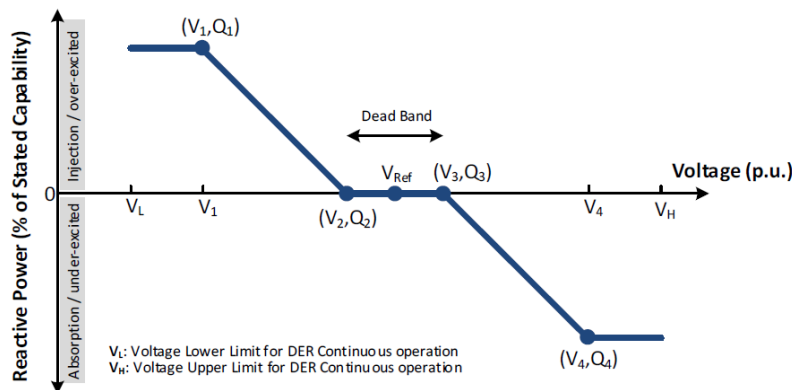


See: R. Seguin, J. Woyak, D. Costyk, J. Hambrick, B. Mather, "High-Penetration PV Integration Handbook for Distribution Engineers." NREL Tech Report TP-5D00-63114, Jan. 2016 - <https://www.nrel.gov/docs/fy16osti/63114.pdf>

Volt/Var for Many Small DERs

- Specifically for mitigating voltage issues, volt/var functionality increases HC by:

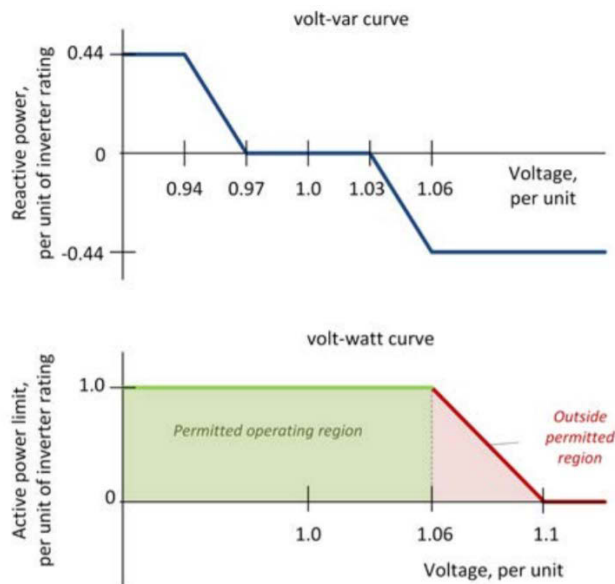
2x-7x



See: B. Palmintier, R. Broderick, B. Mather, M. Coddington, K. Baker, F. Ding, M. Reno, M. Lave, A. Bharatkumar, "On the Path to SunShot: Emerging Issues and Challenges in Integrating Solar with the Distribution System." NREL Tech Report TP-5D00-65331, May 2016 - <https://www.nrel.gov/docs/fy16osti/65331.pdf>

Volt/Var & Volt/Watt Combined

- For mitigating voltage issues, volt/var + volt/watt functionality increases HC by: **2x-5x**



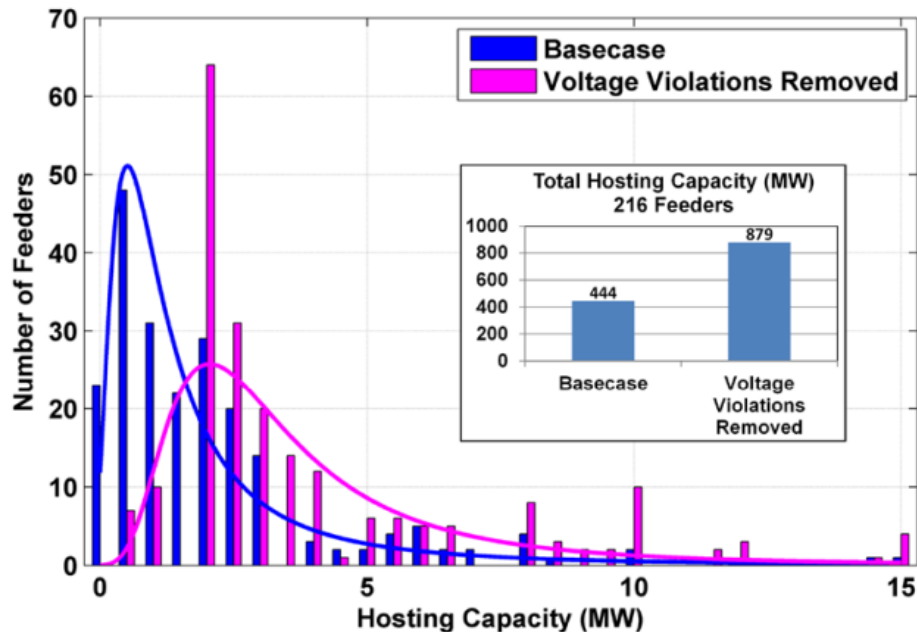
Metrics	GDML penetration levels					
	175%		370%		600%	
	VV	VV-VW	VV	VV-VW	VV	VV-VW
Max GSF Curt.	1.8%	2.3%	1.8%	3.7%	1.8%	5.7%
Ave. GSF Curt.	0.10%	0.07%	0.15%	0.13%	0.24%	0.23%
Ave. Incr. Gen.	2.1%	2%	2.7%	2.6%	2.7%	3%
Ave. Net Gen.	2%	1.9%	2.5%	2.4%	2.4%	2.8%

Note: GDML is gross daytime minimum load (100% GDML \approx 15% Peak), maximum HC improvement is extrapolated to max curtailment of 5%.

See: J. Giraldez, M. Emmanuel, A. Hoke, S. Suryanarayanan, "Impacts of Voltage-based Grid Support Functions on Energy Production of PV Customers." in proc. IEEE PES GM, Atlanta, GA, Aug. 2019.

Max HC Improvement

- If all voltage concerns can be mitigated using advanced functionality the HC increases: **2x**



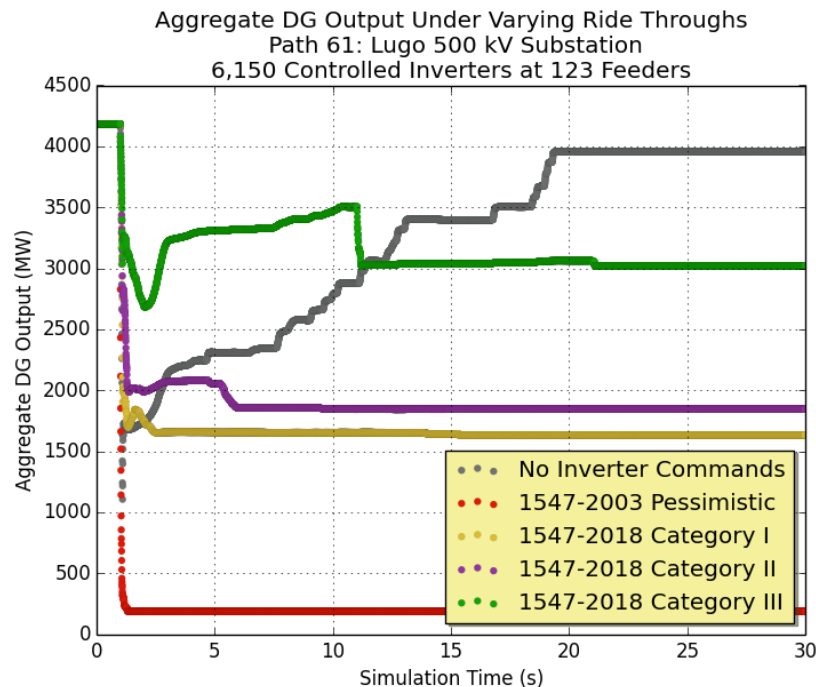
See: B. Palmintier, R. Broderick, B. Mather, M. Coddington, K. Baker, F. Ding, M. Reno, M. Lave, A. Bharatkumar, "On the Path to SunShot: Emerging Issues and Challenges in Integrating Solar with the Distribution System." NREL Tech Report TP-5D00-65331, May 2016 - <https://www.nrel.gov/docs/fy16osti/65331.pdf>

Other Challenges to Increasing HC

- Islanding/protection concerns – low fault current contribution, fault current masking, temporary over-voltage, transient over-voltage...
- Power quality concerns – harmonics, controller interactions...
- Bulk system concern (i.e. aggregate DER concerns)

Bulk System DER Concerns

- 4 GW of DER in the greater Los Angeles Basin responding to a transmission-level fault



Depending of DER
ride-through settings
DER-based generation
loss ranges from 4
GW to 1.5 GW

See: R. W. Kenyon, B. Mather, "Simulating Distributed Energy Resource Responses to Transmission System-Level Faults Considering IEEE 1547 Performance Categories on Three Major WECC Transmission Paths." NREL Tech Report TP-5D00-73071, Feb. 2020 - <https://www.nrel.gov/docs/fy20osti/73071.pdf>

Thank you for your attention.

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