Interconnection Standards for PV Systems

Where are we? Where are we going?

Abraham Ellis

Sandia National Laboratories

aellis@sandia.gov

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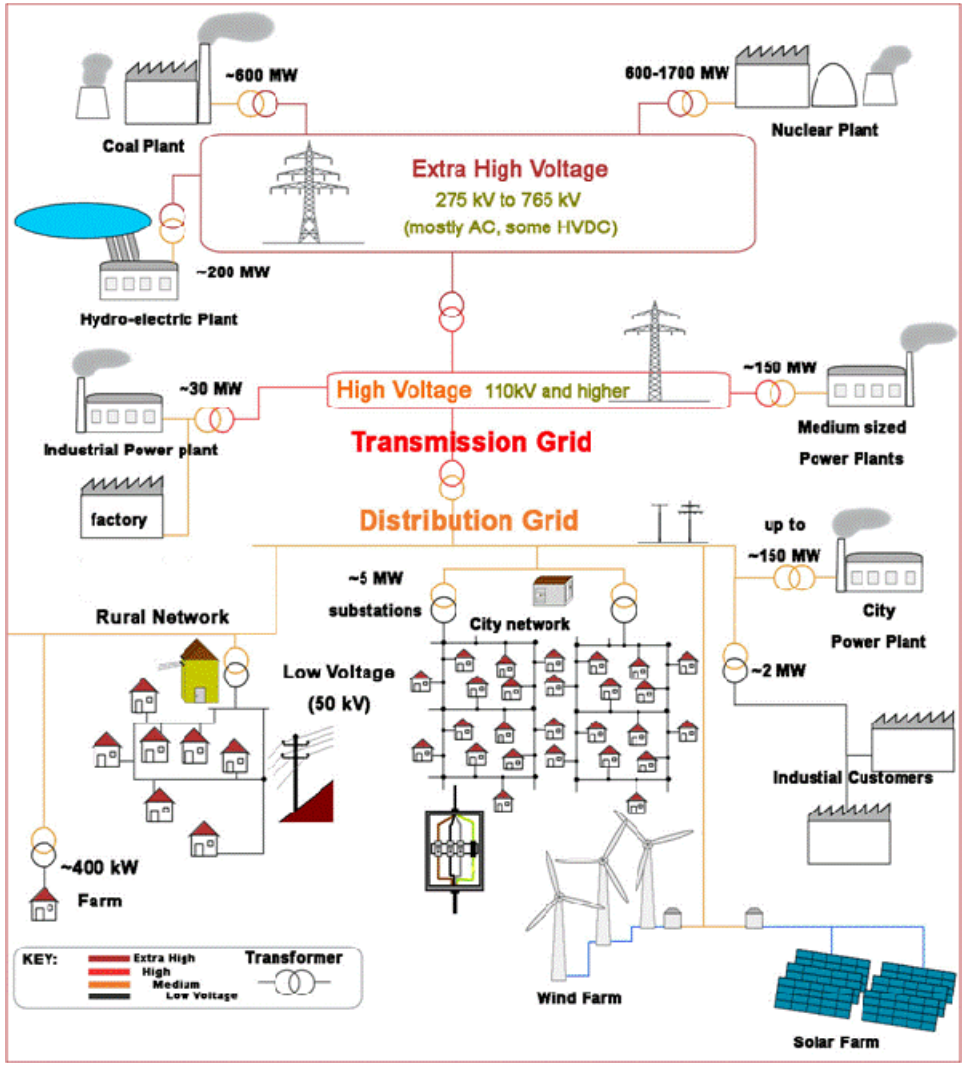
Generator Interconnection Standards

- Establish uniform technical and procedural requirements for interconnection of generation on the electric grid
- Interconnection standards are driven by
  - Safety (people and property)
  - Grid reliability, performance
  - Cost considerations
  - Fairness ("…just and reasonable, and not unduly discriminatory or preferential")

What Interconnection Standards and Procedures Apply?



Bulk System Guidelines
NERC, FERC
IEEE, ANSI, IEC
NESC

Plenty of technical and jurisdictional overlap, confusion, contradiction…

Distribution System Guidelines
IEEE 1547, PUC/PRC
IEEE, ANSI, IEC
NEC

Federal-Jurisdictional Interconnection Standards (FERC Order)

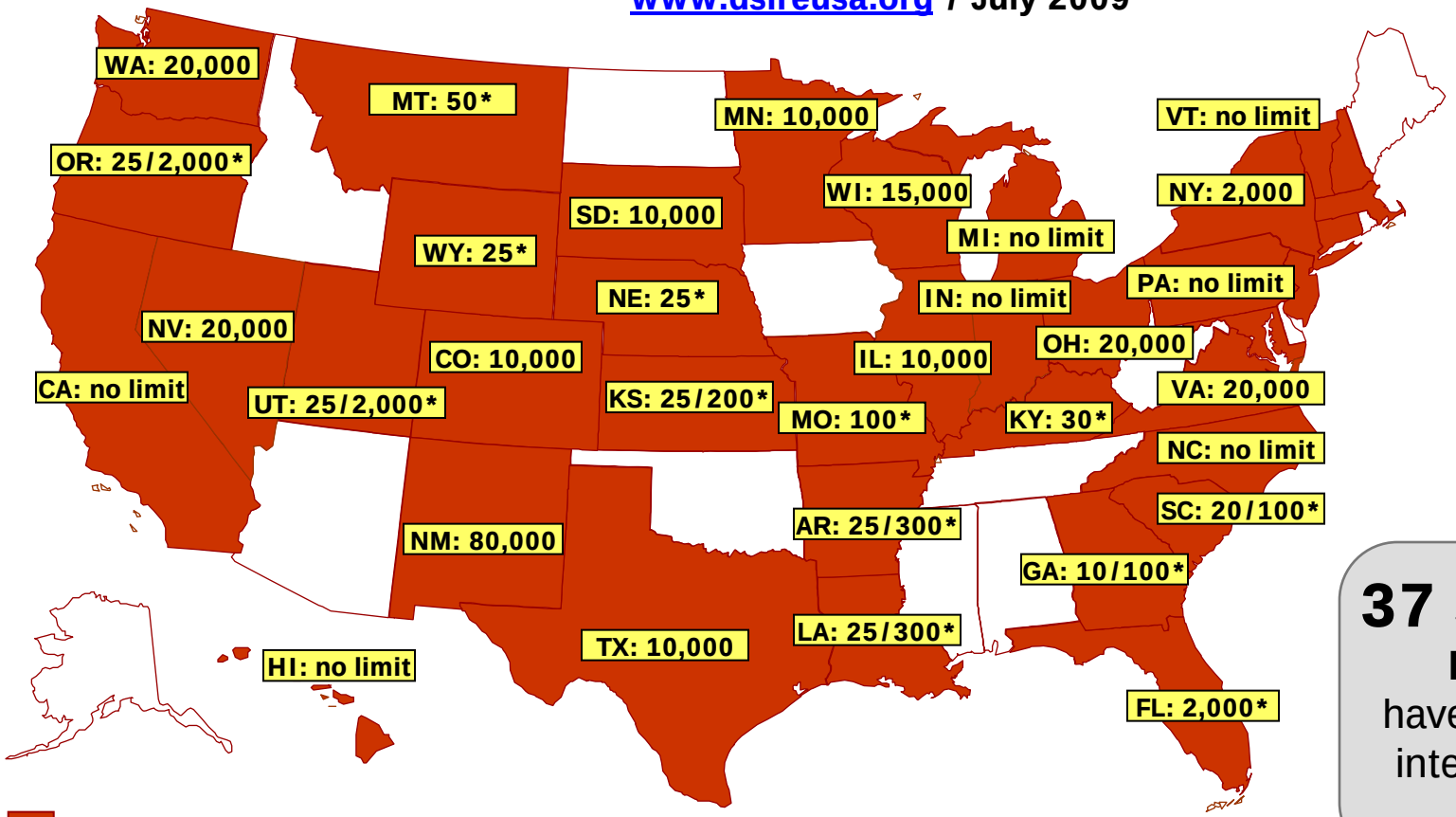
- Apply to generators, participating in wholesale market, regardless of size and interconnection location
  - TSO/DSO follow *pro-forma* procedures via OATT
- Procedures and requirements generally based on size
  - Large Generating Facilities (>20 MW): LGIP/LGIA
  - Small Generating Facilities (SGF) (<20 MW): SGIP/SGIA
- SGIP has streamlined process for smaller DER
  - Fast Track Process for certain generators no larger than 2 MW
  - 10 kW Inverter Process for certified inverter-based generators no larger than 10 kW (SGIP Attachment 5)

State-Jurisdictional Interconnection Standards (PUC/PRC Rule)

- Apply to generators up to a certain size, connected to the grid, but not participating in wholesale market
  - Net Metering, PURPA or similar arrangement for "sale" of electricity to the host utility only
  - Typically cover RE and other DG, all customer classes
- Procedures and standards vary by state
  - Generally conform with FERC SGIP, but some have significant differences
- Technical standards focused on the distribution system and DER

State-Jurisdictional Interconnection Standards

www.dsireusa.org / July 2009



37 states +
DC & PR
have adopted an interconnection policy

Notes: Numbers indicate system capacity limit in kW. Some state limits vary by customer type (e.g., residential/non-residential).“No limit” means that there is no stated maximum size for individual systems. Other limits may apply. Generally, state interconnection standards apply only to investor-owned utilities.

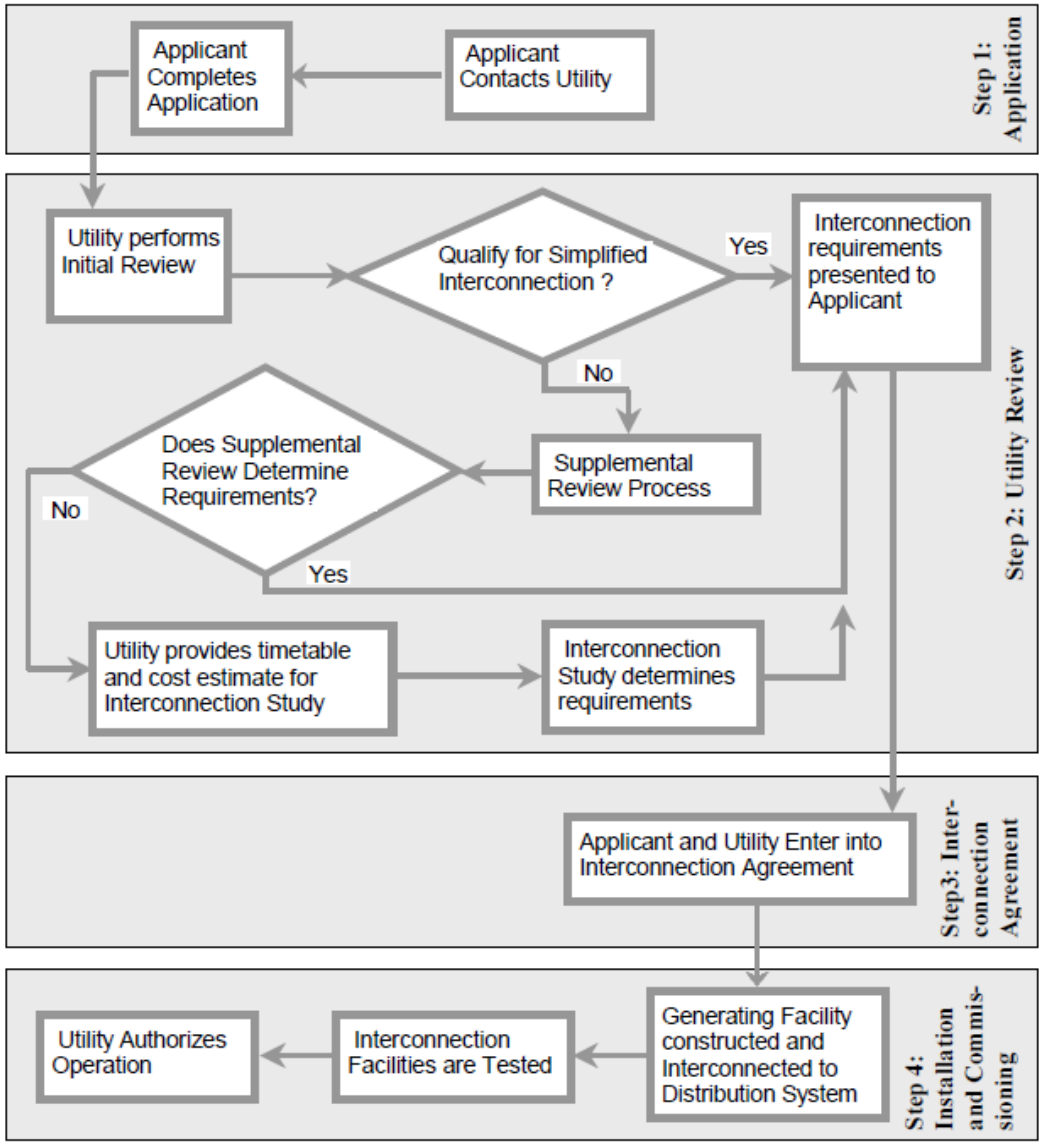
Interconnection Requirements for SGF (FERC Order 2006)

- Fast Track Process for SGF that pass certain “screens”
  - SGF capacity <2 MW
  - SGF meets codes, standards and certification
  - Total SGF capacity <15% of peak load in the circuit
  - If connecting to Spot Network, SGF must be inverter-based, not exceeding 5% of maximum load or 50 kW
  - Total SGF fault current <10% of total fault current
  - Addition of SGF does not cause distribution equipment and protective devices to exceed 87.5% of rating
  - Transformer connection compatible with utility circuit
  - <20kW for single phase, <20%imbalance among phases

Typical DER Interconnection Process

- Example:

CPUC Rule 21 Interconnection Process

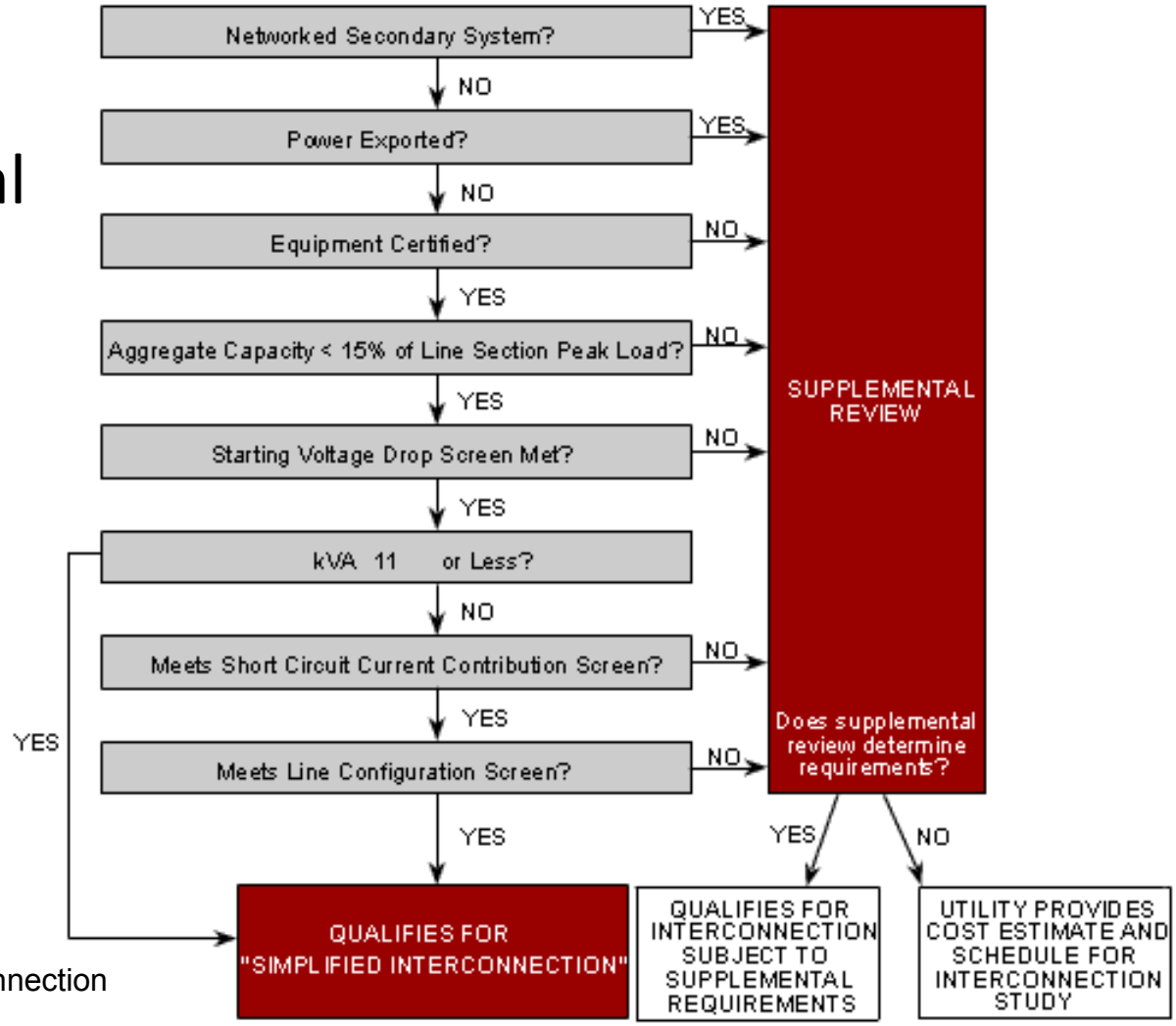


Source: California Interconnection Guidebook
http://www.energy.ca.gov/distgen/interconnection/guide_book.html

Typical DER Interconnection Process

- Example:

CPUC Rule 21 Initial Technical Review Methodology



Source:
http://www.energy.ca.gov/distgen/interconnection/application.html

IEEE 1547 Standard Family

(Applies to DER no larger than 10 MVA)

No.	Title	Status
1547	Standard for Interconnecting Distributed Resources with Electric Power Systems	2003
1547.1	Standard for Conformance Tests Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems	2005
1547.2	Application Guide for IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems	2008
1547.3	Guide For Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems	2007
1547.4	Draft Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems	Pending
1547.5	Draft Technical Guidelines for Interconnection of Electric Power Sources Greater than 10MVA to the Power Transmission Grid	Pending
1547.6	Draft Recommended Practice For Interconnecting Distributed Resources With Electric Power Systems Distribution Secondary Networks	Pending
1547.7	Draft Guide to Conducting Distribution Impact Studies for Distributed Resource Interconnection	Pending

Interconnection Standards for Distributed Energy Resources

- IEEE 1547 Voltage and Frequency Tolerance

Voltage Range (% Nominal)	Max. Clearing Time (sec) *
V < 50%	0.16
50% ≤ V < 88%	2.0
110% < V < 120%	1.0
V ≥ 120%	0.16

(*) Maximum clearing times for DER ≤ 30 kW; Default clearing times for DER > 30 kW

Frequency Range (Hz)	Max. Clearing Time (sec)
f > 60.5	0.16
f < 57.0 *	0.16
59.8 < f < 57.0 **	Adjustable (0.16 and 300)

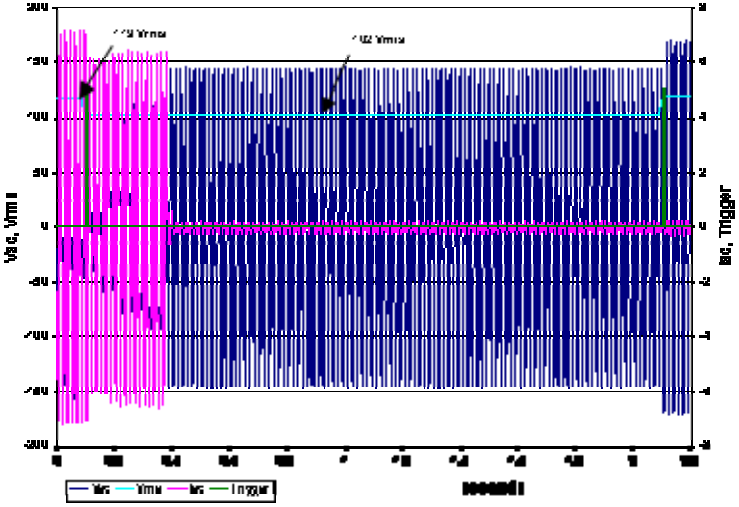
(*) 59.3 Hz if DER ≤ 30 kW

(**) For DER > 30 KW

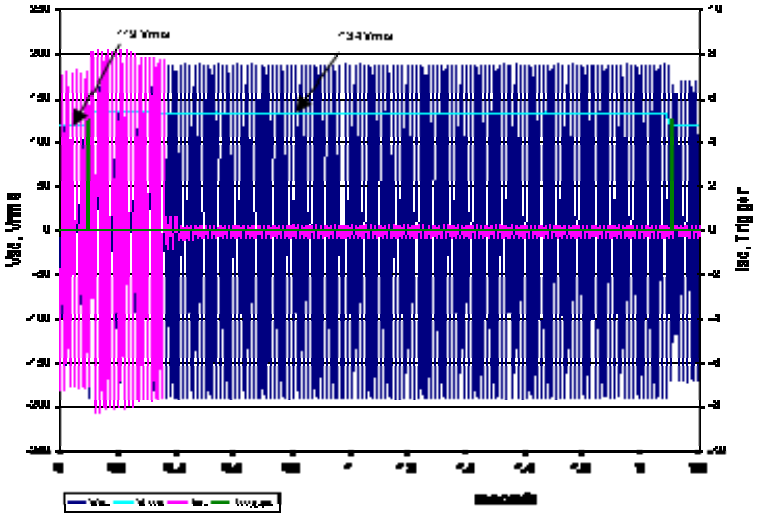
- Additional disconnection requirements
  - Cease to energize for faults on the Area EPS circuit
  - Cease to energize prior to circuit reclosure
  - Detect island condition and cease to energize within 2 seconds of the formation of an island (“anti-islanding”)

Interconnection Standards for Distributed Energy Resources

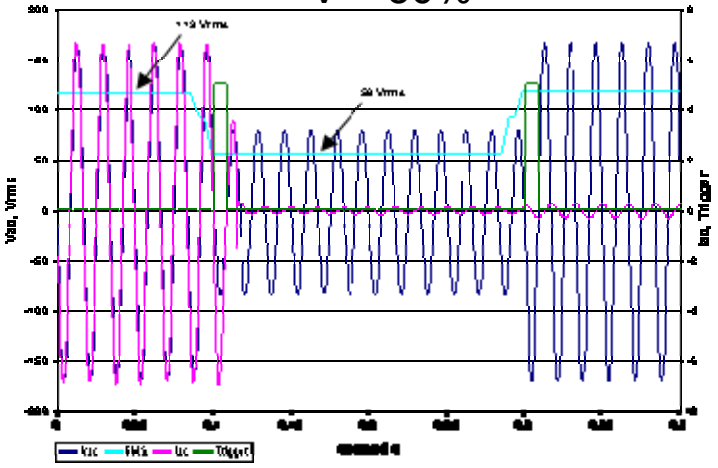
50% < V > 88%



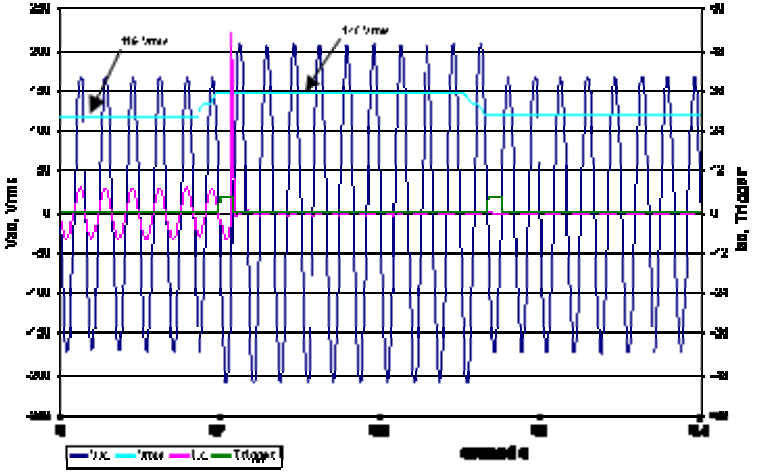
110% < V > 120%



V < 50%



V > 120%



Interconnection Standards for Distributed Energy Resources

- Other applicable codes and standards (not

	Requirement
Voltage Regulation	Maintain service voltage within ANSI C84 Range A (+/-5%)
Voltage control	Not permitted (IEEE 1547)
Flicker	Maximum Borderline of Irritation Curve (IEEE 1453)
Harmonics	<5% THD; <4% below 11^{th}; <2% for 11^{th} – 15^{th}, <1.5% for 17^{th} – 21^{st}; 0.6% for 23^{rd} – 33^{rd}; <0.3% for 33^{rd} and up (IEEE 519)
Power Factor	Output power factor 0.85 lead/lag or higher (equipment typically designed for unity power factor)
Direct Current Injection	<0.5% current of full rated RMS output current (IEEE 1547)
Synchronization and Protection	Dedicated protection & synchronization equipment required, except smaller systems with utility-interactive inverters
Safety	NFPA NEC, IEEE NESC

Interconnection Standards for Transmission-Connected Systems

- Some key differences compared to DER
  - Need to consider some of these for PV as system size & penetration increase

	Requirement
Voltage Tolerance	Ride through 3-phase fault POI for up to 150 ms
Frequency Tolerance	Based on interconnection requirements
Power Factor Capability	+/- 0.95 pf (or higher depending on study results)
Voltage Control	Power factor, reactive power or voltage control at the discretion of transmission operator
Synchronization, Protection	Dedicated switching and protection equipment required for transmission-connected systems
SCADA/EMS integration	Required in all cases
Power Control	Emerging for high penetration wind. May need handle with market instruments in some cases
Other	NERC FAC/TPL/MOD/PRC/VAR standards

Frequency and Voltage Tolerance Standards (Bulk System)

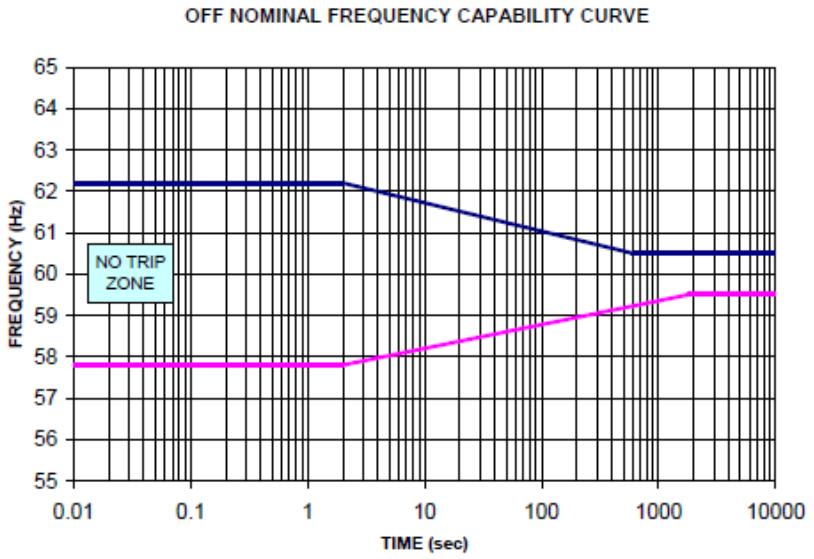
- Voltage Tolerance (LVRT)
  - – Tolerate bolted fault (0 volts) at POI for up to 9 cycles (150 ms)
  - – FERC Order 661-A: applies to wind generators >20 MVA
  - – WECC LVRT criterion: applies to all generators >10 MVA
- Frequency Tolerance
  - – For example, WECC ONF standard, which applies to all generators
- Rules still evolving in the US and elsewhere

WECC Off-Nominal Frequency Tolerance

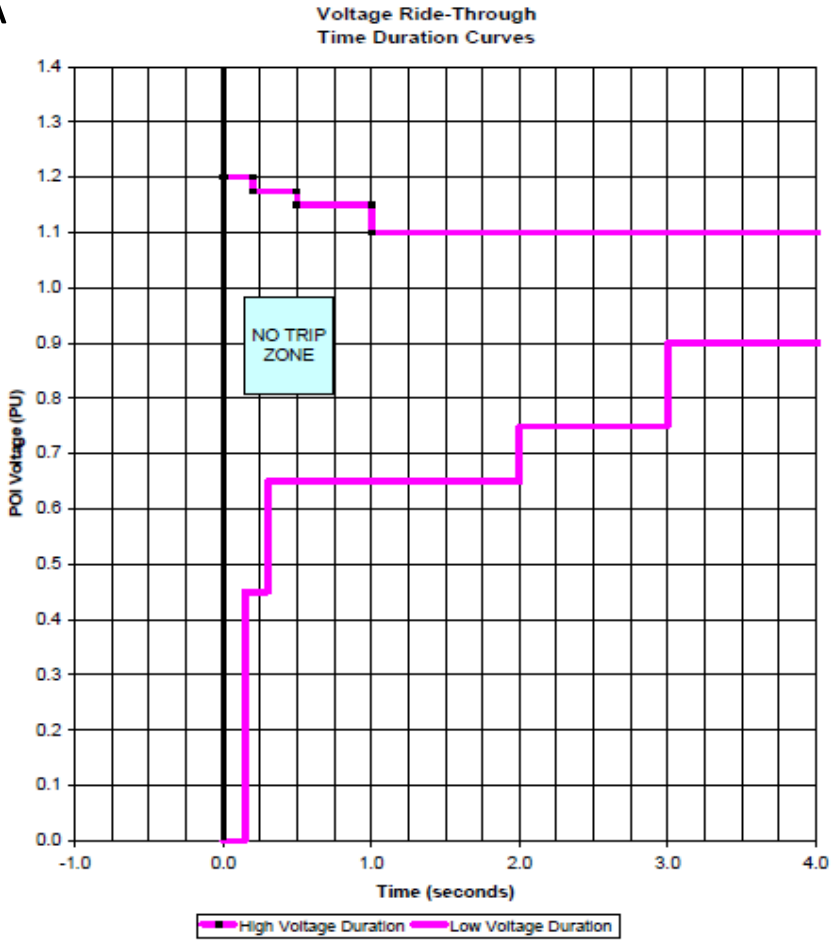
Frequency Range (Hz)	Max. Clearing Time (sec) *
59.4 – 60.5	N/A
59.4 – 58.5 or 60.6 – 61.5	3 min
58.4 – 57.9 or 61.6 – 61.7	30 sec
57.8 – 57.4	7.5 sec
57.3 – 56.9	45 cycles
56.8 – 56.5	7.2 cycles
< 56.4 or >61.7	instantaneous

Frequency and Voltage Tolerance Standards (Bulk System)

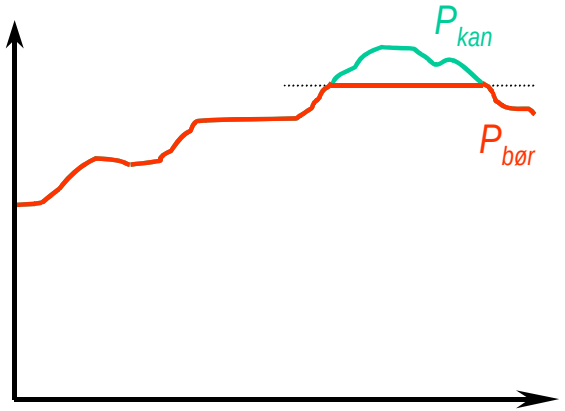
- Proposed NERC PRC-024
  - Would apply to all generators 20 MVA or larger, and stations with multiple units with total capacity of 75 MVA or more



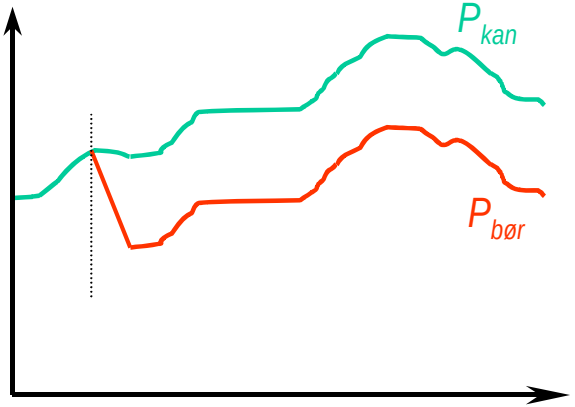
Frequency (hertz)	62.2	60.5	57.8	59.5
Time (seconds)	0 to 2	600 to 10,000	0 to 2	1,800 to 10,000



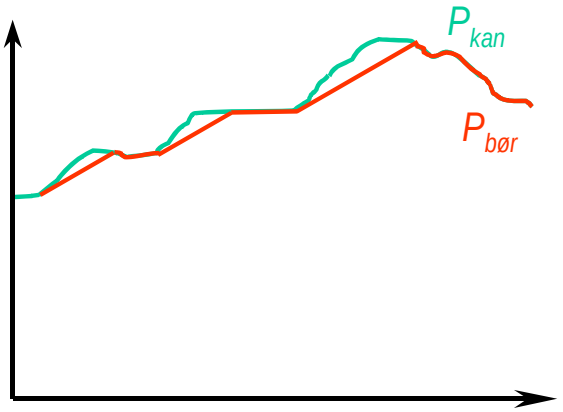
Emerging Power Control for High Penetration Wind



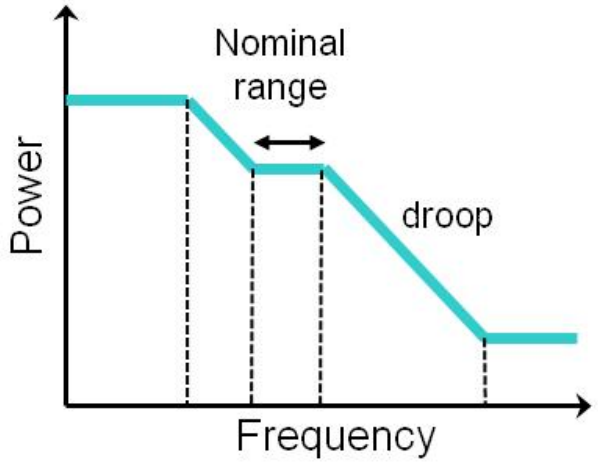
Absolute power limit



Delta power limit



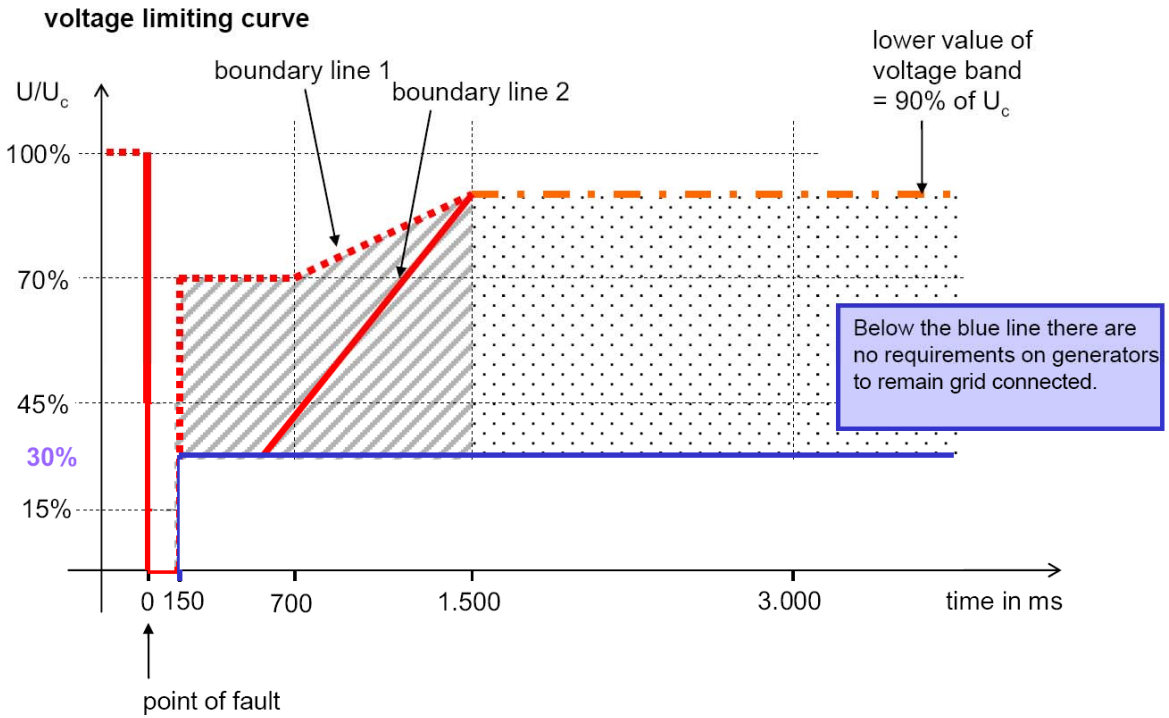
Power ramp limit



Source: Energinet.dk

Medium Voltage Standard in Germany (10 kV to 110 kV)

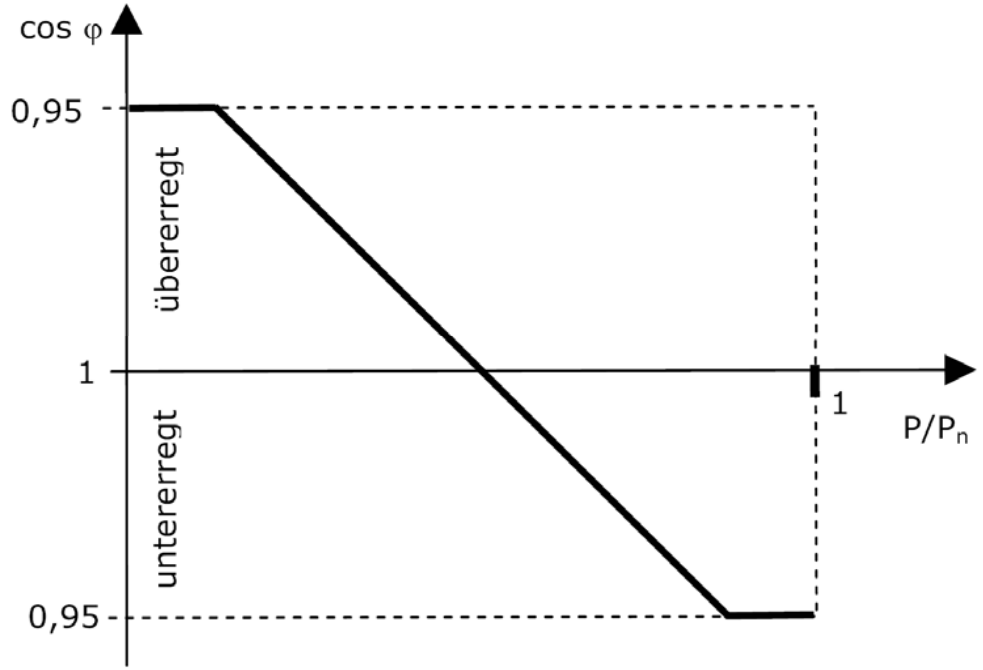
- Fault Tolerance
  - Applies to PV as of 2011
  - Inverters must comply with boundary line 2
  - Must provide reactive support during fault (voltage control)



Source: E. Troester, New German Grid Codes for Connecting PV to the Medium Voltage Power Grid, 2nd International Conference on Concentrating Photovoltaic Power plant

Medium Voltage Standard in Germany (10 kV to 110 kV)

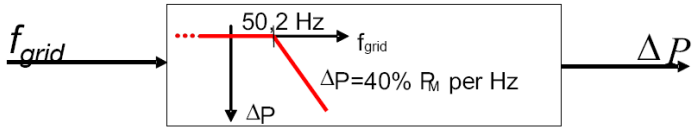
- Static Voltage Support
  - Provide capability of +/- 0.95 pf at full output (impacts equipment rating)
  - Dispatch could be constant pf, constant Var, Var support based on power output (see example below) or Var support based on voltage
  - Applies to PV as of 2010



Source: E. Troester, New German Grid Codes for Connecting PV to the Medium Voltage Power Grid, 2nd International Conference on Concentrating Photovoltaic Power plant

Medium Voltage Standard in Germany (10 kV to 110 kV)

- Active Power Control
  - Reduce power output when frequency is above 50.2 Hz
  - Applies to PV as of 2010



$$\Delta P = 20\, P_M \frac{50{,}2\ Hz - f_{grid}}{50\ Hz} \quad \text{at } 50{,}2\ Hz \leq f_{grid} \leq 51{,}5\ Hz$$

P_M momentary available power

ΔP power reduction

f_{grid} grid frequency

In the range of 47,5 Hz $\leq f_{grid} \leq$ 50,2 Hz no constraint

At f_{grid} $\leq$ 47,5 Hz and f_{grid} $\geq$ 51,5 Hz disconnection

Source: E. Troester, New German Grid Codes for Connecting PV to the Medium Voltage Power Grid, 2nd International Conference on Concentrating Photovoltaic Power plant

A Few Observations

- Wind and PV interconnection standards on different tracks, but converging
- North American approach to bulk system standards tends to be "technology neutral"
  - It makes technical sense to apply different requirements to different technologies (e.g., European approach)
  - Difficult to reach consensus, long process
- IEEE 1547 provides great foundation for DER
- Some future capabilities should be mandated by standards; some should be incentivized by markets
  - E.g., primary frequency support

Where are We Going?

- Reconcile distribution/transmission standards
  - Voltage/frequency tolerance
  - Reactive power capability, volt/var control
  - SCADA integration
  - Power/Frequency control
    - Special cases (e.g., islands) or future very high-penetration?
- Harmonization is important for efficiency and cost
- Several active efforts underway
  - IEEE 1547.4, 1547.5, 1547.6, P2030 (Smart Grid) (http://grouper.ieee.org/groups/scc21/1547/1547_index.html)
  - US: NERC IVGTF (http://www.nerc.com/filez/ivgtf.html)
  - Europe: Medium and low voltage grid codes (GR, SP, FR, IT)

Questions and Discussion

Codes & Standards Specific to PV

Source	Documents
IEEE SCC21 – Standards Coordinating Committee on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage	• IEEE 1547 series (DER up to 10 MVA) • Stand alone PV systems, batteries (several) • P2030 (Smart Grid – New initiative)
Underwriters Laboratories Inc. (UL) PV Standards Technical Panels	• UL 1703 (PV modules) • US 1741 (Inverters, charge controllers)
NFPA	NEC, Article 690 (solar Photovoltaic Systems)
ASTM E44.09 – Technical Committee on Photovoltaic Electric Power Conversion	Several addressing PV module and array testing
IEC TC82 – Solar photovoltaic energy systems	Several addressing measurement, safety, test procedures