Voltage and VAR Regulation

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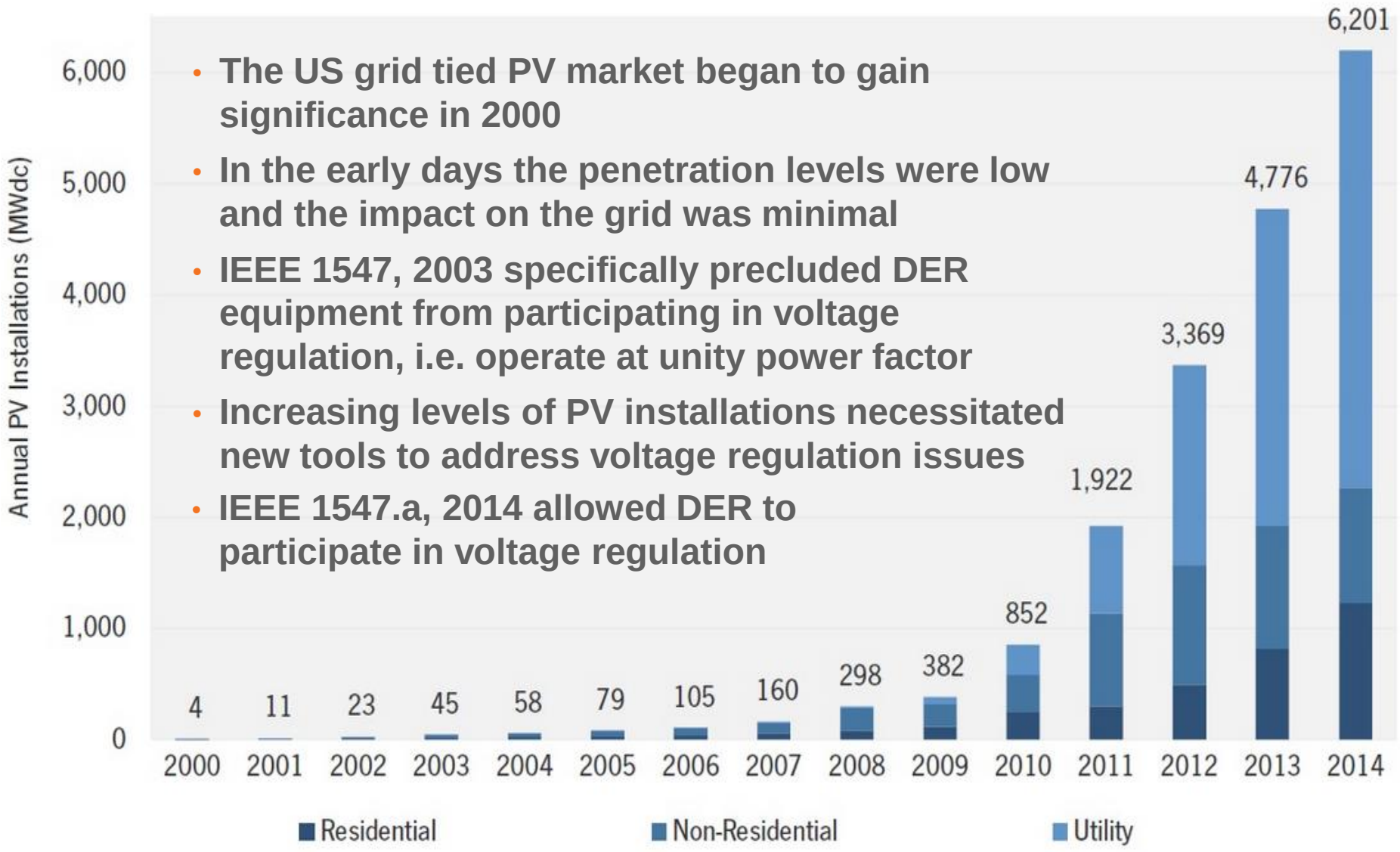
Presentation Outline

- **US Market Historical Perspective**
- **Circuit Handling Capacity**
- **Reactive Power Functions**
  - Power Flow Conventions
- **Operating Area Requirements**
- **Ongoing Standards Activities**
- **Summary and Conclusions**

US Market Historical Perspective

- The US grid tied PV market began to gain significance in 2000
- In the early days the penetration levels were low and the impact on the grid was minimal
- IEEE 1547, 2003 specifically precluded DER equipment from participating in voltage regulation, i.e. operate at unity power factor
- Increasing levels of PV installations necessitated new tools to address voltage regulation issues
- IEEE 1547.a, 2014 allowed DER to participate in voltage regulation



US market development graph courtesy of Greentech Media

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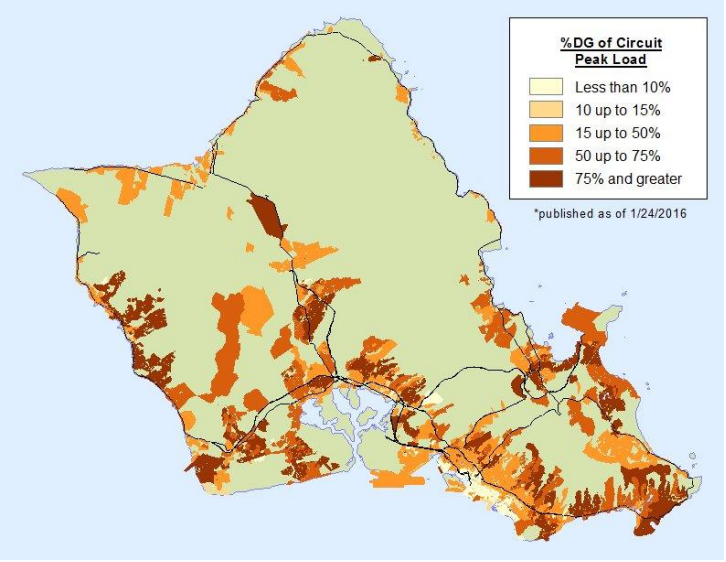
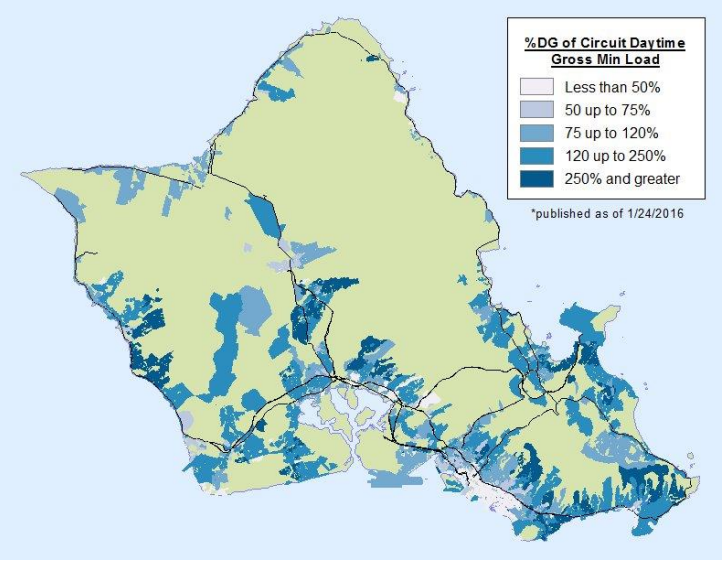
Circuit Handling Capacity as a % of Load

- **Circuit handling capacity is a metric used to determine how much DER can be installed on a given feeder circuit**
- **Circuit handling based on % of nameplate rating and circuit loading**
  - Nameplate generation as a percentage of peak load, e.g. 15% of peak load
  - Nameplate rating as percentage of minimum daytime load, e.g. 250% of MDL
- **These metrics are easily calculated but in field data show to have little to no correlation to actual circuit conditions.**

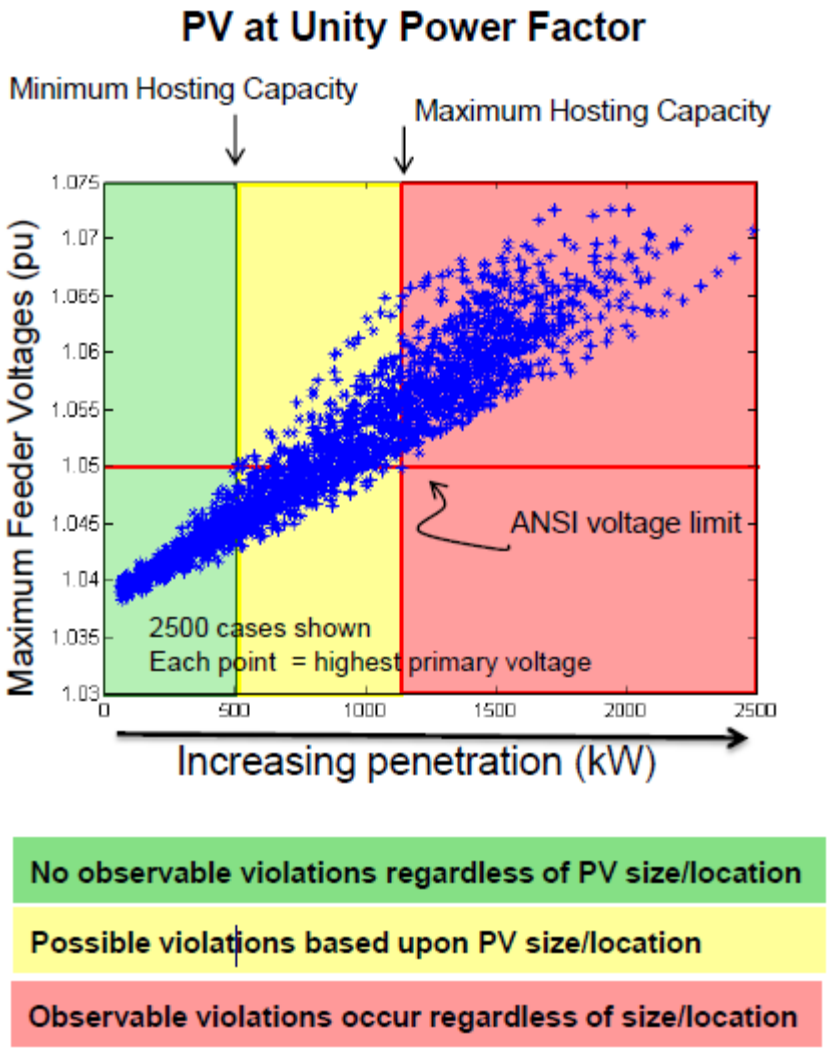




Locational Value maps courtesy of Hawaiian Electric Company

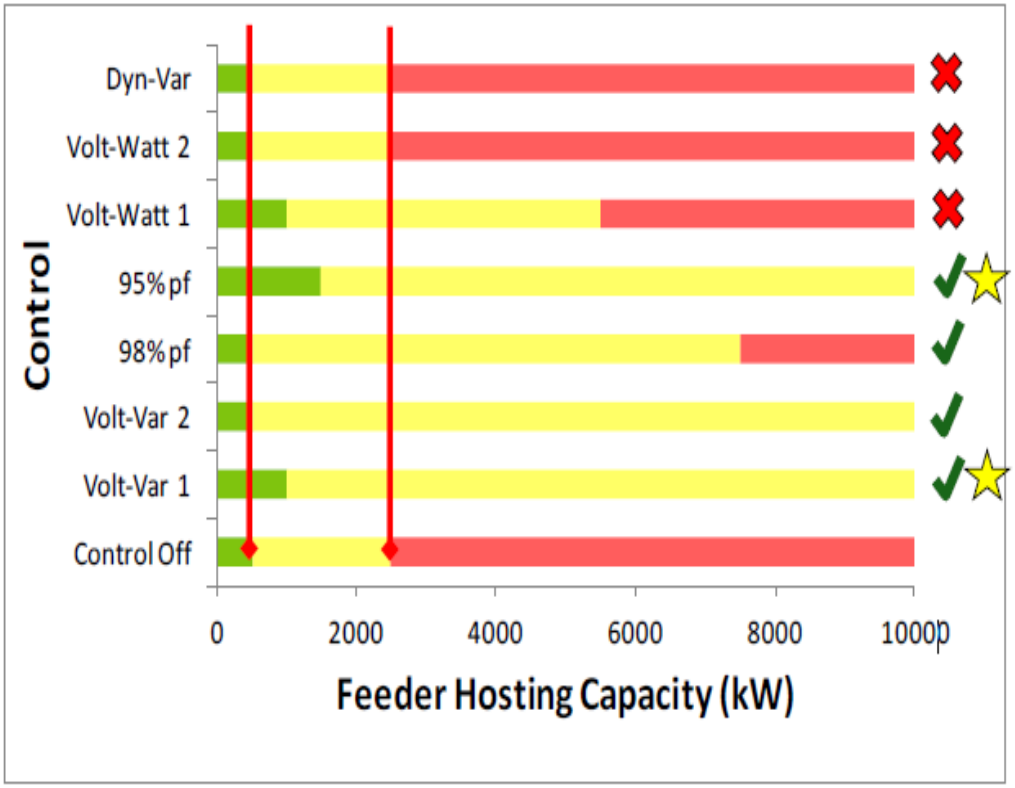
Circuit Handling Capacity based on Voltage

- **A better metric for circuit handing capacity is based on frequency and location of voltage out of range, ANSIC84.1-2011. Range A**
- **Modeling and field data can be used to determine feeder capacity**
  - Characteristics are feeder specific and use of representative feeders is inadequate
  - Location of DER Interconnection is critical in determining hosting capacity
- **More difficult to use as a screen since it requires detailed knowledge and modeling of each feeder**



Graphic Courtesy of EPRI – "*Increasing Feeder Hosting Capacity with Smart Inverter Functions", Jeff Smith, DOE/EPRI Smart Inverter Workshop, May 2014*

Reactive Power Control Strategies



No observable violations regardless of PV size/location

Possible violations based upon PV size/location

Observable violations occur regardless of size/location

- **EPRI modeled over 600 reactive control strategies on three representative feeders**
- **Fixed PF and Volt-Var (Voltage Droop) emerged as leading candidate functions for managing feeder voltage**
- **These functions may have other consequences**
  - Increased number of tap changes
  - Interactions between multiple DER leading to “sloshing VAR”
  - Volt Var settings are critical and feeder specific

Graphic Courtesy of EPRI – “*Increasing Feeder Hosting Capacity with Smart Inverter Functions”, Jeff Smith, DOE/EPRI Smart Inverter Workshop, May 2014*

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Reactive Power Control Functions

- **Fixed PF**
  - DER operates at a fixed, non-unity PF
  - Specified as the default reactive power method in Hawai'I (Rule 14H)
    - 0.95 Inductive (Absorbing VAR, underexcited)
    - Reactive power priority
    - Mandatory compliance date 1 January, 2016
- **Volt/VAR**
  - DER varies VAR output based on voltage at it's terminals
  - Specified as the default reactive power method in California (Rule 21)
  - Requires up PF down to 0.85, ships as unity from factory
  - Active power priority
  - Mandatory compliance date April/May, 2017
  - Time
- **Dynamic Reactive Current**
  - Similar to Volt/VAr with a dynamic dead band based on slow moving average
  - Higher speed reactive injection outside of deadband
  - Still under discussion in IEEE 1547 Full Revision

IEEE 1459, 2010 Sign Conventions

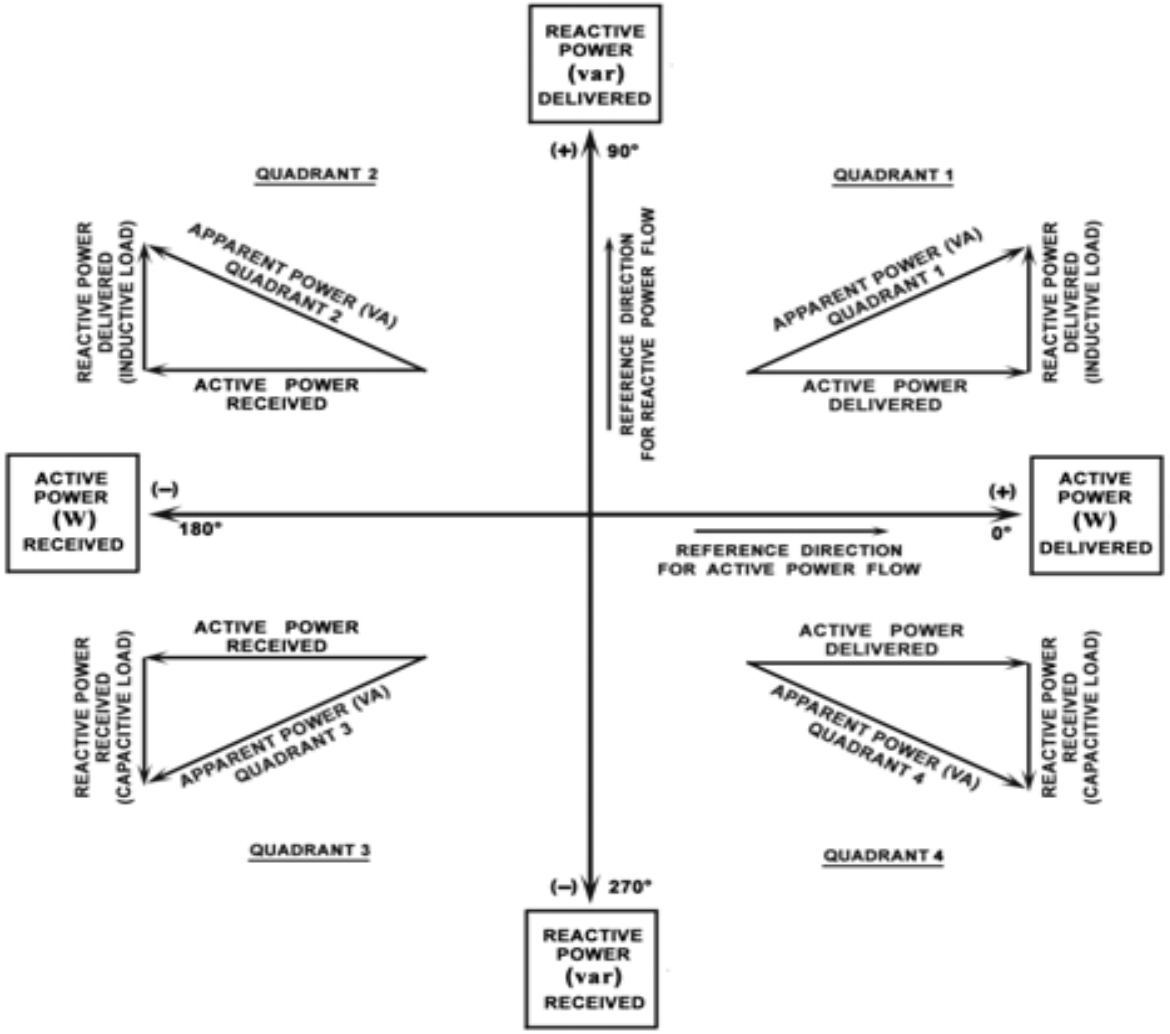

Figure 1 - Four-quadrant power flow directions
(© 1983 IEEE. Reprinted, with permission from the IEEE and R.H. Stevens [B19])
(redrawn by McEachern for clarity, 2012)

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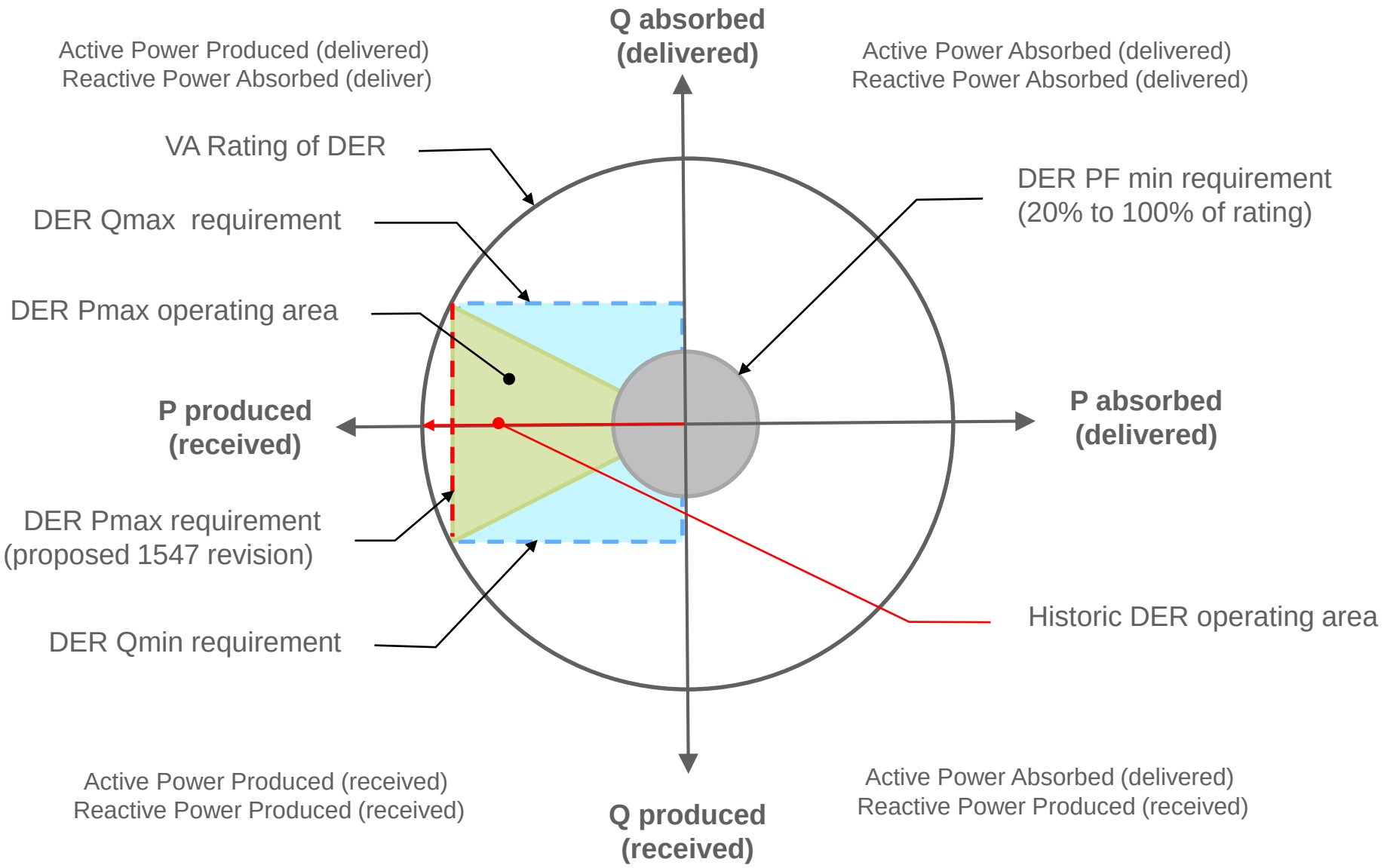
Reactive Power Capability Diagram



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Ongoing Standards Development Activities

- **IEEE 1547 Full Revision**
  - Defines new requirements for reactive power in DER
  - Also defines requirements for active power control functions, ride through, ramp rate, etc.
  - Target first ballot date EOY 2016
- **IEEE 1547.1 Full Revision**
  - Defines test protocols for compliance testing to 1547
  - Activity will begin in Q22016 and schedule for completion in 1H2017
- **UL 1741 Supplement A**
  - Describes interim test procedures to use until 1547.1 is completed
  - First draft completed and comments resolved (~430 comments)
  - Scheduled for completion early in Q2 2016
- **CA Rule 21**
  - CA interconnection requirements including reactive power (V/VAR)
  - Mandatory compliance date – 12 months after publication of UL 1741 SA
- **HI Rule 14H**
  - HI interconnection requirements including reactive power (FPF)
  - Mandatory compliance date 1 Jan 2016 with ongoing activities

Summary and Conclusions

- **New US requirements for reactive power are nearing completion**
  - Will align with existing similar requirements globally
  - Builds on experience gained Internationally, e.g. Germany
  - Will be tailored for North American grids
  - Adds substantial complexity to compliance testing
- **DER will soon be required to produce reactive power**
  - Unity power factor only topologies will not longer be allowed in major markets
  - Nationwide adoption seems likely over next 18 to 36 months
- **Reactive power requirements may require “oversizing” to insure reactive power is available when needed**
- **Settings for reactive power production may be feeder specific**
  - Adds significant complexity to configuration and verification of DER settings
- **Standards development is underway**
  - IEEE 1547, IEEE 1547.1, UL 1741 Supplement A,
  - CA Rule 21, HI Rule 14H
  - All proceedings use open consensus based processes
  - PLEASE PARTICPATE

Thank you
for your attention

Questions ?