DG Standard Updates
IEEE-1547, UL-1741 SA, and Rule 21

CHASE SUN
GII/PG&E
3/28/18
DER Interconnection Standards Chronology

<table>
<thead>
<tr>
<th>Event</th>
<th>Year</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arab Oil Embargo</td>
<td>1973</td>
<td>Gas Rationing. Oil went from $3/barrel (gas at $ 0.35/gal) to $12/barrel in one year</td>
</tr>
<tr>
<td>PURPA</td>
<td>1978</td>
<td>Requiring Interconnection of Qualifying Facilities (Alternative Energy) to reduce oil consumption</td>
</tr>
<tr>
<td>CPUC D.82-04-071</td>
<td>1982</td>
<td>PG&amp;E Rule 21 Issued using existing PG&amp;E requirements</td>
</tr>
<tr>
<td>IEEE-929</td>
<td>2000</td>
<td>For PV inverters 10 kW or less. Established the certification methodology</td>
</tr>
<tr>
<td>D.00-12-037</td>
<td>2000</td>
<td>Developed the Rule 21 Initial and Supplemental Review screens to enable fast interconnection for small units at low penetrations. Adopted certification methodology</td>
</tr>
<tr>
<td>IEEE-1547</td>
<td>2003</td>
<td>National interconnection standard issued. Adopted certification methodology for DER units up to 10 MW</td>
</tr>
</tbody>
</table>

Multiple CA legislations, mandating high renewable penetration levels, 33% RPS (energy) by 2020 and 50% RPS by 2030. The goal is to reduce/eliminate GHG emissions. Grid support was left to the existing conventional generators.
Need For Revising Standards

- Some areas, such as Germany, with higher renewable penetration are experiencing adverse impact, such as a large block of DER trips and high voltages, due to the simplified low penetration approach.

- In 2012, Germany proceeded to retrofit over 315,000 inverters at hundreds of millions of dollars to avoid potential system reliability impact at high DG penetrations.

- Previous requirements specified in IEEE-1547, 2003, and CA Rule 21, 2012, were based on simplified low penetration methodology, similar to Germany, which may cause unintended consequences at high penetration scenarios.

- Desire to use potential inverter capabilities, to mitigate the potentially higher impacts and to improve distribution level service reliability, i.e. microgrids, and power quality.
The existing Rule 21 recognized that DG operating within the existing distribution system design parameters, with no reverse flow, has minimal system impact.

It identified the low impact conditions (Initial Review Screens) and provided simplified requirements to allow small DG units at low penetration levels to be interconnected quickly so long as safety issues are addressed.

Using the existing grid’s operating margin to enable fast DER interconnection significantly simplified the review/approval process and reduced the interconnect review time for the small units.

Currently, the NEM PV units less than 30 kW can be approved and interconnected in 3 days at PG&E.
CA Smart Inverter Requirements

Rule 21 Smart Inverter Phase 1, Autonomous Functions, is mandatory since 9/9/17, Certified to UL-1741 SA.

- Anti-islanding
- Extended ride through for voltage and frequency
- Volt/var control
- Frequency-watt (Optional)
- Normal Ramp Rate
- Connect/Reconnect ramp rate
- Microgrid exemption on ride through

Phase 2 Communication capability- 9 months after national communication test standard is issued (SunSpec certification document pending)

California Common Smart Inverter Profile (CSIP) adopted using IEEE-2030.5 as the default protocol
Summary of Rule 21 Smart Inverter Phase 3 Proposed Changes, CPUC approval pending

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
<th>Rule 21 Section</th>
<th>Requirement Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>Monitor Key DER Data</td>
<td>Hh.7</td>
<td>Later of March 1, 2018 or 9 months after the release of SunSpec Alliance Approved Test Procedure (or another industry-recognized protocol standard)</td>
</tr>
<tr>
<td>Two</td>
<td>DER Disconnect and Reconnect Command (Cease to Energize and Return to Service)</td>
<td>Hh.8</td>
<td>12 months after IEEE 1547.1 standard revision approval</td>
</tr>
<tr>
<td>Three</td>
<td>Limit Maximum Active Power Mode</td>
<td>Hh.8</td>
<td>12 months after IEEE 1547.1 standard revision approval</td>
</tr>
<tr>
<td>Four</td>
<td>Set Active Power Mode</td>
<td>Hh.2.n</td>
<td>Optional Upon Mutual Agreement between Utility and Applicant</td>
</tr>
<tr>
<td>Five</td>
<td>Frequency Watt Mode</td>
<td>Hh.2.I</td>
<td>12 months from Commission approval of the Phase 3 Advance Function Advice Letter</td>
</tr>
<tr>
<td>Six</td>
<td>Volt-Watt Mode</td>
<td>Hh.2.m</td>
<td>12 months from the Commission approval of the Phase 3 Advance Function Advice Letter Commission</td>
</tr>
<tr>
<td>Seven</td>
<td>Dynamic Reactive Support</td>
<td>Hh.2.o</td>
<td>Optional Upon Mutual Agreement between Utility and Applicant</td>
</tr>
<tr>
<td>Eight</td>
<td>Scheduling Power Values and Modes</td>
<td>Hh.6</td>
<td>Later of March 1, 2018 or 9 months after the release of SunSpec Alliance Approved Test Procedure (or another industry-recognized protocol standard)</td>
</tr>
</tbody>
</table>
UL-1741 SA

For Certifying Smart Inverter Phase 1 Autonomous Functions

Issued on 9/8/16, mandatory in CA on 9/9/17

Developed specific test procedures for each required function in Rule 21

Using dead band & droop control for Volt/var control

Test each function for the full range of adjustability.

Test anti-islanding with the new settings.

Provide flexibility for different jurisdictional requirements
Impacts Reviewed/Mitigated during interconnection

Safety

• DER should separate from grid and do not backfeed during abnormal conditions, such as during faults and downed conductors.

Equipment Overload

• DER operation should not cause distribution equipment overloads

Voltage

• DER shall not cause steady state voltage to exceed Rule 2 limits

Transient voltage

• DER shall not sustain high transient voltage during ground fault

Protection coordination

• DER fault current contribution shall not cause mis-coordination of existing protective equipment
IEEE-1547 Re-write Status

Used Germany documents, Rule 21, NERC document as starting reference points.

Reconcile the requirements for inverter based generators and machine based generators to the extent possible.

Due to the different characteristics between inverter and synchronous generations, the current approach is to use two or more performance categories.

Balloted in 2017 with 78% approval rate and 1457 comments. All comments were addressed by the Comment Resolution Team.

Recirculated and approved by IEEE Standards Board on 2/15/2018

Target issuance Q2 2018
IEEE 1547 IS:

A Technical Standard – Functional Requirements For
- the interconnection itself
- the interconnection test

Technology neutral, e.g., does not specify particular equipment nor type

A single (whole) document of mandatory, uniform, universal, requirements that apply at the PCC or Point of DER Connection.

Should be sufficient for most installations.

IEEE 1547 Is NOT:

• a design handbook
• an application guide
• an interconnection agreement
• prescriptive, e.g., does not address DR self-protection, nor planning, designing, operating, or maintaining the Area EPS.
P1547 New Requirements for Ride Through

Three Categories of DER Operational Responses to Support the Grid -- Based on Local and Farther Reaching Grid Requirements and DER

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Category</th>
<th>Foundation</th>
<th>Justification</th>
</tr>
</thead>
</table>
| Voltage Ride-       | Category I     | German grid code for medium voltage-connected synchronous generator-based DER | • Essential bulk system needs.  
| Through             |                |                                                                             | • Attainable by all state-of-the-art DER technologies.                        |
|                     |                |                                                                             |                                                                              |
| Category II         |                | NERC PRC-024-2 but w/o stability exception, extended LVRT duration for 85-88% $V_{nom}$ | • All bulk system needs.  
|                     |                |                                                                             | • Coordinated with existing reliability standards.                           |
|                     |                |                                                                             | • Considering fault-induced delayed voltage recovery.                        |
|                     |                | [based on EPRI White Paper (May 2015)]                                      |                                                                              |
| Category III        |                | CA Rule 21 and Hawaii, minor modifications                                   | • All bulk system needs.  
|                     |                |                                                                             | • Considering fault-induced delayed voltage recovery.                        |
|                     |                |                                                                             | • Distribution system operation.                                             |
| Frequency Ride-     | All Categories | CA Rule 21 and Hawaii, exceeds PRC-024-2 [based on EPRI White Paper (May 2015)] | • All bulk system needs.  
| Through             | (harmonized)   |                                                                             | • Low inertia grids.                                                         |
|                     |                |                                                                             |                                                                              |
P1547 voltage regulation

Two performance categories are defined for DERs with voltage regulation capabilities:

a) Category A covers minimum performance capabilities needed for Area EPS voltage regulation and are reasonably attainable by all state-of-the-art DER technologies

b) Category B covers all requirements within Category A and specifies additional requirements to mitigate voltage variations due to resource variability
P1547 Example New Reactive Power Requirements

The DER shall be capable of injecting reactive power (over-excited) and absorbing reactive power (under-excited) equal to the minimum reactive power (kVar) corresponding to the value given in Table 7 at all exporting active power output greater than or equal to 20% of nameplate active power rating (kW) or the minimum steady state power capability of the DER, whichever is greater. For active power output greater than or equal to 5% and less than 20% of nameplate active power rating (kW) or the minimum steady state power capability of the DER, whichever is greater, DER of Category A and B shall be capable of exchanging reactive power corresponding to a triangular shape with base in the origin.

<table>
<thead>
<tr>
<th>Category</th>
<th>Injection Capability as % of Nameplate Apparent Power (kVA) Rating ( Q_{\text{min inj}} )</th>
<th>Absorption Capability as % of Nameplate Apparent Power (kVA) Rating ( Q_{\text{min abs}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (at DER rated voltage)</td>
<td>44 Full load PF=0.9</td>
<td>25 Full load PF=0.97</td>
</tr>
<tr>
<td>B (at ANSI range A)</td>
<td>44 Full load PF=0.9</td>
<td>44 Full load PF=0.9</td>
</tr>
</tbody>
</table>
P1547 Example New Voltage Regulation Requirements

Voltage–Real Power (Volt–Watt) Mode

When in this mode, the DER shall actively control the active power output as a function of the voltage following a Volt–Watt piecewise linear characteristic. Two example Volt–Watt characteristics are shown in Figure 7. The characteristic shall be configured in accordance with the default parameter values specified in Table 10 for the given DER category. The characteristic may be configured as specified by the Area EPS Operator using the values in the adjustable range. If enabled, the Volt–Watt function shall remain active while any of the voltage–reactive power modes are enabled.
Frequency Droop Example

Example of a frequency–droop function with a 5% droop, 36 mHz deadband, and 20% minimum active power output.
Preparing for the Future

➢ As California moves toward high renewable penetrations, interconnection requirements set up for low penetration, contained in IEEE-1547, UL-1741, & Rule 21, are being modified to account for high penetration effects
  - Cumulative DG impacts at projected high levels are no longer negligible
  - Aggregated impacts to grid has to be considered

➢ Proactively planning using hosting capacity methods to determine “where and when” additional hosting capacity is needed and can be implemented cost effectively on grid to accommodate high penetrations

➢ At high penetration levels, there may not be as many conventional generators available to provide system support and DG will need to be designed and operated to help maintain grid safety & reliability

➢ Additional granular visibility in grid will require investments in tools that improve:
  - Forecasting DG impacts on grid
  - Predicting DER behavior
  - Viewing real time DER response

➢ At higher DG penetrations, there also may be more opportunities to capture potential benefits of DG, *when cost effective, such as providing distribution services as “non-wires alternatives” for distribution capacity, voltage management and resiliency*. 


Let's be more strong with this point since it is key to GII’s Integrated Grid Strategy messages. Therefore, I've reworded this bullet to be:

"DG will need to be monitored and controlled by the distribution system operator at high penetration levels in order to maintain the current safety and reliability levels."

Author, 8/21/2017
The need for advanced DER

Traditional Electric Grid… → Modern Electricity Choices …

- Combined Heat and Power
- Utility Scale PV
- Wind Farms
- Hydrogen Storage
- Industrial DG
- Remote Loads
- Fuel Cells
- Rooftop Photovoltaics
- Smart Substation
- Load as a resource
- EV’s
- Combined Heat and Power
- Power park
Appendix
Interconnection Technical Framework Overview

1. Complete/Valid Interconnection Request
   - Yes
   - No

2. Does the Applicant choose to go directly to Detailed Studies?
   - No
   - Yes

3. Non Export/NEM-1 or Export/NEM-2?
   - Non Export/NEM-1
   - Export/NEM-2

4. Fast Track Eligibility MW Limit
   - Pass
   - Fail

5. Initial Review Screens A-H
   - Pass All Screens
   - Fail Any Screen

6. Does quick review of failed screens determine requirements to address the screens?
   - Yes
   - No

7. Will power be exported across the PCC? * I
   - Yes
   - No

8. Generating Facility ≤ 11kVA? J
   - Yes
   - No

9. Is Generating Facility a NEM project with a nameplate capacity ≤ 500kW? K
   - Yes
   - No

10. T. Dependency / Stability Test L

11. Aggregate generation ≤ 15% of line section peakload? M

12. Proceed with interconnection subject to requirements determined by Initial Review or SR, if any

* Inadvertent Export projects that meet the requirements specified in Section M/H bypass Screens K, L, and are processed under Screen M as described in Section M/H.
If and when voltage issues are identified, PG&E mitigates with voltage regulators and capacitors, and/or reconductoring small primary lines, and upgrading service equipment.
Current DER interconnection status

- The vast majority of the existing inverters are designed for grid interactive mode, set at unity power factor, and certified not to operate when the grid is de-energized, i.e., certified anti-islanding, to address safety concerns.

- A major benefit of the current simplified low penetration approach is that these inverters produced the maximum as-available renewable energy by relying on the grid for voltage and frequency support, for absorbing excess power, and backup service when the DGs are not generating.

- By using the simplified low penetration process, PG&E currently has 3,700 MW and 340,000 installations of DER interconnected.
Existing Rule 21 Sec H, Voltage Settings, still in effect for non-inverter based DG.

<table>
<thead>
<tr>
<th>Voltage at Point of Common Coupling</th>
<th>Maximum Trip Time&lt;sup&gt;(1)&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of Nominal Voltage</td>
<td># of Cycles</td>
</tr>
<tr>
<td>Less than 50%</td>
<td>10 Cycles</td>
</tr>
<tr>
<td>50% &lt; V &lt; 88%</td>
<td>120 Cycles</td>
</tr>
<tr>
<td>88% ≤ V ≤ 110%</td>
<td>No Trip</td>
</tr>
<tr>
<td>110% &lt; V ≤ 120%</td>
<td>60 Cycles</td>
</tr>
<tr>
<td>Greater than 120%</td>
<td>10 Cycles</td>
</tr>
<tr>
<td></td>
<td>0.16 Seconds</td>
</tr>
</tbody>
</table>
Existing Rule 21 Sec H, Frequency Settings, still in effect for non-inverter based DG.

<table>
<thead>
<tr>
<th>Generating Facility Rating</th>
<th>Frequency Range</th>
<th>Maximum Trip Time$^{(1)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less or equal to 30 kW</td>
<td>Less than 59.3 Hz</td>
<td>10 Cycles</td>
</tr>
<tr>
<td></td>
<td>Greater than 60.5 Hz</td>
<td>10 Cycles</td>
</tr>
<tr>
<td>Greater than 30 kW</td>
<td>Less than 57 Hz</td>
<td>10 Cycles</td>
</tr>
<tr>
<td></td>
<td>59.8 Hz &gt; f &gt; 57 Hz</td>
<td>10 - 18,000 Cycles$^{2,3}$</td>
</tr>
<tr>
<td></td>
<td>Greater than 60.5 Hz</td>
<td>10 Cycles</td>
</tr>
<tr>
<td>Region</td>
<td>Voltage at Point of Common Coupling (% Nominal Voltage)</td>
<td>Ride-Through Until</td>
</tr>
<tr>
<td>-----------------</td>
<td>----------------------------------------------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>High Voltage 2 (HV2)</td>
<td>$V \geq 120$</td>
<td></td>
</tr>
<tr>
<td>High Voltage 1 (HV1)</td>
<td>$110 &lt; V &lt; 120$</td>
<td>12 seconds</td>
</tr>
<tr>
<td>Near Nominal (NN)</td>
<td>$88 \leq V \leq 110$</td>
<td>Indefinite</td>
</tr>
<tr>
<td>Low Voltage 1 (LV1)</td>
<td>$70 \leq V &lt; 88$</td>
<td>20 seconds</td>
</tr>
<tr>
<td>Low Voltage 2 (LV2)</td>
<td>$50 \leq V &lt; 70$</td>
<td>10 seconds</td>
</tr>
<tr>
<td>Low Voltage 3 (LV3)</td>
<td>$V &lt; 50$</td>
<td>1 seconds</td>
</tr>
</tbody>
</table>
# New R21 Table Hh.2: Frequency Ride-Through and Trip Settings

<table>
<thead>
<tr>
<th>System Frequency Default Settings (Hz)</th>
<th>Minimum Range of Adjustability (Hz)</th>
<th>Ride-Through Until</th>
<th>Ride-Through Operational Mode</th>
<th>Maximum Trip Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>f &gt; 62</td>
<td>62 - 64</td>
<td>No Ride Through</td>
<td>Not Applicable</td>
<td>0.16 seconds</td>
</tr>
<tr>
<td>60.5 &lt; f ≤ 62</td>
<td>60.1 - 62</td>
<td>299 seconds</td>
<td>Mandatory Operation</td>
<td>300 seconds</td>
</tr>
<tr>
<td>58.5 &lt; f ≤ 60.5</td>
<td>Not Applicable</td>
<td>Indefinite</td>
<td>Continuous Operation</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>57.0 ≤ f &lt; 58.5</td>
<td>57 - 59.9</td>
<td>299 seconds</td>
<td>Mandatory Operation</td>
<td>300 seconds</td>
</tr>
<tr>
<td>f &lt; 57.0</td>
<td>53 - 57</td>
<td>No Ride Through</td>
<td>Not Applicable</td>
<td>0.16 seconds</td>
</tr>
</tbody>
</table>
DER Wholesale Market Participation
Before and After Impacts on Distribution Grid

October 2013

October 2016


**P1547 Revision:** Draft Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces.

**Scope:** This standard establishes criteria and requirements for interconnection of distributed energy resources (DER) with electric power systems (EPS), and associated interfaces.

*Note: Interfaces defined in IEEE 2030: “a logical interconnection from one entity to another that supports one or more data flows implemented with one or more data links.*

**Purpose:** This document provides a uniform standard for the interconnection and interoperability of distributed energy resources (DER) with electric power systems (EPS). It provides requirements relevant to the interconnection and interoperability performance, operation, and testing, and, safety, maintenance and security considerations.
IEEE Std 1547 covers:
- INTERCONNECTION TECHNICAL SPECIFICATIONS & REQUIREMENTS
- INTERCONNECTION TEST SPECIFICATIONS & REQUIREMENTS

Note: P1547 full revision started in year 2015. It also addresses interoperability and interfaces.
Are voltage regulation and ride-through requirements proposed to be mandatory?

The ride-through capability and performance are proposed to be mandatory.

The voltage regulation capability is proposed to be mandatory but the performance category and specific settings are proposed to be at the utility’s discretion (The DER will provide this capability and the utility will decide to enable/disable it and choose the proper operating modes).
**P1547 Example New Requirements for voltage Ride Through**

**Legend**
- **range of adjustability**
- **default value**
- **shall trip zones**
- **may ride-through or may trip zones**
- **shall ride-through zones and operating regions describing performance**

**Category I**
*(based on German requirements for sync. gen.)*

- **Continuous Operation**
  - Permissive Operation
    - may ride-through or may trip
    - 0.16 s
  - Mandatory Operation
    - may ride-through or may trip
    - 0.16 s
    - 2 s
    - 4 s
  - German MV Code for sync. DER
    - may ride-through or may trip
    - 0.16 s
    - 0.16 s
    - 2 s
    - 1 s

- **Mandatory Operation**
  - may ride-through or may trip
  - 0.88 p.u.

- **Permissive Operation**
  - may ride-through or may trip
  - 1.10 p.u.

- **Continuous Operation**
  - may ride-through or may trip
  - 0.88 p.u.

- **Legend**
  - **shall trip**
  - **may ride-through**
  - **may trip**
  - **default value**
  - **range of adjustability**
  - **shall trip zones**
  - **may ride-through or may trip zones**
  - **shall ride-through zones and operating regions describing performance**

**NERC**
*PRC-024-2*

**Example**

- **Category I**
  - **Continuous Operation**
    - Permissive Operation
      - may ride-through or may trip
      - 0.16 s
    - Mandatory Operation
      - may ride-through or may trip
      - 0.16 s
      - 2 s
      - 4 s
    - German MV Code for sync. DER
      - may ride-through or may trip
      - 0.16 s
      - 0.16 s
      - 2 s
      - 1 s
  - Continuous Operation
    - may ride-through or may trip
    - 0.88 p.u.

- **Legend**
  - **shall trip**
  - **may ride-through**
  - **may trip**
  - **default value**
  - **range of adjustability**
  - **shall trip zones**
  - **may ride-through or may trip zones**
  - **shall ride-through zones and operating regions describing performance**
P1547 Example New Requirements for frequency Ride Through (work in progress)

Category I, II, and III (harmonized)

Legend:
- range of adjustability
- default value
- may ride-through or may trip zones
- shall ride-through zones and operating regions describing performance

Continuous Operation
\(V/f \leq 1.1\)

Mandatory Operation

Legend:
- may ride-through or may trip
- shall trip

May ride-through or may trip zones:
- 66.0 Hz

Mandatory Operation zones:
- 60.6 Hz

Legend:
- default value
- range of adjustability
- may ride-through or may trip zones
- shall ride-through zones and operating regions describing performance

Continuous Operation
\(V/f \leq 1.1\)

Mandatory Operation

Legend:
- may ride-through or may trip
- shall trip

Mandatory Operation zones:
- 60.6 Hz

Legend:
- default value
- range of adjustability
- may ride-through or may trip zones
- shall ride-through zones and operating regions describing performance

Category I, II, and III (harmonized)

Legend:
- range of adjustability
- default value
- may ride-through or may trip zones
- shall ride-through zones and operating regions describing performance

Continuous Operation
\(V/f \leq 1.1\)

Mandatory Operation

Legend:
- may ride-through or may trip
- shall trip

Mandatory Operation zones:
- 60.6 Hz

Legend:
- default value
- range of adjustability
- may ride-through or may trip zones
- shall ride-through zones and operating regions describing performance
Voltage and Reactive Power Control

The DER shall provide the capabilities of the following modes of reactive power control functions:

1. **Constant Power factor mode** – The capability is mandatory for categories A and B
2. **Voltage-reactive power (Volt-var) mode** – The capability is mandatory for categories A and B
3. **Active power-reactive power mode (watt-var)** – The capability is optional for category A and mandatory for categories B
4. **Constant reactive power mode** – The capability is mandatory for categories A and B