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Accelerating DER Development and Validation

ISGAN SIRFN, Mission Innovation, Clean Energy Ministerial, CSIRO, & DERlab
"Grid Integration of Renewables – The Role of Research & Testing Facilities"
9th International Conference on the Integration of Renewable & Distributed Energy Resources

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Renewable and Distributed Systems Integration
Sandia National Laboratories, Albuquerque, NM, USA

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Adelaide, Australia

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SIRFN DER Test Protocols Task Objectives

Build **open-source software tools**, **test beds**, consensus **test protocols,** and **automated scripts** to be used by DER vendors, universities, research institutions, certification laboratories, standards organizations, etc.

Inputs to **national** and **international standards** development has major impact on the capabilities of smart grid and DER equipment for electrical performance and communications capabilities.

Utility-Interactive Converter Functions are Smart Grid Building Blocks

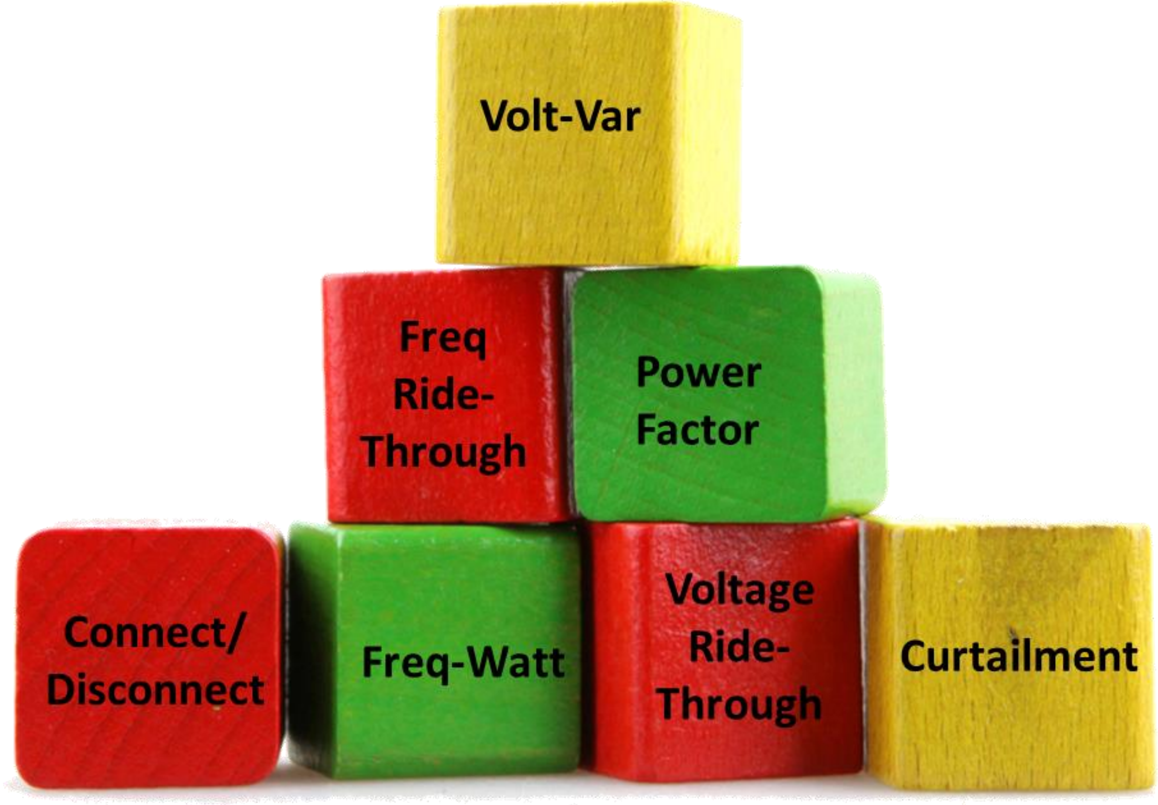


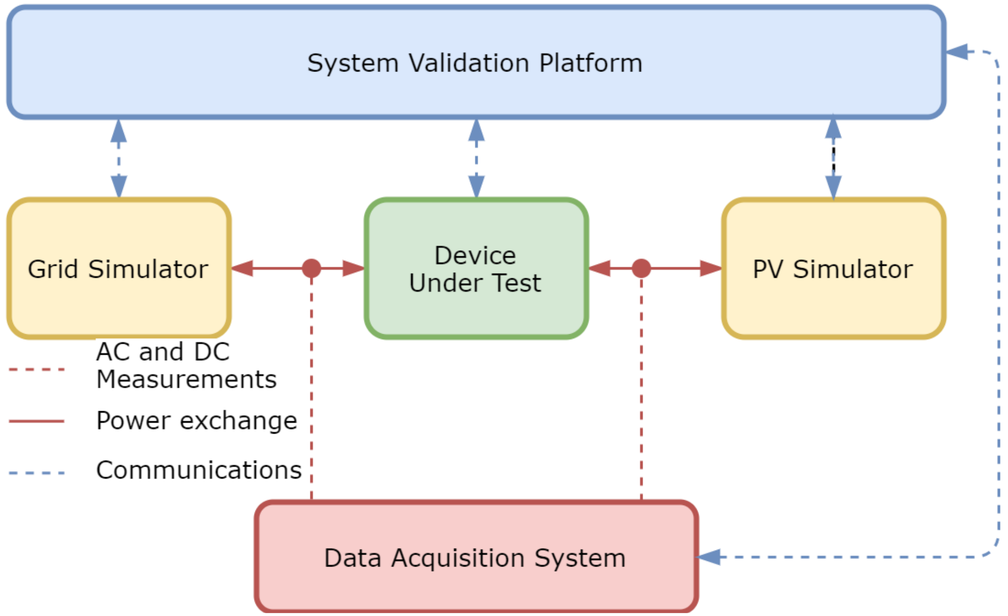
Image: BetaNews

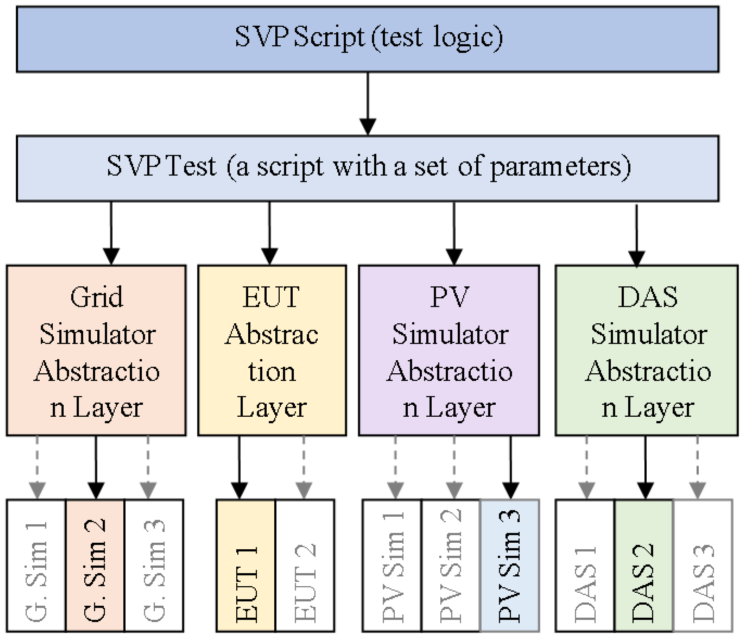
Why is SIRFN doing this?

- **Interoperable DER are critical for increasing renewable energy penetrations** on the power system.
  - DER certification tests **provide grid operators confidence** that the equipment will behave as designed.
- Standards often include **multiple errors**, of varying size, which are undetected in the writing process.
  - **Standards Development Organizations (SDOs) need more quantitative support** in standards development prior to publication.
  - Where possible, SDOs incorporate field observations, industry experience, and simulation results from stakeholders.
  - Unfortunately, some certification standards are written with little or no experimental results to back test procedures, parameters, and pass/fail criteria.
- SDOs benefit significantly when they can gather results from **power system models**, **DER electrical testing**, **interoperability experiments**, **field demonstrations**, etc.
  - Once labs dig deep into (ideally draft) standards, they can drastically **improve the content**.

Automated DER Certification Testing

- The SIRFN community is using the open-source test platform known as **System Validation Platform (SVP)** for evaluating DER test protocols
- It **automates the execution of tests/evaluations by communicating to laboratory equipment** as well as the Equipment Under Test (EUT) in a laboratory test setup
- The SVP uses *abstraction layers* so the same test scripts work for all laboratory testbeds by adjusting the underlying *equipment drivers*





Software Development Progress

Testbed drivers and abstraction layers (SVP Energy Lab)

- DER protocols – SunSpec, IEEE 2030.5, IEEE 1815, Modbus
- HIL systems – Opal-RT, Hyphoon HIL
- Data Acquisition – LabVIEW, Tektronix, Yokagawa, DEWETRON
- DC Simulators – Ametek TerraSAS, Chroma, Keysight, NHR
- Grid Simulators – Ametek, Chroma, Pacific, Spitzenberger Spiess, SunRex

Test scripts for IEEE 1547.1

- Constant power factor, volt-var, frequency-droop, and volt-watt
- Limit active power, constant reactive power, active power-reactive power (watt-var), and prioritization of grid-support functions
- Voltage ride-through, frequency ride-through, and rate of change of frequency (ROCOF) ride-through, and voltage phase-angle change ride-though
- Interoperability for SunSpec Modbus, IEEE 2030.5, and IEEE 1815

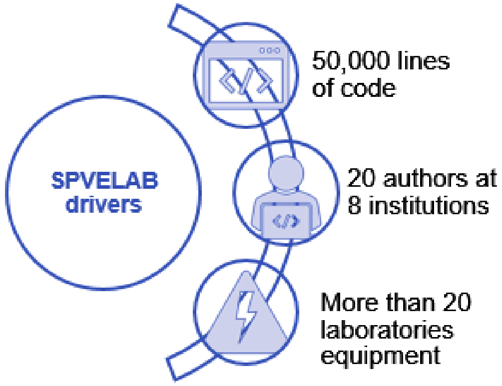
Test scripts for AS-NZS 4777.2

- Constant power factor, constant reactive power, and volt-watt

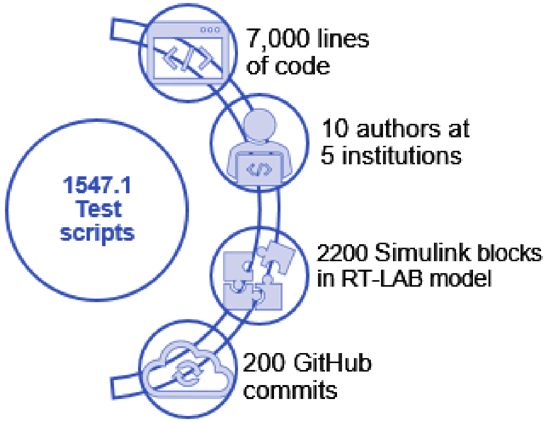
Test scripts for UL 1741 SA and UL 1741 SB

- Normal ramp rate, soft start ramp rate
- Specified power factor, volt-var, and frequency-watt

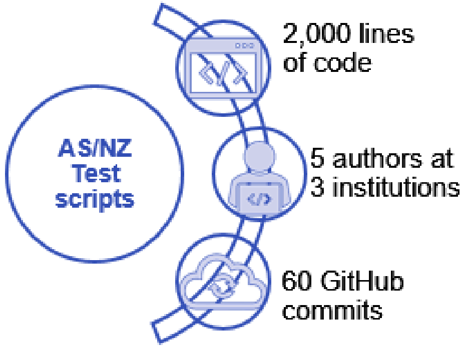
SVP is written in Python 3.7+



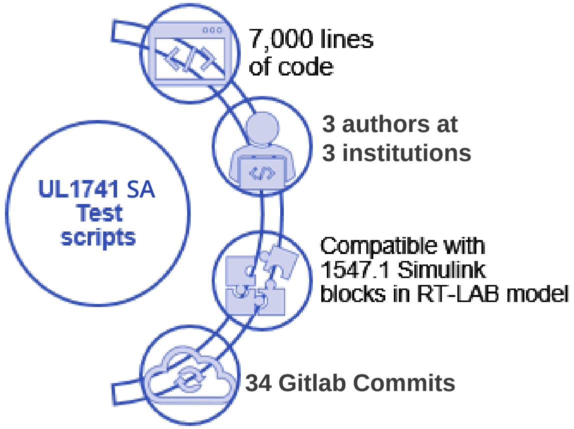
https://github.com/jayatsandia/svp_energy_lab



https://github.com/jayatsandia/svp_1547.1



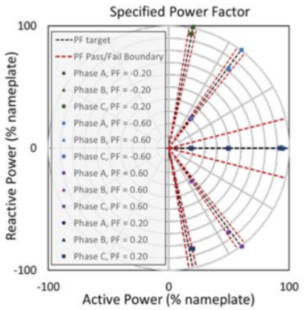
https://github.com/BuiMCanmet/DR_AS-NZS-Scripts



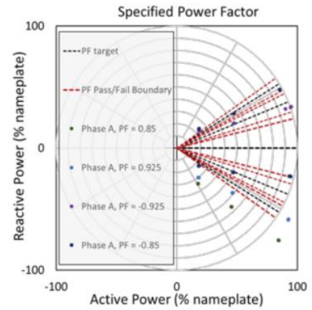
https://github.com/jayatsandia/svp_UL1741SA

Prior Work - Publications

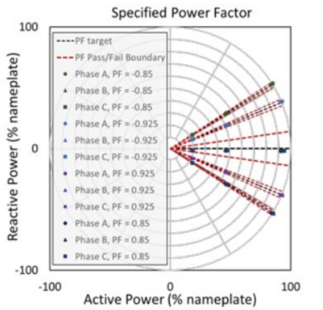
- *Compliance Protocol*: A pre-standardization Sandia test procedure for **IEC TR 61850-90-7** [1], [2]
  - connect/disconnect, active power curtailment, and power factor [3]
  - connect/disconnect, active power curtailment, power factor, reactive power-priority volt-var [4]
- *Compliance Protocol*: A **SIRFN-developed test procedure for ESS devices** [5]
  - active power, fixed power factor, volt-var, and frequency-watt [6]
- *Compliance Protocol*: **UL 1741 SA**
  - volt-var and specified power factor [7]
  - normal ramp rate, soft start ramp rate, specified power factor, volt-var, and frequency-watt [8]
- *Compliance Protocol*: **IEEE 1547.1-2020**
  - constant power factor, volt-var, frequency-droop, and volt-watt [9]
  - limit active power, constant reactive power, active power-reactive power (watt-var), and prioritization of grid-support functions [10]
  - voltage phase-angle change ride-though [11]
  - voltage ride-through, frequency ride-through, and rate of change of frequency (ROCOF) ride-through [12]



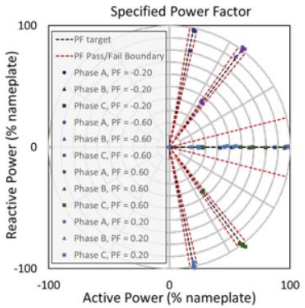
34.5 kW ASGC Solar Inverter, Reactive Power Priority, Sandia



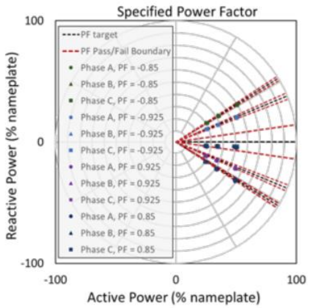
3.0 kW Solar Inverter, Reactive Power Priority, Sandia



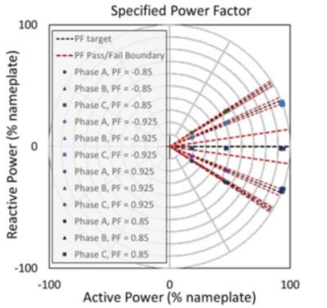
10.0 kW Solar Inverter, Reactive Power Priority, CanmetENERGY



34.5 kW ASGC Solar Inverter, Reactive Power Priority, AIT



15.0 kW Solar Inverter, Reactive Power Priority, CSIRO



10.0 kW Solar Inverter, Active Power Priority, CanmetENERGY

1. J. Johnson, S. Gonzalez, M. E. Ralph, A. Ellis and R. Broderick, "Test protocols for advanced inverter interoperability functions–appendices", 2013.
2. J. Johnson, S. Gonzalez, M. E. Ralph, A. Ellis and R. Broderick, "Test protocols for advanced inverter interoperability functions–main document", 2013.
3. J. Johnson, R. Bründlinger, C. Urrego and R. Alonso, "Collaborative development of automated advanced interoperability certification test protocols for PV smart grid integration", Proc. Eur. Photovoltaic Sol. Energy Conf. Exhib. (PVSEC), pp. 1-7, 2014.
4. J. B. Ahn, J. J. Lee, J. Johnson and J. H. Bae, "Test results for advanced inverter functions based-on IEC 61850-90-7", Proc. 5th Asia–Pacific Forum Renew. Energy (AFORE), pp. 1-13, 2015.
5. M. Verga, R. Lazzari, J. Johnson, D. Rosewater, C. Messner and J. Hashimoto, "SIRFN draft test protocols for advanced battery energy storage system interoperability functions", 2016.
6. D. M. Rosewater, J. T. Johnson, M. Verga, R. Lazzari, C. Messner, K. Johannes, et al., "International development of energy storage interoperability test protocols for photovoltaic integration", Proc. EU PVSEC, pp. 1-11, 2015.
7. J. Johnson, E. Apablaza-Arancibia, N. Ninad, D. Turcotte, A. Prieur, R. Ablinger, et al., "International development of a distributed energy resource test platform for electrical and interoperability certification", Proc. IEEE 7th World Conf. Photovoltaic Energy Convers. (WCPEC) Joint Conf. 45th IEEE PVSC 28th PVSEC 34th EU (PVSEC), pp. 2492-2497, Jun. 2018.
8. J. Johnson, R. Ablinger, R. Bruendlinger, B. Fox and J. Flicker, "Interconnection standard grid-support function evaluations using an automated hardware-in-the-loop testbed", IEEE J. Photovolt., vol. 8, no. 2, pp. 565-571, Mar. 2018.
9. N. Ninad, E. Apablaza-Arancibia, M. Bui, J. Johnson, S. Gonzalez, W. Son, et al., "Development and evaluation of open-source IEEE 1547.1 test scripts for improved solar integration", Proc. 36th Eur. Photovoltaic Sol. Energy Conf. Exhib. (PVSEC), pp. 952-957, Sep. 2019.
10. N. Ninad, E. Apablaza-Arancibia, M. Bui, J. Johnson, S. Gonzalez, R. Darbali-Zamora, et al., "PV inverter grid support function assessment using open-source IEEE p1547. 1 test package", Proc. 47th IEEE Photovoltaic Spec. Conf. (PVSC), pp. 1138-1144, Jun. 2020.
11. R. Darbali-Zamora, J. Johnson, N. S. Gurule, M. J. Reno, N. A. Ninad and E. Apablaza-Arancibia, "Evaluation of photovoltaic inverters under balanced and unbalanced voltage phase angle jump conditions", Proc. 47th IEEE Photovoltaic Spec. Conf., pp. 1562-1569, Jun. 2020.
12. N. Ninad, E. Apablaza-Arancibia, M. Bui, and J. Johnson, “Commercial PV Inverter IEEE 1547.1 Ride-Through Assessments Using an Automated PHIL Test Platform,” Energies, vol. 14, no. 21, p. 6936, Oct. 2021, doi: 10.3390/en14216936.

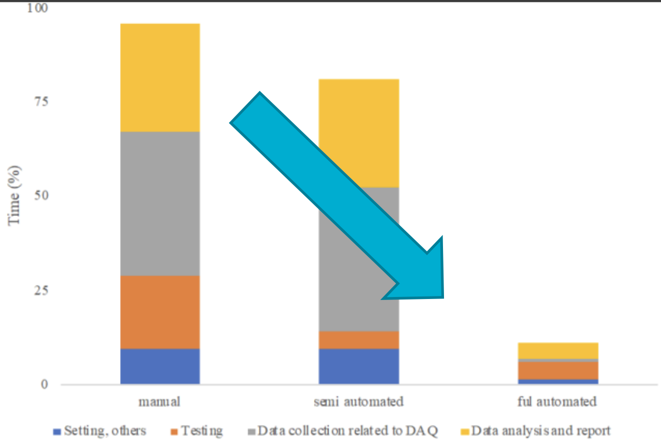
Example of adopting Automated DER Testing

- The test procedure based on IEEE 1547.1 is about 3,000 cases or more, which may increase time and cost.
- Verification was conducted in a facility that is also used for 500 kVA class certification testing, and it was shown that the test time could be reduced by as much as 85%.
- The test automation platform worked on at SIRFN will be applied to a large 5MVA-class test facility at AIST, Japan.

Increased number of test cases

	1st Edition		2nd Edition
1547 technical content:	13 pages	→	127 pages
1547.1 technical content:	54 pages	→	256 pages

The SVP can reduce the test time



The platform will install next 5MVA facility

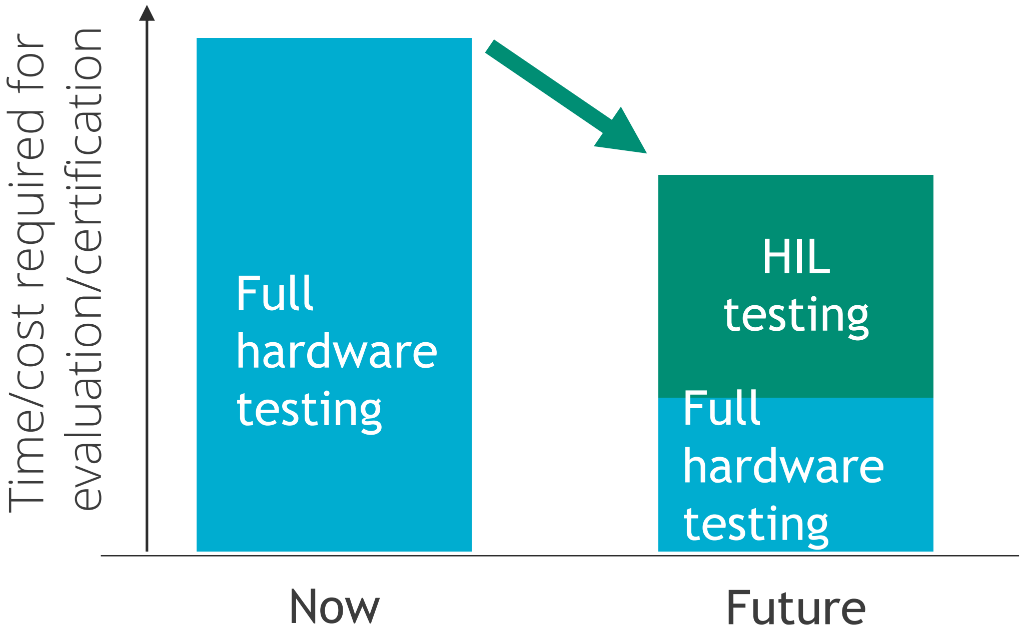
DER Testing and Verification - Overview of IEEE P1547.1, Anderson Hoke, Presentation at PJM Technical Workshop on DER Integration, July 30, 2019

J. Hashimoto, T. S. Ustun, M. Suzuki, S. Sugahara, M. Hasegawa and K. Otani, "Advanced Grid Integration Test Platform for Increased Distributed Renewable Energy Penetration in Smart Grids," in IEEE Access, vol. 9, pp. 34040-34053, 2021, doi: 10.1109/ACCESS.2021.3061731.

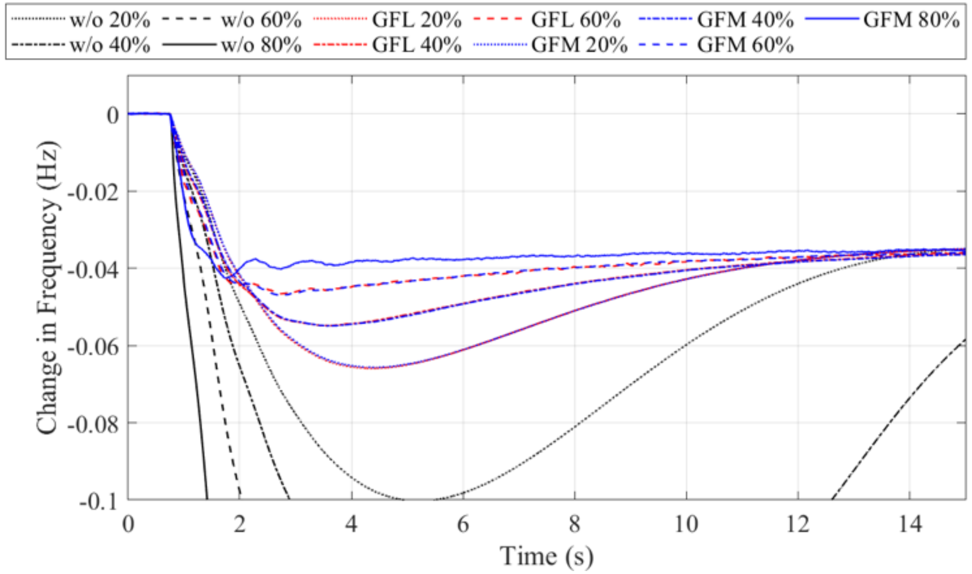
Other SIRFN activities – Advanced Lab Testing Methods

- Encourage participation and collaboration among testing facilities focused on the identification of the next generation of advanced laboratory testing methods
- Significantly reduces the time and cost required for evaluation and certification.
- Enables flexible construction of test environments to meet the increasingly sophisticated and complex requirements of renewable energy power sources.

Advantage to use HIL(virtual) testing



Impact assessment of GFL/GFM inverter on different RE installed capacities.



Thank You

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Standards Development Tradeoffs

- Types of Standards
  - DER Interconnection Standards – e.g., IEEE 1547-2018
  - **Certification Standards** – e.g., IEEE 1547.1-2020
  - Communication Standards – e.g., IEEE 2030.5-2018
  - Cybersecurity Standards/Guides – e.g., IEEE 1547.3-2023
- National and Research Laboratory Role in Standards Development is Critical
  - **Research-based, data-backed direction to standards**
  - Practical, balanced solution to support industry growth
  - Long-term solutions are prioritized
  - **Labs don't have a dog in the fight**
    - DER manufacturers tend to resist requirements
    - Certification labs & grid operators want more extensive requirements

<u>Fewer Requirements</u>
- Lower bar to market entry
- Reduced product cost
- Greater ambiguity in DER performance, communications, security requirements, etc.

<u>More Requirements</u>
- Higher bar to market entry
- Longer product development timelines
- Tighter tolerance in equipment response and behaviors
- Reduced ambiguity in data exchanges, DER performance, etc.

Standards Development Challenges

- Standards often include **multiple errors**, of varying size, which are undetected in the writing process.
  - **Standards Development Organizations (SDOs) need more quantitative support** in standards development prior to publication.
  - Where possible, SDOs incorporate field observations, industry experience, and simulation results from stakeholders.
  - Unfortunately, some certification standards are written with little or no experimental results to back test procedures, parameters, and pass/fail criteria.
  - Once detected, there are **amendments**, **revisions**, or other **"refinements"**

- SDOs benefit significantly when they can gather results from **power system models**, **DER electrical testing**, **interoperability experiments**, **field demonstrations**, etc.
  - **Difficult for labs** to get funding and complete the research in time **to edit the draft.**
  - Once labs dig deep into (ideally draft) standards, they can drastically **improve the content**.

Examples of Issues Uncovered by Lab Experiments

Interoperability Standards

- **Missing/incomplete definitions**
  - Does IEEE 1547-2018 require DER support six-point P/Q and P'/Q' WV curves?
  - IEEE 1547-2018 does not include a standardized unit for reactive power, preferably %VAMax.
  - Missing points, poor naming conventions, problems with scale factors, etc. in interoperability standards, e.g., SunSpec Modbus.
  - The IEEE 1815 DNP3 App Note should add Manufacturer, Model, Serial Number, and Version Data to the AI points.
  - There is no clear IEEE 2030.5 mechanism to disable controls.
- **Ambiguous statements**
  - Not clear if the IEEE 1547.1-2020 DNP3 management information tests require electrical experiments.
  - No description for how values changed in the IEEE 1547.1-2020 Configuration Data Test.
  - Missing IEEE 1547.1-2020 allowable tolerance on test results.
  - Does Reactive Power (Injected) and Reactive Power (Absorbed) Monitoring Information Operating Points indicate the active power direction or excitation in IEEE 1547.1-2020?
- **Harmonization issues** between DER interoperability standard information models
  - SunSpec Modbus 701.Alarm ≠ DNP3 App Note Alarms ≠ IEEE 2030.5 CSIP DERStatus:alarmStatus.
  - SunSpec includes an Anti-Islanding Enable/Disable point; IEEE 2030.5/CSIP and IEEE 1815/DNP3 App Note do not.

J. Johnson, B. Fox, K. Kaur and J. Anandan, "Evaluation of Interoperable Distributed Energy Resources to IEEE 1547.1 Using SunSpec Modbus, IEEE 1815, and IEEE 2030.5," in IEEE Access, vol. 9, pp. 142129-142146, 2021, https://doi.org/10.1109/ACCESS.2021.3120304.

Interconnection Standards

- **IEEE 1547.1-2020 Voltage and Frequency Ride-Through Experiments**
  - **Ambiguous** voltage ride-through momentary cessation test conditions resulted in inconsistent results
    - Team recommended IEEE 1547.1 precisely defined test voltages to standardize test results.
  - **Error**: Frequency ride-through measurement time insufficient to assess DER output power.
    - Team recommended extending the minimum recording time for FRT tests with frequency-droop response to include the response time of frequency-droop function.
- **IEEE 1547.1 Draft Active Power-Reactive Power Mode (Watt-Var)**
  - **Error**: Watt-Var curve was evaluated at 20% and 66% of rated EUT power, but the curtailment does not expose the characteristics of the WV curve.
    - Team recommended three sweeps of the WV curve without any active power limitation.

N. Ninad, E. Apablaza-Arancibia, M. Bui, and J. Johnson, “Commercial PV Inverter IEEE 1547.1 Ride-Through Assessments Using an Automated PHIL Test Platform,” Energies, vol. 14, no. 21, p. 6936, Oct. 2021, http://dx.doi.org/10.3390/en14216936.
N. Ninad *et al.*, "PV Inverter Grid Support Function Assessment using Open-Source IEEE P1547.1 Test Package," 2020 47th IEEE Photovoltaic Specialists Conference (PVSC), 2020, pp. 1138-1144, https://dx.doi.org/10.1109/PVSC45281.2020.9300372.