SAND2018-11500PE

Sandia National Laboratories

Status of SIRFN DER Interoperability Certification Protocol Development

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Smart Grid International Research Facility Network Meeting

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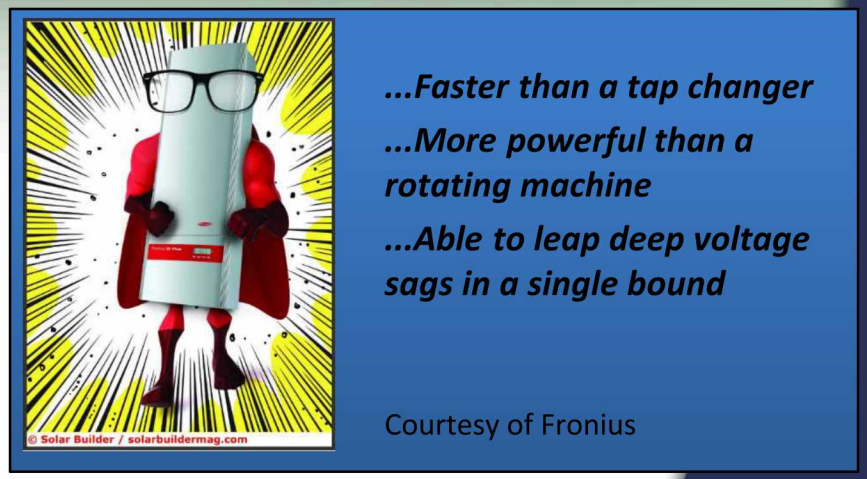
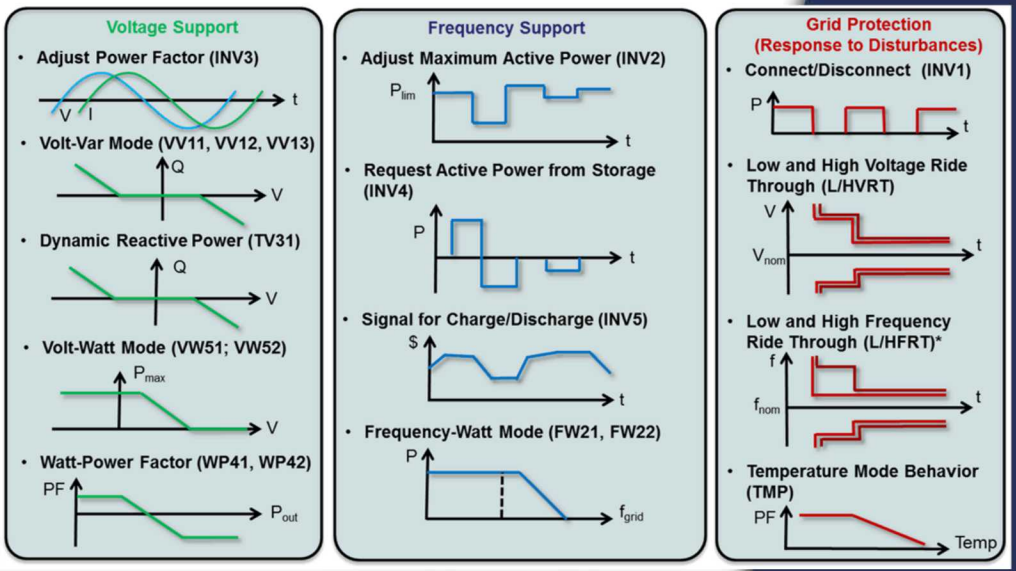
Defining Advanced Inverters

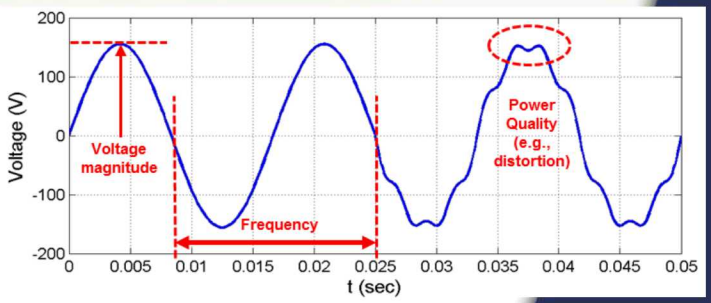
- **The context**
  - Total installed capacity of PV and ESS is growing fast
  - Large growth expected in distribution systems
- **The problem**
  - Because the grid is slow to evolve, we encounter technical challenges with voltage/frequency regulation, protection, etc.
  - Unless mitigated, these challenges will make it increasingly difficult and costly to continue integrating renewable energy
- **Advanced inverters are a big part of the solution**
  - Actively support voltage and frequency by modulating output
  - Have high tolerance to grid disturbances
  - Interact with the system via communications





Importance of SIRFN Collaboration

- **SIRFN collaboration is helping accelerate the deployment of renewable energy around the world**
  - **Urgency in U.S. to certify inverters for new requirements** – both electrical performance and communications
    - Need advanced inverter test protocols for CPUC Electric Rule 21
    - Sandia protocols acted as basis for updates to UL 1741
  - **Goal**: develop a robust consensus certification procedure for advanced inverter functions for adoption by international standards organizations
    - Laboratories around the world are collaborating to create certification protocols for interoperability and grid-support functions.
    - Collaboration is creating both the draft test standards as well as the common testing platform for certification.



SIRFN Certification Test Procedure Development

SIRFN ISGAN INTERNATIONAL SMART GRID ACTION NETWORK CLEAN ENERGY MINISTERIAL iea Energy Technology Network

Advanced Inverter Certification Protocol Timeline: SIRFN Research Parallels and Supports Standards Development

SIRFN Test Protocol Research

- **2012:** SIRFN starts to support development of testing protocols for advanced interoperability DER functions.
- **2013:** Sandia publishes set of test protocols for the IEC 61850-90-7 advanced DER functions [1].
- **2014:** Sandia, AIT, and Tecnalia write EU PVSEC paper on initial test protocols results [2].
- **2014-2015:** Sandia participates in CPUC Smart Inverter Working Group to establish recommendations for Electric Rule 21 DER requirements.
- **2015:** SVP and basic certification scripts for IEC 61850-90-7 released to SIRFN labs.
- **2015:** RSE, Sandia, AIT, and FREA publish results from the BESS certification experiments [3].
- **2016:** Working with the STP, Sandia helps create test procedures for UL 1741 SA.
- **2016:** SIRFN creates first draft of the BESS interoperability testing protocols [4].
- **2017:** AIT and Sandia demonstrate the ability to test CHIL equipment with the SVP to portions of UL 1741 SA [5-6].
- **2018:** The SVP, test scripts, and energy lab drivers are open-sourced and put on GitHub for more direct collaboration [7].
- **2018:** Regular SIRFN contributions to the GitHub SVP codebase expands the SVP scripts and drivers.
- **2018:** 11 SIRFN labs co-author a paper describing the advantages of collaborating to develop a common test platform [8].

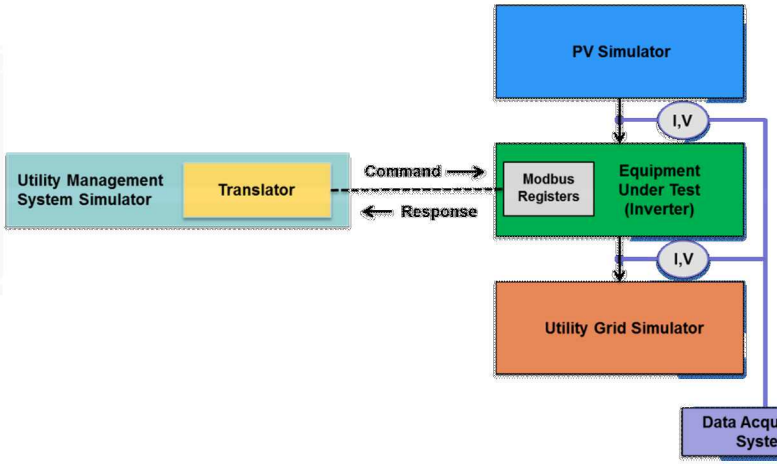
United States Standards Development

- **2008-2012:** Sandia's Solar Energy Grid Integration Systems (SEGIS) program demonstrates advanced inverter controls and communication capabilities.
- **2011:** EPRI publishes 1st edition of "Common Functions for Smart Inverters" describing a set of advanced inverter functions.
- **Feb 2013:** IEC 61850-90-7 standardizes information models for advanced inverter functions. Similar models are later created for IEEE 2030.5, SunSpec Modbus, and DNP3.
- **2014:** IEEE 1547a allows inverters to participate in voltage and frequency regulation with grid operator approval.
- **2016:** California Electric Rule 21 requires 7 autonomous functions. Requirements for communications appear in Rule 21 Phase 2 requirements.
- **2016:** UL 1741 SA published with test protocols for CA Rule 21 functions.
- **2018:** IEEE 1547 US Interconnection Std. updated to require communications and multiple advanced grid-support functions. Test requirements begin to be drafted.
- **2018:** Information models for the IEEE 1547 functions are developed for IEEE 1815 (DNP3), IEEE 2030.5 (SEP2), and SunSpec Modbus.

[1] J. Johnson S. Gonzalez, M.E. Ralph, A. Ellis, and R. Broderick, "Test Protocols for Advanced Inverter Interoperability Functions – Appendices," Sandia Technical Report SAND2013-9875, Nov. 2013.
[2] J. Johnson, R. Bründlinger, C. Urrego, R. Alonso, "Collaborative Development of Automated Advanced Interoperability Certification Test Protocols for PV Smart Grid Integration," EU PVSEC, Amsterdam, Netherlands, 22-26 Sept 2014.
[3] D. Rosewater, J. Johnson, M. Verga, R. Lazzari, C. Messner, R. Bründlinger, K. Johannes, J. Hashimoto, K. Otani, International Development of Energy Storage Interoperability Test Protocols for Renewable Energy Integration, EU PVSEC, Hamburg, 14-18 Sept 2015.
[4] M. Verga, R. Lazzari, J. Johnson, D. Rosewater, C. Messner, J. Hashimoto, SIRFN Draft Test Protocols for Advanced Battery Energy Storage System Interoperability Functions, ISGAN Annex #5 Discussion Paper, 2016.
[5] J. Johnson, R. Ablinger, R. Bruendlinger, B. Fox, J. Flicker, "Design and Evaluation of SunSpec-Compliant Smart Grid Controller with an Automated Hardware-in-the-Loop Testbed," Technology and Economics of Smart Grids and Sustainable Energy, vol. 2, no. 16, Dec. 2017.
[6] J. Johnson, R. Ablinger, R. Bruendlinger, B. Fox, J. Flicker, "Interconnection Standard Grid-Support Function Evaluations using an Automated Hardware-in-the-Loop Testbed," IEEE Journal of Photovoltaics, vol. 8, no. 2, pp. 565-571, Mar 2018.
[7] GitHub Repositories, URLs: https://github.com/sunspec/svp_energy_lab/tree/dev/Lib/svpelab & https://github.com/sunspec/svp_UL1741SA/tree/dev
[8] J. Johnson, et al., "International Development of a Distributed Energy Resource Test Platform for Electrical and Interoperability Certification," 7th World Conference on Photovoltaic Energy Conversion (WCPEC-7), Waikoloa, HI, 10-15 Jun 2018.

Example: Sandia and KERI Test-Bed Hardware Comparison

- **Both Sandia and KERI have built advanced inverter test-beds. These facilities are running inverter tests in parallel using the same software platform.**



PV Simulator
Power: 200 kW
Voltage: 0-1000 V_{dc}/output
Current: 10 A/output

PV Simulator
Power: 10 kW
Voltage: 0-500 V_{dc}
Current: 50 A

Inverter: European Partner
Power: 3 kW
Communications: Modbus, RS-485, SunSpec

Inverter: Korean Partner
Power: 3 kW
Communications: Modbus, RS-485, SEP 2.0

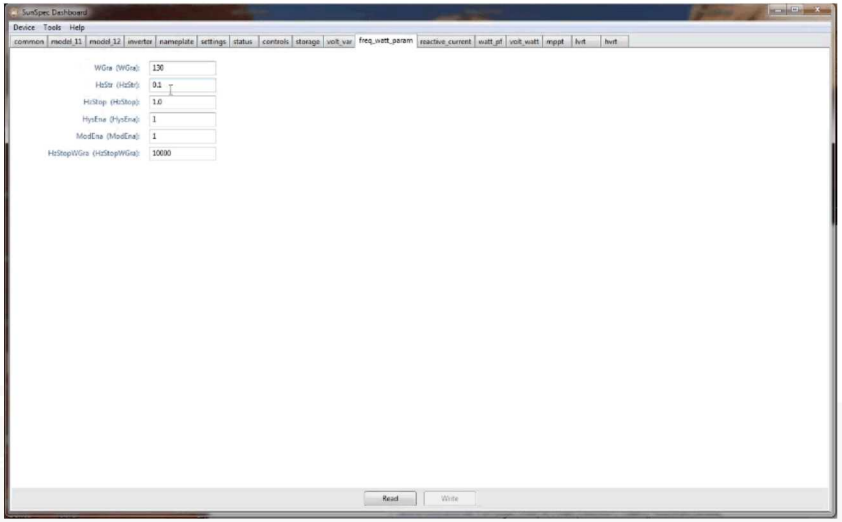
Grid Simulator
Power: 180 kVA
Voltage: 480 V 3ϕ
Current: 250 A/Phase

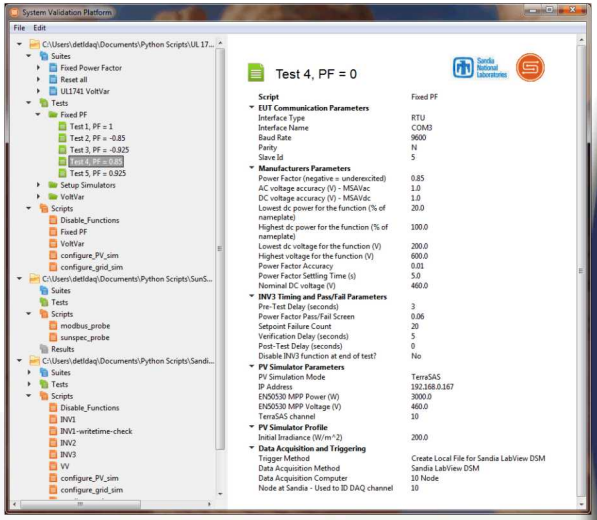
Grid Simulator
Power: 10 kVA
Voltage: 380 V_{L-L}
3ϕ, 4-wire

- Differences in testing hardware demonstrate the robustness of the testing protocols.

SunSpec Alliance Tools

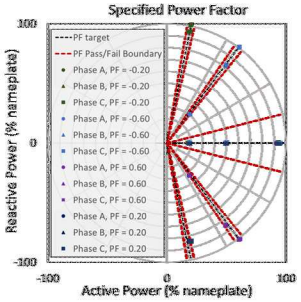
- Dashboard
  - Reads DER SunSpec models
  - Simple read/write functionality
  - Free for SunSpec members
  - Download here: http://sunspec.org/sunspec-dashboard/
- System Validation Platform
  - Scripting capabilities
  - Full automation with results processing
  - Open-sourced
  - Download executable here: http://sunspec.org/sunspec-svp/



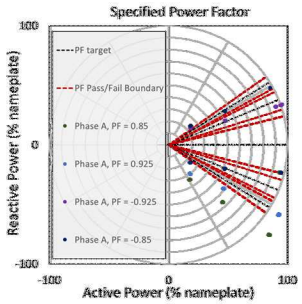


SIRFN Influence on DER Certification Testing Requirements

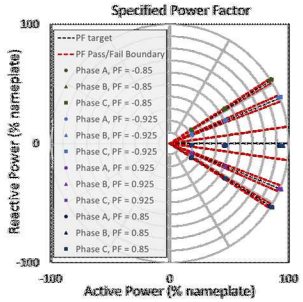
- **International collaboration is producing:**
  - Test protocols for inverters and battery storage systems
  - Software tools for evaluating DER equipment to interconnection and interoperability standards
- **SIRFN Test Results for Fixed Power Factor:**



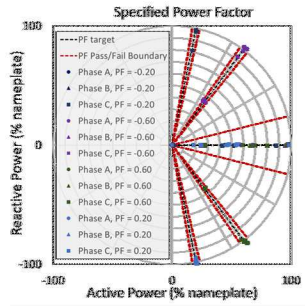
(A) 34.5 kW ASGC Solar Inverter, Reactive Power Priority, Sandia



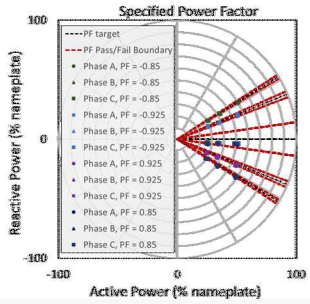
(B) 3.0 kW Solar Inverter, Reactive Power Priority, Sandia



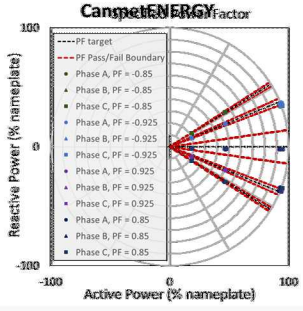
(C) 10.0 kW Solar Inverter, Reactive Power Priority, CanmetENERGY



(D) 34.5 kW ASGC Solar Inverter, Reactive Power Priority, AIT



(E) 15.0 kW Solar Inverter, Reactive Power Priority, CSIRO



(F) 10.0 kW Solar Inverter, Active Power Priority, CanmetENERGY

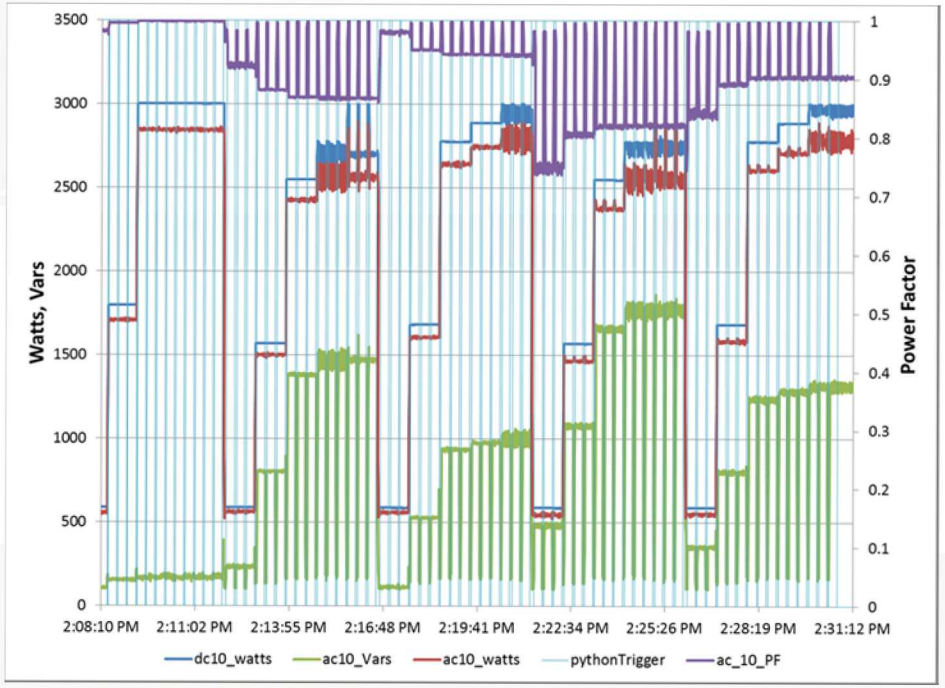
References

1. J. Johnson, et al., "International Development of a Distributed Energy Resource Test Platform for Electrical and Interoperability Certification," 7th World Conference on Photovoltaic Energy Conversion (WCPEC-7), Waikoloa, HI, 10-15 Jun 2018.
2. J. Johnson, R. Ablinger, R. Bruendlinger, B. Fox, J. Flicker, "Design and Evaluation of SunSpec-Compliant Smart Grid Controller with an Automated Hardware-in-the-Loop Testbed," Technology and Economics of Smart Grids and Sustainable Energy, vol. 2, no. 16, Dec. 2017. DOI: 10.1007/s40866-017-0032-7
3. J. Johnson, R. Ablinger, R. Bruendlinger, B. Fox, J. Flicker, "Interconnection Standard Grid-Support Function Evaluations using an Automated Hardware-in-the-Loop Testbed," IEEE PVSC, Washington, DC, 25-30 June, 2017.
4. J. Johnson, R. Bründlinger, C. Urrego, R. Alonso, "Collaborative Development of Automated Advanced Interoperability Certification Test Protocols for PV Smart Grid Integration," EU PVSEC, Amsterdam, Netherlands, 22-26 Sept, 2014.

Power of Testing Automation

- **Large number of permutations in each advanced DER function test protocol:**
  - 75 measurements for draft fixed power factor - takes about 25 minutes with the SVP
  - 375 measurements for draft volt/var - takes about 90 minutes with the SVP

Fixed Power Factor Tests



Volt-var Tests

SVP Script Status

- **UL 1741 SA:** https://github.com/sunspec/svp_UL1741SA/tree/dev/UL1741%20SA
  - SA8 Anti-islanding Protection (requires waveform capture and processing)
  - SA9 L/HVRT Low and High Voltage Ride-Through (requires waveform capture and processing)
  - SA10 L/HFRT Low and High Frequency Ride-Through (requires waveform capture and processing)
  - SA11 RR – Normal Ramp Rate and SS – Soft-Start Ramp Rate (initial version)
  - SA12 SPF – Specified Power Factor (verified)
  - SA13 Volt/VAr Mode (Q(V)) (verified)
  - SA14 Frequency-Watt (FW) (initial version)
  - SA15 Volt-Watt (VW) (initial version)
- **Test Protocols for IEC 61850-90-7:** [Needs to be updated to latest SVP release]
  - INV1 (Connect/disconnect)
  - INV2 (Curtail active power)
  - INV3 (Fixed power factor)
  - VV12 (Volt-var with reactive power priority), VV11, VV13, VV14
  - FW (Frequency-Watt)
  - VRT (Voltage Ride-Through)
- **SVP Energy Lab Scripts (driver container):** https://github.com/sunspec/svp_energy_lab/tree/dev
  - Check communications to EUT, DAS, PV simulator, grid simulator, load bank, and battery simulator
- **General Scripts:** https://github.com/jayatsandia/svp_additional_tools/tree/master/Scripts
  - Disable functions
  - Check communications to PV and grid simulators
  - Simple DER control scripts (adjust PF, P, etc.)
  - Configure Ametek grid simulator
  - Configure Ametek PV simulator

Status of Laboratory SVP Deployments

Many SIRFN labs are beginning to implemented the SVP to conduct DER experiments.

Laboratory	SVP PV Simulator Driver	SVP Grid Simulator Driver	SVP DAS Driver	SVP with ASGC/Typhoon HIL	Conducted DER Tests with Hardware or CHIL
SNL, USA	✓	✓	✓	✓	✓ (SVP)
CanmetENERGY, Canada	✓	✓	✓		✓ (SVP)
AIT, Austria	✓		✓	✓	✓ (SVP)
CSIRO, Australia	✓		✓		✓ (SVP)
FREA, AIST, Japan	✓	Planned	Planned		✓
KERI, Korea	Planned	Planned	Planned		✓
CPRI, India	✓				
RSE, Italy	✓		✓		✓
INEEL, Mexico	Planned	Planned	Planned		Planned
ZHAW, Switzerland				Planned	Planned
Tecnalia, Spain	Planned	Planned	Planned		✓

Future Work

- **Documentation**
  - The SVP, scripts, abstraction layers, and drivers are poorly (i.e., not) documented and commented
  - Need to have simulated equipment (DAS, PV, Grid) for those without equipment – this is started but incomplete
  - Documents explaining how to work with abstraction layers and write drivers are needed
- **Scripts need to be completed for:**
  - UL 1741 SA
  - IEEE 1547.1
  - SNL IEC 61850-90-7 protocols
  - SIRFN BESS protocols
  - European, Asian, other grid codes
- **New drivers are needed for many of the laboratories**
  - Major work is still needed to capture and process waveforms for anti-islanding and FRT/VRT tests.
- **Automated results generation and processing required for scripts**
  - Need to define common results format for all tests/scripts
  - Would like to have results in .csv and .xlsx files
  - Final PDF results processing is desired

Conclusions

- **DER advanced functions help support the electricity grid**
  - **Standardized test methods** for verifying **DER functionality** and **interoperability** are **critical**.
  - **SIRFN members** are **improving certification protocols** by:
    - Building test-beds for advanced inverter testing (electrical performance and interoperability).
    - Comparing advanced DER test results and improving draft certification protocols.
    - Recommending improvements to national and international codes and standards.
- **Progress:**
  - Test script and SVP driver development is active on GitHub.
  - SVP deployments at each of the SIRFN labs are in process.
  - Significant international collaboration in this research space is expected for years to come!