Energy Research and Development Division

PROJECT TASK REPORT

Cost Reduction Forecast Report of Distributed Energy Resources (DERs) in California

California Energy Commission

Edmund G. Brown Jr., Governor

January 2019 | CEC-XXX-2018-XXX

PREPARED BY: SunSpec Alliance

Primary Author(s):
Tom Tansy
Christina Olsen
Suzanne Martinez
Glenna Wiseman

SunSpec Alliance
4040 Moorpark Ave., Suite 110
San Jose, CA 95117
Phone: (831) 227-1073

Contract Number: EPC-14-036

PREPARED FOR:
California Energy Commission

Hassan Mohammed
Commission Agreement Manager

Sandra Raymos
Commission Agreement Officer

Laurie Ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Robert P. Oglesby
Executive Director

ACKNOWLEDGEMENTS

The SunSpec Alliance would like to thank the following smart inverter manufacturers for participating in this project: ABB Group, Advanced Energy, Enphase Energy, Fronius International, Ideal Power, KACO new energy, Pika Energy, Outback Power, SMA America, SolarEdge, and Tabuchi Electric. The impact these companies have had on the advancement of the Distributed Energy Resource (DER) industry is immeasurable.

We would also like to thank Jay Johnson, the smart inverter research team at Sandia National Laboratories, and the Smart Grid International Research Facility Network (SIRFN) members for their contributions to the development of the smart inverter test protocols and test scripts used in this project. These fundamental technologies are a major catalyst for the transformation of global electrical grid into an intelligent resource.

SunSpec would also like to acknowledge the expert counsel provided by Byron Washom of the University of California San Diego. Byron's insights and words of encouragement were essential as we brought this project from concept to fruition.

Finally, we would like to thank the California Energy Commission for both having the vision to invest in research of this type and for their guidance in executing programs of this magnitude.

PREFACE

The California Energy Commission's Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solution, foster regional innovation and bring ideas from the lab to the marketplace. The California Energy Commission and the state's three largest investor-owned utilities – Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company – were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The Energy Commission is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Cost Reduction Forecast Report is the draft Task 5 report for the *Smart Inverter Interoperability Standards and Open Testing Framework to Support High-Penetration Distributed Photovoltaics and Storage* project, CEC EPC-14-036, conducted by the SunSpec Alliance. The information from this project contributes to Energy Research and Development Division's EPIC Program.

All figures and tables are the work of the author(s) for this project unless otherwise cited or credited.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

Distributed Energy Resources (DERs), typically consisting of solar PV and energy storage systems on homes and commercial buildings, are a growing source of power on the electric grid. DERs participate in the retail energy market, reducing energy costs by dispatching energy to offset local load. With the advent of smart inverters, DER systems now have the ability to simultaneously participate in the wholesale market and take advantage of the economic opportunities there as well. This report identifies opportunities and barriers for DER wholesale market participation, using California Rule 21 as a starting framework. This report finds that if device tariffs and communications are harmonized, DERs can participate on the wholesale market to provide additional revenue streams beyond grid stability on the retail market.

Keywords: Distributed Energy Resources, DER, smart grid, wholesale market, retail market, CSIP, Rule 21, tariff, California ISO

Please use the following citation for this report:

Tansy, Tom, Christina Olsen, Suzanne Martinez, Glenna Wiseman. SunSpec Alliance. 2019. *Cost Reduction Forecast Report of Distributed Energy Resources (DERs) in California*. California Energy Commission. Publication Number: CEC-XXX-2018-XXX.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The State of California has set ambitious targets for decreasing greenhouse gas emissions and increasing the production and distribution of clean energy. Notably, the recently adopted SB 100 – the 100 Percent Clean Energy Act of 2018 – establishes a state policy to provide 100% clean energy by 2045.

High PV penetration using legacy inverters on California grid feeder circuits can exacerbate problems associated with grid instability. It is currently both expensive and risky for grid operators to monitor and control diverse DER assets, including participation in ancillary service markets. While inverter power technology exists, a standard and cost-effective communication interface to monitor and control inverter operating functions and address grid operating variability is not available.

The solution is to enable high penetration of solar PV and DER beyond current Institute of Electrical and Electronics Engineers (IEEE) limits (15% total circuit penetration) while improving grid stability and increasing cost effectiveness.

Key barriers impeding the achievement of this vision include: 1) availability of cost-effective communication-capable smart inverters; 2) sufficient empirical data to objectively evaluate the impact of DER installations on substations and feeder circuits; and 3) a detailed understanding of the economic and environmental benefits of solar PV-based DER systems.

This project addressed these critical gaps hindering progress toward creating cost-effective and mass-produced smart inverters that can be integrated into diverse grid systems through standard communications. It also provides concrete, real-world and actionable data, demonstrating that a standards-based approach will deliver significant benefits to California ratepayers, utilities, DER providers, and equipment manufacturers. This project delivers a smart inverter test framework and open source software tools to enable rapid product development and safety testing. A review of costs and benefits of an electric generation, transmission, and distribution network with high penetration of solar PV and DER has also been conducted.

The results of this project prove 100%+ renewables into the California grid is technically feasible, in combination with rapidly declining costs driven by global market efficiencies make state-level clean energy targets achievable. To achieve the necessary full DER penetration, the grid requires data communications as an essential new layer to meet the pressing needs of safe, reliable, and cost-effective clean energy. Smart inverters are one part of this and do not require significant additional costs. However, broader investment will be required in the short-term to create the network needed for a clean energy future. Costs therefore need to be assessed within the context of the larger shifts happening in California's energy sector. An evaluation platform has been developed that, coupled with a continuous improvement approach, will enable the transition from California's current electric delivery system to the necessary networked grid that will allow adequate clean energy resources to meet climate targets while maintaining safety, reliability, and cost effectiveness.

Investments in a better grid will unleash numerous economic benefits to all stakeholders, including:

- Annual operating cost savings of over $1B from leveraging decentralized generation. $313M for leveraging decentralized generation; $8.5M avoided capacity cost; and $33M reduced distribution costs. [1]

[1] Navigant Consulting, 2009, March. "The Value of Distribution Automation," final project report for CEC-500-2007-103.

- Reduced greenhouse gas (GHG) emissions by 68.7 million metric tons with a carbon price savings of over $1B per year.[2]
- More jobs, with an anticipated future increase to the existing 500,000 clean energy jobs in California.
- Training to bridge the existing skilled worker gap in the renewables industry and ensure the workforce is prepared for the specialized nature of new jobs related to DERs and the evolving grid. Community colleges can serve as the centers for this training.
- R&D to meet emerging industry needs to bring high penetration of solar PV and DER. Smart energy laboratories may one day be affordable to the likes of California Community Colleges, high schools, or even primary schools.
- Market support for industry sectors developing products and services to meet California's emerging needs. This project has proven that manufacturers are ready to serve the market now.
- Improved grid resiliency and reliability with avoided costs of outages (including lost productivity for customers during shutdown).
- Avoided costs for grid upgrades and savings in system design, installation, commissioning, and O&M.
- Technological leadership: California as the world leader in 100% renewables with multiplier environmental and economic effects as other jurisdictions follow this model and leverage California's policy, technical, and industry expertise.

The project supports the California Energy Commission's commitment to reduce energy costs and the environmental impacts of energy use - such as greenhouse gas emissions - while ensuring a safe, resilient, and reliable supply of energy.[3] It also helps the State of California reach its ambitious targets for transitioning the electric grid to renewable energy as part of state level action on climate change. SB100 will not be achievable without significant changes in the way energy is produced and delivered across the state.[4]

These latest state-level commitments will require significantly more clean Distributed Energy Resources (DERs) across California. Bringing those energy resources onto the grid while maintaining reliability, safety, and affordability is the big challenge. Demonstrating the feasibility of high-penetration distributed photovoltaics and storage was therefore an urgent and essential task to ensure California's 100% clean energy targets are achievable.

This project was led by the SunSpec Alliance and supported by a team comprised of the University of California San Diego, Southern California Edison, Kitu Systems, Strategen, OSISoft, and an array of Smart Inverter (SI) manufacturers including ABB, Alpha Energy, Fronius, Pika Energy, SMA, and Tabuchi.

---

[2] California Greenhouse Gas Emission Inventory. California Air Resources Board. https://www.arb.ca.gov/cc/inventory/data/data.htm

[3] Toward a Clean Energy Future. California Energy Commission. https://www.energy.ca.gov/commission/

[4] 100% Clean Energy (SB100). California State Senate. https://focus.senate.ca.gov/sb100

INTRODUCTION

Project Purpose

The purpose of the EPC-14-036 project is to develop, demonstrate and evaluate a complete solar photovoltaic (PV) with distributed energy resources (DER) system, solar PV-based DER system, that will address key barriers impeding the progress toward high penetration of solar PV and DER, while improving grid stability and increasing cost effectiveness. The system which includes a standardized communication interface harmonized with the future International Electrotechnical Commission (IEC) (IEC 61850-90-7), will monitor and control inverter operating functions including participation in ancillary service for diverse DER assets.

The work includes development of a CA Rule 21 test framework and test scripts, compliance testing of smart inverters with functionality as described in the California Public Utility Commission (CPUC) CA Rule 21 Smart Inverter Working Group (SIWG) recommendations, deployment of integrated PV and energy storage systems participating in ancillary service markets, and a market impact report to estimate potential impacts of this solution on California distributed generation market development. The project demonstrates the benefits to all stakeholders including ratepayers, utilities, manufacturers, investors and system operators.

Task 5 of the EPC-14-036 project, relating to the Analysis and Validation of Value Propositions, had three objectives:

1. Demonstrate a 10% cost savings of distributed energy resources (DER) system engineering from current baseline estimates for California ratepayers and other stakeholders;
2. Identify new revenue models for DER investors and operators; and
3. Conduct a value proposition analysis including an assessment of ratepayer impacts.

This report constitutes an activity within Task 5 and broadly addresses the economic impacts and related issues of DERs within the context of this project.

Thesis

The Problem

High PV penetration using legacy inverters on California grid feeder circuits can exacerbate problems associated with grid instability. It is currently both expensive and risky for grid operators to monitor and control diverse DER assets, including participation in ancillary service.

While inverter power technology exists to address grid operating variability—voltage and frequency excursions or power surges or sags, for example—a standard and cost-effective communication interface to monitor and control inverter operating functions has not been broadly deployed. Without this interface, it is both expensive and risky for grid operators to monitor and control diverse DER assets, participation in ancillary services markets is beyond reach, and the market for PV systems is constrained because of the 15% limit on grid penetration by DER systems.

With increased PV penetration, and lacking an effective solution, California could face a crisis that will be costly to address and that could even stifle the market. While the international standards community acknowledges this technology gap, development of international standards is slow.

The Solution

The vision of this project is to enable high penetration of solar PV and DER beyond current Institute of Electrical and Electronics Engineers (IEEE) limits (15% total circuit penetration) while improving grid stability and increasing cost effectiveness.

Key barriers impeding the achievement of this vision include: 1) availability of cost-effective communication-capable smart inverters; 2) sufficient empirical data to objectively evaluate the impact of DER installations on substations and feeder circuits; and 3) an understanding of the economic and environmental benefits of solar PV-based DER systems.

The project addresses these critical gaps impeding progress toward creating cost-effective and mass-produced smart inverters that can be integrated into diverse grid systems through standard communications. It also provides concrete, real-world and actionable data, demonstrating that a standards-based approach will deliver significant benefits to all of California ratepayers, utilities, DER providers and equipment manufacturers. This project delivers a smart inverter test framework and open source software tools to enable rapid product development and safety testing. A review of costs and benefits of an electric generation, transmission, and distribution network with high penetration of solar PV and DER has also been conducted.

Project Process

The project commenced February 2015 and will be completed February 2019. In that time, it successfully met its core purpose, proving that achievement of SB 100 solar installation goals of 100% renewables in California is feasible now. This was proven through a combination of lab testing, field testing, evaluation platform development, and related research by the SunSpec Alliance and over a dozen academic and industry partners and participants.

Keeping nearly all of the original participants on board throughout a long project (over four years) that spanned regulatory regimes and business cycles is a major success in itself. It is also remarkable that 10 of the 11 companies that participated in the project have products to market. However, unforeseen circumstances led to a key vendor dropping out of the project. This resulted in major delays and required changes – with the approval by the CEC – in how the project went forward. Fortunately, the replacement vendor brought new and valuable capabilities, particularly a deep understanding of networking. The shift in some of the original planned activities affected how the major conclusion was reached, not the conclusion itself, and the core proposition – establishing feasibility of 100% renewables into the grid – remained consistent throughout the project.

The original project concept of the system being commissioned in a factory changed so costs did go up due to the test being done in the field instead. There are still savings with the use of smart inverters and DERs, as is covered in this report.

However, while the lab and field tests were making a strong technical case for high-penetration of DERs, new insights into the value proposition component developed. It became increasingly clear as the project progressed that investigating cost savings and new revenue models are not best done within the limited context of smart inverters or other technological aspects of DERs.

The entire energy production, transmission, and distribution system model is undergoing a major change in response to critical environmental, economic, and technological challenges. While components within the power generation system – such as DERs – or specific technologies to enable them – such as smart inverters – play key roles in enabling the needed change, teasing out costs attributed to them is not just difficult, but also likely off point. The matter needs to be viewed at a level appropriate to the change that is inducing the costs in the first place.

Significant new investment is now required to help evolve the current electricity grid from its centralized nature defined largely by physical power conversation components toward a responsive decentralized system that integrates the physical components with a new networked layer. This shift is necessary (and as this project proves, is technically feasible now) to meet the State of California's clean energy mandates. The main question concerns where the upfront costs of this transformation will be borne, and by who. The context for a cost and market investigation has to be the entire power generation and delivery system rather than at the level of specific parts of the system. This Cost Reduction Forecast Report is a response to both the core intent of the project as well as an emerging understanding of the complex intersecting factors related to the major evolution already underway within the electricity industry.

CHAPTER 1: Background

Policy Context

California Rule 21[5]

In 2017, the California Public Utilities Commission (CPUC) brought in new requirements for inverters in solar projects through its Electric Tariff Rule 21. The Rule 21 interconnection requirements apply to any DERs that connect to the California grid and are intended to maintain safety and reliability of the distribution and transmission systems.

Rule 21 includes interconnection requirements related to:

- Smart Inverters
- Anti-Islanding
- Fault Ride Through (voltage and frequency)
- Dynamic Voltage-VAR operation
- Ramp rates for connection and reconnection
- Voltage-Watt (optional)
- Frequency-Watt (optional)

Investor owned utilities are responsible for administering Rule 21 in their own service territories.

SB 100: The 100 Percent Clean Energy Act of 2018[6]

California's Governor Jerry Brown hosted the Climate Action Summit in September 2018 to bring people from around the world to build on the commitments made in the Paris Agreement and take stronger action toward zero emissions by midcentury. To kick off the summit, Governor Brown signed SB 100, the 100 Percent Clean Energy Act of 2018, which both accelerates the pace at which electricity providers in the state must achieve renewable energy goals and establishes a state policy to provide 100% clean energy by 2045. At the same time, Executive Order B-55-18 to Achieve Carbon Neutrality was signed, also with a 2045 target.

SB 100 outlines that:

- Eligible renewable energy resources and zero-carbon resources supply 100% of retail sales of electricity to California end-use customers and 100% of electricity procured to serve all state agencies by 2045
- 50% renewable resources by 2026 and 60% by 2030 (up from 25% of retail sales by 2016, 33% by 2020, 40% by 2024, 45% by 2027, and 50% by 2030).

These policy instruments are intended to generate benefits beyond achieving carbon neutrality, such as stable retail rates for electric service. Other anticipated benefits to Californians include:

---

[5] Rule 21 Interconnection. California Public Utilities Commission. http://www.cpuc.ca.gov/Rule21/

[6] 100% Clean Energy (SB100). California State Senate. https://focus.senate.ca.gov/sb100

- Jobs and economic growth throughout California
- Reduced local pollution from reduced fossil fuel use
- Cleaner, healthier air and less pollution in vulnerable communities where power plants are often located

SB X 1-2: California Renewable Energy Resources Act[7]

This bill, made official in 2011, obligates all California electricity providers to obtain at least 33% of their energy from renewable resources by the year 2020. It is considered the most aggressive renewable portfolio standard in the country.

AB-32: The California Global Warming Solutions Act of 2006[8]

Assembly Bill 32 (AB-32) set major precedent for climate policy, not just in California but across the US. It requires California to reduce its GHG emissions to 1990 levels by 2020 which is a reduction of approximately 15 percent below emissions expected under a "business as usual" scenario. The California Air Resources Board (ARB) developed a Scoping Plan to ensure achievement of AB-32's greenhouse gas reduction target and as work advanced, Senate Bill 32 (SB-32) was passed in 2016 which put in place a further GHG reduction target of 40 percent below 1990 levels by 2030. Various strategies have been created, including a Cap-and-Trade Program to limit total GHG emissions and specific strategies for transportation, agriculture, and other sectors. A key area of focus was the generation, transmission, and efficiency of energy in the state; notably, a goal was set to have 33% of energy come from renewable sources by 2020.

CPUC DER Action Plan[9]

The California Public Utilities Commission (CPUC)'s 2016 DER Action Plan – updated in 2017 – created a roadmap for the Commission in distributed energy resource planning within the context of greenhouse gas emission reduction and the "reform of utility distribution planning, investment, and operations".

A range of actions to implement the plan were developed within three initiatives:

1. Rates and Tariffs
2. Distribution Grid Infrastructure, Planning, Interconnection and Procurement
3. Wholesale DER Market Integration and Interconnection

The Commission sees value in DERs and concludes its action plan with a commitment to develop market opportunities and remove barriers to DERs.

---

[7] California Senate Bill SBX1-2. California State Senate. http://www.leginfo.ca.gov/pub/11-12/bill/sen/sb_0001-0050/sbx1_2_cfa_20110214_141136_sen_comm.html

[8]Assembly Bill 32 and Climate Change. California Air Resources Board. https://www.climatechange.ca.gov/state/ab32.html

[9] Distributed Energy Resource (DER) Action Plan. California Public Utilities Commission. http://www.cpuc.ca.gov/General.aspx?id=6442458159

2018 California's Fourth Climate Change Assessment[10]

The State of California's Fourth Climate Change Assessment presents climate projections and analyses of anticipated impacts in a format useful for local decision makers. Hundreds of researchers from state and federal agencies, universities, the private sector, and other stakeholder groups contributed to the report. The California Energy Commission was one of the lead coordinating agencies.

The report succinctly states: "Changing climate conditions will affect the energy system in several ways: by changing energy demand, changing performance of the energy delivery system, and by direct risks to infrastructure."

An example is increasing electricity demand for air conditioning due to hotter temperatures (particularly peak hourly demand during the hottest months). Strategies for the subsequent challenge of electricity generating capacity matching this demand, and other climate adaptation needs, are being considered by the California Public Utilities Commission (CPUC). Climate related sea level rise and storm events increase flood and wildfire risk to energy infrastructure, particularly the NorCal grid and substations in low lying areas.

Possible response measures suggested for areas where capacity may be exceeded include additional substation capacity, distributed energy resources, or load shifting. The main adaptation suggestion for areas with damaged grid infrastructure is increased use of non-generating DERs, such as such as energy storage or smart-charging electric vehicles.

2018 Fourth National Climate Change Assessment[11]

The latest report by the U.S. Global Change Research Program (USGCRP) to Congress and the President on global climate related impacts was released November 2018. With the National Oceanic and Atmospheric Administration (NOAA) as lead agency, a team of over 300 federal and non-federal experts prepared this assessment of the effects of climate change in the decades to come.

The report points out the increased costs and risks to energy production in the US from climate change impacts, including: increasing energy demands related to rising temperatures, extreme weather disrupting infrastructure, and changes to water availability that influence energy production.

The report also calls out the transformation of the energy sector through the increased deployment of renewable energy, widespread policy actions for greenhouse gas reduction, cost reductions for renewables, and increasingly interconnected critical infrastructure systems and telecommunications networks.

[10] California's Fourth Climate Change Assessment. State of California. http://www.climateassessment.ca.gov/state/overview/

[11] Fourth National Climate Assessment: Summary Findings, Volume II: Impacts, Risks, and Adaptation in the United States. United States Global Change Research Program. https://nca2018.globalchange.gov/

CHAPTER 2: Project Outcomes

The project largely addresses critical gaps impeding progress toward creating cost-effective and mass-produced smart inverters that can be integrated into diverse grid systems through standard communications. To fill these gaps, the SunSpec Alliance, including many leading inverter manufacturers and fleet operators, developed a de facto communication standard (SunSpec Modbus) that is harmonized with international standards such as IEEE 2030.5 and IEEE 1815. (At the time of this writing, all three of these protocols have now been incorporated into the IEEE 1547-2018 standard, the national standard for DER.) What was missing was a test framework to prove interoperability, empirical data to validate the effects of smart inverters on the grid, and market data to evaluate the economic impact that smart inverters bring.

This project titled, "Smart Inverter Interoperability Standards and Open Testing Framework to Support High-Penetration Distributed Photovoltaics and Storage," delivers substantially on all three missing elements, demonstrates that the introduction of SI's to the California grid renders the policy of limiting grid penetration to 15% of load obsolete, and advances the state of DER communication in California.

Key project outcomes include:

- A testing framework, called SunSpec System Validation Platform (SunSpec SVP), was delivered with open source test scripts to ensure CA Rule 21 Phase 1 and 2 capability. These scripts are available now at https://github.com/sunspec/svp_directories. SI products from five manufacturers were tested and evaluated using this technology and the UCSD test lab. While most of these products were "in development" at time of evaluation, the majority of them exhibited expected/standard behavior when stimulated by network control systems.
- A CA Rule 21 Phase 2-compliant data communication network, using the SunSpec Modbus protocol on the local system and the IEEE 2030.5 protocol for DER-to-utility communication, was deployed in a pilot system consisting of 25 PV+storage systems on Southern California Edison (SCE) grid. This pilot system proves interoperability between SunSpec Modbus and IEEE 2030.5, that SI's respond accurately to control signals sent from the utility to enforce grid health, and that the measured effect of the controls (e.g. change voltage settings or curtail power output) work as predicted by the computer models.
- SI's that implement CA Rule 21 Phase 1 autonomous functions enable penetration of feeder circuits by PV systems of between 100% and 200%. This project proves that SI's made by different manufacturers perform CA Rule 21 Phase 1 autonomous functions in a manner consistent with the UL 1741 SA standard, thus increasing interoperability of SI's across PV system configurations and expanding customer choice.
- From a grid health viewpoint, the project proves that achievement of SB 100 solar installation goals of 100% renewables are feasible now. With the achievement SB 100 goals, additional benefits associated with decreasing greenhouse gas emissions and the cost of energy also accrue to all Californians.
- Knowledge gleaned from this project allowed SunSpec to play a key role in the development of the Common Smart Inverter Profile, a specification document that forms the basis of CA Rule 21 Phase 2 compliance.
- While additional revenue models for DER investors and operators have been identified, the project uncovered the fact that significant technology, policy, and market development is required before the benefits of these new opportunities can be realized.

These key outcomes are explored in detail below.

Feeder Penetration of Greater than 100%

An earlier report for with this project ("Smart Inverter for High PV Penetration: Analysis of Functionality and Behavior," San Diego, California. Pecanek, Zack et al., California Energy Commission, October 2016) demonstrated that typical feeder circuits in the San Diego Gas and Electric grid could be loaded with PV and PV+storage systems by up to 200% of load while reducing the number of system faults and load tap operations (i.e. improving grid health). One open question in this study was "will SI's installed on real feeder circuits exhibit the same behavior as the simulated devices?"

In both the lab testing at UCSD and field testing in the SCE grid, this project was able to prove that real SI devices respond identically to simulated devices when given control signals (see the detailed report on this topic—to be published in December 2019) via communication networks. Given this result, we can conclude that grid penetration levels of 100% or greater are technically feasible today.

As a result, we can estimate that cost savings associated with supplying 100% of state-wide energy requirements with low cost solar energy could save California approximately $1 billion in 2018 dollars and reduce GHG emissions by 68.7 million tons (cite source of cost estimates).

This same "Smart Inverter for High PV Penetration" estimates that approximately $1B in grid upgrades and maintenance per year by leveraging the capabilities of SI's. While those estimates may have been optimistic (given the efficacy of given SI functions combined with cost data source in the year 2009), significant savings are possible.

NREL recently estimated the costs associated with integrating distributed photovoltaic (DPV). NREL found that "average costs vary significantly between feeders and spatial distribution scenarios, ranging from $0 to $0.04/W DC for the baseline scenario and up to $0.07/W DC for the high inverter cost case when only the economical solutions are considered." [12]Economic solutions were enabled by guiding DPV into low-cost integration locations and using smart inverters. Generalizing and applying these cost estimates to installed DPV capacities on the California networks results in the following total system cost estimates:

Table 1: Cost Estimates Associated with Integrating Distributed Photovoltaic

	CA Total System Cost		
DPV % of CA Peak	**Low**	**Low-Mid**	**High**
20%	0	$ 421,052,632	$ 736,842,105
30%	0	$ 631,578,947	$ 1,105,263,158
40%	0	$ 842,105,263	$ 1,473,684,211
50%	0	$ 1,052,631,579	$ 1,842,105,263

The NREL report suggests that DPV integration has advanced through increased data analysis and process refinements costs are decreasing. Extrapolating NREL's cost estimate to the California network demonstrate this. While more granular analysis should be conducted to

[12] Horowitz, Kelsey, et al., National Renewable Energy Laboratory, 2018, April. "The Cost of Distribution System Upgrades to Accommodate Increasing Penetrations of Distributed Photovoltaic Systems on Real Feeders in the United States."

verify system-wide cost estimates, NREL's cost estimate demonstrate high-level evidence of cost declines for integrating DPV.

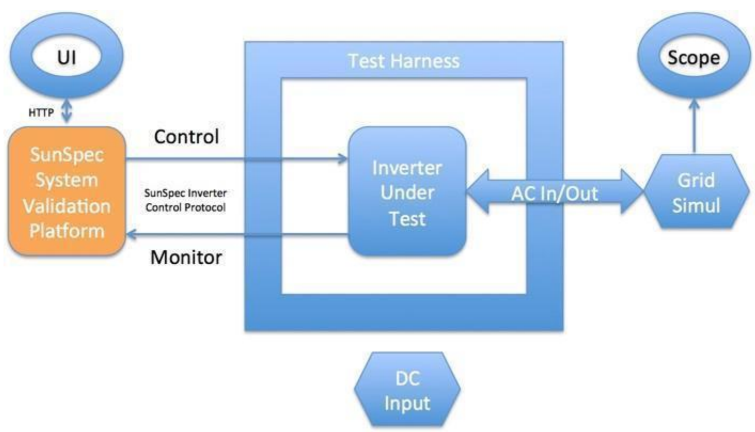
New Evaluation Platform

A description of the lab and field tests for the "Smart Inverter Interoperability Standards and Open Testing Framework to Support High-Penetration Distributed Photovoltaics and Storage" project is below. In undertaking this project, a new capability was developed to rapidly test and evaluate new products. This has potential significant implications for advancing DERs.

SunSpec SVP Testing and Validation Framework and Lab Testing

The SunSpec System Validation Platform (SunSpec SVP) provides a framework for testing and validating SunSpec compliant devices and applications. Three principal types of testing are targeted: SunSpec protocol conformance testing, equipment functional testing, and Application Program Interface testing.

Figure 1: SunSpec Validation Platform



A common use case for device functional testing is inverter control functionality. Functional testing for a device implementing inverter control functionality would typically have the components, shown in the figure at right: equipment under test, grid simulation, PV simulation, data acquisition, and post-test analysis.

Equipment functional testing consists of verifying the behavior of the device with specified settings under specific electrical conditions. These tests are comprised of test cases specified in test protocol documents such as the Sandia Inverter Test Protocols. This project enabled the SunSpec team to develop open source test scripts for evaluating compliance to UL 1741 Supplement A (the core safety test for CA Rule 21). These scripts available here https://github.com/sunspec/svp_directories.

A total of five inverter brands were evaluated using SunSpec SVP and associated test scripts in the UC San Diego advanced function inverter test labs. While not all inverter brands passed all the tests, the majority of the brands passed the majority of the tests. This is a significant accomplishment given that testing preceded the CA Rule 21 requirement for a data communication interface by months or even years in some cases.

The requirements imposed by CA Rule 21 make SI testing more complex and more time consuming by at least one full order of magnitude. UL 1741 SA testing (the standard for CA Rule 21) requires a large number of permutations due to the number of settings in each advanced DER function. For example, the test for the Fixed Power setting requires 75 measurements and the Volt/Var setting requires 375 measurements. Performing these tests by hand could easily consume several days. With SunSpec SVP, tests can be automated and run unattended, taking less than two hours to complete.

Common Smart Inverter Profile (CSIP)

Learning from this project allowed SunSpec to accelerate the development of the Common Smart Inverter Profile (CSIP) document, a document that was co-developed by utilities and other stakeholders, and that is now an essential element of CA Rule 21.

The CSIP guide serves to assist manufacturers, Distributed Energy Resources (DER) operators, system integrators and DER aggregators to implement the Common Smart Inverter Profile (CSIP) for IEEE 2030.5. CSIP was developed as an outgrowth of the California Rule 21 SI process to create common communication profile for inverter communications that could be relied on by all parties to foster “plug and play” communications-level interoperability (outside of out-of-band commissioning) between the California IOU’s and 3rd party operated smart inverters or the systems/service providers managing those inverters. Rule 21 Smart Inverter proceedings segregated smart inverter functionality and implementations into three progressive phases: Phase 1, which comprises the Autonomous functionality and related settings which inverters must support when interconnected to California Investor Owned Utility’s (IOU) distributions system; Phase 2, which prescribes the communications between the IOUs and DER aggregators, DER management systems, and DERs themselves; and Phase 3 which details the use of Phase 2 communications for monitoring and control and other necessary uses.

This implementation guide was a required outcome of Phase 2, which prescribed IEEE 2030.5 as the default protocol for Rule 21 Smart Inverter communications. This guide, along with the IEEE 2030.5 specifications, was also used to develop the IEEE 2030.5 Client conformance test plan and certification program that is required in California. SunSpec manages this certification program now.

While the impetus and scope of this profile of 2030.5 was to meet the needs of the California IOU’s requirements for communications, the profile implements widely applicable use cases making CSIP generic and likely applicable to other regulatory jurisdictions beyond California‘s borders.

CHAPTER 3: Discussion and Implications

Technical Feasibility of SB 100

As discussed above, both lab and field testing proved that SI devices respond in the same way as simulated devices when controlled through communication networks. From these results, we can conclude that grid penetration levels of 100% or greater by DERs is technically feasible today. This far surpasses the 15% limitation previously claimed to maintain grid balance and stability.

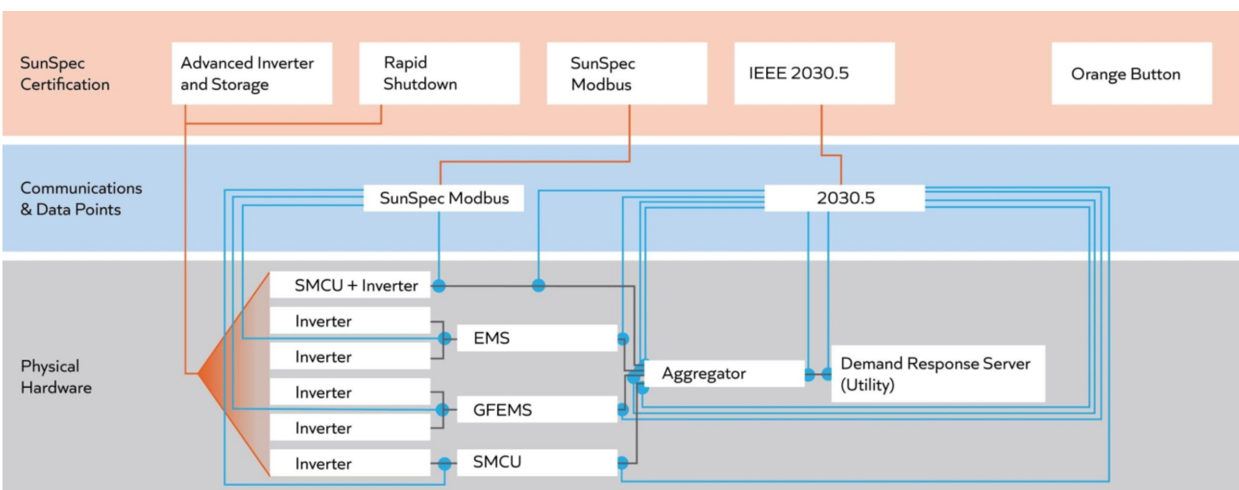
Demonstrating the feasibility of high-penetration distributed photovoltaics and storage is game-changing. As it's now proven that 100%+ renewables into the grid is possible, California's target of 100% clean energy is also attainable.

Required Network Investment

Getting the needed DER penetration onto the California grid to meet state clean energy targets is technically feasible. It will however require near-term investment to create the network ecosystem necessary to modernize electricity delivery that actualizes the clean renewable energy vision.

Enables more precise grid performance modeling and Smart Inverter ("SI") evaluation by virtue of the delivery of an open, software-based evaluation platform for this purpose.

Figure 2: Network Diagram



EMS: Energy Management System
GFEMS: Generating Facility Energy Management System
SMCU: Smart Inverter Control Unit

Benefits of SI/DER Ecosystem

Good long-term for California in two key ways:

- Environmental: We can get to SB100 goal of 100% renewables (solar plus storage is 100% feasible)
- Economic: Long range prosperity, including a reliable grid

CHAPTER 4: Conclusions and Recommendations

Conclusions

The project largely addresses critical gaps impeding progress toward creating cost-effective and mass-produced smart inverters that can be integrated into diverse grid systems through standard communications. A testing framework, called SunSpec System Validation Platform (SunSpec SVP), was delivered with open source test scripts to ensure CA Rule 21 Phase 1 and 2 capability. A pilot system consisting of 25 PV+storage systems on Southern California Edison (SCE) grid proves interoperability between SunSpec Modbus and IEEE 2030.5. The SI's respond accurately to control signals sent from the utility to enforce grid health, and that the measured effect of the controls (e.g. change voltage settings or curtail power output) work as predicted by the computer models. In addition, SI's that implement CA Rule 21 Phase 1 autonomous functions enable penetration of feeder circuits by PV systems of between 100% and 200%. This project proves that SI's made by different manufacturers perform CA Rule 21 Phase 1 autonomous functions in a manner consistent with the UL 1741 SA standard, thus increasing interoperability of SI's across PV system configurations and expanding customer choice. From a grid health viewpoint, the project proves that achievement of SB 100 solar installation goals of 100% renewables are feasible now. With the achievement SB 100 goals, additional benefits associated with decreasing greenhouse gas emissions and the cost of energy also accrue to all Californians. While additional revenue models for DER investors and operators have been identified, the project uncovered the fact that significant technology, policy, and market development is required before the benefits of these new opportunities can be realized.

Recommendations

There are several recommendations based on the findings and outcomes of this project.

1. Invest in the Network

The physical network build-out is critical yet unfunded. This investment takes several forms:

a) Continue investing in standardization.
b) Insist on certification because it is the only objective way to measure interoperability.
c) Invest in continuous improvement. The network will evolve from a static grid to a dynamic grid over years and requires constant attention. Each improvement makes it more user friendly, cost effective, and relevant to changing needs.
d) Support power movement capabilities to even out the "duck curve". The network creates a dynamic grid with capabilities to move power to load to help overcome the timing imbalance between peak demand and energy production. Use of EVs for storage and demand response to enable "prosumer" choice to reduce electricity reduction during peak times (through incentives) can be a part of flattening the duck curve.
e) Combine multiple benefits in one network. It is difficult to extract benefits from separate networks but interoperability and the "network effect" compound benefits for all (utilities, consumers, and society as a whole).

2. Invest in Security

Best practices are not driven by law but will be if there is no other intervention. Security investment could not only mitigate cyber threats, but can help avoid external regulation.

3. Invest in Smart Inverter R&D

The SunSpec System Validation Platform and UCSD test lab is the template for smart inverter research and development.

4. Clarify the Relationship Between Different Regulations

The regulations for safety, such as Rule 21 and UL1741SA, should be differentiated from the rules needed for interoperability and cybersecurity. How they work together should also be resolved.

5. Invest in Training

To meet 100% renewable energy targets, new training is needed in areas such as DER networking and cybersecurity. The SunSpec Alliance is working on this front with online training through the UCSD Extension program and executive training via in-person workshops.

6. Bring DERs, DR, and EVs Together

Tie electric vehicles (EVs) into DER networks. Treating EVs and DERs as equivalent aspects of the network can create efficiencies and save money. Just as worst-case scenarios for DERs and safety have been overcome, so can justifications for keeping EVs separate. The technology exists to safely bring them together.

7. Turn CA Rule 21 and Networked Digital Energy Grid into Ratepayer Win

a) Research and outline how the networked DER environment can be a win for ratepayers contributing to the emerging trend of educated energy “prosumers”.

b) Implement a plan of education and training that will avert a smart meter type of ratepayer backlash and instead help move the state’s DER goals forward.

REFERENCES

100% Clean Energy (SB100). California State Senate. https://focus.senate.ca.gov/sb100

Assembly Bill 32 and Climate Change. California Air Resources Board. https://www.climatechange.ca.gov/state/ab32.html

California's Fourth Climate Change Assessment. State of California. http://www.climateassessment.ca.gov/state/overview/

California Greenhouse Gas Emission Inventory. California Air Resources Board. https://www.arb.ca.gov/cc/inventory/data/data.htm

California Senate Bill SBX1-2. California State Senate. http://www.leginfo.ca.gov/pub/11-12/bill/sen/sb_0001-0050/sbx1_2_cfa_20110214_141136_sen_comm.html

Distributed Energy Resource (DER) Action Plan. California Public Utilities Commission. http://www.cpuc.ca.gov/General.aspx?id=6442458159

Fourth National Climate Assessment: Summary Findings, Volume II: Impacts, Risks, and Adaptation in the United States. United States Global Change Research Program. https://nca2018.globalchange.gov/

Horowitz, Kelsey, et al., National Renewable Energy Laboratory, 2018, April. "The Cost of Distribution System Upgrades to Accommodate Increasing Penetrations of Distributed Photovoltaic Systems on Real Feeders in the United States."

Navigant Consulting, 2009, March. "The Value of Distribution Automation," final project report for CEC-500-2007-103.

Rule 21 Interconnection. California Public Utilities Commission. http://www.cpuc.ca.gov/Rule21/

Toward a Clean Energy Future. California Energy Commission. https://www.energy.ca.gov/commission/