Energy Research and Development Division

PROJECT TASK REPORT

Coordinated DER Assets Report - Final For EPC-14-036

California Energy Commission

Edmund G. Brown Jr., Governor

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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 increased 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.

This is the final 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.

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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. Paired with Smart Inverters, DERs have vast potential as a controllable resource for the grid. This project successfully demonstrated that Smart Inverters compliant with CA Rule 21 Phase 1 requirements can be installed safely at penetration levels of 100% or higher while eliminating the reverse energy flow and thermal problems associated with non-Smart Inverters. The resulting Smart Inverter Value Proposition Analysis shows a value of $640 million to $1.4 billion due to the benefits of Smart Inverters.

This project furthermore includes a framework that enables Rule 21-compliant Smart Inverters to be easily deployed and integrated into the grid. The combined results in lab and theoretical testing, marketing, cybersecurity, education, verification, and certification for Smart Inverters provide a pathway for DERs to achieve critical mass to provide solutions and services throughout the California grid.

Keywords: *Distributed Energy Resources, DER, smart grid, smart inverter, CSIP, CA Rule 21, Rule 21, value proposition analysis, testing, standardization, cybersecurity, solar , energy storage*

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EXECUTIVE SUMMARY

The goal of the EPC-14-036 project was to develop, demonstrate and evaluate a turn-key, Smart Inverter standardization and go-to-market solution to enable high PV penetration beyond the 15% Institute of Electrical and Electronics Engineers (IEEE) guideline, which currently inhibits the growth of Distributed Energy Resources (DERs) on the grid.

The project accomplished this by enabling a collection of Smart Inverter brands to be standardized around support for the CA Rule 21 Smart Inverter functions as well as the open source de facto SunSpec communication interface. The interface is low-cost and scalable from residential to large-scale commercial systems, and results in plug and play compatible solutions. This new capability fills a critical technology gap, enables grid operators to monitor and control DER assets cost effectively, improves grid stability, and enables DER systems to participate in ancillary services markets.

This project delivered the following direct results:

- Developed and deployed a low-cost, standard test lab platform for Smart Inverters that utilizes standard communication interfaces and conformance validation procedures to prove CA Rule 21 compliance. This test lab platform is based on an open specification (also developed in this project) that can be implemented in any commercial or academic facility.
- Demonstrated that five Smart Inverter manufacturers support CA Rule 21 Phase 1 autonomous functions and settings changes via CA Rule 21 Phase 2 compliant networks.
- Demonstrated that CA Rule 21 Phase 2 compliant networks, including the IEEE 2030.5 protocols, can be deployed and implemented as intended.
- Demonstrated, via laboratory testing and field verification, that the cost of DER network deployment can be reduced by $100-$150 per system by using a standard communication interface.
- Demonstrated, via simulation and field verification, that Smart Inverters enable DER systems to safely generate 100% of circuit load (i.e. 100% DER grid penetration).

The project delivered additional benefits associated with enabling the DER workforce and mitigating cybersecurity costs:

- Developed an in-person CA Rule 21 executive education workshop, accredited by UC San Diego, that has been attended by approximately 100 individuals during two sessions and that will be offered during three additional sessions in 2019.
- Developed an online, three-unit CA Rule 21 engineering course, accredited by UC San Diego, that has served 48 students so far (17 completed, 31 enrolled in current term) and that will be offered in three additional terms in 2019.
- Convened the SunSpec-Sandia Smart Inverter cybersecurity working group to focus on issues related to CA Rule 21 network deployment. This group is comprised of 350 professionals.

By demonstrating that 100% DER grid penetration is possible, this project shatters the 15% DER ceiling currently enforced by utilities across the country within the IEEE 1547 standard guidelines. This represents significant value and benefits from Smart Inverters to the state of California. This report includes a Smart Inverter Value Proposition Analysis to quantify these benefits; the results of this analysis are presented below, showing value of $640 million to $1.4 billion due to Smart Inverters.

Table 1. Smart Inverter Value Proposition Analysis Summary

BENEFIT	LOW CASE	HIGH CASE
Reliability	$ 290,000,000.00	$ 660,000,000.00
Power Quality	$ 30,000,000.00	$ 100,000,000.00
Energy Delivery Efficiency	$ 30,000,000.00	$ 70,000,000.00
Dispatchable Resources	$ 270,000,000.00	$ 530,000,000.00
Avoided/Deferred T&D Upgrades	$ 20,000,000.00	$ 70,000,000.00
TOTAL	$ 640,000,000.00	$ 1,430,000,000.00

Summary table of Value Proposition Analysis results. Dollar values rounded to the nearest $10MM.

As a result, SunSpec has demonstrated that Smart Inverters enable DER systems to safely generate 100% of circuit load and developed a streamlined standardization Smart Inverter platform to enable 100% DER grid penetration. SunSpec's Smart Inverter platform enables a networked energy environment, with DERs serving multiple purposes and providing multiple benefits to the grid and the state of California.

CHAPTER 1: Introduction

Project Description

The goal of the EPC-14-036 project was to develop, demonstrate and evaluate a turn-key, Smart Inverter standardization and go-to-market solution to enable high PV penetration beyond the 15% IEEE guideline, which currently inhibits the growth of distributed energy resources (DERs) on the grid. The project accomplished this by enabling a collection of Smart Inverter brands to be standardized around support for the CA Rule 21 Smart Inverter functions as well as the open source de facto SunSpec communication interface. This interface is compatible to IEEE 1547-2018. It is low-cost, scalable from residential to large-scale commercial systems, and results in plug and play compatible solutions. This new capability fills a critical technology gap, enables grid operators to monitor and control DER assets cost effectively, improves grid stability, and enables DER systems to participate in ancillary services markets.

These Smart Inverters are complemented by a Smart Inverter test framework and open source software tools to enable rapid product development and safety testing. To estimate grid impacts, the project team developed power flow models to emulate target feeder conditions. To validate the power flow models and to prove data communication interoperability, the project team deployed a field pilot and collected circuit data. Finally, the project team assimilated and analyzed the data collected during the lab tests and field pilot to demonstrate the validity of the predicted benefits specified in the project goals.

The project had five specific objectives:

- Provide a standards-ready Test & Certification Framework that enables timely execution to support CA Rule 21 updates.
- Reduce DER system engineering costs by 10% from current baselines through integration of existing standards and by providing plug-and-play interoperability across manufacturers.
- Demonstrate mitigation of the impact of increased PV penetration on the feeder circuits above the IEEE-mandated 15% penetration level limit, through seamless communication between CA Rule 21-compliant Smart Inverters and a standard communication network.
- Demonstrate the ability of Smart Inverters to support the power grid during system disturbances and increase overall power grid reliability.
- Identify new revenue models for DER investors and operators by enabling standards-compliant systems to participate in ancillary grid services markets, accelerating the achievement of SB X1-2 goals.

Participants

To achieve the program goals, SunSpec engaged with a team of Smart Inverter manufacturers (ABB, Advanced Energy, Enphase Energy, Fronius International, Ideal Energy, Kaco New Energy, Pika Energy, Outback Power, SMA, and Tabuchi Electric), UC San Diego DER researchers, an IOU (Southern California Edison), a DER communication protocol software developer (Kitu Systems), and an extended team of DER system installers and cybersecurity experts.

CHAPTER 2:
Project Background

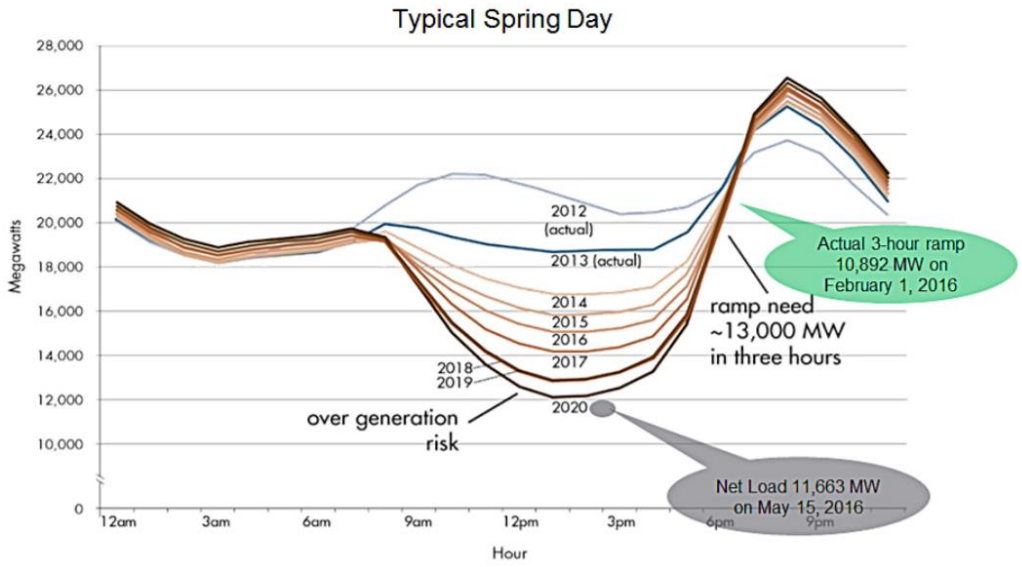
In order to properly evaluate this project's unique value proposition, sufficient context must be provided on the role of Smart Inverters as it relates to Distributed Energy Resources (DERs). As DERs are uniquely situated on the grid, interspersed throughout the distribution system at the "grid edge", Smart Inverters will most effectively leverage their capabilities when deployed as part of an integrated DER solution. This chapter presents the current and future state of the DER market, as well as policy influencing both current and future implementation of DERs.

Current State of DER Market

This section discusses the status quo of the DER market as currently implemented. With a minimal penetration of Smart Inverter DERs, this section aims to understand what is currently being spent on integrating DER as a basis for identifying further saving opportunities with Smart Inverters.

Current discussions around DERs mainly focus on solar PV, as about half of expected DER capacity additions will come from distributed PV.[1] While a valuable source of renewable energy, the grid impact and value of solar PV is also a particularly contentious resource due to its intermittency and production curve. This is most apparent in the infamous California ISO duck curve, which shows the ramp in the "neck" of the duck caused by the mismatch between the PV production curve and the load demand. This ramp exacerbates with increasing PV penetration, and could result in sub-optimal grid performance and even grid instability.

Figure 1. California Independent System Operator Duck Curve



Credit: California ISO

1 (John, 2018)

To limit further effects, the "15% rule" is instituted in many utilities, which limits the penetration of DERs to 15% of the peak feeder load. This rule follows the same guideline set in the IEEE 1547 standard.[2] In practice, further penetration levels can trigger a feeder impact study, or even distribution capacity upgrades. Both can extend the commission and installation process for DERs and incur significant costs to developers, hindering the spread of DERs beyond 15% penetration. For example, in the high-DER penetration grid of Hawaii, the Hawaii Public Utilities Commission ultimately decided to end the net-metering program in 2015, citing difficulties with maintaining grid stability.[3] This led to a 52% drop in PV permitting from 2016 to 2017.[4]

Since this project was initiated, new policies and regulation have encouraged, and in some cases mandate, the growth of DERs. The Commission has published on the energy storage legislative activity in California; two landmark bills are AB 2514, which directed the Commission to set targets for utilities to procure grid-connected energy storage systems and directed IOUs to adopt appropriate storage targets, and AB 2868, which requires the Commission to direct the IOUs to implement programs and investments to accelerate deployment of distributed energy storage, with a total goal of 500 MW in addition to the targets set by AB 2514.[5] While not explicitly requiring additional DER capacity, FERC Order 841 includes language that allows for simultaneous retail and wholesale market participation by DERs, enabling further usage and deployment of DERs on the grid.[6]

SB 100, California Renewables Portfolio Standard Program, enacted in September 2018 ahead of Governor Brown's Global Climate Action Summit, legislates an increase to 60 percent, from 50 percent, of California's electricity portfolio to renewables by 2030 and establishes a further goal to have an electric grid that is entirely powered by clean energy by 2045.[7]

Future State of DER Market

DERs, in particular those with renewable energy resources (such as solar PV and storage), have the potential to address the California policy goals stated above. In particular, Smart Inverters will play an integral role in reaching the 100% clean energy goal outlined by SB 100 by enabling and enhancing flexibility on the distribution system.

If the "15% rule" penetration limit can be removed, then DERs can provide substantial benefits to the health and operation of the grid. Unlike the traditional grid structure, with centralized generation providing power to loads through the transmission and distribution network, DERs allow for additional generation resources throughout these networks. The addition of DERs on the grid, with the correct grid architecture to support it, can enable "bidirectional" or "two-way" power flow operation and allow ratepayers to become "prosumers", both providing and consuming power.

As additional generation resources, DERs represent added power capacity to support the grid. Storage DERs are particularly useful for this application, as they represent not only additional power capacity but a stored and deployable energy capacity. With the proper regulation, DERs could be utilized to participate not only in local retail markets, but also regional wholesale

2 (Anderson Hoke, 2012)
3 (Hawaiian Electric Companies Motion for Approval, 2015)
4 (Wesoff, 2017)
5 (California Energy Commission, 2018)
6 Federal Energy Regulatory Commission. 2018. Electric Storage Participation in Markets Operated by Regional Transmission Organizations and Independent System Operators. Department of Energy. 162 FERC ¶ 61,127.

7 (Koseff, 2018)

markets. Therefore, DERs present a significant opportunity for both utilities and ISOs as a market resource.

Large networks of DERs can provide alternative transmission or distribution solutions (ATS or ADS) to support a changing grid. For example, as distribution loads grow, capacity upgrades such as additional power lines and transformers are needed to support the increased power flow from the centralized generation through the distribution network. With DERs, these upgrades can be deferred and even avoided due to the additional generation resources DERs provide in the distribution network.[8] Such DER solutions have also been extensively studied in the context of California ISO's Transmission Planning Process (TPP), through which ATS are decided and implemented for the transmission network.[9]

This potential, however, comes with some caveats and requirements. In order to deploy DERs at scale, the supply chain must be improved, including creating and enforcing operating standards, as well as ensuring that DERs conform to those standards. If DERs are not properly visible to the ISO or distribution operators, ISO-DSO coordination is not sufficient, or DER are not properly incentivized, controlled or managed, then increasing the penetration of DERs on the grid becomes difficult, leading to increased operational challenges that could incur further system costs. Smart Inverters, along with the results delivered in this project, represent an important component in mitigating these issues and allow for the proliferation of DERs and their benefits throughout the grid.

Additionally, resolutions addressing network cost and maintenance to transport CA Rule 21 mandated data communications bidirectionally from Smart Inverters to Aggregator and Utility infrastructure and the preservation of DER asset power generation by asset owners are challenges and opportunities for the California Smart Grid.

[8] (MARK DYSON, 2018)

[9] (Kerinia Cusick, 2019)

CHAPTER 3:
Project Results

This project resulted in many significant achievements in Smart Inverter research, conformance testing, standardization, cybersecurity, and education. This chapter details these project results and deliverables. Each section covers a single project result, describing the result delivered and its significance and impact to the Smart Inverter DER industry.

Smart Inverters Enable 100%+ Penetration of DERs

This project successfully demonstrated that Smart Inverters can enable DER penetration of more than 100% of peak instantaneous distribution circuit load. This success is validated by the PV Penetration Impact Forecast conducted in conjunction with the University of California San Diego (UCSD), and the Coordinated DER Assets Report. These results are additionally supported by the "Integration of Big Data for Advanced Automated Customer Load Management" report by SCE, under California Energy Commission contract ID# FT-14-063.

This result shatters the 15% DER ceiling currently enforced by utilities across the country within the IEEE 1547 standard guidelines. It also enables achievement of CA energy policy goals such as SB 100, along with other benefits which provide state-wide value, such as reduced greenhouse gas emissions, improved air quality, enhanced consumer choice, and the spread of renewable energy and electric vehicles within marginalized communities. This could also enable other states' energy policy goals, such as Hawaii's target of 100% clean energy by 2045.[10]

Conclusion

This project successfully demonstrated that Smart Inverters compliant with CA Rule 21 Phase 1 requirements can be installed safely at penetration levels of 100% or higher while eliminating the reverse energy flow and thermal problems associated with non-Smart Inverters. The implication here is that there is no technical barrier imposed by Smart Inverters that would preclude California from reaching its 100% renewable energy goals.

In summary, SunSpec has developed a streamlined standardization Smart Inverter platform for 100% DER penetration. SunSpec's Smart Inverter platform enables a networked energy environment, with DERs serving multiple purposes and providing multiple benefits to the grid and the state of California.

[10] (State of Hawai'i, 2019)

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