GRID INTEGRATION CHALLENGES FOR A ZERO NET ENERGY FUTURE

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ABSTRACT

California's policy goals for achieving zero net energy (ZNE) in buildings along with the renewable portfolio standard (RPS) requirements will flex and strain the state's existing electricity grid. Changing load profiles from high efficiency ZNE buildings, enhanced demand response (DR) capabilities for reducing peak; and the high penetration of distributed generation (DG), especially solar PV, present a new set of challenges for the grid. By conservative estimates the solar market for residential new construction alone will need to increase 50 fold to meet the state's ZNE goal by 2020. An even larger proportion of distributed generation is expected from other market sectors, increasing the challenges the utilities face in managing the electricity grid. The CSI Program was launched in 2007 and is overseen by the California Public Utilities Commission (CPUC). With a budget of over $2 billion dollars, the CSI aims to install 3000 MW of solar capacity in ten years. To support this lofty goal, the Commission approved a $50 million dollar carve out for solar research, development and demonstration. This paper will discuss the grid integration challenges facing the ZNE future along with how the California Solar Initiative's (CSI) Research Development Deployment and Demonstration (RD&D) Program is finding solutions through a portfolio of solar research projects. The range of RD&D projects include software tools for optimizing integrated demand side management (IDSM) by combining energy efficiency measures, demand response strategies with advanced storage and PV at the building and community level, to utility-scale analysis tools that study the impacts of DG on the distribution feeders and grid operations. These research projects address grid integration issues including interconnection of intermittent DG resources, innovative utility tariffs, and incorporation of advanced storage, solar forecasting, and advanced inverters for smart operation.

1. A ZERO NET ENERGY FUTURE

California's 2008 Strategic Plan calls for all new construction to be zero net energy (ZNE) by 2020 in the residential sector and 2030 for the commercial sector. ZNE described at a high level is when on-site generation is equal to building consumption, typically on an annual basis, resulting in minimum impact to the utility grid. This makes ZNE a compelling strategy to achieve overarching goals of greenhouse gas (GHG) and peak load reduction. In California

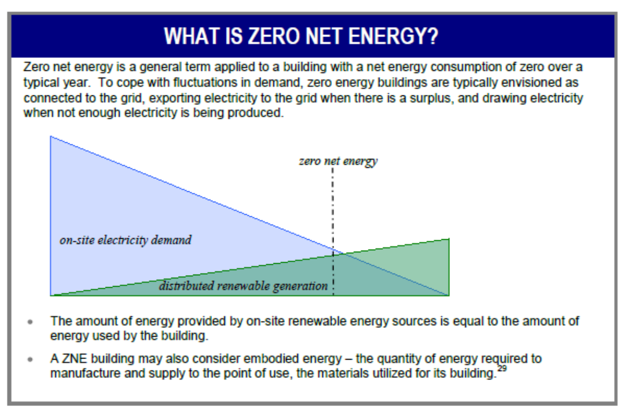

Fig 1: Zero Net Energy
Source: California Energy Efficiency Strategic Plan 2008

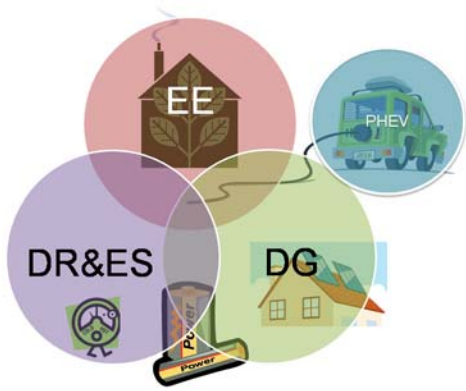

Fig 2: Integration of demand side management with on-site generation. (Energy Efficiency; Demand Response; Energy Storage; Distributed Generation; Plug in Hybrid Electric Vehicles)

AB 32, the state's primary GHG legislation drives the need for these bold ZNE strategies. ZNE in California is defined in terms of the code compliance metrics that aim to reduce peak load, and avoid emissions from inefficient power plants which have to come online to meet peak demand. The concept of zero net energy is also gaining traction on a national level. The Department of Energy's (DOE) Challenge Home Program for builder partnerships has been rebranded as the "Zero Energy Ready Home" Program highlighting the focus towards "zero". This is aligned to the concept of "ultra-low energy" buildings which employ all high efficiency measures and can be driven to ZNE with the addition of on-site generation to fill the gap to zero. However, the more important aspect of ZNE for consideration is the concept of integrated demand side management (IDSM) which enables the optimal combination of all EE measures with demand response, on-site renewable generation (usually solar PV) and energy storage, in a cost effective and holistic manner.

2. GRID INTEGRATION OF SOLAR

On-site energy generation, particularly using solar PV coupled with energy efficiency, is a critical part of the ZNE future resulting in high penetration of distributed solar generation along with a flattened demand profile due to the higher efficiency in buildings This change in profile is especially challenging to the grid since it will flex in ways that it was not designed for. One such manifestation has been the California ISO's published "duck curve" (Fig 3) which predicts scenarios of the changing load profile to a greener grid with more renewables that shifts the load profile to later in the day with higher peaks and troughs.

The traditional transmission and distribution (T&D) grid was not designed to take this level of flexing along with the two way power flow which comes with distributed generation connected to the grid. The changing shape of the effective load profile as well as a ZNE future with high solar penetration presents some real challenges to maintain the integrity and reliability of the grid.

2.1 Challenges

There are several challenges that a high solar penetration future poses to the grid, however, at the core, is the concern of compromising the reliability and integrity of the electricity supply and distribution system.

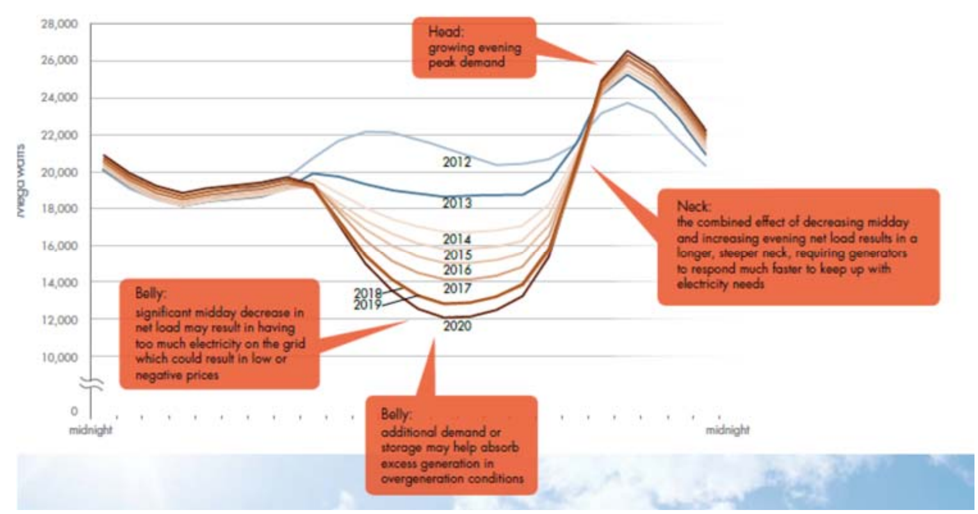

Fig 3: The "Duck Curve"
California Independent System Operator's (CAISO) graph of the future expected net load profile due to increasing penetration of renewable generation and shifted time of demand over time.
Source: California ISO, Building a Sustainable Energy Future, 2014-2016 Strategic Plan

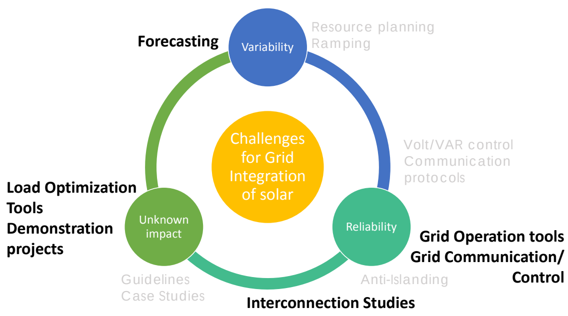

Fig 4: Grid Integration of Solar

Distributed PV systems are often outside the scope of utility planners and engineers, due to their small individual size and historically low rates of market-penetration. On a practical level, many utility personnel may not be familiar with the operational characteristics of these systems. In addition, due to the rapid growth in distributed PV systems, utility grid operation models and planning tools lack the ability to account for distributed PV generation technologies and resources.

Challenges also exist with the current methods for estimating solar resources and predicting PV system output. Existing solar resource models are based on lower resolution insolation data sets and usually provide only hourly resource values. Only with the emergence of higher concentrations of PV onto distribution feeders has there been recognition that rapid changes in atmospheric conditions over relatively small areas can have significant impacts on the aggregated PV system output and on the associated electricity distribution system.

Existing methods for predicting and planning for high penetration PV limit the ability of utilities to strategically locate this technology within their T&D systems. New solar resource and utility planning models provide utilities with the means to identify optimal locations for high density PV installations. As PV and other DG resources form a larger portion of the electricity generation mix, it will be increasingly important to have electric system planning, design, and operation modeling tools that provide utilities, the solar industry, and utility customers with the ability to accurately assess and forecast energy output and account for distributed PV systems.

2.2 Opportunities

The solar coupled ZNE future while challenging the infrastructure also addresses the underlying goal of a more predictable, lower and flatter, load profile for the utilities and the system operators. This opportunity is best addressed through location, design and operation of the built environment, and the appropriate sizing and operation of the distributed resources such a PV coupled with storage.

3. CSI RD&D PROGRAM

The goal of the California Solar Initiative's Research, Development, Demonstration and Deployment (RD&D) program is to help build a sustainable and self-supporting industry for customer-sited solar in California. This goal is complimentary to the goal of installing over 3000 MW of distributed solar which was also initially termed the "Million Solar Roofs" program. Therefore addressing the high penetration of distributed solar is a key factor in achieving the program goals. High penetration of solar can only be achieved through the successful integration of solar into the utility grid. To address these goals, the CSI RD&D program uses several strategies to maximize the return of ratepayer investment on publically-funded solar research while reducing risk. These include funding different stages of RD&D activities, allocating more funds to mature and near-term technologies and projects, leveraging cost-sharing funds from other entities, and building on past knowledge, research and lessons learned. The CSI RD&D Program target areas include: 1) grid integration; 2) improved solar technologies; and 3) innovative business models. The majority of funds are spent on projects which can show results within two to three years. Five solicitations for funding have been conducted to-date with 36 project awards that span the three primary target areas.

4. THE GRID INTEGRATION PORTFOLIO

The CSI RD&D Program has created a rich portfolio of research projects that address the challenges and opportunities presented in the grid integration of solar towards a ZNE future. There are 23 projects (Table 1) in various stages of development and execution that address one of the aspects related to grid integration identified below:

1. Solar Forecasting
2. Interconnection Studies
3. Grid Communication
4. T&D modeling tools
5. Tools and strategies to optimize net load profile
6. Grid integration demonstration projects

In the following sub sections the highlights of a few projects under each of the six aspects will be discussed to demonstrate the level of effort and strides made towards achieving the grid integration of high levels of solar.

4.1 Solar Forecasting

Solar forecasting research and the availability of high resolution solar data are an important step towards mitigating

Table 1: List of CSI RD&D Grid Integration projects

Project Title	Awardee	Solar Forecasting	Interconnection	Grid Communication	T&D tools	Optimization tools	Demonstrations
Advanced Modeling and Verification for High Penetration PV	Clean Power Research	X					
Improving Economics of Solar Power Through Resource Analysis, Forecasting and Dynamic System Modeling	University of California San Diego	X					
High-Fidelity Solar Forecasting Demonstration for Grid Integration	University of California San Diego	X					
Mitigation of Fast Solar Ramps through Sky Imager Solar Forecasting and Energy Storage Control	University of California, San Diego	X					
Quantification of Risk of Unintended Islanding and Re-Assessment of Interconnection Requirements in High-Penetration of Customer-Sited Distributed PV Generation	General Electric International, Inc. Energy Consulting		X				
Screening Distribution Feeders: Alternatives to the 15% Rule	Electric Power Research Institute, Inc.		X				
Analysis to Inform California Grid Integration Rules for PV	Electric Power Research Institute		X				
Development and Analysis of a Progressively Smarter Distribution System	University of California Irvine - APEP			X			
Analysis of High-Penetration Levels of PV into the Distribution Grid in CA	Southern California Edison/ NREL			X			
Standard Communication Interface and Certification Test Program	Electric Power Research Institute			X			
Advanced Distribution Analytic Services Enabling High Penetration Solar PV	Southern California Edison			X			
Supervisory Controller for PV and Storage Microgrids	Tri-Technic			X			
Integrating PV into Utility Planning and Operation Tools	Clean Power Research				X		
High Penetration PV Initiative	Sacramento Municipal Utility District				X		
Tools Development for Grid Integration of High PV Penetration	DNV KEMA				X		
Comprehensive grid integration of solar power for SDG&E	University of California, San Diego				X		
Beopt-CA (EX): A Tool for Optimal Integration of EE/DR/ES+PV for California Homes	Davis Energy Group/ NREL					X	
Specify, Test and Document an Integrated Energy Project Model	kW Engineering					X	
PV Integrated Storage - Demonstrating Mutually Beneficial Utility-Customer Business Partnerships	Energy and Environmental Economics						X
Low-Cost, Smart-Grid Ready Solar Re-Roof Product Enables Residential Solar Energy Efficiency Results	BIRAenergy						X
West Village Energy Initiative: CSI RD&D Project	University of California Davis						X
Demonstration of Locally Balanced ZNE Communities Using DR and Storage and Evaluation of Distribution Impacts	Electric Power Research Institute						X
Monitoring and Evaluation of a Zero Net Energy Retrofit Home with Energy Storage, Demand Response and Home Energy Management System	BIRAenergy						X

the reliability issues that come with an unpredictable generation source like solar. Solar lends itself to the vagaries of weather, especially those related to cloud cover and speed of cloud movement. Even a small patch of cloud on an otherwise clear day moving across a large solar array can take down a disproportional amount of production depending on the electrical layout and string design. This kind of sudden unpredictable loss in production if not accounted for can result in large fluctuations, leading utilities and system operators to keep a high level of overhead and costly spinning reserve available to dampen the effects of solar generation. Therefore having a solar forecast with high temporal and spatial resolution can potentially mitigate much of the costs associated with maintaining reliability of supply on the grid. The cost effectiveness of solar can be improved with high resolution forecasts resulting in more grid parity for solar. However, the forecast resolution requirements vary depending on the application, from minutes and hours ahead for grid operation at the system and distribution level to a week ahead for the energy markets.

Clean Power Research through CSI RD&D funding has developed a portal for solar resource data for California (ca.solaranywhere.com) that provides high temporal and spatial resolution data (30 min and 1 km) for use in forecasting and planning tools. The California high resolution data is available free of charge to anyone as part of this grant. The project also developed an algorithm for PV Output Variability through data collection and validation in various geographical locations and which can be applied in operation and planning tools to estimate the variability of a single plant or solar fleet. A tool was also developed for calculating the economic value of distributed PV fleets including energy value, generation capacity value, environmental value, fuel price hedge value, T&D capacity value, and loss savings. In a follow up project the Clean Power Research team further enhanced the solar resolution data with algorithms that can generate 1 min temporal resolution on demand. This 1 min resolution forecast was supplied to the California Independent System Operator (CAISO) to test drive in their planning and operations on a rolling 30 min interval. Validating and integrating high resolution solar forecasts into PV fleet simulation tools enables utilities and independent system operators (ISOs) to cost-effectively integrate distributed PV along with utility scale resources into their planning, scheduling and operating strategies. A key element of this project was the interfacing with CAISO and their use of solar forecasting data in their operations and planning to enable higher penetration of solar on the grid.

Two University of California, San Diego projects focused on providing utilities and the solar industry with electricity system planning, design and operation modeling tools for accurately assessing and forecasting energy output from distributed PV systems. Geographic shading profiles along with one-year solar irradiance dataset (downscaled from metered 15 minute generation data to less than a second data) have been generated for locations throughout the state. A 6 hour ahead forecast of PV power output throughout California was also developed. These high resolution (both temporal and spatial) resource maps and modeling tools are a critical component in addressing high penetration PV. Follow on work included demonstrating that solar resource forecasting can be the most cost effective strategy for integrating large amounts of PV into distribution systems. Historical aggregate PV ramp rates were analyzed and a baseline of solar forecast performance under the extreme ramps was created. Sites for additional measurements to improve solar forecast accuracy were selected based on statistical analysis. For resource adequacy applications, the UCSD team improved and demonstrated forecasts for the marine layer meteorological conditions that affect a large fraction of solar PV in San Diego Gas and Electric (SDG&E) territory on summer mornings. This is a very typical case for most of costal California climates which experience marine layer fog in mornings and late evenings. High resolution numerical weather prediction and statistical models were also developed and applied to improve forecast accuracy. Local applications of solar forecasting using sky imagery were also demonstrated on five typical feeders with variations in PV penetration, location/meteorology, and voltage regulation equipment. On these feeders, fast demand response potential based on demand and solar forecasting and dynamic loading were demonstrated. Through increased granularity in modeling distribution feeder voltages and their reaction to fluctuations in solar PV output, geographic diversity is expected to reduce previously observed impacts at high solar PV penetration levels.

4.2 Interconnection

Interconnection of solar into the grid is a major concern for utilities as they manage the operation of their distribution network. With higher levels of solar penetration, utility operators are obligated to carefully assess the potential impacts of new solar interconnecting to their grid. As a rule of thumb, the National Electricity Regulatory Corporation (NERC) has established a 15% rule which is also referred to as Rule 21 in California. This essentially establishes a trigger point for the utilities to require detailed interconnection studies of solar projects and their impacts on the distribution feeder if the level of distributed generation exceeds 15% of peak load on the feeder. This has placed significant burden on the solar industry and slowed the pace of integrating new solar into the grid. Several of the CSI RD&D funded projects are addressing the issue of expediting the interconnection process through a revised set of rules and guidelines that utilities can use to protect the integrity of their feeder operation.

The Electric Power Research Institute (EPRI), in partnership with the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories, is developing an interconnection screening methodology that takes into account individual distribution feeder characteristics. Distribution modeling and simulation techniques are being used to determine the level of PV that can be accommodated on individual feeders without impacting distribution system operations. This measure of "hosting capacity" is expected to become more critical as PV deployment increases. The utility partners will help to detail which tools and penetration screens are most commonly used and which procedures have been most effective for evaluating PV interconnection requests in California. The utilities will also help review distribution feeder classification methods currently used in California to identify and map areas with additional capacity for hosting PV.

Some of the factors known to be important to feeder hosting capacity, and included in the screening methodology, are steady state voltage regulation limits, tap changer cycling issues, reverse power flow issues, unintentional islanding risks, fault current contribution issues, ground-fault relaying desensitization issues, neutral grounding compatibility, ground fault overvoltage issues, and harmonics. These factors will be used to develop a higher-level screening methodology that can then be applied to other distribution systems, without necessitating the need for detailed analysis.

Another collaborative project between General Electric (GE) and Pacific Gas and Electric (PG&E) is quantifying the risks of unintended islanding in distribution circuits with high penetration of customer-sited distributed PV generation. The GE/PG&E team is using full-scale laboratory testing to determine the risks to both utility and customer equipment that may result from an unintended islanding situation. Additionally, the team will review PG&E's interconnection requirements with respect to islanding and provide recommendations on potential changes based on the findings from this project. The results of this research will inform PG&E's interconnection requirements and also will be of value to the other utilities (both investor-owned and publicly-owned). This research can also inform the CPUC in making decisions regarding interconnection requirements relating to anti-islanding operations of PV inverters (Rule 21).

4.3 <u>Grid Communications</u>

The transfer and communication of information between the solar plants, especially distributed solar and the grid can assist in alleviating some of the concerns that are associated with high penetration of solar. Grid communication capabilities provides utility operators with a level of comfort in being able to control the quality of the power being fed back into the grid with volt and variable amperage regulator (VAR) control. The volt and VAR control is important to maintain the power factor and integrity of the system. A lower power factor results in high losses since the wires and hardware are not designed to handle the higher current flow which is associated with lower power factors. Therefore it is important that the utility be able to control and detect any loss in volt/VAR on a circuit and possibly disconnect or island the plant that is causing this loss in fidelity. Communication protocols for smart are a critical piece in ensuring the quality and controllability of the power fed into the grid by distributed generation resources such as solar.

The Southern California Edison (SCE) team along with NREL focusing on accelerating the placement of high levels of PV penetration into the existing distribution circuits and identifying new circuit configurations that will help increase penetration levels of PV. For the first year of this project, the SCE team conducted modeling, simulations, and testing of possible advanced hardware and software solutions. Laboratory testing has been conducted on advanced inverters and control systems, and these advanced systems were installed in projects in the Southern California Edison territory. The team is also evaluating the advanced technologies as part of the project.

4.4 <u>T&D Modeling tools</u>

SMUD, in partnership with Hawaiian Electric Company (HECO) is demonstrating new hardware and software tools that provide communication and management between PV systems and utility controls using advanced metering infrastructure (AMI). The team developed a software visualization tool that enables identification of high value locations for distributed PV. The tools developed through this project have been tested and validated at residential, commercial, and utility-scale deployments in California and Hawaii. The project is providing utilities with tools to integrate increased levels of PV into the grid.

4.5 <u>Tools for optimizing loads</u>

For utilities, energy efficiency and distributed PV can help defer the need to build additional peaking generation and T&D system infrastructure. For utility customers, distributed PV provides more control over energy prices. Installing a PV system is one of a number of options available to these customers. Their other choices include energy efficiency, energy storage, and demand response. Energy efficiency provides the most cost-effective means for addressing energy use within a home, business or community. Implementing energy efficiency measures not only reduces electricity demand but also helps reduce the size and required capital for a PV system. The choices available can leave customers at a loss to determine the optimum balance of energy efficiency measures and PV system type and size for the specific application. At present, there are no clear guidelines (especially in retrofit situations) on the energy efficiency measures that utility customers should consider prior to, or in conjunction with, procuring a PV system. Additionally, there is a critical gap in the ability of the current market to provide combined energy efficiency services along with PV services for the residential sector. Also, integration of energy efficiency, demand response, storage along with renewable generation is the path towards zero net energy, both at individual and community scale.

The Integrated Energy Project (IEP) was also developed through the CSI RD&D Program. The IEP is a data model that enables the capture of best practices for integrating energy efficiency measures with PV system deployment. The IEP

Model introduces a common language to project stakeholder software applications for assessing energy efficiency or solar and provides a comprehensive, standardized definition for EE/DR+PV projects. This data model is publically available and aims to simplify and streamline the procurement process, reduce time and costs for both the consumer and contractors, produce a better return on investment for both, and remove a key market barrier for the adoption of both efficiency measures and PV. Project website: www.iepmodel.net

A project by NREL developed the Building Energy Optimizer for California Existing Homes BEopt-CA (EX) modeling tool that supports the integration of energy efficiency, demand response, and energy storage with PV with a focus on getting to "Zero Net Energy" in the residential retrofit market. The project enhanced the capabilities of the original BEopt tool developed by NREL to address the retrofit market. It also extended the economic analysis to allow utility program managers (utility cost tests) and contractors the ability to optimize the integration of EE, DR, ES with PV, from their unique perspective. BEopt website: beopt.nrel.gov

4.6 Demonstration projects

Field demonstrations are a key component of the CSI RD&D Program. Several research projects conducted site demonstrations integrating solar generation into the grid thus unfolding and exposing real world challenges that must be overcome to meet the California's solar goals. These challenges range from regulatory barriers to the logistics of bring hardware together and getting interconnected to the grid.

BIRAenergy, in partnership with San Diego Gas & Electric (SDG&E) and General Electric (GE) demonstrated the effectiveness and efficiency of installing 'plug and play' AC solar modules on residential roof tops. The project also demonstrated the integration of solar with energy efficiency measures, demand response and energy storage in a ZNE home retrofit. The home energy management system and intelligent battery operation have been integrated to demonstrate the potential effectiveness of integrated demand side management resulting in a flatter utility load profile.

The West Village Project at the University of California, Davis, is one of the first large scale communities to be Zero Net Energy entirely through energy efficiency and on-site generation. With funding from the CSI RD&D Program, West Village became the setting to test and demonstrate several technology innovations that enable high penetration on solar. Two demonstrations were focused on using solar for electric vehicle charge and the controls. This is an especially forward looking scenario where several electric plug in vehicles are expected to be connecting to the grid in conjunction with solar. The interactive controls that balance the use and generation of these resources will become increasingly important to utilities in managing the grid. The testing and monitoring results and findings from this project are expected to provide useful insights into the impacts and issues of combining solar and electric vehicles on the electricity grid. The West Village project team also demonstrated the potential of using hybrid PV and thermal systems to offset not only electric but also gas use for water heating. The results are expected to show the overall load profile with this dual generation technology and its impact on the grid.

A recently awarded research project with EPRI will test the idea that a ZNE community can drastically reduce and respond to the modulating needs of the utility grid by adding distributed storage at the feeder level. The ZNE homes are expected to produce a lower and flatter load profile offset by solar and storage and are expected to minimize the adverse impact on the feeder and provide the utility operators with more control on managing the integrity of the distribution grid at a feeder level. If proved successful, this work can serve as a model for future ZNE communities on managing and mitigating grid impacts of high levels of solar.

5. CONCLUSIONS

While all the challenges holding back the seamless grid integration of solar are far from met, the CSI RD&D Program has made significant strides in enabling higher penetration of solar on the California grid. It is essential that utilities, government entities, research organizations, universities and interested stakeholders continue to identify and address current and future barriers to enable larger scale market adoption of solar resulting in a future where zero net energy buildings are no longer on the cutting edge but a standard industry practice.

6. ACKNOWLEDGMENTS

The authors wish to acknowledge the California Public Utilities Commission for their oversight to Itron which serves as Program Managers for the CSI RD&D Program. We also wish to acknowledge the efforts of all the CSI RD&D Program participants and researchers who are conducting the valuable research to enable meeting the goals of higher penetration of distributed solar. More details about the research presented here and other projects is available at the CSI RD&D website: CalSolarResearch.ca.gov

7. REFERENCES

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