Austin Sustainable and **H**olistic **IN**tegration of **E**nergy Storage and **S**olar PV
Final Technical Report

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Section 1 **Acknowledgements**

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This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Section 2 **Executive Summary**

The Austin SHINES solution is a Distributed Energy Resource (DER) management platform that optimizes value, for a system with a high penetration of distributed photovoltaic (PV) solar generation, while maintaining the traditional power quality and reliability associated with electric grid service. This project developed and deployed the platform as a DER Management System (DERMS), engaging multiple advanced controls, to evaluate operation and optimization of a fleet of diverse DER assets, deployed at several locations among Austin Energy's customers and distribution system. The project also produced a methodology to create a replicable DERMS template, adaptable to other regions and market structures. Last, Austin SHINES aimed to demonstrate the solution's methodology would enable the DER grid ecosystem to serve load at a technical cost (System Levelized Cost of Electricity, or System LCOE) of less than the U.S. Department of Energy SHINES program metric of $0.14/kWh, in a defined boundary, while enabling a high penetration of distributed PV.

Research is categorized in the Final Deliverable (FD) reports, FD-1 – 6, as listed below, with titles indicating which area of understanding was investigated. These reports are referenced throughout the Final Technical Report and available in full, in the Appendix.

FD-1: System Levelized Cost of Electricity (System LCOE) Methodology

FD-2: Software Platform Product Description

FD-3: Optimal Design Methodology

FD-4: Austin SHINES Ownership and Operation Models for DER System Performance

FD-5: Economic Modeling & Optimization

FD-6: Fielded Assets

In total, the Austin SHINES project added value to the DER subject area in each layer of integration. From utility, to commercial to residential scales, the sheer hierarchy of

communication and coordination was a significant accomplishment in addition to learnings from what these communications revealed was unique to each. The technical effectiveness required for accomplishing the Austin SHINES solution included both the effectivity of technology and personnel, where integrating utility systems to DERs and DERs to utility systems provided opportunity for process development and feedback for our stakeholders and the industry more broadly. Economically, the most effective method demonstrated was the criticality of planning phases. Contingencies and multiple projection scenarios helped guide the project to deploy optimal design as close as feasible, in real world conditions. The project and reports will serve public benefit by outlining specific areas of DER strategy and installation where many stakeholders and needs can be addressed with improved efficiency. Overall, communities and utilities should use the results to guide the increasing options available for powering the grid with DER, renewables, and carbon considerate energy.

Section 3 **Background**

Austin SHINES recognizes that emerging DER assets such as solar and battery energy storage are part of an integrated, interconnected grid system and the benefits of these resources are maximized only when they are holistically coordinated with one another and other grid assets. Table 3-1 includes a reference list of DER field publications, for comparison.

Table 3-1: DER Field Related Publications

Title	Paper Number	Conference/ Proceedings Title	Conference Location	Dates	CD Rom Vol. or Vol., pp (##-##)	ISBN
How Solar and Storage Can Reduce Coincident Peak Loads and Payments: A Case Study in Austin, TX	IMECE2018-86482	*Proceedings of the ASME 2018 International Mechanical Engineering Congress and Exposition*	*Pittsburgh, PA*	*Nov 9-15, 2018*	*Vol. 6B: Energy ():V06BT08A023*	*DOI:10.1115/ IMECE2018-86482*
Energetic Potential for Demand Response in Detached Single-Family Homes in Austin, TX	32	*Proceedings of the 2019 IEEE Texas Power and Energy Conference*	*College Station, TX*	*Feb 7-8, 2019*	*pp 1-6*	*DOI: 10.1109/ TPEC.2019.8662166*
A Decision Support Tool for Distributed Solar and Storage Investments: A Case Study in Austin, TX	IMECE2019-11068	*Proceedings of the ASME 2019 International Mechanical Engineering Congress and Exposition*	*Salt Lake City, UT*	*Nov 8-14, 2019*	*N/A*	*N/A*

The first publication, "*How Solar and Storage Can Reduce Coincident Peak Loads and Payments: A Case Study in Austin, TX*", authored by Arkasama Bandyopadhyay, Julia P. Conger, Joshua D. Rhodes, and Michael E. Webber and presented in late 2018, is a study that developed a calculation tool to forecast:

a) the change of 4 Coincident Peak (4CP) loads[1], and

b) payments based on varying amounts of solar, storage capacity, and population estimates over a 10-year period for utilities within the Electric Reliability Council of Texas (ERCOT).

An optimization model that maximized the sum of revenue earned from Energy Storage Systems (ESSs) operation was also included. The revenue earned, as well as net 4CP payments received by the utility, by attempting to arbitrage the ERCOT energy market were maximized within the model. As 4CP payments can be on the order of tens of millions of dollars, results derived from empirical data from the municipally owned utility in Austin, TX, indicate that solar and storage capacity can substantially lower these payments. For example, a 20 MW increase in solar capacity in 2018 would reduce Austin Energy's payment by an estimated $200,000 for each subsequent year. By using the novel approach of incorporating coincident peak demand charge reductions at the DSP level, this study highlights the economic value of local generation and storage.

The second publication, "*Energetic Potential for Demand Response in Detached Single-Family Homes in Austin, TX*", authored by Arkasama Bandyopadhyay, Julia P. Conger, and Michael E. Webber and presented in early 2019, focuses on a study that builds a generalized tool to quantify the maximum peak load reduction achievable with residential demand response and DERs. The tool is demonstrated by using empirical energy usage data from detached single-family households within the service territory of Austin Energy - the local municipal utility in Austin, TX. The demand response optimization algorithm shifts energy usage of four controllable, high-consumption residential devices to off-peak hours: HVAC (heating, ventilation, and air conditioning) systems, electric water heaters, electric vehicles, and pool pumps. In addition, rooftop solar generation on individual residences is considered to reduce net load to the utility, and an energy storage system optimization model performing energy arbitrage further reduces peak demand. Results from the aggregate demand response and battery optimization study indicate that peak demand for the 2017 summer peak in Austin Energy could have been reduced by 26 MW or 2.9%. By considering the combined effect of controllable consumer loads, solar generation, and energy storage systems, this study highlights the potential of strategic demand response and energy.

A study by ACEEE (American Council for an Energy-Efficient Economy) in 2015 found that potential demand response energy savings across 28 utilities in the United States

[1] The 4CP program aims to generate revenue for the holistic ERCOT transmission system costs of transmission service providers, by incentivizing distribution service providers to curtail load during each of ERCOT's four 15-minute coincident peak events that occur during the summer months of June, July, August and September. Load during these events, from distribution service providers is then charged at a calculated $/MW, and paid out to the transmission service providers.

ranged from 2% to 27% with an average value of 10% [33]. This study shows that Austin Energy's 2017 peak demand could have been reduced by 2.9%, which falls within the range mentioned above. At the present day, demand response still has many challenges associated: low customer participation levels, need for increased investment in advanced metering, development of fair time-based pricing structures, etc. [34]. However, demand response participation increased by 6% between 2009 and 2016, with demand response reducing 5.7% of peak load in 2016 nationwide [35]. As more utilities employ demand response initiatives and customer participation rates increase, demand response and DERs will be key tools employed by electricity distributors to maintain power reliability and reduce peak load.

The third publication, "*A Decision Support Tool for Distributed Solar and Storage Investments: A Case Study in Austin, TX*", authored by Arkasama Bandyopadhyay, Julia P. Conger, Michael E. Webber, and Benjamin D. Leibowicz and presented in late 2019, showcases a study that builds a decision support tool to evaluate when it is a good economic decision (least cost with minimum discomfort) for the residential customer to invest in DERs based on different electricity rate structures, DER ownership frameworks, and DER rebates offered by electric utilities. The tool is demonstrated using empirical electricity consumption data from Pecan Street Inc. (a non-profit entity based on Austin, Texas), residential rates from Austin Energy (the municipal electric utility in Austin, Texas), DER ownership costs from various nationwide pilot programs, and incentives offered by electric utilities in the United States. Results show that for constant electricity rates, the overall expenditure is least when the customer owns solar panels without storage, while for time varying pricing structures, the least expensive scenario is one where the customer does not own any DERs. As the capital costs for DERs decline, utilities incentivize customer ownership of DERs, and more residential customers face the decision of whether to invest in DERs, this study aims to be a key tool in aiding that decision-making process.

Results show that although the electricity bill is reduced when customers invest in onsite solar and storage, the capital costs for DERs need to decrease further to keep the overall customer expenditure low under various time-varying pricing options. Solar and ESS rebates offered by electric utilities as well as federal grants for utility-owned customer-sited DERs can lower overall costs for the customer and potentially result in increased penetration of residential-scale DERs.

DER assets are still very expensive at the present day although studies have shown that the capital and installation costs for solar panels and lithium-ion batteries have been decreasing steadily [33,56]. As the prices continue to decline, more residential customers will decide on whether or not to invest in small-scale generation and storage. This study will be an integral part of that decision-making process. Finally, electric utilities will also be able to use this study to make decisions about electricity rate and DER rebate design to help incentivize residential DER adoption.

Finally, while the publications touch on aspects or investigate topics with varied degrees of granularity, none are as encompassing and holistic as the Austin SHINES solution. And from technical standpoints the project was as granular as any demonstration project in that the full suite of engineers in our utility were utilized for designing and deploying the assets safely.

With regards to leveraging publications and conference proceedings to improve the project, feedback was continually incorporated. From award to completion, abstracts were submitted to industry forums and during every presentation or panel the discussions which emerged certainly influenced the Austin SHINES solution. The multi-layered scope garnered a lot of interest and these dialogues along with learnings from attending and listening to other DER work was considered for reference. The current state of DER is still changing, in that the norm will always be in flux. To date however, the Austin SHINES scope will likely remain a precedent for studying utility capabilities, reach, potential, and limitations. For example, while some ownership and operation DER models exist it will remain to be seen which become regulated, standardized, or popular first. And testing models without these are then primarily driven by vendor and customer interest, groups which are also evolving. Thus, it was well suited for the point in time to tackle a broad and layered scope, offering quantitative insights to future success in DER and a next generation electric grid.

Section 4 **Project Objectives**

Over the course of the project, Austin SHINES undertook installing more than 3 MW of distributed battery energy storage, smart PV inverters, a DER control platform, and other enabling technologies utilizing customer and utility locations and aggregation models. All of these resources were to be integrated and optimized at the utility level. DER assets and control methodologies were designed to achieve a credible pathway to a System LCOE for energy delivered to load of $0.14//kWh or less by 2020, while maximizing distributed solar generation and maintaining acceptable standards of power quality. The project also established a template for other regions to follow, to maximize the adoption of distributed solar PV in support of an economic and efficient grid. All aforementioned objectives are summarized as:

- The creation and use of the System Levelized Cost of Energy (System LCOE) to Serve Load metric that encompasses the holistic, system-level costs and benefits of all resources, and enables them to be evaluated based on their ability to support an efficient and low-cost integrated grid ecosystem.
- The creation of new DER control methodologies deployable within a utility-grade software platform that enable DER's to maximize their benefit within a grid, that is capable of serving load enabling a high penetration of distributed PV generation;
- Optimal design methodologies for individual DER installations that enable utilities to determine the optimal combinations and sizing for individual DER sites;
- A comparison of multiple DER aggregation and ownership methodologies including direct utility control, third-party aggregator, and autonomous;
- A comparison of multiple DER technology mixes and configurations within the distribution system, providing insight into an optimal blend of technologies that best

enable the distribution system to serve load at the lowest cost at high penetrations of solar.

A task summary with outcomes, metric definitions, milestones, and go/no-go decision points are included in the next portion, below.

BUDGET PERIOD 1

The first 4 quarters of the project focused largely on system design, including the MW scale community storage system, residential solar and storage systems, commercial solar and storage systems, and the integration of controls among the systems with an integration platform.

Task 1 − DESIGN

Task 1.1 Community Energy Storage System (ESS) Design

Problem Statement: The proposed megawatt-scale energy storage system at the community site required a design process that determined the optimal size, battery technology, and control methodologies that support efficient grid operations and meet cost and physical constraints. This design and cost estimate was developed in order to ensure that the ESS maximizes its contribution to grid performance and meets standard utility criteria for safe and reliable installation and operation.

Value Proposition: A properly designed energy storage system will reduce the *System LCOE* by providing local power quality services (that are particularly valuable with high PV penetration), making the circuit more efficient, creating revenue through active participation in energy and ancillary service markets (market functions will be simulated for this project), all while maximizing the amount of locally-generated energy that can be consumed by local circuit load.

Approach

Subtask 1.1.1 Mueller Conceptual Design (M1-M6): Doosan will deliver a Conceptual Design Report (CDR) that will establish the optimal size (kW & kWh) and system design for the Mueller site. The report will include an evaluation of alternative Li-ion battery suppliers including Tesla and Samsung and recommend a preferred vendor. The CDR will include vendor capital and operating costs, a scope of work listing all design documents required in 1.1.2, and technical requirements for ESS performance.

Milestone 1.1.1a: Conceptual Design Report submitted

Milestone 1.1.1b: Notice to Proceed with Detailed Design and Procurement provided to Doosan from Austin Energy.

Subtask 1.1.2 Mueller Detailed Design (M7-M12): Doosan procures vendor and the selected energy storage technology vendor will use the results of the CDR in 1.1.1 to create the detailed design documents for all aspects of a substation integrated ESS at the community site.

Milestone 1.1.2: Detailed design documents provided to Austin Energy.

Subtask 1.1.3 2016-2020 cost and performance estimates (M7-M12): Doosan will use the detailed design to revise the projected cost and performance characteristics of the community ESS over its life-cycle. Projected cost and performance data will be utilized in calculating the *System LCOE in Task 1.6*.

Milestone 1.1.3: Revised cost and performance report for the Mueller ESS based on the detailed design.

	Metric Definition (From Measurement)	***Success Value***	***Measured Value***	***Assessment Tool***	***Goal Met (Y/N)***	***Supporting Data (pg. #)***
Milestone 1.1	Design accepted and Construction notice to proceed (NTP) issued by Austin Energy to Doosan.	NTP issued.	1 or 0	Formal notice issued by Austin Energy.		

Milestone: Conceptual Design Report is completed by Doosan and the design approved by Austin Energy. A detailed design is developed by Doosan and the selected storage vendor based on the Conceptual Design Report. Doosan revises the projected ESS cost and performance characteristics based on the detailed design.

Metric Justification: Design approval and Construction Notice to Proceed (NTP) by Austin Energy indicates that the ESS design and project plan meets Austin Energy requirements for installation in the field and serves as notice to Doosan to proceed to the construction phase.

Go/No-Go Decision Point: Successful completion of all milestones, culminating in the issuance of a Construction Notice to Proceed by Austin Energy to Doosan.

Task 1.2 Design and Test of Residential Solar PV with Utility Control

Problem Statement: Without adequate inverter communications and controls installed and utilized, residential solar systems produce power in an uncontrolled manner that can negatively impact distribution system components and performance which limits the value proposition for both the homeowner and the serving utility. Smart inverters provide the mechanism for utility control to reduce the adverse impacts of solar to the grid and provide valuable supportive functions to the grid.

Value Proposition: Utility-coordinated smart inverter functions, enabled by smart inverter communications and controls, can minimize the negative impact that uncontrolled solar can have on grid performance, thereby raising the circuit carrying capacity of distributed solar. Smart inverter functions can also provide value-added services such as VAR optimization support that represent an additional (currently un-tapped) value from distributed solar. Communications also enable coordination with other circuit assets such as energy storage assets.

Careful sizing and control parameters of each solar inverter system will be based on optimizing circuit performance and reducing *System LCOE*.

Approach

Subtask 1.2.1 Detailed Design (M1-M9): Doosan will develop detailed design, testing and implementation plans for installing an estimated 10-20 new Solar Edge smart inverters and Smart ConnectDER devices on existing residential rooftop PV in the Mueller subdivision. The design will include 3 different methods to communicate between the Smart ConnectDER and the Doosan platform: Advanced Metering Infrastructure (AMI) by Landis & Gyr, cellular modem, and Wi-Fi over a gateway managed by Pecan Street Inc. In all cases, the inverter will send and receive signals via the Smart ConnectDER using the SunSpec protocol to the Doosan Intelligent Controller (1E-IC).

Milestone 1.2.1: Design documents and test plan.

Subtask 1.2.2 Communications and Performance Testing (M4-M9): Pecan Street will test the communications and performance of a Smart ConnectDER with the Solar Edge smart inverter using each of the 3 communications pathways in the Pecan St. lab at Mueller. The team will use the results of this lab testing to select the single preferred communications channel based on cost and performance. The final field design will utilize only the preferred communications channel.

Milestone 1.2.2: Final preferred communications channel selection, report on test results and final field design.

Subtask 1.2.3 2016-2020 cost estimates (M4-M9): Doosan will use the detailed field design to revise the projected cost and performance characteristics of the Smart ConnectDER, SolarEdge inverters, and best value PV panels available in Austin for 2016. Use case(s) employing hypothetical residential rates to incentivize consumer engagement will be applied to support cost analysis. Projected cost and performance data will be utilized in calculating the *System LCOE in Task 1.6*.

Milestone 1.2.3: Cost and performance report on residential PV system.

	Metric Definition (From Measurement)	***Success Value***	***Measured Value***	***Assessment Tool***	***Goal Met (Y/N)***	***Supporting Data (pg. #)***
Milestone 1.2	Design and communications channel recommendation accepted by Austin Energy. Austin Energy and Pecan St. approve design.	Design approval issued.	1 or 0	Formal notice issued by Austin Energy.		

Milestone: Field design plans will be completed by Doosan and approved by Austin Energy based on performance testing as detailed in 1.2.2. The plans will

include a preferred communications pathway based on Pecan Street lab testing and evaluated on cost and performance. Design will also be based on optimizing the LCOE. Revise projected solar system cost and performance characteristics based on the detailed design. Austin Energy approves the detailed design and issues Notice to Proceed with Construction to Doosan.

Metric Justification: Design approval and Construction NTP by Austin Energy and Pecan Street indicates that the solar system design and project plan is sufficient and suitable for installation in the field and has permission to proceed to the customer enrollment and installation phase.

Go/No-Go Decision Point: Successful completion of all milestones, culminating in the issuance of design approval by Austin Energy and Pecan Street which provides the authorization for Pecan Street to proceed with customer acquisition and installation of solar systems.

Task 1.3 Residential Solar PV and Storage – 3rd Party Aggregator

Problem Statement: Residential solar systems currently produce power in an uncontrolled manner, which can overtax distribution system components and limits the value proposition for both the homeowner and the serving utility. Power in excess of home demand is currently exported to the grid, also in an uncontrolled manner, with no method of storage. Communication with and control of multiple endpoints to resolve these issues presents a significant challenge to utilities from both a staffing and cost perspective. These challenges will be overcome by managing the combination of residential demand, solar output, and energy storage operations charging using a 3rd party aggregator.

Value Proposition: Allowing the utility to have visibility and control over solar inverter and energy storage assets enables the utility to better integrate solar operations with grid operations. Careful sizing and control parameters of each solar and energy storage system will be based on optimizing *System LCOE*. The complexities of managing multiple sites through system design, testing and operation will be tasked to the aggregator, making this integration more efficient for the utility.

Approach

Subtask 1.3.1 Hardware Identification and Selection (M1-M12): Pecan Street, acting as an aggregator, will identify product vendors that are able to provide UL listed smart inverters and residential energy storage units to be retrofitted onto homes that already have rooftop PV installations.

Milestone 1.3.1: List of candidate inverter and battery systems.

Subtask 1.3.2 Lab Integration and Testing (M1-M12): Candidate smart inverter and battery systems will be first tested at the Pecan Street labs to verify functionality and safety specifications. Pecan Street will design and conduct tests which will operate the candidate systems under typical residential load conditions using the existing PV arrays on the lab roof and the appliances available in the lab.

Pecan Street will also test the systems using programmable loads driven by actual load profiles using a high-resolution residential energy database.

Milestone 1.3.2: Test requirements and test results for candidate inverter and battery systems.

Subtask 1.3.3 Detailed Design (M1-M12): Based on the results of 1.3.2, and the details of the particular homes selected for demonstration, one or more standard installation configurations will be designed for field implementation. The design will support multiple utility-dispatchable functions that may include frequency response, regulation response, and ramping response capabilities where battery storage is present and frequency response and displacement power factor correction where there is only grid-tied PV with a Smart inverter.

Milestone 1.3.3: Detailed system design, software and system bill of materials.

Subtask 1.3.4 2016-2020 cost estimates (M1-M12): 2016 and 2020 system costs will be estimated based on forward cost projections for the selected components installed and the detailed design. Cost projections from the component vendors will be checked against expected learning curve driven cost projections which may disrupt vendors' current pricing roadmap. Projected cost and performance data will be utilized in calculating the *System LCOE in Task 1.6*.

Milestone 1.3.4: Updated asset cost and performance report on residential PV & storage by 3rd Party Aggregator that reflects the selected hardware and detailed system design.

	Metric Definition (From Measurement)	***Success Value***	***Measured Value***	***Assessment Tool***	***Goal Met (Y/N)***	***Supporting Data (pg. #)***
Milestone 1.3	Final design completed by Pecan St.	Final design issued.	1 or 0	Final design report from Pecan St.		

Milestone: A detailed system design, software, and bill of materials will be completed. The detailed system design will include an evaluation of multiple hardware options and rational for the selected hardware. Revise projected solar system cost and performance characteristics based on the detailed design.

Metric Justification: A completed detailed design will enable Pecan Street to proceed with customer acquisition and installation.

Go/No-Go Decision Point: Successful completion of all milestones, culminating in the issuance of a final detailed design by Pecan Street which provides the means for Pecan Street to proceed with custom acquisition and installation of solar systems.

Task 1.4 Design of Commercial Solar PV & Storage with Utility Control

Problem Statement: Commercial solar systems currently produce power in an uncontrolled manner, which can overtax distribution system components and limits the value proposition for both the facility owner and the serving utility. Power in excess of facility demand is currently exported to the grid, also in an uncontrolled manner, with no method of storage. Solar systems have increased value when paired with storage, however the complexity of control over the system combined with capital costs present a significant challenge to commercial businesses. These challenges will be overcome through the synchronization of solar output with demand from the facility and grid, as well as optimization of storage charging by the utility in a manner that is financially beneficial to both the utility and the customer.

Value Proposition: Allowing the utility to have visibility and control over solar inverter and energy storage assets enables the utility to better integrate solar operations with grid needs. Careful sizing and control parameters of each solar and energy storage system will be based on minimizing *System LCOE* while simultaneously reducing customer utility bills.

Approach

Subtask 1.4.1 Detailed Design (M1-M12): Ideal Power Converters will provide the design work. Ideal Power Converters and Doosan will design the communications pathway and interface between the Ideal Power Converter and the 1E-IC.

Milestone 1.4.1: Design documents and test plan

Subtask 1.4.2 Communications and Performance Testing (M1-M12): Ideal Power Converters will provide initial communications and performance testing on the first system configuration at their test facility, including testing of the communications pathway and for the interface with the 1E-IC.

Milestone 1.4.2: Report on test results and final design

Subtask 1.4.3 2016-2020 cost estimates (M4-M12): Austin Energy's Energy Market Operations group will refine initial cost and performance estimates based upon the final design and including pricing trajectories for system components, market forecasts for the value of distribution system support, and market prices for ancillary services. Projected cost and performance data will be utilized in calculating the *System LCOE in Task 1.6*.

Milestone 1.4.3: Updated asset cost and performance report on commercial PV and storage that reflects the selected hardware and detailed system design.

	Metric Definition (From Measurement)	***Success Value***	***Measured Value***	***Assessment Tool***	***Goal Met (Y/N)***	***Supporting Data (pg. #)***

Milestone 1.4	Detailed design completed.	Design formally approved by Austin Energy.	1 or 0	Final Design Report from Ideal Power Converters.		

Milestone: Detailed design documents and communications integration design will be completed. Revised system performance and cost estimates based on the detailed design will be completed.

Metric Justification: A completed detailed design will enable Ideal Power Converters to proceed with customer acquisition and installation. Updated cost and performance estimates will enable an accurate *System LCOE* to be calculated in Task 1.6.

Go/No-Go Decision Point: Successful completion of all milestones, culminating in the issuance of a final detailed design by Ideal Power Converters which provides the means to proceed with customer engagement and installation.

Task 1.5 Design of Commercial Solar PV & Storage by 3rd Party Aggregator

Problem Statement: Commercial solar systems currently produce power in an uncontrolled manner, which can overtax distribution system components and limits the value proposition for both the facility owner and the serving utility. Power in excess of facility demand is currently exported to the grid, also in an uncontrolled manner, with no method of storage. Solar systems have increased value when paired with storage, however the complexity level of control over the system combined with capital costs present a significant challenge to commercial businesses. Finally, program enrollment, coordination and control of multiple endpoints present a significant challenge to utilities from both a staffing and cost perspective. These challenges will be overcome through the engagement of a third-party aggregator to enroll customers, design systems, and control systems to provide grid services to Austin Energy.

Value Proposition: The utility's ability to utilize multiple sites will be simplified by engaging a 3rd party aggregator. Careful sizing and control parameters of each system will be based on minimizing *System LCOE*. System design, testing and operation will be left to the aggregator, reducing cost to the utility. Grid services offered to Austin Energy by the aggregator can be utilized in ERCOT ancillary services, energy markets, and transmission cost reduction programs.

Subtask Summary: Austin Energy will select a third-party vendor to provide a PV and storage offer to commercial customers and grid services.

Approach

Subtask 1.5.1 Vendor Selection (M1-M6): Austin Energy will select a vendor based upon qualifications to provide a fully integrated package.

Milestone 1.5.1: Vendor selection for 3rd Party commercial PV & storage services

Subtask 1.5.2 Detailed Design (M6-M12): Selected vendor will provide the design work for third party aggregation model, including guideline for sizing of the systems by customer. Vendor will work with Doosan on the application protocol interface (API) for the communications with the 1E-IC.

Milestone 1.5.2: Detailed design documents

Subtask 1.5.3 Communications and Performance Testing (M1-M12): Selected vendor will provide initial communications and performance testing on the first system configuration at their test facility, including testing of the communications pathway and for the interface with the 1E-IC.

Milestone 1.5.3: Report on test results and final design

Subtask 1.5.4 2016-2020 cost estimates (M4-M12): Austin Energy will refine initial cost and performance estimates based upon the final design and including pricing trajectories for system components. Projected cost and performance data will be utilized in calculating the *System LCOE* in Task 1.6.

Milestone 1.5.4: Updated asset cost and performance report on commercial PV and storage that reflects the selected hardware and detailed system design.

	Metric Definition (From Measurement)	***Success Value***	***Measured Value***	***Assessment Tool***	***Goal Met (Y/N)***	***Supporting Data (pg. #)***
Milestone 1.5	Final design complete and approved by Austin Energy.	Design approved by Austin Energy.	1 or 0	Final Design Report from selected 3rd Party Aggregator.		

Milestone: Vendor selection for commercial PV and storage. Successful test results from factory testing by vendor. A detailed system design will be completed. Projected solar system cost and performance characteristics will be completed based on the detailed design.

Metric Justification: A completed 3rd party aggregator selection and detailed design will enable Austin Energy to authorize the vendor to proceed with customer acquisition and installation. Updated cost and performance estimates will enable an accurate *System LCOE* to be calculated in Task 1.6.

Go/No-Go Decision Point: Successful completion of all milestones, culminating in the issuance of a final detailed design by the selected 3rd party aggregator which provides the means for Austin Energy to proceed with customer acquisition and installation of systems.

Task 1.6 Controls Integration Design

Problem Statement: Distributed energy resources are of the greatest value to the utility when they are able to work together with each other and with existing grid assets using coordinated utility controls. Today most distributed energy resources

have little or no grid-supportive capability and are not integrated within utility communications and control schemes. This will be overcome by the integration of the 1E-IC with all DERs to control their operations in a way that optimizes distribution circuit performance and efficiency.

Value Proposition: When adequately controlled, DER's will work together to minimize negative impacts on the circuit and provide useful services to the circuit, lifting constraints to their deployment and increasing their value proposition. Control of DERs into an aggregated resource allows participation in ERCOT ancillary services and energy markets. Individual customer constraints can be accommodated while load management leverages diversity to maintain reliability and power quality. Open protocols allow reduced integration costs when adding additional DERs.

Approach

Subtask 1.6.1 Design & specify communication architecture (M1-M12): Doosan will design the communications architecture for communicating from the 1E-IC located at the substation to the distributed energy resources on the feeder including residential PV, commercial PV and storage, MW-scale storage, and third party aggregated rooftop PV and storage. Doosan will evaluate AMI, cellular, and Wi-Fi as communications channels to field assets. Doosan will also design the communications from the 1E-IC to the Austin Energy SCADA system. All asset communications will utilize open, non-proprietary standards such as SunSpec and MESA where they are available.

Milestone 1.6.1: Communications design documents

Subtask 1.6.2 Circuit analysis for control/optimization algorithms (M6-M12): Doosan will analyze the impact of existing and projected PV on the Mueller circuits and model the application of different control algorithms to send signals to DERs on that circuit in order to maintain power quality and shift energy from mid-day to evening peak.

Milestone 1.6.2: Simulations using existing circuit load and solar irradiance data and recommendations on preferred algorithms.

Subtask 1.6.3 Stakeholder engagement on optimization algorithms (M7-12): Doosan will present the analysis from 1.6.2 to residential, commercial, and utility stakeholders to build agreement on the preferred control strategies for the Mueller PV and storage assets. In particular, Doosan will help stakeholders find the balance between utility-oriented services to the grid and customer-oriented benefits.

Milestone 1.6.3: Stakeholder meetings and report.

Subtask 1.6.4 Controls integration plan: (M7-14): Doosan will design the specific algorithms and detailed communications designs for integrating the MW-scale ESSs and the smaller distributed energy resources. This task will describe the relationships and hierarchy of control from individual inverters to the 1E-IC on each circuit to the Distributed Energy Resource Optimizer (DERO) that works

through Austin Energy's SCADA system to manage the relevant fleets of PV and storage.

Milestone 1.6.4: Final design and controls schemes for 1E-IC and DERO.

Subtask 1.6.5 2016 & 2020 LCOE for integrated system: (M10-14): Doosan and Austin Energy will develop and codify a *System LCOE* methodology that accurately encompasses the holistic system performance of the Austin Energy distribution system. The *System LCOE* will provide a methodology to account for the performance and cost impacts when all DER combinations are included within the circuit system. A preliminary *System LCOE* analysis will be conducted that includes the post-detailed design revised cost projections of all components. A baseline *System LCOE* will be calculated that reflects the current configuration of the system without the addition of new DERs or controls. (In the proposed formulation below, PV stands for present value over 20 years rather than photovoltaic)

$$System\ LCOE = \frac{\left(\begin{array}{c} Present\ Value(PV) of\ Capital\ and \\ Operating\ Costs\ \text{of all} \\ distribution\ circuit\ assets\ (including\ DER) \\ +\text{PV of}\ cost\ of\ imported\ energy \end{array}\right) - PV\ of\ Net\ Ancillary\ Services\ Sold}{PV\ of\ kWh\ of\ load\ served\ by\ distribution\ circuit\ (including\ DER)}$$

Milestone 1.6.5: Report on the System LCOE methodology and preliminary estimate.

	Metric Definition (From Measurement)	***Success Value***	***Measured Value***	***Assessment Tool***	***Goal Met (Y/N)***	***Supporting Data (pg. #)***
Milestone 1.6	System LCOE	System LCOE ≤ $0.14	System LCOE using design cost data for: 1. Base case 2. 2020 costs, 2% PV 3. 2020 costs, 4% PV 4 2020 costs, 8% PV 5. 2020 costs, 16% PV 6. 2020 costs, 32% PV	SAM plus circuit modeling tools		

Milestone: A detailed and finalized controls architecture design. A *System LCOE* methodology and preliminary analysis including a baseline *System LCOE* (no new DERs or controls) and *System LCOE*'s of five DER asset configurations.

Metric Justification: A proven, coordinated control plan allows aggregated load sufficient to meet the requirements of ERCOT ancillary services programs (100kW minimum) while maximizing the value of DERs to the utility. A sound *System LCOE*

methodology enables multiple circuit configurations to be evaluated in a consistent manner that reflects how utilities make asset installation decisions. For example, adding energy storage may enable the utility to avoid investing in other T&D assets which will be accounted for in this analysis.

Go/No-Go Decision Point: Successful completion of all milestones, culminating in the issuance of detailed controls architecture design and a *System LCOE* methodology and preliminary *System LCOE* projections.

BUDGET PERIOD 2

Deployment of all systems continues through the second year, with most activities consisting of installation, acceptance testing, and communications integration.

Task 2- DEPLOYMENT

Task 2.1 ESS Deployment

Problem Statement: Megawatt-scale storage systems require adequate land space in a location with an opportunity for grid connection that provides benefit to the distribution system. This task will complete community site readiness, installation, commissioning and testing.

Value Proposition: Acceptance testing and commissioning is required to ensure successful integration with the 1E-IC, as well as future performance when entered into service on the grid.

Approach

Subtask 2.1.1 Permitting (M7-M14): Doosan and Austin Energy will obtain all necessary permits

Milestone 2.1.1: State and local permits

Subtask 2.1.2 Site Preparation (M7-M12): Doosan and Austin will prepare the community site to accept the ESS including all electrical and communications interconnections.

Milestone 2.1.2: Mueller site ready for ESS installation.

Subtask 2.1.3 Factory Integration Testing (FIT) (M12-M14): Doosan and relevant equipment vendors will test the ESS and 1E-IC integration prior to shipment to the site with Austin Energy witnessing.

Milestone 2.1.3: FIT report

Subtask 2.1.4 Installation and Commissioning (M15-M16): Doosan will install and commission the ESS. Doosan and Austin Energy will complete communications integration between the ESS and the Austin Energy SCADA system and control platform.

Milestone 2.1.4: Commissioning report.

Subtask 2.1.5 Acceptance Testing (FIT) (M17): 1E, Austin Energy, and a third party will review and approve the performance of the ESS and mark the transfer of title to Austin Energy

Milestone 2.1.5: Acceptance testing report approved by Austin Energy and ESS title transferred from Doosan to Austin Energy.

Task 2.2 Deployment of Residential PV with Utility Control

Problem Statement: Distributed residential PV systems require the participation of customers as well as numerous contractors. This task addresses the steps required to identify potential sites and install the systems.

Value Proposition: Customer cooperation and project management by Pecan Street will insure successful installation and operation of the systems to benefit both the customer and the utility.

Approach

Subtask 2.2.1 Permitting (M7-M14): Pecan Street will obtain all necessary permits

Milestone 2.2.1: Local permits

Subtask 2.2.2 Recruitment (M7-M12): Pecan Street will recruit homeowners with existing PV systems to participate.

Milestone 2.2.2: Signed agreements with homeowners

Subtask 2.2.3 System Deployment (M12-M14): Pecan Street will deploy the Smart ConnectDER, Smart Edge inverters, and establish communications for the 1E-IC.

Milestone 2.2.3: 18 installed solar systems with communications established between the local sites and the Doosan platform.

Subtask 2.2.4 Operations and Monitoring (M15-M30): Pecan Street will monitor system operations.

	Metric Definition (From Measurement)	***Success Value***	***Measured Value***	***Assessment Tool***	***Goal Met (Y/N)***	***Supporting Data (pg. #)***
Milestone 2.2	Installed solar inverters respond to control signals issued from utility-sited control platform (1E-IC)	Measured response of solar inverters to utility-issued command signal.	1 or 0	Local solar meter measurements of solar inverter behavior.		

Milestone: Permits are obtained and target customers successfully enrolled. Systems are installed and successfully monitored by Pecan Street. Communication with the1E-IC is established and control is validated per specifications developed in Task 1.2.

Metric Justification: Successful installation and communication enables the solar inverters to participate in utility control schemes that benefit the grid and drive down the *System LCOE*.

Go/No-Go Decision Point: Successful completion of all milestones, culminating in the measured response of the solar inverters to a command signal issued from the Doosan platform.

	Metric Definition (From Measurement)	***Success Value***	***Measured Value***	***Assessment Tool***	***Goal Met (Y/N)***	***Supporting Data (pg. #)***
Milestone 2.1	Successful transfer of Mueller ESS to Austin Energy with 3rd Party approval.	Title Transferred to Austin Energy.	1 or 0	Mueller ESS title documentation.		

Milestone: Permits are obtained and site prepared to specifications identified during the conceptual design phase (Task 1.1). ESS factory testing completed with Factory Integration Test report issued. Installation, commissioning and acceptance testing completed with respective reports issued.

Metric Justification: Equipment must be properly installed and ESS system performance must meet testing and commissioning requirements identified during the Conceptual Design phase (Task 1.1).

Go/No-Go Decision Point: Successful completion of all milestones, culminating in an approved Acceptance Test Report and Title transfer of the ESS to Austin Energy.

Task 2.3 Deployment of Residential PV with 3rd Party Aggregator

Problem Statement: Distributed residential PV and storage systems require the participation of customers as well as numerous contractors. This task addresses the steps required to select sites, install the systems per the detailed design, and establish communications between the assets and the Doosan platform via a 3rd party aggregator.

Value Proposition: Customer cooperation and project management by Pecan Street will insure successful installation and operation of the systems to benefit both the customer and the utility. 3rd party aggregator control simplifies the control and deployment of these resources for the utility.

Approach

Subtask 2.3.1 Permitting (M7-M14): Pecan Street will obtain all necessary permits

Milestone 2.3.1: Local permits obtained

Subtask 2.3.2 Recruitment (M7-M12): Pecan Street will recruit homeowners with existing PV systems to participate.

Milestone 2.3.2: Signed agreements with homeowners

Subtask 2.3.3 System Deployment (M12-M14): Pecan Street will deploy the selected inverter-battery combination per the detailed design specifications created in Task 1.3

Milestone 2.3.3: 6 installed systems.

Subtask 2.3.4 Operations and Monitoring (M15-M30): Pecan Street will monitor system operations and respond to control signals issued from the Doosan platform.

Milestone 2.3.4: Data collection and system operation successful.

	Metric Definition (From Measurement)	***Success Value***	***Measured Value***	***Assessment Tool***	***Goal Met (Y/N)***	***Supporting Data (pg. #)***
Milestone 2.3	Installed systems respond to control signals issued from utility-sited control platform (1E-IC) via the 3rd party aggregator.	Measured response of solar inverters and ESS's to utility-issued command signal.	1 or 0	Local solar meter measurements of solar inverter behavior, provided by Pecan St.		

Milestone: Permits are obtained and project participating customers successfully enrolled. Systems are installed and successfully monitored by Pecan Street. Communication with the 3rd party aggregator is established and end-to-end control is verified per specifications identified in Task 1.3.

Metric Justification: Successful installation and communication allows solar and energy storage assets to participate in grid support functions while also supporting local site objectives.

Go/No-Go Decision Point: Successful completion of all milestones, culminating in the measured response of the solar inverters and ESSs to a command signal issued from the Doosan platform via the 3rd party aggregator.

Task 2.4 Deployment of Commercial PV/Storage with Utility Control

Problem Statement: Distributed commercial PV/storage systems require the participation of customers as well as numerous contractors. This task addresses the steps required to identify potential sites and install the systems.

Value Proposition: Commercial sites have larger square footage available for the installation of solar panels, more available financial capital for investment, increased value proposition due to commercial demand charge rates, and benefit from economies of scale more so than residential customers.

Approach

Subtask 2.4.1 Lab Integration and Testing (M10-M12): Ideal Power will provide system testing of all inverters prior to shipping. The initial integrated system will be tested at Ideal Power's test facility prior to shipment.

Milestone 2.4.1: Testing results

Subtask 2.4.2 Permitting (M7-M14): Will be done through the City's permitting process, and follow utility interconnection guidelines

Milestone 2.4.2: Local permits

Subtask 2.4.3 Recruitment (M7-M12): Will be done by Austin Energy through the Key Accounts Group, Solar Program, Energy Efficiency Services Group and Green Building Group

Milestone 2.4.3: Signed agreements with building owners

Subtask 2.4.4 System Deployment (M12-M14): Installation performed by Contractors, overseen by Ideal Power and including communications integration between the assets and the Doosan platform.

Milestone 2.4.4: At least 3 installed systems.

Subtask 2.4.5 Operations and Monitoring (M12-M32): Through onboard metering provided by Ideal Power, may employ utility grade IDR metering by Austin Energy.

Milestone 2.4.5: Operations and performance reports.

	Metric Definition (From Measurement)	***Success Value***	***Measured Value***	***Assessment Tool***	***Goal Met (Y/N)***	***Supportin g Data (pg. #)***
Milestone 2.4	Installed systems respond to control signals issued from utility-sited control platform (1E-IC).	Measured response of solar inverters and ESS's to utility-issued command signal.	1 or 0	Local meter measurements of solar inverter and ESS.		

Milestone: Permits are obtained and target customers successfully enrolled. Systems are installed and successfully monitored.

Metric Justification: Successful installation and communication validation allows control of output and battery charging/discharging for financial and reliability optimization.

Go/No-Go Decision Point: Successful completion of all milestones, culminating in the measured response of the solar inverters and ESSs to a command signal issued from the Doosan platform.

Task 2.5 Deployment of Commercial Solar PV with 3rd Party Aggregator

Problem Statement: Distributed commercial PV/storage systems require the participation of customers as well as numerous contractors. This task addresses the steps required to identify potential sites, install the systems, and establish end-to-end controls integration, via a 3rd party aggregator, between the field assets and the Doosan control platform.

Value Proposition: Commercial sites have larger square footage available for the installation of solar panels, more available financial capital for investment,

increased value proposition due to commercial pay demand charge rates, and benefit from economies of scale more so than residential customers.

Approach

Subtask 2.5.1 Lab Integration and Testing (M10-M12): Selected vendor will provide the design work for third party aggregation model, including guideline for sizing of the systems by customer. Vendor will work with Doosan on the API for the communications with the 1E-IC.

Milestone 2.5.1: Testing results

Subtask 2.5.2 Permitting (M7-M14): Will be done through the City's permitting process, and follow utility interconnection guidelines

Milestone 2.5.2: Local permits

Subtask 2.5.3 Recruitment (M7-M12): Will be done by Austin Energy through an existing account management process from the Key Accounts Group, Solar Program Group, Energy Efficiency Services Group, and Green Building Group

Milestone 2.5.3: Signed agreements with building owners

Subtask 2.5.4 System Deployment (M12-M14): Installation performed by Contractors, overseen by vendor

Milestone 2.5.4: Installed systems with connectivity established to the Doosan platform.

Subtask 2.5.5 Operations and Monitoring (M12-M32): Onboard metering provided by Ideal Power, the solution may employ utility grade IDR metering by Austin Energy.

Milestone 2.5.5: Operations and performance reports.

	Metric Definition (From Measurement)	***Success Value***	***Measured Value***	***Assessment Tool***	***Goal Met (Y/N)***	***Supporting Data (pg. #)***
Milestone 2.5	Installed solar systems respond to control signals issued from utility-sited control platform (1E-IC).	Measured response of solar inverters to utility-issued command signal.	1 or 0	Local meter measurements of solar inverter.		

Milestone: Permits are obtained and target customers successfully enrolled. Systems are installed and successfully monitored and controlled via the Doosan platform via a 3rd party aggregator.

Metric Justification: Successful installation and communication allows solar and energy storage assets to participate in grid support functions while also supporting

local site objectives. The use of a 3rd party aggregator simplified the installation and management of multiple assets for the utility.

Go/No-Go Decision Point: Successful completion of all milestones, culminating in the measured response of the solar inverters to a command signal issued from the Doosan platform via the 3rd party aggregator.

Task 2.6 Deployment of Controls Integration

Problem Statement: Without integrated utility control, individual DER devices are unable to deliver the full suite of value to the grid, including grid reliability and efficiency objectives, and may even create negative impacts on the grid. DER control must be integrated to a central platform to coordinate control in order to maximize the overall delivered value of each asset. This will be accomplished using a control platform (1E-IC) that can coordinate and control multiple asset types to enable DERs to work together to optimize grid operations for the lowest *System LCOE*.

Value Proposition: A central DER control platform that can coordinate across multiple asset types ensures that all assets are working together for a common objective: to lower the overall *System LCOE*, support a high penetration of solar generation, and maintain circuit power quality and efficiency objectives. Asset coordination reduces zero-sum value transfer within the system (for example, from the distribution circuit to a customer) and enables assets to work together to provide additional grid support services (such as ancillary services) without degrading local circuit performance. The use of open standards for communications reduces the complexity and cost of integrating between different manufacturers and asset types and also expands choices for customers and encourages lower capital costs through increased competition.

Approach

Subtask 2.6.1 Install and commission Community 1E-IC (M13-M15): Doosan will install and commission the 1E-IC at the community site and will establish SCADA connections to the 1E-ICs at Kingsbery and the community substations. This task is completed when Austin Energy SCADA can send commands and receive data back from 1E-IC.

Milestone 2.6.1: Communications commissioning report.

Subtask 2.6.2 Install the Doosan Distributed Energy Resource Optimizer (DERO) and establish 1E-IC and DER connectivity with DERO (M16-18): Doosan with support from Austin Energy will install the DERO control platform within Austin Energy's utility control environment per specifications developed in Task 1.6. The 1E-IC at the community site and Kingsbery will interact with the Distributed Energy Resource Optimizer (DERO) to accept signals. Task is complete when end-to-end connectivity and control is established between DERO, the community site and Kingsbery 1E-ICs, and all DERs.

Milestone 2.6.2: Fully installed DERO control platform and communications commissioning report

Subtask 2.6.3 Install and configure appropriate circuit control algorithms on the 1E-IC and DERO (M19-M25): Doosan will install and configure utility control algorithms that coordinate assets in an appropriate way for the Austin Energy circuits and market environment. Doosan will develop a test plan to activate and test various control algorithms throughout Year 3 of the project.

Milestone 2.6.3: Algorithm test plan and schedule for year 3.

	Metric Definition (From Measurement)	***Success Value***	***Measured Value***	***Assessment Tool***	***Goal Met (Y/N)***	***Supporting Data (pg. #)***
Milestone 2.6	Algorithms running in DERO and the 1E-IC send commands that control fielded DER.	Measured response of DERs to command signals issued from DERO and 1E-IC control algorithms.	1 or 0	Comparison of algorithm commands and measured asset responses via local meters.		

Milestone: Doosan control platforms (Mueller 1E-IC and DERO) successfully demonstrate communications and control to fielded DER assets per the commissioning specifications developed in Task 1.6.

Metric Justification: Successful installation and communication validation allows control of all DERs for financial and reliability optimization. Appropriate control platforms and DER assets are installed and connected to enable testing of various utility control schemes that drive down *System LCOE*.

Go/No-Go Decision Point: Successful completion of all milestones, culminating in the measured response of fielded DER assets to a command signals issued from the 1E-IC's and DERO control platforms via various communications channels.

BUDGET PERIOD 3

Deployment of all systems is completed. Executing the test plan, data collection and analysis are the main activities. Final reports on the *System LCOE* and all systems are produced.

Task 3. DEMONSTRATION

Task 3.1- Demonstration Reporting

Problem Statement: Multiple utility control schemes will be tested using a diverse array of DERs focused on optimizing system operations to drive down *System LCOE*. Large amounts of data will be collected that require analysis. Final reports will present analysis, conclusions, and lessons learned based on a full year of operation of the entire solution.

Value Proposition: Final reports will show a credible pathway toward high PV penetrations with a *System LCOE* of less than or equal to 14 cents kWh by 2020 that can be replicated by other utilities. Reports will include the recommended DER asset and control mix that results in the lowest *System LCOE* across an increasing

level of distributed solar penetration. *System LCOE* calculations, using the *System LCOE* framework developed in Task 1.6, will be justified with field performance of deployed assets.

Approach

Subtask 3.1.1 ESS Performance Report (M30-M35): Doosan will write a report on the ESS performance during 12 months of operation. The report will describe the physical, electrical, and economic performance of the ESS including an updated cost and performance metrics using the first year of data.

Milestone 3.1.1: ESS performance report

Subtask 3.1.2 Residential PV with Utility Control Performance Report (M30-M35): Pecan Street will report on residential PV system performance during 12 months of operation. The report will describe both the physical and electrical performance. 1E will report on the economic performance of the distributed PV systems.

Milestone 3.1.2: Performance report

Subtask 3.1.3 Residential PV & Storage with 3rd Party Performance (M30-M35): Pecan Street will analyze data recorded during the 12 month operation and data collection period. The data will include consumption, power quality and generation data at the individual home level, aggregated system resource level and information on power quality impacts at the distribution transformer level. The report will describe the physical and electrical performance. 1E will report on the economic performance of the distributed PV systems.

Milestone 3.1.3: Performance report

Subtask 3.1.4 Commercial PV & Storage Performance Report (M30-M35): Ideal Power will report on system performance during 18 months of operation; Austin Energy will report on modeled economic performance

Milestone 3.1.4: Performance report

Subtask 3.1.5 Commercial PV & Storage by 3rd Party Performance (M30-M35): Vendor will report on system performance during 18 months of operation; Austin Energy will report on modeled economic performance

Milestone 3.1.5: Performance report

Subtask 3.1.6 Controls Integration (M30-M35): Doosan will produce a report on the performance of the control systems at managing a diverse set of DER assets on a utility feeder. Austin Energy and Doosan will summarize the economic performance of the integrated system and project performance at increasing levels of PV penetration.

Milestone 3.1.6: Final report

	Metric Definition	***Success Value***	***Measured Value***	***Assessment Tool***	***Goal Met (Y/N)***	***Supporting Data (pg. #)***

	(From Measurement)					
Milestone 3.1	System LCOE	System LCOE ≤ $0.14/kWh	System LCOE using field data for: 1. Base case 2. 2020 costs, 2% PV 3. 2020 costs, 4% PV 4 2020 costs, 8% PV 5. 2020 costs, 16% PV 6. 2020 costs, 32% PV	12 months of asset performance data to update SAM plus circuit modeling tools		

Milestone: Final reports issued that validate a *System LCOE* analysis of the entire integrated system showing the system operation meets the less than or equal to 14 cents per kWh by 2020 LCOE requirement using the SAM model and circuit modeling tools.

Metric Justification: A projected LCOE less than or equal to 14 cents per kWh by 2020.

Final Deliverables:

1. A replicable and documented technique to quantify the *System Levelized Cost of Energy (LCOE) to Serve Load.* The resulting Austin SHINES solution will enable 25% PV penetration (by energy) with LCOE <= 14 cents/kWh. The deliverable includes reports and software tools used to quantify the *System LCOE* in this project.
    a. This tool will serve as a metric for other utilities across multiple jurisdictions and will be configurable.
    b. Publication of this methodology will be sought in a reputable utility publication such as IEEE PES Magazine.
2. A software platform, commercialized and deployable by utilities, that includes advanced DER control algorithms. Written reports and product descriptions will describe how each platform and methodology algorithms enhances grid performance and the ability to the grid to host high penetrations of solar generation. Individual control algorithm code and detailed utility performance data will remain proprietary. No patent filings related to the detailed algorithmic techniques and control methodologies are associated with this product or project.
3. A written report documenting the methodology and results for obtaining the optimal design methodologies for individual DER installations. Reports will contain information on asset sizing techniques, communications methodologies, and technical performance characteristics. The target audience for these reports are other utilities seeking to deploy DER's in a grid-supportive manner as well as equipment vendors seeking to enable their technology to better participate in grid-supportive functions.

4. A report comparing multiple DER aggregation and ownership methodologies including direct utility control, third-party aggregator, and autonomous. The report will provide other utilities with guidance about which technologies and ownership models result in the best overall system performance.
5. A report comparing multiple DER technology mixes and configurations within the distribution system, providing insight into an optimal blend of technologies that best enable the distribution system to serve load at the lowest cost at high penetrations of solar.
6. Deployed DER assets within the Austin Energy SHINES circuits that remain in the field after the project is completed. Assets may remain under various different ownership configurations at the completion of the field testing. Assets without the appropriate ownership model and support will be removed from the field at the completion of the project.

Section 5 **Project Results and Discussion**

This section will focus on the Scope of Project Objectives (SOPO) Final Deliverables (FDs), listed at the end of the previous section. All milestones were accomplished and in support of achieving the SOPO FD language, which resulted in six separate reports. The following are excerpt descriptions of each and some key results. The comprehensive reports may be found in the Appendix.

5.1 System Levelized Cost of Electricity Methodology (FD−1)

Austin SHINES sought the creation and use of the System Levelized Cost of Energy to serve load metric (System LCOE). A System LCOE encompasses the holistic, system-level costs and benefits of all resources and enables them to be evaluated based on their ability to support an efficient and low-cost integrated grid ecosystem. The System LCOE is used as a key metric in the design and optimization of a holistic control strategy, illustrated in Figure 5-1.

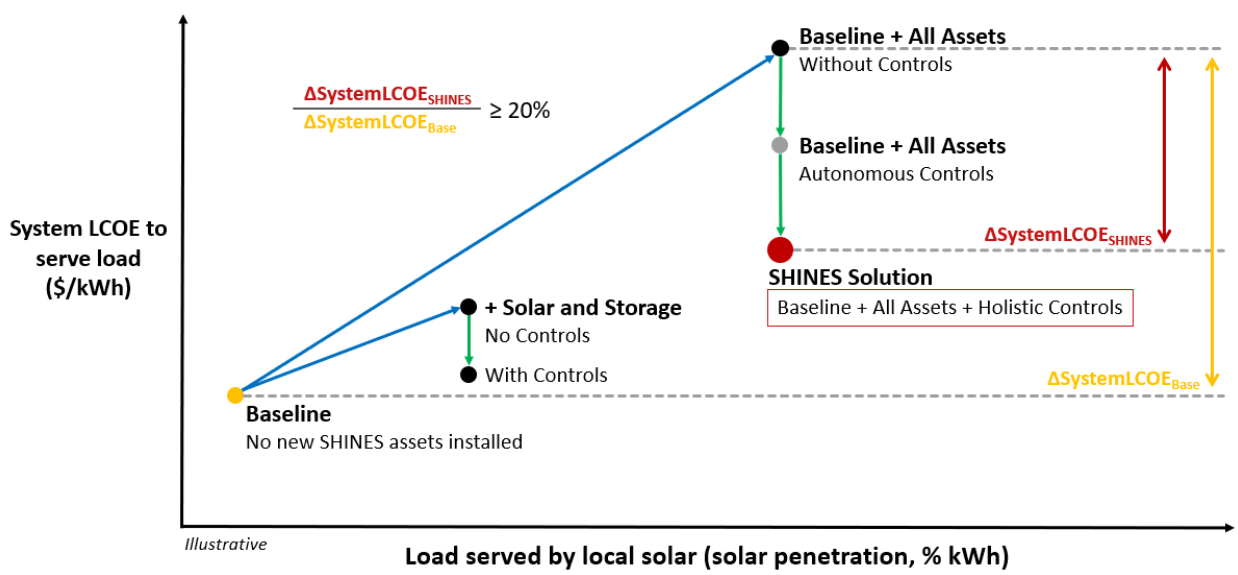

Figure 5-1 System LCOE Controls Scenarios and Metrics

It is used to calculate the differential value of integrated DER management, as compared to the value of uncoordinated DERs, and is not meant to be a ratemaking exercise or to calculate the tariff to be paid by customers. A conceptual diagram of an example system is shown below in Figure 5-2. Energy and services which cross the system boundary are quantified along with the capital and operating costs and value of all assets within the system.

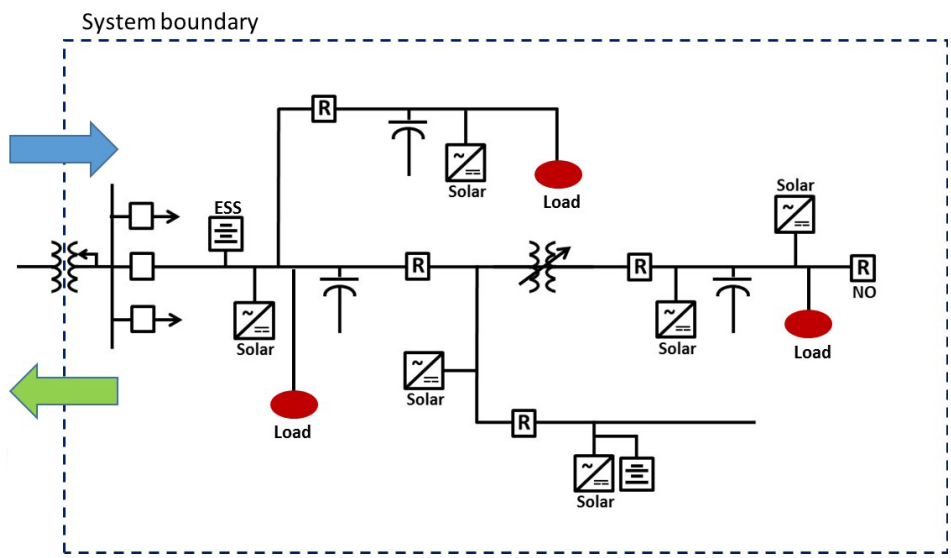

Figure 5-2 Illustrative System Boundary

Figure 5-3 below shows the simplified System LCOE equation. Economic data from Austin Energy's 2016 cost of service rate case, ERCOT markets, and DER cost estimation tools including the National Renewable Energy Laboratory's (NREL) System Advisor Model (SAM) are supplemented with circuit analysis tools to properly represent the economics of an entire distribution circuit.

$$\textit{System LCOE to Serve Load (\$/kWh)} = \frac{\left[\text{Capital cost of all equipment within system (\$)}\right] + \left[\text{Operating cost of all equipment within system (\$)}\right] + \left[\text{Net value of energy, capacity, and services that cross system boundary (\$)}\right]}{\left[\text{All load served within the system (kWh)}\right]}$$

Figure 5-3 System LCOE simplified equation

The Austin SHINES project used performance data from field assets and control systems combined with market and economic information to calculate and compare the System LCOE of the defined Austin Energy distribution system under a variety of scenarios, with different assets and controls present.

The purpose of the System LCOE is to be a clear metric, absent of ownership considerations, for identifying the lowest cost DER configuration and controls scheme. Once the lowest cost solution is identified, economic exchange mechanisms for enabling that solution can be developed; that stage is a second step, to be carried out after the System LCOE calculation. The focus of this work is the calculation of the System LCOE as a mechanism for system design; the question of which costs should be borne by which entities in the system is outside the scope of this project.

The Austin SHINES solution sought to enable 25% photovoltaic (PV) penetration (by energy) with a System LCOE <= $0.14/kWh. This report serves as the documented technique for replication and configuration of the System LCOE metric, for other utilities across multiple jurisdictions. Report elements include:

- The methodology of the System LCOE metric
- The System LCOE results for the baseline system
- The impact of higher solar penetration on the system
- DER controls in the Austin SHINES project
- An example of the implementation of the System LCOE methodology
    - The basis for understanding Final Deliverable Report 5, and finally
- The methodology findings and takeaways.

The report differs from Final Deliverable 5, which seeks to discuss the outcomes of methodology, as applied to multiple scenarios, to identify the optimal mix and configuration of assets, which meet the criteria for 25% PV penetration (by energy) with System LCOE <= $0.14/kWh.

Key findings from the methodology spanned included qualitative and quantitative results. Circuit analysis of the was the first step of the System LCOE calculation. Assigning yearlong 5-minute load and PV generation time-series to all (or in case of PV generation, a subset of) Service Point IDs (SPIDs) made circuit analysis computationally expensive. The computational burden was especially significant for the software-in-the-loop (SiL) simulations, in which an optimization must be run prior to solving power flow. The average runtime for SiL simulations was between 6 and 10 days. This significantly long runtime made debugging and modification of simulations difficult, especially when the methodology was applied to determine the optimal mixture of assets for Austin Energy. The search for the optimal mixture required examining several simulation scenarios to determine the key parameters that had major contributions to System LCOE. As a solution, for scenarios with significant computational burden, instead of running the yearlong simulation, two 1-month simulations were run, one over a shoulder month and the other over a summer month. Yearlong simulations were run after verification of the results of 1-month simulations.

Another solution to the heavy computational burden was to reduce the entire circuit to a single node. This is equivalent to applying the System LCOE methodology only at the substation, which is the point through which all the energy, services and capacities cross into the upstream grid. This solution is feasible only when 1) the mixture of assets in the circuit, under any conditions, does not cause violations of operational limits (current and voltage), and 2) system losses are not significant enough to skew the economic calculations. Since System LCOE method is applied at a ‘system’ level, the System LCOE

of the single-node model will be very close the System LCOE of the actual circuit if the aforementioned conditions hold true.

In case of Austin Energy, both studied circuits had relatively high hosting capacity. Simulations at 25% solar penetration, did not show any significant violations of operational limits for any combination of assets, except for infrequent overvoltage confined to a small area in the circuits. The overvoltage could be easily resolved by adjusting the settings of voltage regulating devices for a high solar penetration scenario. As a result, all the simulation scenarios at 25% solar penetration could be run on a single node model instead, which could significantly reduce the computational burden as running power flow every 5-minutes would not be necessary. At 40% solar penetration however, significant solar back feeding, widespread overvoltage and voltage fluctuations, will not allow for the use of the single-node model. Here, reducing the burden would be the implementation of parallel computing techniques.

Another lesson learned from applying System LCOE was that in Austin SHINES Peak Load Reduction control application was by far the most valuable application, compared to Energy Arbitrage and Real-Time Price Dispatch. Holistic control was the only successful control strategy in capturing the full value of Peak Load Reduction. Therefore, the most significant difference between no controls, autonomous, and holistic strategies was in the value of Peak Load Reduction. The analysis of System LCOE results for 1-month simulations showed that in shoulder months when there was no ERCOT 4CP value to capture, no controls, autonomous and holistic controls had very similar System LCOE and the %delta metric was very small. Again, this signifies the importance of selection of controls and applications based the system characteristics and energy market regulations and policies

5.2 Software Platform and Product Description (FD−2)

This report serves as a reference manual for verification of the creation and use of two separate but dependent systems, which enable the Austin SHINES solution. Product descriptions specify how each platform and methodology algorithms enhance grid performance and the ability for the grid to host high penetrations of solar generation. Individual control algorithm code and detailed utility performance data will remain proprietary. No patent filings related to the detailed algorithmic techniques and control methodologies are associated with this product.

The Doosan GridTech Intelligent Controller (DG-IC™) is a sophisticated site dispatch controller for utility-scale and grid-integrated energy storage systems. It enables the operator to monitor and control any device connected to and configured into the system, including (but not limited to): the control modules and system controllers of storage devices and other energy resources; the inverters and power conversion systems that manage the flow of AC and DC power into and out of the storage system; and, the power and signal meters that provide the real-time data needed for its operating modes to intelligently dispatch power and provide grid-stabilizing services. The DG-IC also provides the interface for communications between the devices in the system and remote operators and other data collection systems, such as SCADA (Supervisory Control and Data Acquisition). It consists of a substation-hardened computer operating the Doosan

GridTech control software and a monitor that displays the human-machine interface (HMI).

Complementing DG-IC's monitoring capabilities, is Doosan GridTech's Distributed Energy Resource Optimizer (DG-DERO®), which allows users to holistically schedule, optimize, and manage a fleet of assets. This software works with any MESA-ESS or DNP3-enabled ESS control system to securely aggregate and optimize the economic value of DERs connected to a distribution grid. Based in the control center of an electrical distribution system, DG-DERO employs standards-based, real-time communication with external services such as a market trading system, internal operational technology, such as SCADA (Supervisory Control and Data Acquisition), and an operational historian. Combining the resource-based DG-IC with DG-DERO offers fleet- and circuit-management applications that control the energy storage systems and other distributed resources.

5.3 Optimal Design Methodology (FD−3)

The intent of this report is to provide applicable guidance for optimized Energy Storage System (ESS) design in four key areas of functionality, sizing, siting, and communications. These elements are defined along with discussion of using open standards. The body sections recognize significant differences also exist across ESS applications in grid-scale, commercial, and residential settings, respectively. With a focus on issues specific to each, these sections consider optimal design, negative impacts of alternate options, along with details about the systems installed for the SHINES demonstration project. This report is agnostic to the Final Deliverables around the System LCOE to serve load metric. By identifying measures of success, trade-offs, and the resulting deployment in the Austin SHINES solution, a framework for design methodology is presented to address conventional constraints, many stakeholders, and derive multi-use value.

Intelligent system design is carried out in a step-wise process that begins with defining project objectives to ensure the subsequent analyses and design are conducted in a way that results in an ESS of the greatest possible value. Once objectives have been defined, potential value creation mechanisms are identified and prioritized. Evaluation of each mechanism's value, technical feasibility, and practical considerations leads to a set of target ESS use cases. A thorough accounting of local physical, electrical, and financial constraints is also necessary at this design phase. Establishing objectives, use cases, and constraints early in the design process allows battery power and energy sizing, control and communications strategy, physical layout, and technology/vendor selection to best support the full range of project objectives and selected functionalities. Figure 5-4 provides a visualization of this methodology.

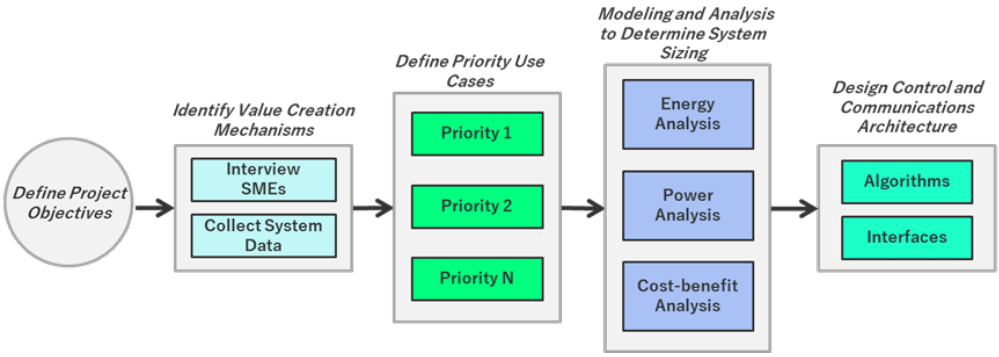

Figure 5-4 System design process methodology

Of the four design areas mentioned, all are ordered with distinct intention. ESS functionality starts with a holistic examination of use cases available to the ESS and ends with a set of complementary priority use cases that best meet project objectives. Engagement with grid operators, subject matter experts, and customers helps to assess the potential value and technical feasibility associated with each and identify practical concerns.

A cross-functional team at the ESS operating entity assesses each potential use case considering the project objectives and requirements for value creation. Different use cases have different scales of influence (site, feeder, balancing area, ISO, etc.) and create value at different timescales. Figure 5-5 shows the influence scale and temporal scale of several common grid-scale ESS use cases. Some use cases can be performed simultaneously, while others require the full ESS capacity or are not permitted to be performed concurrently in some markets.

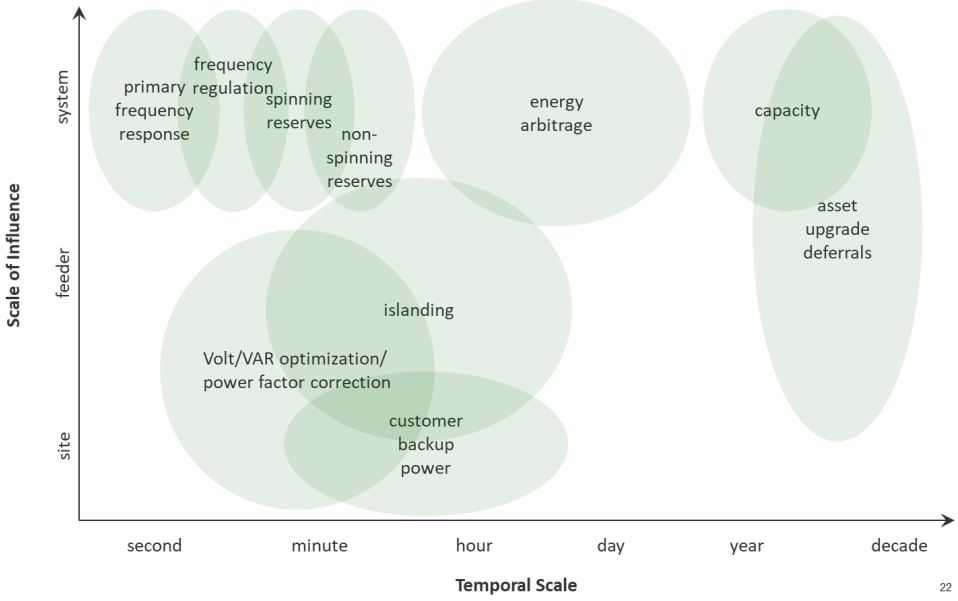

Figure 5-5 Grid-scale use case influence scale and temporal value horizon

The cross-functional team selects the set of complementary use cases that are technically feasible and best meet project value creation objectives. Prioritizing these use cases based on value added, financial cost, and practical challenges aids later design stages.

System design is an iterative process, and selected use cases may be eliminated or re-prioritized due to sizing, siting, and controls considerations. Subsequent design decisions around sizing, siting and functionality remain very particular to the scale which they are applied.

Reflecting over the project lifetime, this report testifies to dual states of learning. The optimal sections embody planning stages, in which deployment and operation had not yet been achieved. The alternate impacts and results reveal how optimal intensions were tested against the reality of experimentation. All systems deployed as a part of the Austin SHINES project were done so with the best available information, through many years. Time and patience were needed to identify and re-identify the inherit opportunities and risks associated with the technology exploration. And on all levels of ESS, both optimized and impactful alternate solutions were taken to get the assets operational. Beyond the design, however the "human" communication required to solve these iterative processes and commune on decisions opens up the subsequent discussion in FD-4, where the interplay of ownership and operating entity are evaluated against the functionality, scales of DER, and value(s) of best fit. As different business models emerge from the dynamic ability of the technology itself, so will the schemes and sophistication in which they harness value. FD-4 serves as an added layer to the design methodology, where the transition within the Austin SHINES project joined experience from asset deployment with application demonstration.

5.4 Ownership and Operation Models for DER System Performance (FD−4)

This report provides other utilities guidance about which technologies and ownership models result in the best overall DER system performance. While FD-3 considered the design and deployment phases of the Austin SHINES project, this document addresses relational aspects, when roles and responsibilities transfer from installation to operation. Stakeholders can influence or serve as a barrier to successful DER ecosystems. For the purposes of this report, technology is defined as the control schemes of Direct Utility Control, Third-Party Aggregator Control, and Autonomous control.

For the Austin SHINES project, DUC assets included the following:

- Kingsbery Energy Storage System (KB ESS)
    - 1.5 MW / 3 MWh Li-Ion battery storage
- Mueller Energy Storage System (MU ESS)
    - 1.75 MW / 3.2 MWh Li-Ion battery storage
        - 7 Energy Storage Units (250 kW each)
- 12 Utility-Controlled Residential Solar PV via Smart Inverters

Aggregated battery energy storage installations included the following:

- 18 kW / 36 kWh Li-Ion battery storage + 57 kW Solar PV
- 72 kW / 144 kWh Li-Ion battery storage + 60 kW Solar PV
- 72 kW / 144 kWh Li-Ion battery storage + 100 kW Solar PV
- 6 homes w/ stationary battery storage systems (10 kWh each) + existing PV

- 1 Electric Vehicle installed as Vehicle-to-Grid (V2G)

Autonomous assets included the following:

- 6 Autonomously-Controlled Solar PV via Smart Inverters

Further, these schemes are considered as Operators. The ownership models, or Owners, as defined as Utility, Third-Party, and Customer. Based on the Owner and Operator of DER, certain opportunities and constraints exist. These were characterized as use cases and more specifically, all 19 of the original applications, selected as a part of the DER control software functionality and are shown in Figure 5-6. Although only six were chosen for software implementation, it is worthwhile to consider all value streams possible, for utilities to understand their potential.

	Application
Customer	*Demand Charge Reduction (DCR)* *Back-Up Power* *Time-of-Use (TOU)*
Renewable Integration	*Solar Variance* *Wind Variance*
Energy Market Operations	*Peak Load Reduction (PLR)* *Energy Arbitrage (EA)* *Load Marginal Price (LMP) Opportunities*
Ancillary Services	*Fast Frequency Response* *Emergency Response Service* *Regulation Up/Down*
Dist. Operations Support	*Congestion Management (CM)* *Voltage Support* *Harmonics* *Loss Avoidance* *Power Factor Correction*
Tx. Operations Support	*Constraint Avoidance* *Voltage Support* *Peak Loss Avoidance*

Figure 5-6 DERMS Control System Applications

From here, an Evaluation Matrix facilitates discussion for each of the 9 segments of the matrix, in Table 5-1, as relevant to the use cases in Figure 5-6. Costs associated with ownership and control are to be understood as not influencing the System Levelized Cost of Electricity (System LCOE) equation, as the assets themselves remain the same and influencing stakeholders are considered outside the technical system boundary. And limitations of the described methodologies are contingent on many industry uncertainties, including regulatory and business model potential. The following is not intended to serve as an exhaustive discussion of possibility, but rather feasibility. Considering what was evaluated and accomplished, the utility anticipates maturity in all described relationships, some of which were experienced during the scope of the project. Utilities can use their preference or interest in each section, to compare why and how value can be maximized.

Table 5-1: System Performance Evaluation Matrix

	Operator		
Owner	*Direct Utility Control*	*Third-Party Aggregator*	*Autonomous*
Utility			
Third Party			
Customer			

Thus, the best system performance is unique to each model, and utilities should consider their preference or interest, to determine why and how value can be maximized. The Austin SHINES project attempted to incorporate as many of these models as possible for evaluation purposes. All DER assets in the project were, in fact, owned by the utility, Austin Energy, as per the structure of the partnership with the Department of Energy. However, in an effort to model other scenarios, the operation of some assets were not prioritized with utility value applications. The three control methodologies of DUC, third-party aggregator and autonomous were successfully demonstrated respectively:

- The two large grid-scale energy storage systems were utility owned, and under direct utility control. The five utility value applications tested were congestion management, voltage support, energy arbitrage, real-time price dispatch, and utility peak load reduction. Also, under DUC were the 12 Utility-Controlled Residential Solar PV via Smart Inverters, which were controlled for the utility value application of voltage support.
- The six residential energy storage systems as well as the electric vehicle were operated under aggregated control and were called upon for the utility value applications of congestion management, voltage support, energy arbitrage, real-time price dispatch, and utility peak load reduction. The three commercial sites were also operated under aggregated control, and although they were also utility owned, the demand charge reduction application was given precedence over the three utility value applications of utility peak load reduction, energy arbitrage, and real-time price dispatch.
- Six additional residential solar PV systems with smart inverters were enabled to run under autonomous control, providing voltage support.

Optimizing the performance of a fleet of DER assets is determining the appropriate methodology from the options above based on the specifics of each application. The optimal solution will look different for each utility based on the several factors mentioned in this report, along with the goals of the utility and its customers. Rather than a one size fits all, successful DER programs will include a variety of these methodologies coordinated to operate in a holistic manner. All methodologies presented in this report come with costs borne by different entities. FD-5 delves into the details of these costs, and how they contribute to the calculation of the System LCOE as well as the impact of value applications in optimizing this cost metric

5.5 Economic Modeling and Optimization (FD−5)

The Austin SHINES project deployed a fleet of DERs to validate the establishment of the System LCOE methodology; wherein FD-1 stated the load served would enable 25%

photovoltaic (PV) penetration (by energy) at a System LCOE cost of <= $0.14/kWh, while maintaining system reliability and power quality. A fleet of DERs can assume different mixtures, each of which serves the load at a different LCOE. The optimal mixture of DERs will serve load at the smallest System LCOE. The search for the optimal mixture is an iterative process and involves studying numerous DER deployment scenarios, identifying the significant variables, the sensitivity of System LCOE with respect to these variables, and altering the combination of DERs in the model. Based on the key assumptions and economic data described in FD-1, the design is 'locally' optimal meaning that in case of Austin SHINES, this mixture of DERs has the smallest System LCOE among all the examined scenarios, at a certain solar penetration. The optimal mixture can change, if the conditions of the system including the economic data, regulation, or policies of the energy market change.

Remembering the Austin SHINES project has two key metrics for System LCOE:

- $SystemLCOE_{SHINES} < \$0.14/kWh$
- Modeled $\Delta SystemLCOE_{SHINES}/\Delta SystemLCOE_{Base} \geq 20\%$ at same solar penetration

The first metric was easily achieved by every scenario considered. The goal was set when the Department of Energy's SHINES Funding Opportunity Announcement was written in 2015 and was a more difficult target at the time. Due mostly to rapidly declining costs for DERs and the significant decrease in the Electric Reliability Council of Texas (ERCOT) energy market prices, which results in lower net cost of energy purchases, the System LCOE is well below this target for all scenarios considered.

The second metric (hereinafter %delta metric) asks that the holistic controls reduce the incremental cost above the baseline of going to a high solar penetration future by at least 20% as compared to the case of a DER deployment with no sophisticated controls. Many comparison sets were created throughout this project, including contrasting DER deployment strategies. These comparison sets are generated in plots like Figure 5-7.

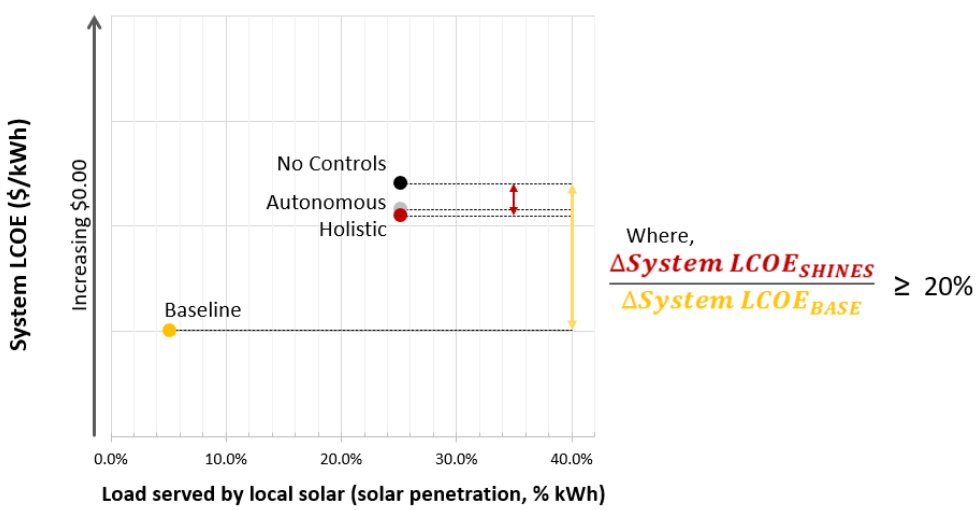

Figure 5-7 Example set of System LCOE results

In general, the %delta metric can be met when the wholesale market value that DER can capture is significantly enhanced by holistic controls, or when the case with no control involves significant system integration costs.

Table 5-2 demonstrates modeled results across 14 evaluated scenarios, with the far right column containing the holistic System LCOEs from the economic optimization. Based on the conclusions of the economic optimization, utility-scale storage is the most economical option among the three available technologies, compared to commercial and residential sized ESS. Also, load control is a very economical asset for reducing System LCOE through peak shaving. The smallest System LCOE, as expected, thus belongs to Scenario 14, which deploys 2MWh of utility-scale storage and a load control mechanism. If the local utility system is expected to grow in the near future, the second most viable option would be a system with more utility-scale storage (depending on the expected load, and solar penetration growth) and a load control mechanism in place. The second smallest System LCOE belongs to Scenario 13, which deploys 2MWh of EV capacity. System LCOE of this scenario is small, mainly because the storage capacity came at no cost. However, due to very low availability, the aggregate EV storage capacity is very small, which limits the availability of grid services. Scenarios 2, 6, & 8, nearly guarantee the storage will be available (assuming it has the right SOC), but with the EVs, the availability is not guaranteed. Needing a certain amount of storage to enable increased penetration in solar, 2MWh of EV capacity is not equivalent to 2MWh of stationary storage capacity, due to its transient nature and other uses. Therefore, Scenario 13 may be viable in the system with 25% penetration of solar, but this Scenario cannot accommodate any additional solar capacity, in near future.

Table 5-2: Summary of System LCOE results

Scenario	Solar penetration by energy (%)	Distributed solar (MW)	Community solar (MW)	Utility ESS (MWh)	Residential ESS (MWh)	Community ESS (MWh)	EV (MWh)	Load Control	System LCOE* ($/kWh)	%delta Metric
1	25	4.9	0	1	0	0	0	No	$0.100	8%
2	25	4.9	0	2	0	0	0	No	$0.101	10%
3	25	4.9	0	4	0	0	0	No	$0.103	14%
4	25	4.9	0	6	0	0	0	No	$0.106	17%
5	25	4.9	0	0	1	0	0	No	$0.101	5%
6	25	4.9	0	0	2	0	0	No	$0.103	5%
7	25	4.9	0	0	0	1	0	No	$0.100	5%
8	25	4.9	0	0	0	2	0	No	$0.101	5%
9	25	4.9	0	2	1	1	0	No	$0.105	9%
10	25	4.9	0	1	2	1	0	No	$0.106	6%
11	25	4.9	0	1	1	2	0	No	$0.105	7%
12	25	1.8	0	2	0	3.1	0	No	$0.102	10%
13	25	4.9	0	0	0	0	2	No	$0.099	6%
14	25	4.9	0	2	0	0	0	Yes	$0.097	46%

*Represents “moderate DER costs/moderate ERCOT prices” of Holistic controls

Within the Austin SHINES project, the idealized solution has been framed as a pathway towards optimizing design of both DER asset mix and control values of these assets, on the distribution grid. Just as any equation can yield percent error, this should be adequately considered before interpreting the scenario results of this report. And as many changes have occurred through the years of this project, including capital costs or simply the cost associated with naiveté and setting precedents, these fluctuations also carry some influence. From input to output of the methodology, however, the proportional relations brought out by these scenarios does provide important illuminations and answers to the optimal design solution.

Modeling demonstrated the differential value of DER integration, should be further investigated and refined. Both modeling and field demonstrations indicate costs for DER deployments and integration are higher than the potential value they can generate at this time. Understanding the sensitivity of models is critical to predictive analytics and ability to forecast tipping points for the economic viability of future deployment and integration. To realize a positive differential value of DER from a control perspective, some combination of the following would need to occur.

- Additional market opportunities paired with more responsive controls and inverters, would need to become available in the ERCOT market
    - Market prices would need to rise and/or become more volatile
- Reliability issues would need to start occurring on Austin Energy's system, likely due to higher (>25% load served by PV) renewable penetration, and the value of reliability would need to be quantified
- The costs of communicating with smaller DER assets beyond the grid's edge would need to reduce, potentially from using monthly cellular subscriptions to leveraging the network in place for Advanced Metering Infrastructure (AMI)
- Additional DER types with differing value propositions, such as electric vehicles and load control, would need to be integrated into the control platform at larger scales to realize the benefits of value stacking through asset diversity, as recognized in Scenario 13

In seeking to prosper DER penetration and make sensible its application, scenario results show the utility would be better suited to engage in further modeling versus fielded demonstration. Utilizing assets deployed during the project, continued activities will include continued performance analysis of the ESS's, streamlining control system architecture, developing integrations for additional DER types, and adopting tools to monitor grid opportunities for DERs. From the utility perspective, to cooperatively develop a modeling tool and deploy three scales of assets required one concerted leap of faith. The work of engineers, analysts, developers, and many other experts challenged their capabilities against emerging technology. With the project results, those involved, and the report audience may translate this leap into strategic footsteps and roadmaps.

5.6 Fielded Assets (FD−6)

This report provides information of the fielded Distributed Energy Resource (DER) assets, which were deployed by the utility. It includes tables and images of the Energy Storage Systems (ESSs) at grid-scale, commercial and residential levels and co-located solar PV. These descriptions serve as verification of installation, for testing grid performance and

the ability for the grid to host high penetrations of solar generation. Detailed utility data will remain confidential, such as location and other interconnection components.

In Table 5-3, the high-level metrics of both grid-scale assets are provided. Under controls, DUC stands for Direct Utility Control, where the systems were sent signals via an on-site holistic controller. The Kingsbery (KB) Energy Storage System (ESS), is located within the Kingsbery Substation. The KB ESS site layout may be seen in Figure 5-8, where the La Loma community solar farm resides adjacent.

Table 5-3: Grid-Scale Asset Metrics

Site ID	Control	Install Date*	ESS Power (MW)	ESS Energy (MWh)	Battery Model	Inverter Model (Power Rating)	Solar Feeder Capacity (MW)	Solar Feeder Type
KB	DUC	6/8/2018	1.5	3	LC Chem	Parker-Hannifin 1.5 MVA	2.6	Community Solar
MU	DUC	11/8/2019	1.75	3.2	Samsung (7 Aggreko Y.Cubes)	Parker-Hannifin 7 per Y.Cube each at 250 kVa	4.9	Distributed Rooftop

**Note: Install Date refers to completion of Final Acceptance Testing of the systems*

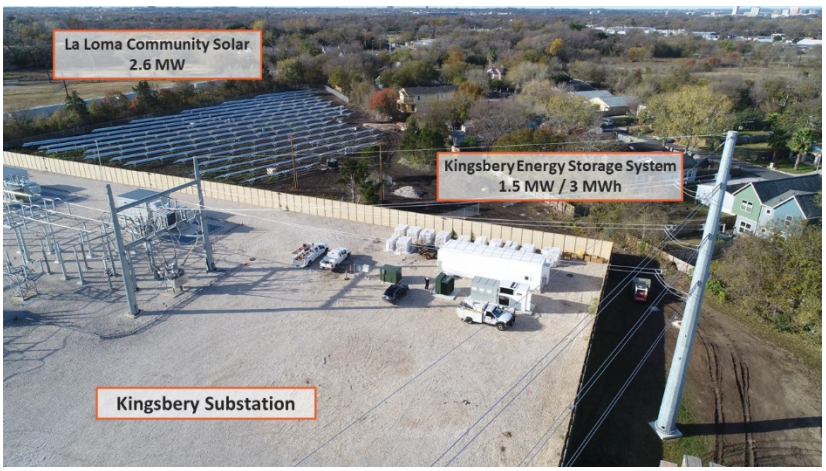

Figure 5-8 Aerial KB ESS site view (image taken on 12/11/2017)

The Mueller (MU) ESS site, in Figure 5-9, is incorporated within the Mueller neighborhood of Austin and contains 7 individual battery storage containers.

Figure 5-9 Aerial MU ESS site view (upper left image taken on 6/18/2019)

These containers are all interconnected to the same pieces of equipment, but a modular design approach was taken.

In Table 5-4, the high-level metrics of all commercial assets are provided. All three were installed indoors and a part of the third-party aggregation control use case. However, unlike the residential systems, these commercial assets partitioned their availability between the ESS vendor's demand charge reduction application and SHINES DUC holistic controls. Stem, the vendor, were the priority controller while the utility was able to test outside the peak demand usage window. The peak demand windows varied per site and respective customer's electrical usage.

Table 5-4: Commercial Asset Metrics

Site ID	Control	Install Date	Power (kW)	Energy (kWh)	Battery Model	Inverter Model (Power Rating)	Solar Capacity (kW)
A	Aggregated/DUC	2/21/2018	72	144	Panasonic	Vendor/Proprietary	100
B	Aggregated/DUC	2/21/2018	72	144	Panasonic	Vendor/Proprietary	60
C	Aggregated/DUC	2/21/2018	18	36	Panasonic	Vendor/Proprietary	57

In Table 3-5, the high-level metrics of all residential assets are provided. Not every site contained a battery, and this was because the residential systems were testing many different control use cases, amongst a mix of DERs. They can be represented by the following breakdown:

- Aggregated storage installations
  - 6 homes with stationary battery storage systems (10 kWh each + existing solar PV)
  - 1 Electric Vehicle as Vehicle-to-Grid, or V2G (Site 25)
- 12 Direct Utility Controlled (DUC) solar PV via Smart Inverters
- 6 Autonomously controlled solar PV via smart inverters

Table 5-5: Residential Asset Metrics

Site ID	Control	Install Date	Battery Model	Inverter Model (Power Rating)	Solar Capacity (kW)
1	DUC	3/8/2018		Fronius Primo 10.0	9.99
2	Aggregated	7/1/2017	LG RESU10H 9.8kWh 400V	SolarEdge SE7600A	3.43
3	DUC	3/5/2018		Fronius Primo 7.6	6.66
4	Aggregated	9/12/2017	LG RESU10H 9.8kWh 400V	SolarEdge SE7600A	6.5
5	DUC	9/20/2017		Fronius Primo 6.0	6.37
6	DUC	1/26/2018		Fronius Primo 7.6	6.615
7	Autonomous	1/12/2018		Fronius Primo 6.0	6.25
8	Aggregated	9/29/2017	LG RESU10H 9.8kWh 400V	SolarEdge SE7600A	6.1
9	DUC	1/8/2018		Fronius Primo 6.0	6.37
10	DUC	3/8/2018		Fronius Primo 6.0	6.37
11	DUC	1/22/2018		Fronius Primo 7.6	7.25
12	Aggregated	11/29/2017	LG RESU10H 9.8kWh 400V	SolarEdge SE7600A	4.56
13	Aggregated	1/19/2018	LG RESU10H 9.8kWh 400V	SolarEdge SE7600A	3.67
14	Autonomous	2/15/2018		Fronius Primo 6.0	6.25
15	DUC	1/10/2018		Fronius Primo 7.6	6.615
16	Autonomous	1/9/2018		Fronius Primo 6.0	6.3
17	Autonomous	3/21/2018		Fronius Primo 6.0	6.25

18	Autonomous	9/13/2017		Fronius Primo 6.0	6.25
19	DUC	2/20/2018		Fronius Primo 7.6	6.5
20	Aggregated	4/25/2018	LG RESU10H 9.8kWh 400V	SolarEdge SE7600A	7.2
21	DUC	2/16/2018		Fronius Primo 7.6	6.84
22	DUC	3/7/2018		Fronius Primo 7.6	7.8
23	Autonomous	3/2/2018		Fronius Primo 6.0	6.27
24	DUC	1/24/2018		Fronius Primo 6.0	6.25
25	Aggregated	11/14/2018	2018 Nissan Leaf 10kW/28kWh	Princeton CA-10 Power Systems fast charger	n/a

Site 25 represents the Electric Vehicle (EV) installed in the partnering residential aggregator lab. This vehicle and associated equipment were developed to test Vehicle-to-Grid (V2G) capabilities, in which the car's battery system can provide bi-directional flow of energy back into the "grid". Figure 5-10 shows the car itself at the aggregator lab.

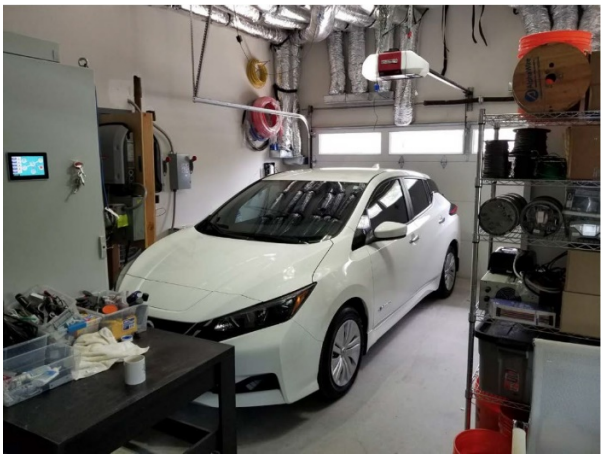

Figure 5-10 2018 Site 25 V2G, Nissan Leaf Electric Vehicle (image taken on 8/15/2018)

Figure 5-11 depicts the EV with the fast charger, allowing for the V2G charging. This installation added battery capacity while parked, for the residential aggregator ESS fleet by 10kW and 28kWh.

Figure 5-11 Site 25 V2G, Princeton CA-10 Power Systems fast charger (image taken on 11/14/2018)

It is the first V2G system installed in Austin, and possibly in Texas. The aggregator implemented “opt-out” local control switch for immediate charging needs. Finally, the charger is robust and designed more for commercial settings than residential, however given the lab test setting the inclusion of this scope of work was largely beneficial for lessons learned through deploying this asset.

Section 6 **Significant Accomplishments and Conclusions**

6.1 Important Assumptions and Outcomes

A key deliverable of the Austin SHINES project documented in this report is the definition and use of the System LCOE, that encompasses the holistic, system-level costs and benefits of all resources. This enables resources to be evaluated based on their ability to support an efficient and low-cost integrated grid ecosystem. Over the course of this 50-month project, Austin Energy and partners have installed more than 3MW of distributed storage, smart inverters, a DER control platform, and other enabling technologies utilizing customer and utility locations and multiple aggregation models. These resources were integrated and optimized at the utility level using a variety of management strategies. DER assets and control methodologies were designed to achieve:

- A credible pathway to a System LCOE of $0.14/kWh or less by 2020
- A holistic controls design with a 20% decrease in System LCOE, as compared to the no controls case
- Ability to enable high (25%) penetration of distributed solar generation
- And maintaining acceptable standards of power quality

There are several assumptions implicit in the definition of System LCOE that are crucial to respect while using the metric for comparing DER deployment strategies or controls optimization:

1. The System LCOE metric does not determine which entity in the system should incur costs or own assets. It is not a ratemaking exercise or a calculation of expected cost to customers, nor is it a prediction of future prices. The purpose of the System LCOE metric is to calculate the total cost of the system that serves load, from a technical perspective, so the question of what DER deployment strategy and controls configuration would minimize the cost can be answered. The question of who should own assets could be taken up as a secondary consideration or negotiation in a later stage of analysis, after the optimal configuration is determined.
2. The System LCOE metric does not discriminate between any asset in the system (i.e., grid-side or Behind-the-Meter (BTM)). The meter is not an electrically significant point in the system. Because the question of ownership is not considered, the focus is maintained on the technically and economically optimal DER deployment strategy.
3. The technical System LCOE consists of hardware, software, control, and communications costs. Cost to society and externalities such as the social cost of carbon are not considered.
4. Credit is assigned to the value of services provided upstream. For example, if DERs provide Ancillary Services (AS) such as regulation, the value of those

services crosses the system boundary, and is calculated as a negative contribution to the third term in the numerator (thus reducing the overall cost in the numerator).

5. Energy flows and services that do not cross the system boundary are not considered; energy flows and services that do cross the system boundary are considered. For example, consider the addition of DER assets deployed within the system boundary. The capital and O&M cost of assets inside the boundary will increase. Generation by solar PV will supply load inside of the boundary, and less energy will need to be purchased from wholesale markets, decreasing the cost of energy flows through the boundary, reflected in the third term in the numerator as a positive value. Because there is energy lost in the cycling of batteries and prices vary with time, the shifting of energy from one time to another by energy storage will result in a decrease at some time intervals, and increase at other time intervals, and may lead to an incremental increase in the cost of the net, integrated wholesale energy purchases, also reflected in the third term of the numerator. Optionally, when the DER provides AS in the wholesale markets, which is a positive value that crosses the system boundary, this additional DER deployment will affect all three terms in the numerator. It will not change the total demand for energy inside the system boundary, and therefore will not change the denominator.
6. It is assumed that power quality and reliability of service is held to a consistent level when comparing scenarios. If a system configuration leads to a violation of ANSI C84.1 voltage limits, for example, then the configuration is not valid. Steps must be taken to bring the system back into compliance, which may involve increased costs reflected in the first two terms of the numerator, if additional voltage control equipment must be purchased and installed. Changes in the reliability of the system are not reflected in the System LCOE calculation, unless reliability degrades to the point where a system configuration is determined to be nonviable.

Austin SHINES provided an opening for state-of-the-art technology products to be deployed, providing a rich opportunity for improving how each of the products perform as stand-alone products, and in concert with other complementary products.

6.2 Scope Impacts

Always with a focus on safety, Austin SHINES carefully moved through each project phase, closely monitoring grid scale battery installations in reaction to 2018 and 2019 battery fire incidents in the US and abroad. Austin SHINES temporarily took assets offline and performed a detailed look at its battery storage safety posture to establish short, mid, and long-term goals. After collaborating with 3rd-party safety efforts, Austin SHINES executed steps to meet all original mitigating requirements to bring the Kingsbery Energy Storage System (KB ESS) back online and continue final system acceptance and commission of the Mueller Energy Storage System (MU ESS). Due to these extenuating circumstances, Austin SHINES requested and was granted a 6-month, no cost extension on the grant timeline, allowing additional time for hardware and software performance data to be collected from each ESS. Austin SHINES continues collaborating with industry experts, other utilities, and the Austin Fire Department to remain vigilant, informed, and

responsive to battery safety standards and strategies. The extended demonstration phase allowed Austin SHINES to gather larger datasets in support of performance requirements including how the hardware and software provide a credible pathway to a System LCOE, ability to identify technologies with long service lives, and apply and test value streams to maximize economic value. Additionally, Austin SHINES sought to foster technology innovation, create a vendor agnostic platform allowing integration of a range of DERs, and maximize PV penetration.

It should be noted that as a municipally owned utility, Austin Energy approached the project goals with a particular lens that may not apply to others wishing to re-create the same steps. Always with our customers in mind, it was challenging to meet the objective of a single cost metric. Striving for best cost options for the utility service territory while balancing regulatory and market signals, it was difficult to estimate conditions at the beginning of the project and true these with changes over the course of the project duration. This limited our pure research capability, and placed boundaries on assets; other companies/customers need to map out what assumptions they operate under and apply the best approach for their needs. An example and interesting factor that arose during the project was cost of storage dropping faster than originally predicted.

6.3 Acknowledgements and Appreciation

A special thanks to the reports and project contributors, for their work to design, deploy and demonstrate an extensive and collaborative integration of new technology in Austin, Texas.

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Section 7 **Inventions, Patents, Publications, and Other Results**

No patent filings related to the detailed algorithmic techniques and control methodologies are associated with this project. The following tables list accepted manuscripts, media recognition, awards, and collaborations tied to the effort. The safety and regulatory collaborations, from Table 7-5, will continue in conjunction with Austin Energy's intent to run and maintain the fielded assets.

Table 7-1: Accepted Manuscripts of Journal Articles

Conference Title	Conference Location	Dates	Article Title	Full Author List	Paper #	CD Rom Volume or Volume, pp. (##-##)	ISBN
Proceedings of the ASME 2018 International Mechanical Engineering Congress and Exposition	Pittsburgh, PA	November 9-15, 2018	*How Solar and Storage Can Reduce Coincident Peak Loads and Payments: A Case Study in Austin, TX*	Arkasama Bandyopadhyay, Joshua D. Rhodes, Julia P. Conger, Michael E. Webber	IMECE2018-86482	Volume 6B: Energy ():V06BT08A023	DOI: 10.1115/IMECE2018-86482
Proceedings of the 2019 IEEE Texas Power and Energy Conference	College Station, TX	February 7-8, 2019	*Energetic Potential for Demand Response in Detached Single Family Homes in Austin, TX*	Arkasama Bandyopadhyay, Julia P. Conger, Michael E. Webber	32	pp 1-6	DOI: 10.1109/TPEC.2019.8662166
Proceedings of the ASME 2019 International Mechanical Engineering Congress and Exposition	Salt Lake City, UT	November 8-14, 2019	*A Decision Support Tool for Distributed Solar and Storage Investments: A Case Study in Austin, TX*	Arkasama Bandyopadhyay, Julia P. Conger, Michael E. Webber, Benjamin D. Leibowicz	IMECE2019-11068	Volume 6: Energy V006T06A094	DOI: 10.1115/IMECE2019-11068
Proceedings of the ASME 2020 International Mechanical Engineering Congress and Exposition	Virtual	November 16-19, 2020	*Energetic and Economic Potential for Load Control for Residential Customers in Austin, TX*	Arkasama Bandyopadhyay, Julia P. Conger, Emily A. Beagle, Michael E. Webber, Benjamin D. Leibowicz	IMECE2020-23114	Accepted and awaiting publication	Accepted and awaiting publication

Table 7-2: Media Recognition

Publication Date	Publication	Title
1/6/2016	AmericanInno	*Austin Energy is Plotting a New, More Efficient Grid*
1/20/2016	Think Progress	*The Future of The Grid Is Here, In These Two Products*
2/9/2016	Utility Dive	*How Austin Energy is looking to manage solar plus storage on its grid*
3/30/2016	Austin Monitor	*Federal grant offers Austin chance to be leader in solar energy storage*
4/2016	Frontier Group	*Shining Cities 2016: How Smart Local Policies Are Expanding Solar Power in America*
4/26/2016	PV Magazine	*US DOE: Austin Energy biggest winner under SHINES storage program*
5/4/2016	Microgrid Media	*Austin Readies Launch of 2 SHINES Solar-Storage Pilot Projects*
6/21/2016	Houston Chronicle	*Grid-scale batteries gain ground, research continues to seek lower cost*

1/16/2017	APPA	*Exploration of utility-scale storage includes compressed air*
6/21/2017	Greentech Media	*Austin Energy Seeks to Boost Value with a United Fleet of Solar and Storage*
1/2019	Solar Power World	*What is optimal mix of solar on the grid?*
5/2019	T&D World	*How to Determine the Right Mix of DER*
10/2019	Distributed Energy	*At Austin Shines, layers of control unlock value from DER -- on both sides of the meter*
10/2019	Utility Dive	*Austin Shines: A working model for both sides of the meter*
11/2019	Utility Dive	*Austin SHINES: How Intelligent DERMS Controls at Multiple Levels Maximize the Impact of Energy Storage*
12/2019	Power Engineering	*Austin Shines: a field study in power systems design for the renewables era*
1/2020	Utility Dive	*The new yardstick: How to optimize operations and economics in a high renewables grid*
1/2020	Utility Dive	*Austin Shines: How to Optimize Storage & Solar in Complex DER Systems [webinar]*
11/2020	PLMA	*17th PLMA Award-Winning Load Management Initiatives: A Compendium of Industry Viewpoints [pages 24-28]*

Table 7-3: Project Awards

Recipient	Award	Sponsor	Date of Award
Austin Energy	2017 Utility of the Year	*SmartCitiesDIVE*	*12/4/2017*
Austin SHINES Project	2018 Smart 50 Award	*Smart Cities Connect*	*3/26/2018*
Austin SHINES Project	2018 Grid Edge Innovation Awards	*Green Tech Media*	*4/26/2018*
Austin Energy	2018 Public Power Utility of the Year	*Smart Energy Power Alliance*	*7/10/2018*
Austin Energy	2018 Greater Austin Business Awards – Innovation Category	*Austin Chamber of Commerce*	*8/31/2018*
Austin SHINES Project	PMLA Technology Pioneer	*Peak Load Management Alliance*	*3/19/2020*

Table 7-4: Austin Energy Support/Participation on EPRI Projects Related to DER

Project Name	Project Lead	Number	Role	Additional Associated Project Areas/Members	Project Stage
DER Integration	EPRI	P174	Advisory	EPRI Members	Execution
SOLACE	EPRI	P174	Project Participant	P200 (Distribution Operations and Planning), P40 (Transmission Planning)	Planning
Distribution Operations and Planning	EPRI	P200	Advisory	EPRI Members	Execution
Energy Storage and Distributed Energy	EPRI	P94	Project Participant	EPRI Members	Execution

DER Communication Standards and Protocols Harmonization Project	MESA Alliance	N/A	Project Participant	MESA Alliance	Planning
Improving Firefighter Situational Awareness and Safety on Fire grounds Involving Lithium-Ion Batteries	University of Texas	N/A	Project Participant	Local Fire Stations	Initiation: UT seeking grant

Table 7-5: Austin Energy Support/Participation with Internal and External Entities

Effort	Forum	Host	Audience	Frequency	Did a Policy or Operations Guideline Result from Collaboration? Y/N/TBD
AE/Austin Department Safety Collaborations	Conferences	AE	AE, AFD	As needed	Y – Operating Guideline for AE Control Center
Lithium-Ion Battery Fire Analysis	WebEx	EPRI	Various Utilities	Ongoing	TBD - informational
Fire Safety Tech Seminar	WebEx	Snohomish PUD	Various Utilities, Fire Safety Specialists	1x/year	TBD - informational
Smart Utility Summit	In-person conference	AE	AE groups and invited utilities	1x/year from 2014-2018	N
Advanced Technology Reviews with VP	In-person group meeting	AE	AE Program Managers, including the DER area	1x/month from 2018 – 2019	N – forum for new ideas
Regulatory Working Group	In-person group meeting	AE	AE groups affected by policymakers such as ERCOT, NERC, TRE, etc.	1x/month	Y
DER Working Group	In-person group meeting	AE	AE groups with vested interest, resources, or funding in DER projects, regulations, and market trends	1x/month	N

Section 8 **Path Forward**

As DERs expand throughout Austin Energy's service territory, so is the need to integrate them intelligently, to mitigate any substantial impact they may have on our critical infrastructure. Customer and grid-scale DER penetration has increased to include hundreds of MW of local solar, battery storage products are becoming more available to residential and commercial customers, inverters are becoming increasingly "smarter," load control is being used for more than demand response, and electric vehicles (EVs) are reaching two-way functionality. Austin Energy has developed a DER Committee (executive/director level) and DER Working Group (manager/individual contributor level) to coordinate cross-functionally on emerging trends and projects. Regulatory Affairs leads another cross-functional team focused on Energy Storage Policy topics at ERCOT, the

PUCT and in the State Legislature. Along with dedicated teams like solar, demand response, and electric vehicles, awareness and knowledge has grown significantly over the past five years. DER Integration is multi-faceted, and Austin Energy understands the importance of acting on multiple fronts.

Austin Energy continues to be successful in receiving grants and awards at the federal, state and private level, which help offset the costs while expediting learning. The team which managed the Austin SHINES project will be continuing work from Figure 8-1.

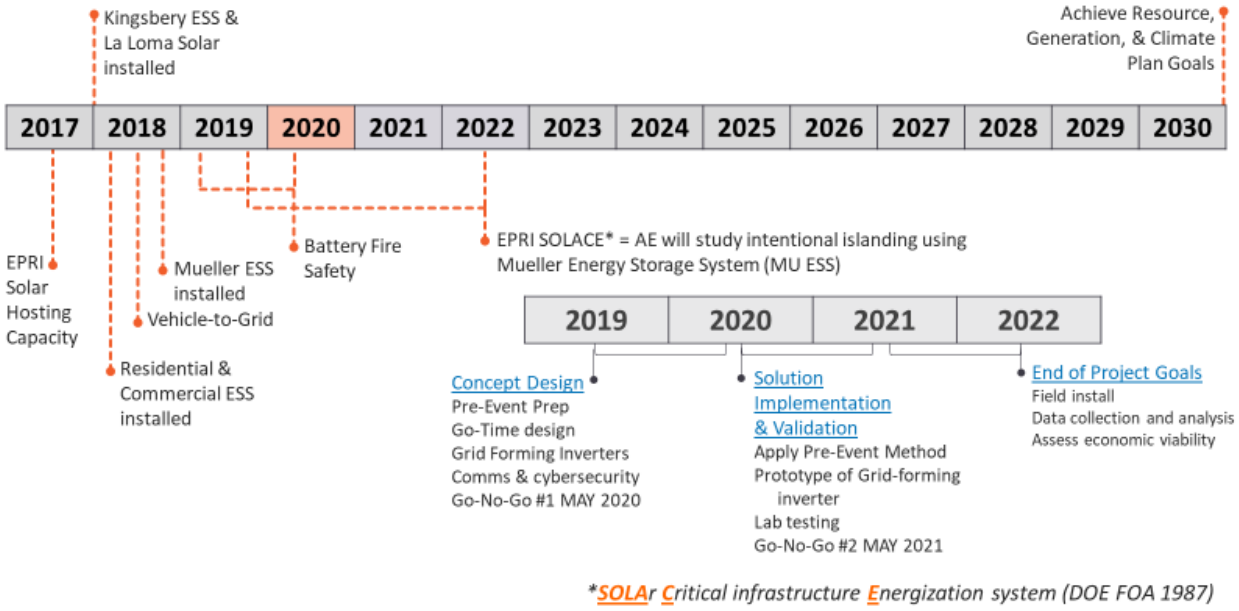

Figure 8-1 Austin Energy DER Integration Team project map

Sub-Initiatives and projects are described below:

- In early 2019, EPRI's Solar Critical Infrastructure Energization System (SOLACE) project received a $5 million DOE funding award. Austin Energy is listed as a sub recipient. The project objective is to develop a pre-planning analysis technique, using new communications standards and advanced inverters, to determine how to methodically supply power to critical infrastructure with any resource available on the grid. Austin Energy will study intentional islanding using Mueller Energy Storage System (MU ESS) during the demonstration phase of this project.
- Austin Energy is working with the MESA Alliance in support of agnostic, open communications standards protocols for controllers. The goal is to alleviate heavy dependence on proprietary code/equipment and create a "plug and play" approach for the grid appliances.
- Other initiatives include ongoing battery fire safety, demand response programs, and continued electric vehicle studies.

Section 9 **References**

Any references or footnotes are included in the FD reports themselves. Please look to these individually, for more information.

Appendix

A. Final Deliverable−1: System Levelized Cost of Electricity (System LCOE) Methodology
B. Final Deliverable−2: Software Platform Product Description
C. Final Deliverable−3: Optimal Design Methodology
D. Final Deliverable−4: Ownership and Operation Models for DER System Performance
E. Final Deliverable−5: Economic Modeling & Optimization
F. Final Deliverable−6: Fielded Assets