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Final Deliverable – 3

Optimal Design Methodology

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How to Read this Document

The audience for this report includes utilities, vendors, customers, policy makers, and anyone looking to design, integrate, operate, or own Distributed Energy Resources (DERs) and specifically Energy Storage Systems (ESSs). The intent is to provide applicable guidance for optimized ESS design in four key areas of functionality, sizing, siting, and communications. These elements are defined in Section 1 along with discussion of using open standards. Section 2, Section 3 and Section 4 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. Section 5 offers context for the subsequent SHINES Final Deliverable 4, and how the design phase impacts the ownership and operational schemes of these systems. The following report is agnostic to the Final Deliverables 1 and 5, System Levelized Cost of Electricity (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.

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Section 1 General Design Framework

The increasing penetration of Distributed Energy Resources (DERs) on the United States electric grids presents new opportunities as well as new challenges for utilities and customers alike. The decreasing cost of equipment and controls, in combination with increased functionality, is driving the supply chain and installation of DERs across all customer segments and among utility grids. At the present technology phase, these varied stakeholders can explore and define optimal design for DER installations. Characterizing elements of DER system design include functionality, sizing, siting, and communications. In this order and unison, they provide a comprehensive approach towards optimizing the system's value, or use case. Particularly for the customer, value derives from maximizing economic opportunities while avoiding increased costs in the overdesign of any four elements. Utilities share these concerns in their own applications, but must consider reliability while realizing flexibility in DER deployment. Further, despite increasing justification for DER installation in isolation, it is becoming widely recognized a holistic planning methodology which evaluates several value streams, for multiple stakeholders, is a mature path towards optimizing DERs across applications.

The first section of this report seeks to provide an overview of the Energy Storage System (ESS) design considerations common to installations, regardless of scale. The four elements of functionality, sizing, siting and communication paths are discussed separately, but each is closely interdependent to the other three. This section also includes the importance of open standards, and identification of the specific standards employed in the Austin SHINES solution.

1.1 Characterization Overview

The characterization of ESS design as influenced by equipment functionality, sizing a system, siting a system, and choosing a communication path are explored in detail. Each section acknowledges the scope of the design element, measured commonalities, and how decisions in each area affect the other three. These will be reviewed iteratively in the report, from the granular perspective of grid, commercial and residential scales in optimal, alternate, and SHINES solution perspectives. However, agnostic of installation type, understanding the linear influences will ensure the ultimate system is founded on holistic operational needs.

1.1.1 Functionality Defined

While stationary energy storage technologies have been available for many decades, they have historically served as backup systems. Provided with a small power flow from the grid to offset standby losses, they have remained largely inactive, and called into service only during grid outage events to supply building systems and occupants with critical power needs. Advances in controls, inverter technology, and battery chemistry have greatly expanded the functionalities of ESSs available and its applications. Simple on/off capabilities have given way to fully controllable charge and discharge rates of both real and reactive power, enabling peak demand reduction to power factor correction.

Designing for functionality, in any application, begins with identification of the value streams available to all stakeholders. And aptly, this design element is suited for consideration first as the evaluation will typically produce a primary opportunity, or rather the largest financial benefit to one or more stakeholders. Electric tariffs, energy market prices, intermittent energy sources present on the system, transmission costs, and ancillary services programs can all greatly influence potential energy storage system value and factor into the determination of cost-effective functionalities to implement. The Austin SHINES team identified 19 potential functionalities, applicable to the Austin Energy service area as well as most other service areas in the United States. They cover a wide range of stakeholders and demands on the electric grid, as shown in Figure 1-1. The team grouped these functionalities into the six distinct categories of customer value, renewable integration, energy market operations, ancillary services, transmission operations support, and distribution operations support. Consideration of these functionalities led the team towards focusing on six to implement, based on project schedule, Austin Energy grid conditions, budgets available, and resources, both personnel and technical. The six chosen control system applications are represented in blue.

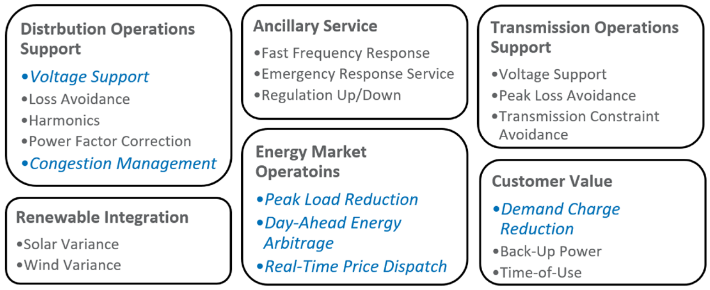


Figure 1-1 DER Control System Applications

Although it was later determined how to prioritize these six functions amongst themselves, Table 1-1 provides a synopsis of value, for the considerations above.

Table 1-1: SHINES DER Control System Applications

Application	Description
Demand Charge Reduction (DCR)	*Aimed at reducing a demand charge customer's monthly bill through the release of energy from an ESS during times when the customer's demand is peaking, and recharging the ESS during low customer demand periods. Enabling this functionality requires both historical and predictive analytics, with an ESS installation behind the customer meter.*
Peak Load Reduction (PLR)	*In the ERCOT market, an allocation program to recover transmission costs for the ERCOT grid presents a unique opportunity for Distribution Service Providers (DSP) to realize value through the Peak Load Reduction functionality. Each year, the load contribution of every DSP to the total ERCOT load is recorded on the peak 15 minute (market price settled) intervals of June, July, August and September. The DSP's coincident peak during these four ERCOT peak periods establishes their percent contribution to the overall ERCOT load, leading to the term Four Coincident Peak, or 4CP, which is applied to assess transmission fees to each DSP throughout the year. Reduction via the discharge of stored energy during the 4CPs can lead to significant savings for DSPs in the ERCOT market. Enabling this functionality requires predictive analytics of the ERCOT forecast and real time loading conditions, in addition to temperature and weather of not only the local area but ERCOT territory, as larger load zones (cities such as Houston or Dallas) can heavily influence this peak period. Thus, as the load increases throughout the afternoon, when temperatures rise and a majority of consumers use more air conditioning, the application seeks to predict the last moment in which the ESS can charge to have full discharge capacity available during the estimated coincident peak interval.*
Day-Ahead Energy Arbitrage (EA)	*Involves the discharging of ESSs when prices are high in each market, as well as the absorption, or charging of ESSs when prices are low. The value is highly dependent not only on the volatility of energy markets, but also on the ability to correctly anticipate the high and low prices, leading to significant development efforts to implement these functionalities. Two options for achieving value from the Day-Ahead Market (DAM). The first option involves making a commitment to buy/sell energy a day in advance based on real-time market price predictions being higher/lower than the day-ahead prices. The second option provides a target day-ahead schedule based on the prices, but can be adjusted in real-time.*
Real-Time Price Dispatch (RTPD)	*Real-Time Price Dispatch takes advantage of volatility in real-time energy prices. The price volatility is typically higher in areas that do not have a capacity market (such as ERCOT). By design, ERCOT allows energy prices to spike high to encourage generation to come online. The mechanism is similar to energy arbitrage, but the time scale is different. The time horizon at which RTPD application looks ahead is from 5 minutes to 6 hours, but it must act as a real-time application and automatically deploy schedules as frequently as 5 minutes. Typically, price spikes only last a short (5-15 minute) interval, so short-term prediction and fast response is important. Energy storage, being bi-directional, can take advantage of both spikes and troughs in prices.*
Distribution Voltage Support (VS)	*Voltage support brings primarily reliability value to the utility and seeks to maintain the voltage of a distribution circuit within the ANSI C84.1 limits of 0.95 and 1.05, offsetting any volatility that may occur. Solar PV systems on the distribution system, particularly at higher penetrations, are a primary cause of voltage volatility due to their intermittent power generation and rapid ramp rates. The release and absorption of reactive power in response to voltage fluctuations can achieve this functionality.*
Distribution Congestion Management (CM)	*Congestion events in power systems occur when electricity flow across a system component (such as distribution line or transformer) exceeds safe design capacity. High penetration of DERs in distribution systems increases the probability of congestion events. Because congestion can cause voltage and overloading problems, it is important for the distribution system operator to prevent equipment damage and manage congestion. The goal of the congestion management application is to use active power capability of DERs on a circuit to relieve congestion problems in the circuit. This application helps utilities prevent potential load shedding events, increase life of assets, and increase hosting capacity of distribution circuits for renewable energy.*

In view of the selected applications, all seek to improve the electric service delivery for energy consumers either by direct economic benefit, indirect utility expenses, or reliability. This mix allowed the SHINES project to evaluate the performance of functions from measured savings. In addition, the functionality objectives could then inform the design element of capacity needs.

1.1.2 Sizing Defined

Just as the chosen DER control system applications revealed preference to enable all three energy market operation functions, a critical factor when sizing ESSs include the revenue stream portfolio. Revenue streams vary widely according to opportunities enabled by markets, rates, ancillary services, demand response programs, and ESS functionality. All installations should identify these opportunities and allow them to play a large part in driving the sizing process, to avoid missed financial opportunity as well as unnecessary oversizing.

Another factor affecting the sizing of an ESS is the presence of another pre-existing or planned DER. Whether behind the meter of a customer or on a distribution feeder, co-located DERs such as a solar PV system can be sized to adequately harness renewable generation. Scalability should also be assessed in the case where the co-located DER is additional energy storage. Modular systems present the opportunity to defer increased capacity based on anticipated future use cases until such use cases become economically feasible, for example. Changes in building use, rates or peak load could justify increasing the size of a commercial system at some future time. Similarly, a rise in energy prices or increased demand could present financial incentive for a utility to increase a grid-scale system, which would again be facilitated by the selection of a modular type energy storage system.

Lastly, supporting physical infrastructure should influence the sizing of an energy storage system because it can impact multiple stakeholders. When system sizes exceed the limits of distribution system infrastructure, upgrades for reliability and safety can potentially impact both the utility and the system owner depending on utility requirements. In systems other than grid-scale applications, upgrades to site electrical infrastructure can limit the size of systems from a cost effectiveness perspective.

1.1.3 Siting Defined

Many of the same factors influencing the size of an ESS also play a role in optimal siting. National and local codes generally arise from a fire safety standpoint and are continually evolving as the technology itself develops. Code requirements can restrict ESS siting based on the type and distance of other mechanical or electrical equipment in the vicinity. Indoor installations are frequently compulsory to be in spaces with 1 or 2 hour-fire rated construction and may contain ventilation or fire suppression system requirements. And in the case of industry maturity, or rather nascency, the desire for fire suppression systems and ventilation can present conflicting installation needs where the former may necessitate an entirely closed structure which the later seeks to aerate. Security to the installation site is also typically specified in codes, and even occupancy characteristics of adjacent areas can restrict ESS installations, both interior and exterior.

Environmental conditions should also be accounted for when siting an ESS. Outdoor installations may free up valuable interior space, however rated enclosures are typically higher priced, and will need to include HVAC that can handle both the extremes of outdoor temperature and humidity. Indoor applications may also require some form of additional cooling and humidity control, and other heat or humidity producing equipment in the same space must be carefully considered.

Aesthetics should not be overlooked, particularly in outdoor locations. While indoor applications typically occur in mechanical or electrical rooms, outdoor locations can range from rooftops to loading docks to more public areas. Choosing less public or hidden areas is typically the first choice, avoiding costs which may be associated with siting in areas of high visibility. These extra costs can range from maintained landscaping to physical structures that seek to camouflage the ESS from view as much as possible and/or enhance the visual appeal.

Existing infrastructure should be a factor in retrofit ESS applications. If the infrastructure includes other DERs, to complement the operation, this should also be a goal. Whether in grid-scale, commercial or residential applications, the existence of sufficient electrical infrastructure and the ability to locate the ESS as close as possible to existing interconnection points will reduce costs of running additional conduit or other construction.

Perhaps the most obvious factor in siting is the available square footage. Although a prerequisite for all installations, a careful site planning process should include consideration of future needs. As ESS technology evolves in function and form, emerging business cases can present new opportunities enabled through expansion of the system. Similarly, the expansion of a building may also justify increasing an existing ESS capacity.

After determining what functions to implement, how much energy storage is conducive to the application or many, and where the capacity can reside, the design can ultimately address how to supply and relay information about ESS and controls.

1.1.4 Communications Paths Defined

For many decades, electrical grid hardware components were confined to distribution system deployment and operate autonomous modes. They were also overdesigned to account for anticipated anomalies, lack of real-time status, and control capabilities. The advent of cost-effective communication technologies has enabled the introduction of new hardware, which are consequentially dependent on reliable communication systems transferring information in a short latency timeframe. ESS applications are extremely limited when operating in an isolated or one-way state and it is only through the exchange of signals and information the functionality can be optimized.

Similar to the sizing of an ESS, the design of the optimal communication infrastructure is greatly influenced by the characteristics of a specific application. However, a number of the considerations are similar across applications. Perhaps the first decision during communication system design, wired vs non-wired, should be driven by more than budgetary factors. Wireless communications, although offering higher sensor density and better access points must assess the range, battery life, and site topology for latency and reliability. Since most systems involve a hybrid design involving both wired and non-wired portions of the communications path, as well as more than one communication protocol, interoperability standards have become essential in ensuring not only successfully end-to-end communication, but also a way to hedge for future expansion as technologies mature and evolve. Measurement frequency and output can also inform the appropriate option. While the costs of commercially available cellular and wireless systems are a strong incentive to drive these choices, utilities are increasingly recognizing established AMI systems can be leveraged, providing competitive choices and flexibility for a portion of the overall communication path.

Cybersecurity should also be a significant influencer when designing communication systems. Their unique capability to send power in either direction, at a varying controllable level, while electrically connected to potentially both grid supply and load, presents greater risk than some other DERs such as solar PV. Protection from cyberattacks or physical ones should be evaluated to preserve data security as a utility, the grid, and customers and can be exposed by this type of vulnerability.

From application selection to a command signal, optimization of energy storage systems is realized when the design elements consider safety, reliability, and the ecosystem with which they exist. Synchronizing these elements relies on not only a utility's internal decisions but industry leadership. The following section recognizes how standards and protocols impact DER and ESS technology, of which the operational process is pivotal towards deployment and development.

1.2 Open Standards

Crucial to the long-term success of DERs across all sectors is the use of open standards. Software open standards define how information is stored and communicated between different programs, in order to function smoothly as a larger system. These standards are freely available and developed with input from all interested stakeholders who commit to requiring and implementing the standards into future projects. The Open-Source Hardware (OSH) concept is similar, calling for easily discernable information regarding hardware to include aspects such as drawings, specifications, integrated circuit layouts and device drivers that facilitate hardware upgrades and modifications.

The design and implementation of DERs with open standards bring several benefits to the multiple stakeholders. DERs in general, and ESSs in particular, are a rapidly developing technology which bring new functionality and performance with each new iteration. A system implemented with open standards reduces risk for the ESS owner, by ensuring future expansion or modification to the system will be lower cost and barrier to implement compared to proprietary standards. This is truer when it comes to choosing between different suppliers of similar technology, helping the purchaser to avoid ESS vendor "lock-in", from the prohibitive cost of switching vendors due to extensive integration resultant from proprietary standards.

Installing an ESS and integrating it with grid or building operations requires numerous software programs, from different suppliers, communicating with one other. In a poorly coordinated industry with no open standard interfaces, the project-specific process of "stitching" is unique to each pair of suppliers who are connecting their software. Project owners pay for stitching work as part of their overall project cost. Open standards take away much of the need for customized project stitching by defining it for the entire industry of suppliers. In general, projects using open standards will require much less custom work compared with projects using the same components but not using open standards. Some suppliers will say they lower this cost for owners by pre-engineering interfaces between their software and all the options out in the market, but owners should be wary of this claim. This claim requires the supplier keep up with all the innovations in the entire industry, even ones they do not currently sell, and absorb the cost of maintaining that stitching without passing it along to their customers.

In addition to these benefits, open standards bring a safety benefit. Standardization simplifies engineering of a multi-part system because designs can rely on certain components remaining the same. This certainty makes it easier to train personnel on how to operate, maintain, troubleshoot and repair the overall system. This is valuable in every industry, but perhaps particularly in the electricity system where mistakes can carry safety costs in addition to financial costs. These safety benefits are even more valuable to evolving technologies such as energy storage, which seek to establish themselves as a reliable, cost-effective, and most importantly, safe technology for implementation at all levels of the electrical grid.

The Austin SHINES solution employed three main open standard protocols. Perhaps the most widely known among energy storage standards are the Modular Energy Storage Architecture (MESA) set of standards developed by the MESA Standards Alliance[1]. This group of industry stakeholders includes equipment vendors and utilities working to develop an open set of specifications which seek to allow utility grid operators to manage multi-vendor storage assets with minimal custom integration, while also addressing the effective communication of energy storage components with each other. This set of standards was applied in both grid-scale applications, as described in Section 2.

Another open standard employed in Austin SHINES was the Sunspec set of standards developed by the SunSpec Alliance. Similar to the MESA Standards Alliance, the SunSpec Alliance[2] is a trade alliance of solar and storage DER stakeholders seeking to develop open standards that enable "plug & play" system interoperability. This standard was applied at the residential scale as described in Section 4.

Finally, the OpenADR standard developed by the OpenADR Alliance[3] was employed at both the residential and commercial level of ESS installations. From its origin as a set of standards for automated demand response (ADR), the OpenADR Alliance has been developing updated 2.0 specifications to support increased functionality of evolving demand response and energy storage technologies.

Section 2 **Grid-Scale**

2.1 Optimized Grid-Scale Methodology

Grid-scale storage systems have the flexibility to address the full range of grid real and reactive power needs, performing distinct services at the generation, transmission, and distribution levels of the electricity system. This flexibility means that grid-scale storage systems typically stack multiple functionalities to maximize value. Selecting the functionality set that best satisfies project objectives is a key step in system design. This process, in turn, informs the sizing and siting of the system, as well as the design of a secure control and communications strategy that integrates the ESS into the existing asset ecosystem.

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

[1] http://mesastandards.org/

[2] https://sunspec.org/

[3] https://www.openadr.org/

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 2-1 provides a visualization of this methodology.

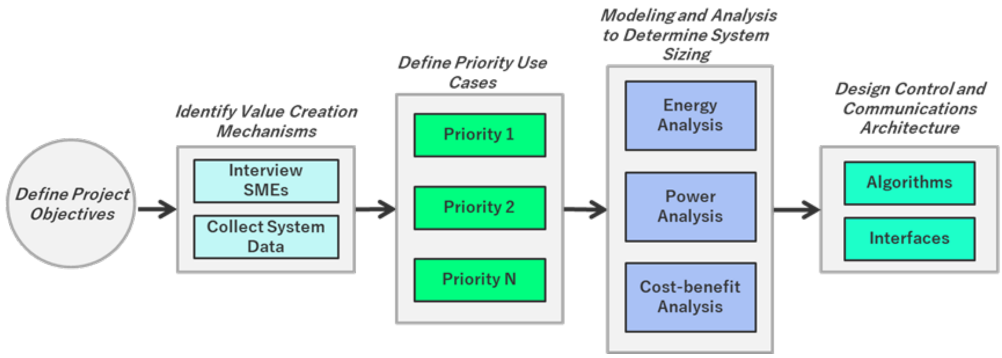


Figure 2-1 System design process methodology

2.1.1 Optimal Grid-Scale Functionality

Determination of grid-scale 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 2-2 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.

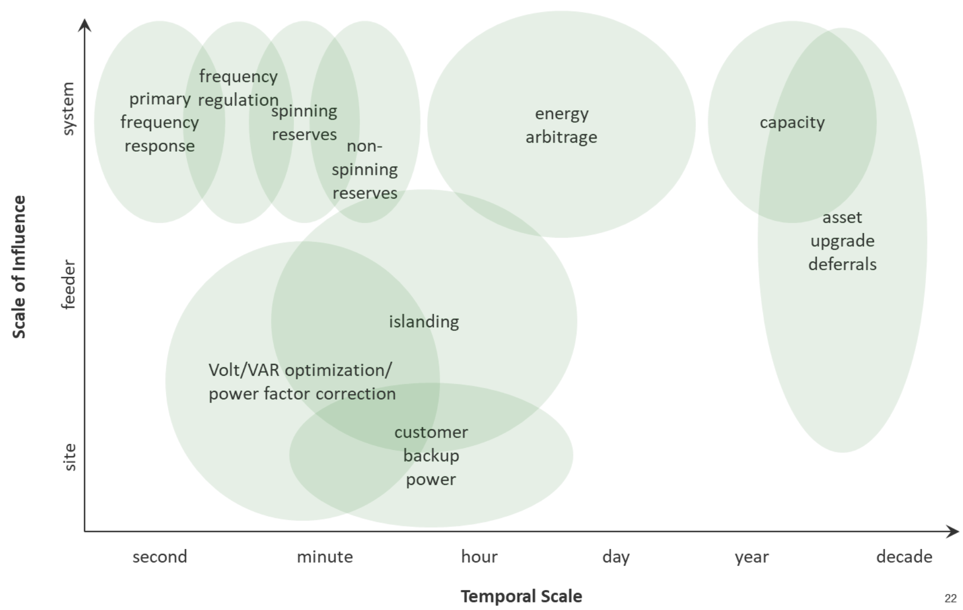


Figure 2-2 Use case influence scale and temporal value horizon

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.

2.1.2 Optimal Grid-Scale Sizing

Defining and prioritizing the target set of use cases (or functionalities) is a prerequisite to successful grid-scale energy storage sizing. Once the planned use cases are established, system designers can analytically determine the system size that maximizes value for each individual use case. Ideally, the system energy capacity is set as the largest optimal energy capacity of all the individual selected use cases, and the system power capacity is set as the largest optimal power capacity of all the individual selected use cases. In most cases, however, there are physical space constraints, electrical system constraints, and/or financial constraints that limit system size. This sizing section discusses analytical approaches to maximizing value for power quality, reliability, and market participation grid-scale ESS use cases. Common physical, electrical, and financial constraints that must be accounted for to achieve optimal sizing are discussed in the Siting section.

Grid systems are increasingly populated with distributed generation resources, so power quality use cases that mitigate that negative impacts of intermittent distributed generation are among the most commonly selected for grid-scale ESS deployments. These negative impacts include voltage flicker, real power volatility, and power factor issues. The power requirement for these use cases is determined through circuit modeling. Simulated control algorithms take in historical or projected real power, reactive power, and/or voltage data and model ESS response as well as the resulting grid effects. Figure 2-3 provides an example output from a solar smoothing model. The modeled 1.5 MW ESS in this example responds to projected solar generation data by discharging or charging in the opposite direction of measured solar generation power spikes to reduce real power volatility. Similar models can be used to simulate circuit power smoothing, voltage support, power factor correction, and other power quality applications that involve responding in real time, to meter readings.

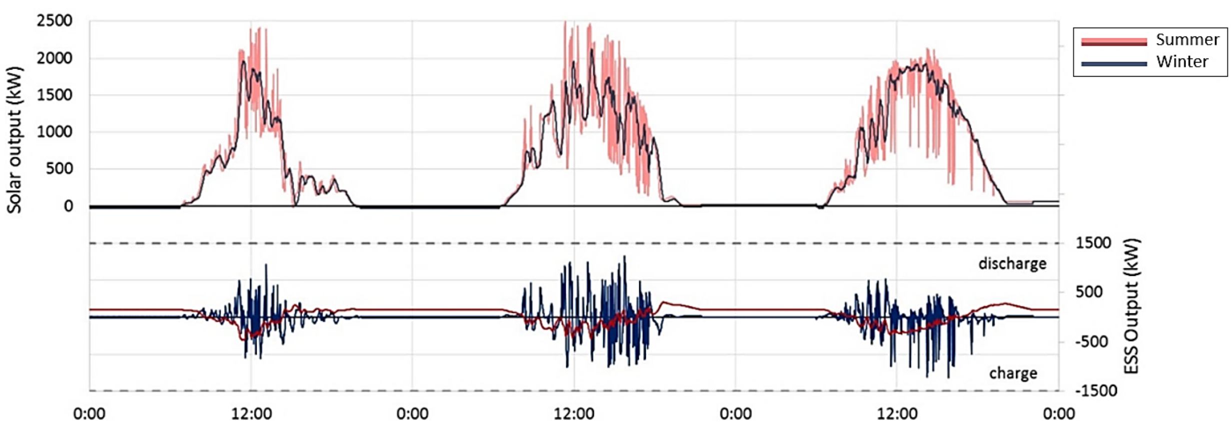


Figure 2-3 Solar smoothing simulation example

ESS power capacity is varied until the optimal power capacity is determined. The optimal power capacity depends on project-specific power quality improvement goals. For example, a circuit may be in violation of the IEEE 1547.7 voltage flicker limit, so the optimal ESS power capacity is the lowest KVA value that brings the circuit into compliance. For volatility smoothing scenarios when there is no violation of a power quality standard, utility- or RTO-imposed limit, or other target value that must be achieved, ESS power capacity is then determined by evaluating the point of diminishing capacity improvement. Linear regression can be used to calculate the “smoothing effectiveness” that indicates how much the ESS reduces the average fluctuation for each modeled power capacity. Figure 2-4 provides an example of smoothing effectiveness plotted against ESS power capacity. In this example, smoothing effectiveness rapidly increases with ESS power capacity up to an inflection point around 1-1.5 MW. After that point, there is diminishing smoothing effectiveness improvement with added system power. If a utility attaches economic value to smoothing effectiveness, ESS power capacity can be optimized by weighing added system cost of increased capacity against added system effectiveness. Examples will be shown for the SHINES systems in Results Section 2.2.3.

Many grid-scale energy storage use cases are based on the concept of peak shaving. An ESS performs peak shaving by discharging to keep load beneath a threshold value and charging at an off-peak time when load is below the threshold. Peak shaving can create value in several ways, including peak load reduction, capacity upgrade deferral, and congestion management. Sizing for all use cases relies on a projected load profile that accounts for all expected load growth during the project lifetime. Figure 2-5 illustrates the energy capacity and power capacity required to shave the shaded peak above a threshold using projected load data.

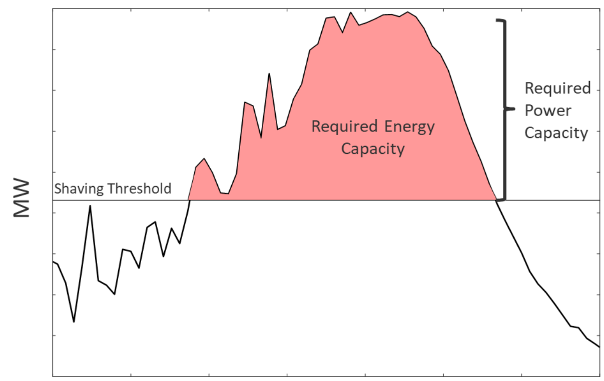


Figure 2-4 Peak shaving sizing capacity evaluation

Peak shaving use cases like capacity upgrade deferral and congestion management require peak reduction to a specific threshold for the use case to provide any value. For example, to defer the cost of upgrading a transformer, peak load must never exceed the transformer rating. In these cases, the optimal power and energy capacity are those required to fully shave all projected peaks above the threshold value during the ESS lifetime.

Other use cases, like peak load reduction, create incremental additional value for every additional kW shaved off the system peak. The optimal size for these use cases is determined through cost benefit analysis that weighs the cost of additional power and energy capacity against expected peak load cost reduction.

Availability of charging energy is an important factor to consider for peak shaving applications on systems that experience large peaks above a shaving threshold in close succession. Figure 2-6 shows required peak shaving in red and available charging energy in blue. If there is not sufficient charging energy available following one peak to support the next, the energy capacity may have to be sized larger than simply the energy required to ride through the largest single peak.

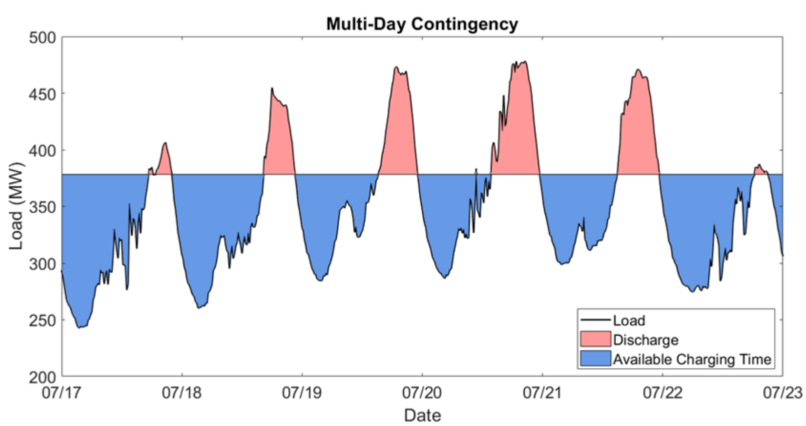


Figure 2-5 Peak load reduction energy availability

Grid-scale storage systems are also frequently used for reliability use cases, where they form an electrical island and support all load, or selected critical loads, on a grid segment or circuit through a service outage. To size an ESS for this use case, the load profile during the highest expected load period during ESS lifetime is projected and the outage ride through duration requirement is determined. Outage ride through requirements are typically based on outage history or local maintenance/circuit reconfiguration/alternative backup option response time capabilities.

The energy requirement to support an electrical island through an outage is the area under the projected load curve for the duration of the outage. Figure 2-7 shows the energy required to ride through an example 5-hour outage. The ESS energy capacity requirement is the maximum energy requirement of all possible outages that last the required ride through duration. The ESS power capacity requirement is the maximum value in the projected load profile. Assuming Figure 2-7 shows both the maximum area under the load curve during any 5-hour period in the example projected load profile and the peak load value, a 2.5 MW/10 MWh ESS would be required for this load profile and a 5-hour outage ride though duration requirement.

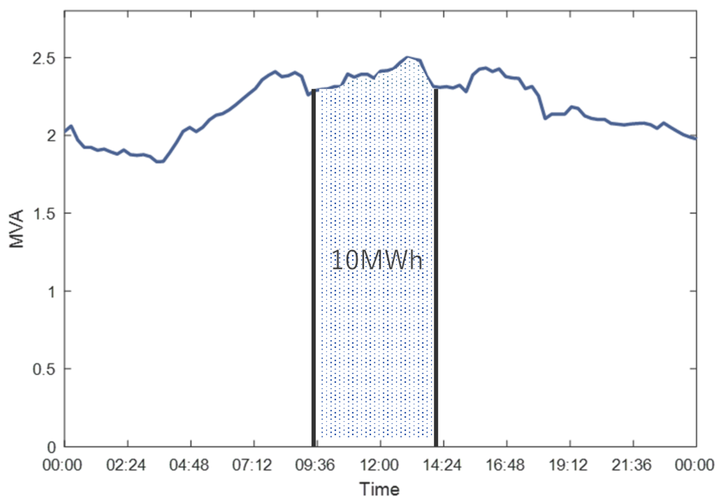


Figure 2-6 Outage ride through energy capacity requirement

The final class of grid-scale storage use cases discussed in this report is direct market participation. These use cases include arbitrage in the real-time and day-ahead energy markets, ancillary services, and capacity market participation. Sizing for market participation use cases requires a cost/benefit analysis that balances greater revenues achievable through larger ESS size with capital, operating, and degradation costs. Local market participation requirements and coordination strategy between market use cases must also be considered. Engagement with an organization's market operations group is helpful in achieving correct sizing for market use cases.

Once the optimal sizing for each selected priority use case is determined, the largest individual use case power capacity and largest individual use case energy capacity set the system size. Table 2-1 demonstrates a scenario where optimal sizing has been determined for three priority use cases: solar smoothing, peak load reduction, and energy arbitrage. In this illustrative case, the system power capacity is set by the 2 MVA required for optimal solar smoothing and the energy capacity is set by the 3MWh required for optimal peak load reduction.

Table 2-1: Example system sizing based on individual use case sizing

Use Cases	Optimal Power Capacity (MVA)	Optimal Energy Capacity (MWh)
Solar Smoothing	2	N/A
Peak Load Reduction	1.5	3
Energy Arbitrage	1	1
System Size	2	3

One caveat to this approach is that some battery systems must perform multiple use cases simultaneously or reserve capacity for high value use cases that initiate at unknown times. For example, a battery may need to maintain a specific

State of Charge (SOC) to provide backup power during an unplanned outage or participate in capacity markets. In these cases, total system size may be set by adding individual use case optimal power and/or energy capacities rather than selecting the largest.

Lithium-ion cell degradation necessitates oversizing system energy capacity at installation or battery augmentation over the course of project lifetime. Cell degradation rate depends on duty cycle, battery chemistry, and local environmental conditions, so a system-specific projected degradation profile must be calculated to inform oversizing and/or augmentation planning. A complex set of financial priorities and practical limitations must be considered when devising an oversizing/augmentation plan. Dynamic economic factors may dictate when large capital expenditures are funded, and site space limitations and component availability may limit the degree of oversizing that can occur at one time.

2.1.3 Optimal Grid-Scale Siting

Properly siting a grid-scale storage system requires careful consideration of a range of economic, physical, environmental, and electrical factors. Potential ESS sites each come with a set of physical constraints that can limit ESS construction, or add cost and time. This is particularly true in densely populated areas. The most basic constraint is footprint area, but the shape of candidate sites can dictate ESS configuration, truck access is required for construction and maintenance, some municipalities have aesthetic and noise requirements that affect ESS design, building a system that contains flammable materials is prohibited or limited in proximity to certain buildings, and other physical factors unique to each site must be considered.

When evaluating potential site footprint and shape, it is important to consider that ESS component layout may evolve over project lifetime. Battery augmentation may be necessary to account for degradation and/or new functionality requirements. Components may be retrofitted due to changing regulations or safety practices and standards. Planning for equipment modification and expansion at project outset can remove constraints and reduce costs later, in asset management and lifetime.

Potential ESS sites are also constrained by the electrical system at their interconnection point. A battery system mitigating power quality issues caused by intermittent generation or load will be most effective the closer the ESS is placed to the issue source. A battery performing use cases with large real power swings can cause power quality issues that lead to unacceptable circuit stability. Frequency regulation market participation, for example, can require near-instantaneous swings from full discharge to full charge or vice-versa. Circuit modeling can reveal suitable interconnection locations or alert system designers to a necessity for additional equipment upgrades, compensating for power quality issues.

There are also many environmental considerations when siting grid-scale storage systems. The presence of wetlands, endangered species, forestation, vegetation, and/or many other environmental factors affect project viability, timeline, and cost. An environmental permitting review of several potential sites should be carried out before a project location is finalized.

Grid-scale storage systems are often co-located with an existing substation, but this approach does not always result in optimal design. As noted previously, system design is an iterative process and siting considerations may cause system designers to adjust sizing and revise target use case selection.

2.1.4 Optimal Grid-Scale Communication Paths

Optimal grid-scale communication path design involves minimizing component cost while meeting control architecture, cybersecurity, and reliability requirements. The first step in this process is to determine which groups or entities within the operating organization need control access to the ESS. Additional internal and external groups may also require real-time visibility into ESS status and schedule. Once the groups requiring control access and visibility have been identified, ESS control mechanisms and architecture can be established. There are many control mechanisms to consider, and the optimal design is based on the operator's objectives and standard practices, the suite of existing or planned distributed resources on the grid, and the planned ESS use cases. A single battery performing only reliability and power quality use cases might be directly scheduled by a utility's distribution operations group, while a battery participating in wholesale energy markets may be scheduled by an internal or third-party market operations group, and multiple ESSs and/or distributed resources may be collectively scheduled by fleet optimization software. Some fast-response market applications, such as frequency regulation, require an ESS to follow a dispatch signal sent from an ISO or balancing authority. Control responsibility often shifts between groups at an operating organization (i.e. market operations and distribution operations) based on scenario to enable different functionalities.

Identification of control groups and mechanisms enables mapping of the control architecture. Figure 2-8 shows an example high-level control architecture diagram with necessary communications pathways noted. The example architecture in Figure 2-8 depicts one potential configuration where the ESS is scheduled by a utility distribution operations group via a SCADA network. Each communication pathway must be implemented to meet requirements for latency, security, reliability, and interoperability while minimizing cost.

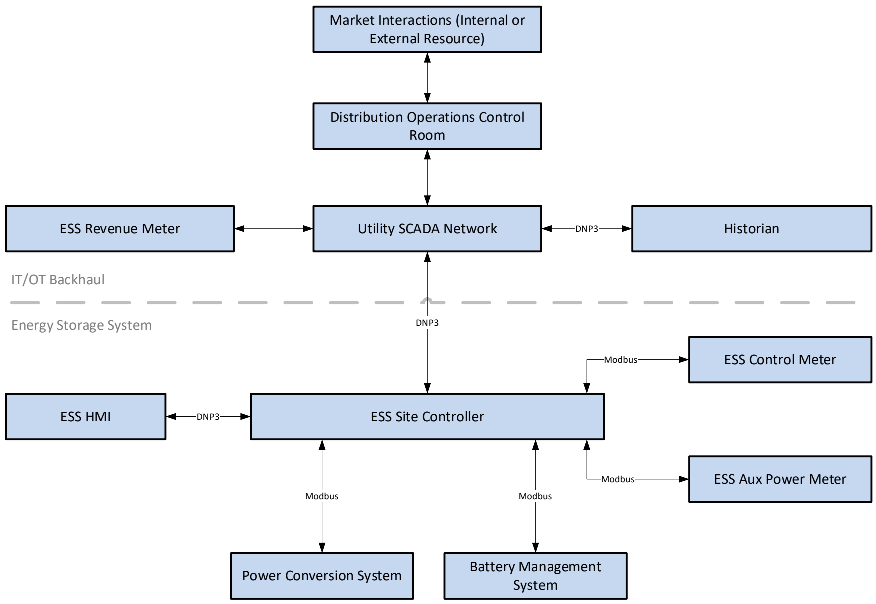


Figure 2-7 Example ESS control architecture

It is typically best practice for ESS communications to utilize open or widely used communications protocols such as DNP, Modbus, and RDP to maximize component choice and interchangeability. Implementing open communications standards such as MESA also enhances interoperability and significantly reduces integration work. Particularly sensitive data may require proprietary communications protocols and the ability to convert between protocols.

Optimal hardware selection varies by communication path and ESS use case. Wireless communication options are often the cheapest but result in higher latency and lower security. Fiber is an expensive option, but the cost can be warranted for use cases that require near-instantaneous response and for transmitting sensitive data. Overhead wire solutions are subject to treefall and other weather-based reliability issues, balanced against the feasibility and cost of underground options.

While the process flow of defining clear project objectives, identifying and prioritizing use cases, sizing for those use cases, and then moving onto detailed siting, sizing, component selection, and communications design provides a framework to maximize value creation, system design is a cyclic process. Any step in the process may raise issues or new information that requires previous steps to be revisited. Project deployment should only occur after several iterations of this design process and exhaustive engagement with stakeholders occurs at each level.

2.2 Impact of Alternate Grid-Scale Design

Suboptimal design of any of the four design elements discussed in this document can hamper the efficacy of all other elements. This section describes the impacts on ESS performance, when each of these four elements is not holistically analyzed during the ESS design phase.

2.2.1 Alternate Grid-Scale Functionality

Incorrect selection of ESS use cases can lead to missed revenue opportunity, unmet financial goals, resource/staffing constraints, and technical constraints that limit intended ESS capability. If the full range of use cases and feasible use-case stacking configurations are not considered during the design phase, the selection may fail to capture potential revenue or value creation projections may be unrealistic. Battery sizing, siting, and communications will be based on the selected use cases, so it may not be technically feasible to incorporate additional or alternative use cases after construction.

Stacking use cases is an important method of maximizing ESS value, but system designers must be wary of double counting the value of use cases that cannot be concurrently implemented. Many markets have participation rules that limit the ways storage systems can provide multiple market products. A storage developer risks overpromising or overestimating market revenues if these rules are not considered. If a storage system is participating in a capacity or reserve market, the energy capacity necessary to satisfy market requirements cannot be used for peak shaving, islanding, or other use cases without risk of financial penalty or market disqualification. This limitation can be addressed during battery sizing, but should be considered when selecting use cases as well.

If the electrical constraints of the surrounding grid system are not considered when selecting use cases, dispatch may be limited, or expensive equipment upgrades may be required to use the ESS as intended. For example, participation in frequency regulation markets may seem to be a financially lucrative functionality, but the large real power output swings associated with the use case may cause impermissible grid instability in weak electrical systems. Some use cases require a threshold power value for implementation and may not be feasible if circuit hosting capacity is not considered during functionality designation. Similar to use case stacking limitations, grid constraints can sometimes be addressed through battery siting, but should also be considered when selecting use cases.

2.2.2 Alternate Grid-Scale Sizing

Incorrect grid-scale ESS sizing can severely hamper project effectiveness, limit revenues, shorten project lifetime, and cause wasteful capital and operating expenditure.

Undersized ESS power capacity can result in lost market revenue potential and inability to participate in markets with threshold power requirements. If power capacity is not sufficient to shave an entire peak above a grid constraint, the ESS will not successfully defer distribution or transmission upgrades. An ESS with undersized power capacity performing reliability use cases may not be able to support all critical loads in an electrical island or maintain grid stability if load shedding is not possible. If load growth is not adequately accounted for, the ESS will be undersized by the end of project lifetime, potentially creating the negative impacts described above.

Undersized energy capacity similarly can limit potential market revenues and hamper peak shaving for peak load reduction and grid constraint avoidance. If an ESS is sized based on a single event (a single peak above a grid constraint, for example) and there is not sufficient recharging time between events, the ESS can be rendered ineffective. Failure to adequately size an ESS for lifetime degradation will result in the impacts described above before the end of project lifetime and may prematurely void manufacturer warranty.

An undersized system also experiences accelerated degradation as maintaining a required MWh capacity with a smaller system results in the system resting at a higher SOC than a larger system. A smaller system also sees a greater depth of discharge performing the same duty cycle as a larger system, further accelerating degradation.

Oversizing also contains negative impacts, the most obvious is the excessive capital expenditure for unnecessary ESS components. Overspending wastes stakeholder money in the short and long term and can reduce the chance of project financing and regulatory approval. In addition to needlessly inflating ESS capital cost, oversizing ESS the power capacity can trigger unnecessary grid equipment upgrades if grid hosting capacity is exceeded.

2.2.3 Alternate Grid-Scale Siting

Poor placement of an ESS within an electrical system can render an otherwise optimally designed system ineffective. An ESS located far from intermittent generation assets or other sources of power quality issues may not be able to effectively mitigate voltage flicker, low power factor, and other power quality issues. An ESS interconnecting to a weak electrical system may not be able to perform use cases that involve large real power injections and output fluctuations. If an ESS interconnection exceeds circuit hosting capacity, expensive equipment upgrades may be required.

Like poor electrical placement, poor physical placement of the ESS can limit project efficacy. Small property size can limit ESS capacity, make construction more difficult, expensive, and time-intensive, and limit future expansion. Small property footprint also constrains maintenance space and can threaten the safety of work crews. Failure to consider environmental factors early in the design process can lead to drawn-out permitting, unforeseen construction expense and evaluation, and project-hindering site use restrictions.

2.2.4 Alternate Grid-Scale Communication Paths

A robust communication and control architecture is crucial to project success and poorly designed communication pathways can severely limit ESS performance. If control responsibilities within the ESS operating organization are not clearly defined, the system may not perform the highest value use case at any given time and there may be internal ambiguity over situational control responsibility.

Incorrect communication hardware selection has several potential negative ramifications. If market information, generation forecasts, and other data crucial to correct optimization are not received rapidly or at all, correct optimization of use cases and dispatch is not possible and the ESS cannot capture all of the value it is capable of creating. Communication latency can slow ESS response time and incur financial penalties and/or reduced performance. Breaches of sensitive customer data expose ESS operators to considerable financial and legal risk.

If proprietary communications protocols and standards are unnecessarily chosen over open options, ESS operators will be tied to vendors for component replacement and upgrades. This eliminates price-shopping opportunities and can severely increase integration costs for future components, or hinder expansion.

2.3 Grid-Scale Results

System design of the Kingsbery and Mueller grid-scale storage systems generally followed the step-wise process outlined in the Optimized Methodology 2.1. This section describes the design considerations associated with each project and discusses factors that led to some instances of alternate design.

2.3.1 Grid-Scale Functionality Results

2.3.1.1 *Kingsbery Functionality*

Kingsbery ESS functionalities were determined and prioritized based on project objectives and value potential. Austin Energy identified use cases that support the integration of distributed renewable energy as the highest priority for the Kingsbery ESS project. Use cases that support the general reliability and efficiency of the distribution system and support bulk power system energy applications (for example, energy arbitrage) were chosen for implementation, but designated as lower priority. Table 2-2 shows the full list of use cases considered for implementation through the Kingsbery ESS.

Table 2-2: Use cases considered for Kingsbery ESS

Use Case Classes	Renewable Integration	System Efficiency & Operational Benefits	Economics	Reliability
Use Cases	• Automatic Voltage Regulation (Volt/VAR) • Real-power smoothing • Power Factor Correction • Ramp-rate Limiting	• Circuit level peak shaving • Substation peak shaving • Transmission constraint avoidance • Max loss avoidance • Spinning reserves • Frequency regulation	• Energy Arbitrage • Renewable energy firming • Upgrade deferral	• Back-up power (islanding) • Demand response

After identification of potential use cases that address the Kingsbery project objectives, each use case was evaluated for feasibility and potential to create value. The following criteria were used to evaluate objectives:

- Relevance in addressing the prioritized project objectives (Renewables integration support, grid efficiency/reliability, bulk-system economic benefits)
- Ability to create benefits on the KB-1 circuit with the 2.3 MW solar array online
- Ability to create benefits on the KB-1 circuit and Kingsbery substation with or without solar online
- Operational complexity and impact on project scope
- Long-term value creation prospects for Austin Energy
- Technical constraints of the KB-1 circuit and Kingsbery substation

Based on these considerations, eight use cases were chosen for implementation. Table 2-3 lists these use cases (ranked by priority) and describes the benefits that each provide.

Table 2-3: Selected use cases for Kingsbery ESS

	Use case	General Description	Benefit
Renewable Integration Support	1. Automatic Voltage Regulation (Volt/VAR)	Ability for the ESS to measure voltage at its connection point and automatically inject capacitive or inductive reactive power to push voltage towards a specified setpoint.	Supports circuit voltage management and provides a dynamic response to rapid voltage fluctuations caused by solar intermittency
	2. Circuit smoothing	Measure KB-1 circuit loading and charges/discharges the ESS to counteract rapid load fluctuations.	Reduces active power volatility of the KB-1 circuit load, enabling the substation LTC to better manage voltage and reducing wear and tear on substation components
	3. Solar output smoothing	Measures solar active power output and charges/discharges the ESS to counteract rapid output fluctuations.	Reduces active power volatility of the solar array, enabling the substation LTC to better manage voltage and reducing wear and tear on substation components
	4. Power Factor Correction	Measures the power factor of the KB-1 circuit and injects capacitive or inductive reactive power to push the pf towards a specified target (typically unity pf)	Increases the efficiency of the AE distribution and transmission grid by reducing the magnitude and variability of reactive current needed to supply the KB-1 circuit.
Energy Operations	5. Energy scheduling	Enables a schedule to be created to control ESS operations over time. Schedules include kW, kVAR, or SOC vs time.	Enables AE to schedule the ESS to contribute to bulk power operations. Schedules can be built to create benefits via energy arbitrage, peak capacity avoidance, max loss avoidance, etc.
	6. Circuit level peak shaving	Responds to loading on the KB-1 circuit to charge/discharge to limit peak and/or minimum loading on the circuit.	Increases circuit load factor, limits maximum circuit kW capacity, limits circuit back-feed, and normally creates energy arbitrage value.
	7. Substation peak shaving	Responds to loading on the KB 12.47 kV bus to charge/discharge to limit peak and/or minimum loading on the bus.	Increases circuit load factor, limits maximum circuit kW capacity, limits circuit back-feed, and normally creates energy arbitrage value.
	8. Solar energy shifting	Charges and discharges based on solar output conditions to shift solar production to higher-value times.	Increases the value of solar energy by shifting it in time to displace more expensive alternative energy sources.

2.3.1.2 *Mueller Functionality*

During the design phase, Austin Energy identified the following ESS objectives for the Mueller ESS:

1) Demonstrate the ability of energy storage technology to improve power quality on the distribution circuit
2) Demonstrate the ability of energy storage to provide system level ancillary services (for example, frequency regulation and responsive reserves)
3) Demonstrate the ability of energy storage to support energy arbitrage

The use cases implemented to achieve the desired distribution circuit objectives (1) are:

- Volt/VAR – responds to voltage by dispatching VARs in accordance with a curve
- Volt Smoothing – dispatches reactive power when voltage deviates from a moving average
- Power Smoothing – dispatches real power when load deviates from a moving average

The following market dispatched services are utilized to achieve objectives (2&3):

- Ancillary Service (AS) – dispatches real power to a market signal
- Real-Time Price Dispatch – charges real power at low prices and discharges during high prices in response to Location Marginal Price (LMP) variance

This suite of use cases formed the basis for Mueller system design and power and energy capacity sizing. Evolving market participation strategy and re-evaluation of potential value streams in the context of the fleet of integrated DERs controlled by the Doosan GridTech Distributed Energy Resource Management System (DERMS), called the Distributed Energy Resource Optimizer (DERO™™) resulted in the decision not to implement the ancillary services use case at Mueller. Additionally, reduction of Austin Energy's 4CP, was identified as a high-value use case. Assets larger than 1 MW are ineligible to participate in 4CP reduction, so the Mueller and Kingsbery systems cannot realize this value stream. Holistic analysis of the range of potential short-term and long-term use cases at the outset of the design process can prevent suboptimal sizing and enable the highest-value functionality.

2.3.2 Grid-Scale Sizing Results

2.3.2.1 *Kingsbery Sizing*

Doosan analyzed the optimal power and energy capacities of the Kingsbery ESS needed to effectively achieve the identified priority use cases. MATLAB simulations produced optimal sizing for each identified use case and final installed system size was a function of these optimal sizes weighted by use case priority and commercially available component offerings. Figure 2-9 illustrates this process and summarizes the resulting target power and energy capacities.

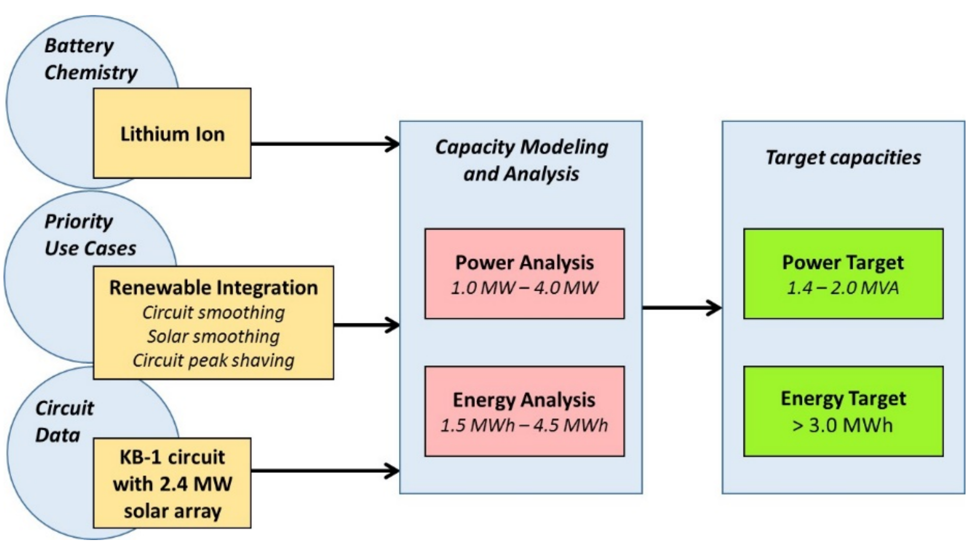


Figure 2-8 Kingsbery sizing summary

The analysis to determine the required power rating (MVA) utilized two priority use cases associated with mitigating the power volatility created by solar energy: circuit smoothing and solar output smoothing.

The ESS power capacity requirements for circuit smoothing and solar output smoothing modes of operation were each determined by modeling the modes using KB-1 circuit data and varying the ESS capacity between 1 MW and 4 MW. In each scenario, a smoothing effectiveness factor was calculated using the optimized methodology described in Section 2.1.2. Figure 2-10 shows the point of diminishing capacity improvement for the circuit smoothing mode and Figure 2-11 shows the point of diminishing capacity improvement for the solar smoothing mode. Based on these analyses suggest a target ESS power capacity of 1.25-1.5 MW. The installed power capacity of 1.5 MW was based on these use-case target values and commercially available component options from reputable vendors.

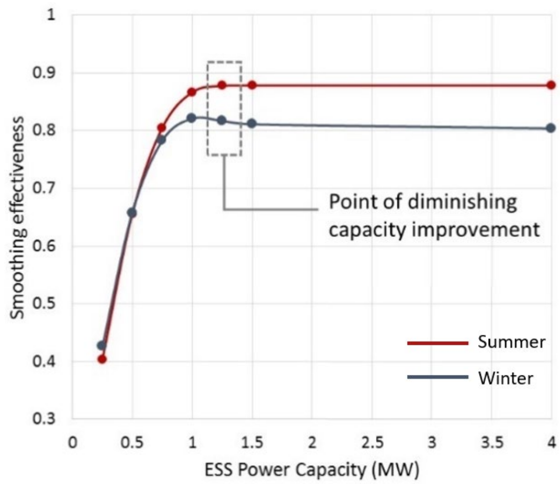


Figure 2-9 Kingsbery ESS circuit smoothing effectiveness

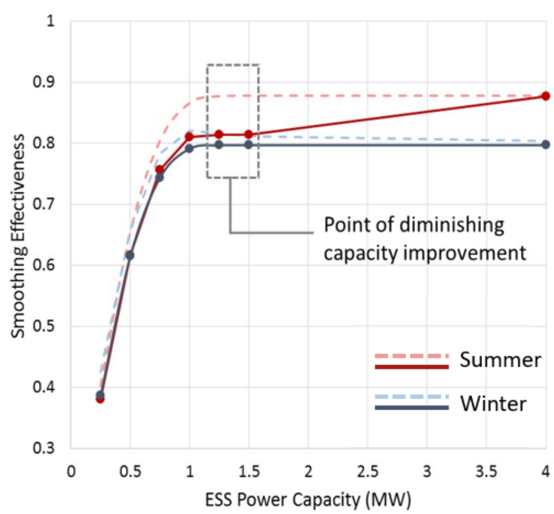


Figure 2-10 Kingsbery ESS solar smoothing effectiveness

The Kingsbery ESS energy capacity sizing was based on analysis of peak shaving potential on the KB-1 circuit. The effectiveness of circuit level peak shaving on the KB-1 circuit was assessed based on the mode's impact on the standard deviation of load measurements on the circuit. To compare the effectiveness of various power and energy capacity combinations, the peak shaving mode was modeled using the power and energy capacities shown in Figure 2-11. The baseline standard deviation of KB-1 load (with no mode employed) was then subtracted from each modeled standard deviation to determine the achieved benefit of each power/energy combination. Figure 2-11 shows the results of this analysis, with red-yellow-green color scheme indicating the worst (red) to best (green). Based on this analysis, the target ESS energy capacity for peak shaving is greater than 2.5 MW. The installed energy capacity of 3 MWh is based on this target, system cost, and commercially available component options.

kW \ kWh	500	1000	1500	2000	2500	3000	3500	4000
500	8.1	15	22	35	47	40	41	41
1000	7.9	25	43	61	82	142	155	169
1500	7.9	25	45	64	98	149	184	208
2000	7.9	25	45	65	98	150	184	211
2500	7.9	25	45	67	98	152	184	211
3000	7.9	25	45	67	98	152	184	211
3500	7.9	25	45	67	98	152	184	211
4000	7.9	25	45	67	98	152	184	211

Figure 2-11 Kingsbery ESS peak shaving effectiveness

2.3.2.2 *Mueller Sizing*

The Mueller ESS power and energy capacities were based on MATLAB simulations that produced optimal sizing for each identified use case. Final installed system size was a function of these optimal sizes weighted by use case priority and commercially available component offerings.

System power capacity was determined through analysis of the voltage and power smoothing use cases. Table 2-4 shows the optimal MVA values modeled for each use case. These values were determined using the point of diminishing returns optimized methodology for power quality use cases outlined in Section 2.1.2. Based on these use case-specific optimal power capacities, use case weighting by priority, and commercially available options from preferred vendors a power capacity of 1.75 MW was installed.

Table 2-4: Mueller ESS use case optimal power capacities

Use Case	Optimal Size	Use Case Priority
Voltage Fluctuations: Summer	1.5 MVA	High
Voltage Fluctuations: Winter	1.5 MVA	High
Power Smoothing: Summer	2.0 MVA	Medium
Power Smoothing: Winter	1.5 MVA	Medium

The Mueller system energy capacity was determined through analysis of the lower-priority ancillary service and energy arbitrage use cases. MATLAB time series analysis was employed to analyze revenue achievable through different energy capacities while assuming power values roughly within the range determined for the higher-priority power quality use cases (1.4-2.1 MVA). Table 2-5 shows optimal energy capacities for these use cases. The installed energy capacity of 2.9MWh was based on these optimal sizes, use-case weight, and vendor offerings that met project requirements.

Table 2-5: Mueller ESS use case optimal energy capacities

Use Case	Optimal Size	Use Case Priority
AS Revenue: Summer	3.0 MWh	Medium
AS Revenue: Winter	2.5 MWh	Medium
Energy Arbitrage Revenue: Summer	2.0 MWh	Low
Energy Arbitrage Revenue: Winter	2.5 MWh	Low

Figure 2-12 compiles the information in Table 2-4 and Table 2-5 to show how the individual use case sizes and use case prioritization led to the installed ESS power and energy capacity.

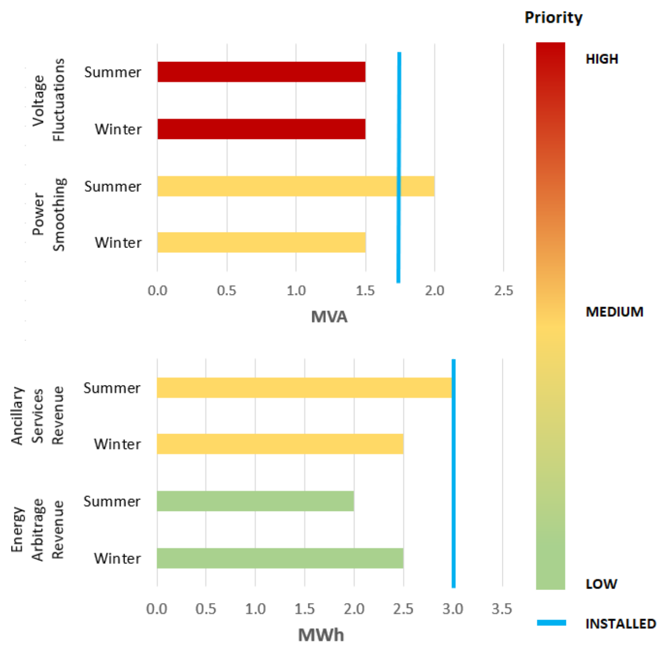


Figure 2-12 Mueller ESS sizing by use case summary

2.3.2.3 *Sizing Conclusion*

The sizing process for the Mueller and Kingsbery storage systems largely followed the optimized methodology outlined in Section 2.1.2, though as noted in the functionality section above, market participation strategy and ESS functionality evolved after system design and the power capacity limited the ESS' ability to participate in 4CP reduction. This highlights the importance of establishing priority ESS functionality and considering potential future use cases ahead of the sizing process

2.3.3 Grid-Scale Siting Results

2.3.3.1 *Kingsbery Siting*

Austin Energy's Kingsbery substation was identified as a strong candidate location for grid-scale storage due to its proximity to intermittent solar generation assets and the numerous advantages of deployment within an existing Austin Energy substation. Siting an ESS at an operational substation streamlines the permitting process, eliminates real estate transaction time and expense, allows the system to utilize existing communications equipment, simplifies maintenance, and enhances security. The Kingsbery substation had sufficient open space within the existing fence line for the footprint of an ESS of the desired size and it is not located adjacent to densely developed properties.

2.3.3.2 *Mueller Siting*

The Mueller location was chosen for a grid-scale storage system due to the Mueller neighborhood's focus on sustainability, renewable energy, and responsible urban planning. The highly-planned neighborhood provides Austin Energy with a public platform to demonstrate the capabilities of grid-scale storage. While the Mueller site was not optimal from a technical perspective – the available space required several irregularly-spaced modular containers, there was no existing communications or security equipment on-site, and the interconnection location was analytically determined to maximize power quality improvement use case effectiveness. To this last point, the power quality improvement use case relates to the high penetration of roof-top solar in the Mueller neighborhood, and therefore opportunity to demonstrate effective correction of intermittent generation, or voltage. The visibility of the site and location within the Mueller neighborhood further SHINES project objectives.

2.3.4 Grid-Scale Communication Path Results

The control architecture implemented at the Kingsbery and Mueller grid-scale storage systems employ time and cost saving measures like open standards while meeting or exceeding Austin Energy's reliability, latency, and cybersecurity requirements.

Modular Energy Storage Architecture (MESA) is used to provide a standards-based communications network. By standardizing the communications interface between multiple components within the ESS and between the ESS and AE's SCADA platform, the MESA Standard enables AE to control the Kingsbery ESS, Mueller ESS, and any subsequent ESS's that may be installed in a consistent manner. The MESA Standard also drives out non-recurring engineering costs as additional ESS's are deployed by standardizing system design. Additionally, the MESA protocol enables the control system to employ multiple advanced ESS control algorithms that dispatch the ESS to achieve the desired use cases on the grid.

Both systems are controlled at the site-level by Doosan GridTech Intelligent Controllers (DG-IC). The ESS control systems require interfaces with various metering points (e.g. substation equipment, solar interconnection points, etc.) and provide a MESA-ESS compliant interface to an Austin Energy host platform system.

The DG-IC employs two interfaces: (1) MESA-ESS complaint interface to the Austin Energy ADMS, the fleet optimizer (Doosan GridTech's Distributed Resource Optimizer or DERO™), and PI historian for indications, alarming, control and configuration parameters, and (2) a remote user access point for troubleshooting and monitoring. Both of these interfaces are achieved via a single fiber optic communication connection to Austin Energy's backhaul network.

The DERO™ interface is the primary way the ESS is dispatched remotely. Remote desktop protocol (RDP) is available for users external to Austin Energy's network to monitor and control (pending Austin Energy approval) the ESS via a VPN connection through an REM server. User accounts and permissions for the VPN tunnel are configured and managed by Austin Energy.

The majority of the communications and control equipment within the ESS is housed in the Control and Protection Cabinet at each location. Underground single-mode fiber connects from AE's communication infrastructure to the ESS Control and Protection Cabinets in order to provide access to AE's network. Underground fiber conduits also link the various components within the ESS to the Control and Protection Cabinet.

The ESS communications architecture and control software also incorporate relevant cyber security standards and requirements including required firewalls, intrusion protection, authentication, account management, access management, access logging, and auditing. All system components minimize the use of shared and/or default accounts – all user interaction with the controller are through individual user accounts for activity logging purposes. The system and its components are hardened against willful attack and human negligence.

Figure 2-13 shows the communications pathways implemented for the Kingsbery ESS and Figure 2-14 shows the communications pathways implemented for the Mueller ESS.

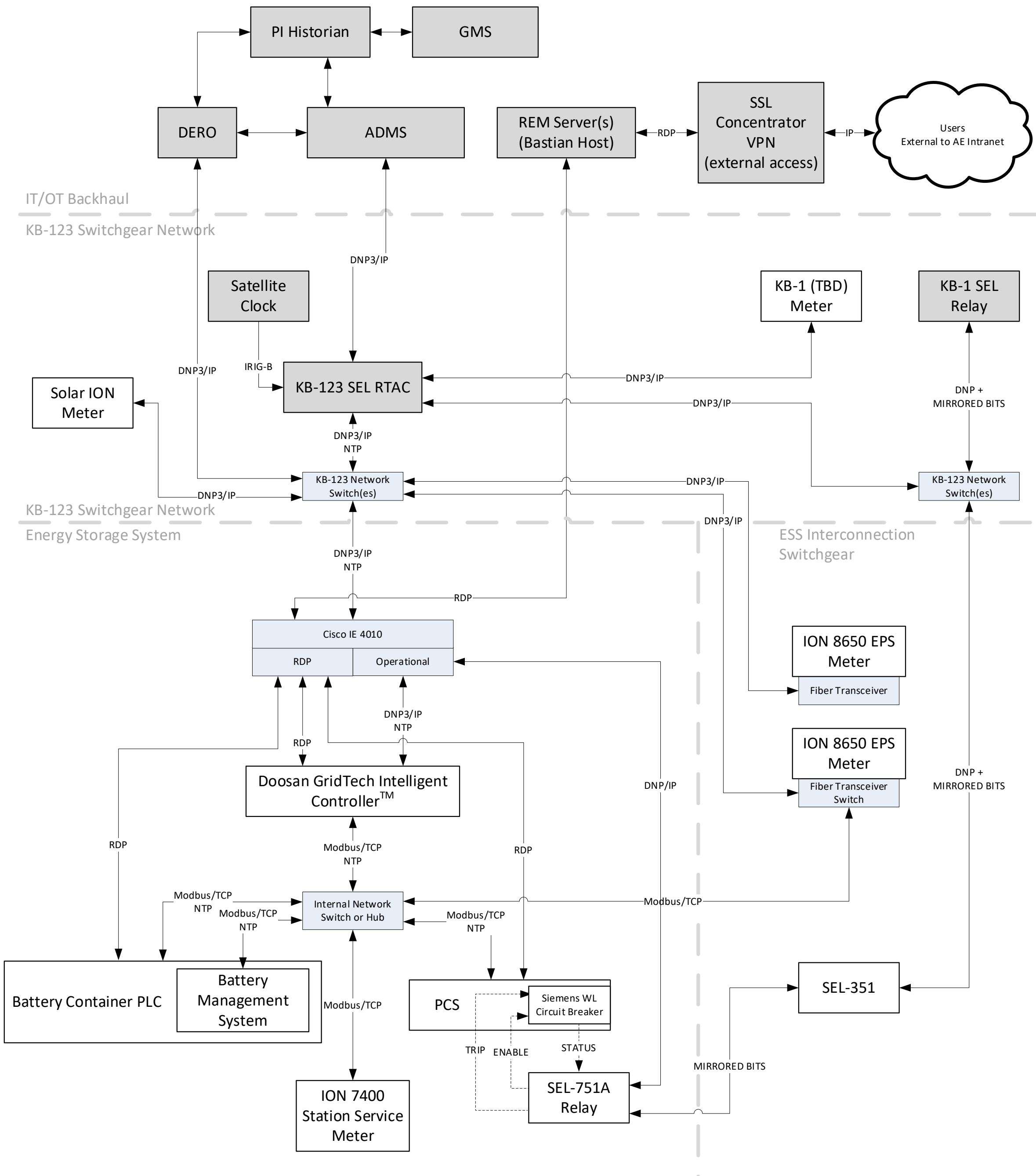


Figure 2-13 Kingsbery ESS communication paths and control architecture

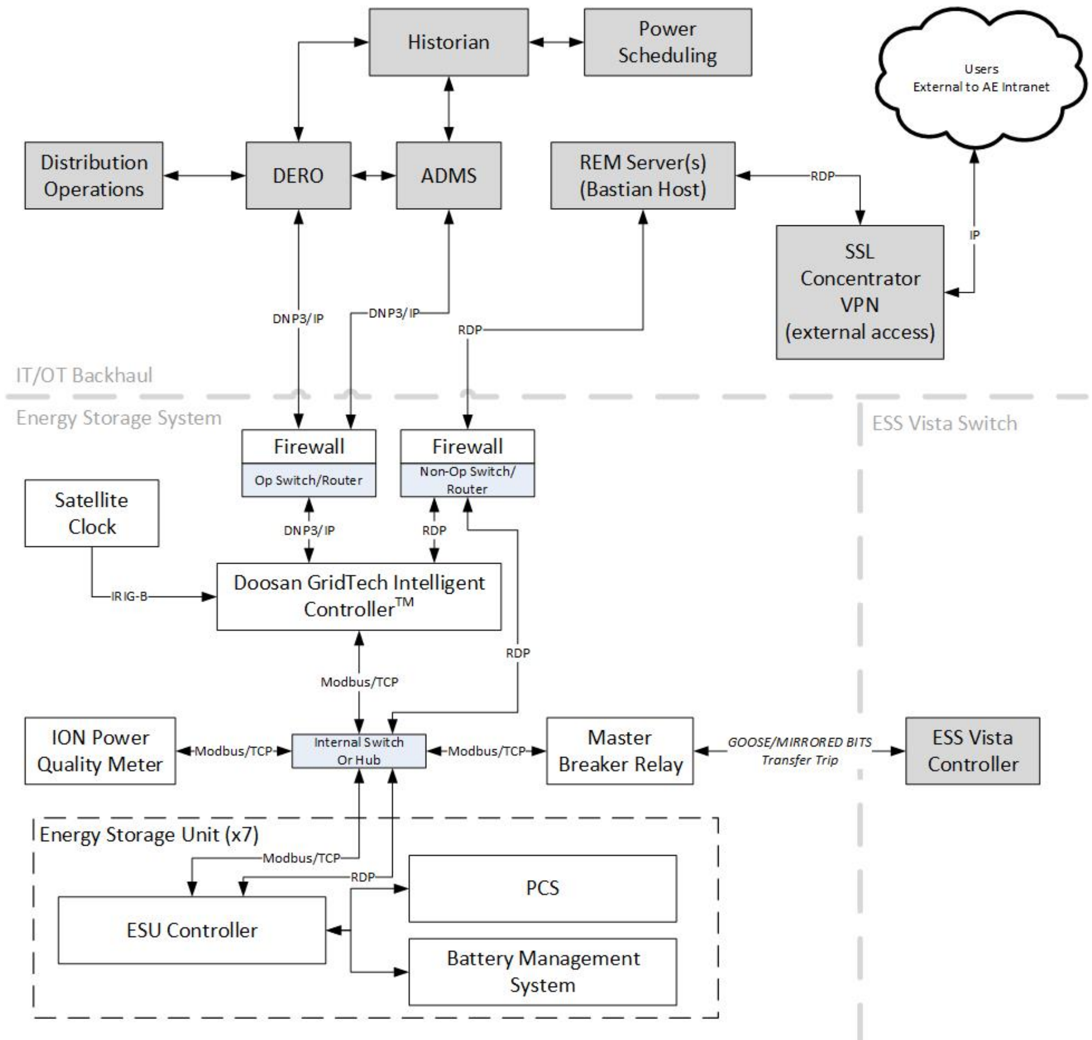


Figure 2-14 Mueller ESS communication paths and control architecture

The diagrams reveal not only a network of communication but also work groups and stakeholders integrating their expertise to develop a system that informs the technology itself and those same groups and users. Ultimately the design process of four key elements, and what was determined for the SHINES project allowed the optimized methodology to be tested and expose not only lessons learned through planning but a tested approach of many touchpoints.

Section 3 **Commercial**

3.1 Optimized Commercial Methodology

The optimization of commercial DER applications, while similar in some respects to grid-scale and residential applications, includes unique opportunities. Utility rate structures provide some of the largest drivers for the commercial segment including peak demand rates, which in turn greatly influence the functionality, and other design elements.

3.1.1 Optimal Commercial Functionality

Designing for functionality, begins with identification of the value streams available to all stakeholders. Customers, utilities, service providers and aggregators are all potential stakeholders in the commercial sector. Most commercial and industrial electric utility customers in the US are subject to peak demand rates, which can easily exceed 50% of a customer's monthly bill and present a prime value opportunity for ESS applications in these sectors. Additional value streams addressing power factor correction and time-of-use rates are also frequently available to commercial and industrial customers. Controlled charging and discharging can provide demand charge billing reduction to the customer as well as utility peak demand reduction, for example. Power factor correction many also be a value to the customer to minimize low power factor penalties in the monthly electric billing, however requires increased functionality in form of reactive power control. Existing and planned DERs must be accounted for when determining functionality for optimum value. Solar PV systems can move building load peaks, cause rapid power ramping or reduce power factor at the meter. An ESS can potentially provide value in any of these cases enabled with the appropriate functionality.

While each new functionality enables potential financial gain, it must be weighed against costs for more sophisticated hardware as well as increased controls and integration development costs. Increasing controls sophistication also requires increased operator expertise and experience, which could involve participants from the customer, the utility and/or the operating service provider/aggregator, increasing complexity.

Equipment which meets the latest standards for smart inverters increases the availability of functionality in the future when present budgets, schedule, or resources limit functionality at the time of installation. And at the time of March 2020, some of these requirements include IEEE 1547, UL 1741 SA, UL 1973, and UL 9540.

3.1.2 Optimal Commercial Sizing

The optimal sizing of an ESS in a commercial scale application can encompass a wide array of business types, from industrial manufacturing to offices or retail. The varied activities inside buildings drive a wide variety of electric use load shapes. Each facility is subject to electric rates, (which can sometimes be based in part on the load profile) which then determine the financial cost of the load shape, and, in turn, opportunities for ESS value. Larger demand spikes in historical load shapes can frequently justify increased system size based on the anticipated demand charge reduction enabled by storage discharge. Sizing an ESS to take advantage of time-of-use rates may also prove cost effective. In both cases, the incremental cost of increasing battery size must be weighed against the anticipated financial gain in electricity bill savings. The ability to export back to the grid for financial compensation, if applicable, may also factor into ESS sizing.

Existing electrical infrastructure for battery interconnection is a physical constraint which must be investigated in retrofit applications. Upgrades to building electrical infrastructure or utility distribution equipment, such as transformers, will typically incur a financial and logistical impact on the customer that can frequently limit ESS size.

Another factor in commercial ESS sizing is the impact of other DERs. A solar PV system behind the meter must be accounted for, including its impact on the building load profile and any rate implications, when sizing an ESS for optimal value. The effect of a solar PV system on the load of a commercial customer can clearly be seen in Figure 3-1.

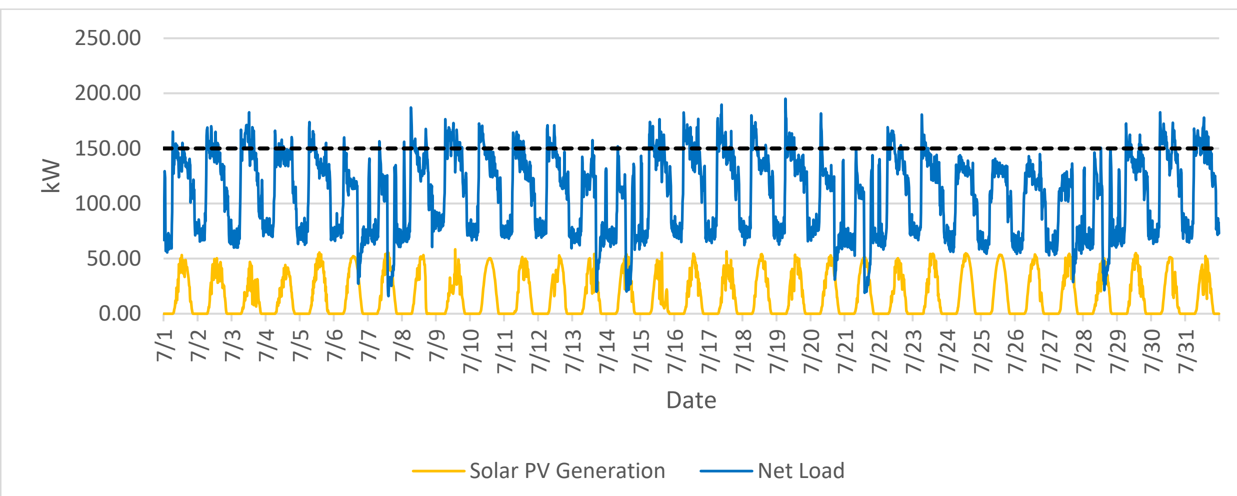


Figure 3-1 Typical Building Load Profile with Solar PV Generation

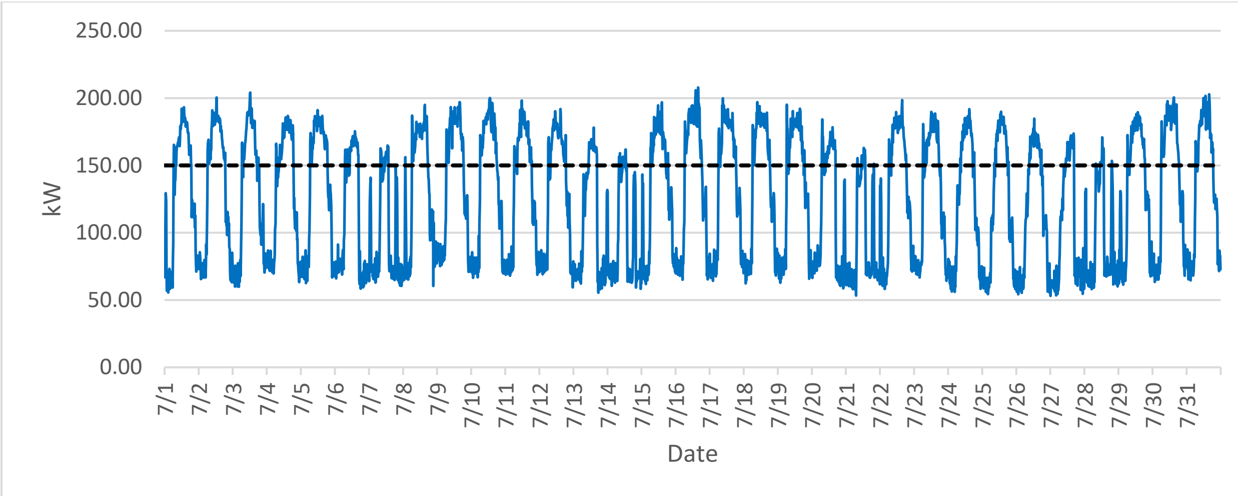


Figure 3-2 Typical Commercial Building Load Profile

Figure 3-2 shows the monthly load profile for a typical commercial customer. For a customer wishing to keep the peak below 150 kW, an ESS with sufficient power and capacity would be required to discharge each day, and for several hours each weekday. In Figure Y, solar PV generation results in a reduced net load on the meter with much shorter peaks on all days, requiring a much smaller ESS to maintain the 150 kW limit, and/or the ability to reduce the peak loads even further with an ESS application. This can be even more significant in cases where the battery is intending to not only reduce a commercial customer's peak but also respond to signals from the utility. A solar PV system may move the customer's peak demand to another time of day, which could impact the storage state of charge at other times of day, when the utility wishes to deploy the system. A typical example would be an afternoon peaking facility, which frequently coincides with a utility's peak during warmer months. A battery discharge would be able to achieve both value streams simultaneously. However, a solar PV system could shift the facility peak earlier of later, requiring multiple discharges in one day and risking reduced capacity to meet the requirements of the second discharge if the time and load between the two discharges is insufficient for the battery to fully recharge without causing a new peak.

Finally, commercial ESS sizing should weigh the characteristics of the storage itself. The incremental cost of a larger battery may be justified if it results in an average lower depth of discharge over time, potentially increasing the life of the battery. Battery degradation over time must also be factored into sizing in order to optimize financial benefits over the life of the installation.

3.1.3 Optimal Commercial Siting

Commercial facilities are typically designed and constructed to utilize every square foot for cost effectiveness, making ESS retrofit applications quite challenging in many commercial spaces. Mechanical and electrical rooms are typically preferred by customers, and are also the most likely spaces in a commercial building to have a point of electrical interconnection. Available square footage is often limited and can include other building equipment. A thorough inventory and understanding of the other equipment in the space is required for several reasons. The other equipment will have clearances required by code (as will the ESS), based on their function, which will need to be factored into calculating available square footage. Other equipment is also likely to be heat producing and may also be susceptible to temperature increases that may be caused by ESS operation. Possible gas, vapor or liquid emissions of other equipment, either in normal operation or in the event of equipment failure should be identified and risk assessed.

Potential spaces for battery installation will also likely be required by code to have fire ratings (typically 1-2 hours), and perhaps fire suppression systems which may exceed usual code requirements. Security of the space will typically also be required, and occupancy patterns of not only the ESS installation area but also adjacent spaces may impact many of these requirements or disqualify the space altogether.

Environmental controls for temperature, humidity and ventilation are not always present in the type of utility spaces where ESSs are commonly installed in commercial buildings. Although not always required by code, a thorough understanding of the battery limitations and assessment of these conditions both before and after battery installation is recommended for optimal siting.

Outdoor siting of an ESS in a commercial setting can mitigate some of these issues but will also raise new ones. Available square footage may be easier to identify, but security will still be necessary from a safety as well as a vandalism perspective. Excessive temperature extremes along with other weather issues such as humidity, rain, snow, ice, etc., will likely require an ancillary HVAC system to maintain a proper ESS operating condition in an enclosed compartment. A site closest to a point of electrical interconnection will reduce the installation costs.

3.1.4 Optimal Commercial Communication Paths

The optimization of DER communications involves balancing the cost of each option against the requirements for latency, security, scalability, reliability, capacity, interoperability, and signal strength. Many of these requirements will be driven, in turn, by the desired functionality of the ESS. For example, frequency control would require a robust system capable of high frequency data in real time, demanding low latency with high capacity versus day ahead arbitrage communication requirements would be reduced by comparison.

Site characteristics may also influence communication choices, particularly in interior applications and/or retrofit applications. Existing communications infrastructure that meet project requirements may be leveraged, providing an opportunity for capital and operational savings. Existing DERs in a retrofit situation may also provide low cost communications pathway, but may also increase costs to coordinate operation of all site assets in a holistic manner. Interior applications may be subject to issues wireless signal issues due to physical obstructions, driving a requirement for stronger signal strength or a wired solution.

Security concerns in commercial applications are as important as grid-scale applications, but include distinct perspectives stemming from different stakeholders. Customer end use data is a confidentiality issue, both for the customer and the utility. In some commercial applications, an aggregator is involved, adding an additional security dimension. The aggregator may view some of the data being exchanged as proprietary, wary of sharing anything that could be considered intellectual property. This concern drives aggregators to proprietary communications protocols. Utilities, on the other hand, wish to encourage open protocols as a way to increase interoperability and keep integration costs lower. The result can be a communication path that requires the ability to handle multiple communication protocols, usually consisting of a mix of wireless and wired solutions along the path.

Finally, after the identification of a primary communications path, backup paths should be explored as reliability requirements warrant. In addition to cost, the anticipated usage as well as the implications of missing or slow data need to be evaluated.

3.2 Impact of Alternate Commercial Design

The design of a commercial scale ESS system risks diminished performance and value when the factors listed above are not fully accounted for in a holistic analysis. In the likely scenario where a commercial customer has financed the equipment or is paying a third-party for service, this can lead to dissatisfaction with vendors and the utility, as well as creating a negative impression of an emerging technology that impedes future adoption. In the worst case, a commercial customer could experience an increased electric bill when an ESS fails to perform. Similar to most electrical devices, an ESS consumes energy due to an efficiency less than one, meaning a behind-the-meter commercial scale system must provide monetary gain through at least one intended value stream to offset not only capital or service costs, but also increased energy costs.

3.2.1 Alternate Commercial Functionality

Enabling excessive functionality that will not be utilized needlessly increases development costs. It may also increase operating costs if the functionality is mistakenly activated with no financial incentive, forcing the equipment cycle through extra charge/discharge cycles, using more energy. This may also cause a conflict with a desired functionality if the battery is left insufficient time to establish a state of charge, for the desired activity. In an emerging technology such as stationary storage, the cost of development may be excessively high for a newer functionality that could be enabled with less cost later. In this case, evaluating function selection on a timeline could better weigh and address the present or near future needs of the system.

3.2.2 Alternate Commercial Sizing

The impacts of improper evaluation related to equipment sizing mirror those of functionality selection. Incorrect sizing can lead to negative financial impacts in capital and operational costs, like lost revenue opportunity. Failure to address even a single factor when sizing as described above can result in a less than optimally sized system.

The most obvious effect of under sizing a system is the lost revenue potential for stakeholders. This includes not only the inability to provide sufficient active or reactive power to maximize a particular value stream. Under sizing also limits the ability of an ESS to maximize value through several value streams. An undersized system may be unable to provide discharging services later in the day due to a discharge earlier in the day in the service of a different value stream which leaves the battery at a low state of charge with insufficient opportunity to recharge. This can be especially pertinent to commercial applications where demand charge reduction is the primary value stream, particularly in the event of an unexpected peak.

Under sizing may also affect equipment degradation. An undersized system may be driven to lower depths of discharge in an effort to obtain sufficient revenue, ultimately shortening the life of the battery and decreasing the lifetime value of the system.

Lastly, an undersized system will provide no capacity for expansion in the future as other revenue streams become available. This could range from the inability to address a changing load profile due to a building expansion to the lost opportunity of participating in a new utility program.

Oversizing an ESS system, on the other hand, raises the obvious issue of increased system capital cost for equipment that is underutilized in the field, lowering cost effectiveness. But this incurs other penalties more indirectly, such as potentially occupying increased commercial square footage that is always at a premium with no value to justify the increased space required. When the system exceeds the capacity of existing electrical infrastructure in retrofit applications, additional costs are needlessly incurred, further reducing the cost effectiveness of the application. This effect can extend to infrastructure outside the facility, to the distribution grid. The replacement of transformers or wires may be required, further eroding the value of the ESS.

3.2.3 Alternate Commercial Siting

The impacts of poor siting in commercial installations can be similar to those of improper sizing, while varying in severity. The failure to consider temperature, humidity, and other environmental factors when siting an ESS is a primary contributor to increased battery degradation and decreased battery life. This is especially pertinent to commercial applications, where the hardware is frequently installed in mechanical or electrical rooms which are unconditioned. Heat produced by the ESS, as well as other equipment in the space, can quickly increase temperatures beyond optimal battery operating temperatures. The long-term effect will be the decreased battery performance over the lifetime of the ESS, while short term impacts can include complete cell failure requiring more frequent replacement hardware, or the suspension of ESS operation during times of temperature extremes.

Neglecting to plan for future expansion when siting can lead to negative long term financial impacts. Building load profiles can change over time due to building expansion or usage characteristics. These changes can occur in such a way the inability to add additional battery capacity negates the opportunity to take advantage of new value streams and/or maintain current value streams. This situation runs the risk of reducing the cost effectiveness of the ESS, or, in some cases, resulting in insufficient justification for its continued operation.

Failure to account for other DERs when siting has potentially the greatest negative impact of all siting miscues. Unsynchronized DERs can easily cause reliability issues related to voltage congestion, voltage fluctuations or power factor issues. Safety issues are also possible if circuits become overloaded due to multiple DER uncoordinated operation, and value of the applications at one or all of the DERs can be degraded by conflicting operations among the assets.

The placement of an ESS without careful attention to a point of interconnection can have negative financial impacts. Long distances to the point of interconnection in large rooms will require more labor and materials to achieve, while placing the ESS in rooms without a point of interconnection can lead to extensive labor such as drilling through walls or ceilings and requiring long runs of conduit, causing the project to be harder to cost justify.

3.2.4 Alternate Commercial Communication Paths

Inadequate communication paths can impede the entire ESS system. The exchange of data and commands in a timely manner is essential to optimizing the value of the system. Even in the simplest of commercial applications where demand charge reduction is the only value stream, building load data must be collected in real time for analysis in order to correctly anticipate a monthly peak and send commands for discharge. The lack of data for even a short time could result in lost revenue for the month if a peak is missed. Latency issues and poor reliability become even more impactful when receiving signals in real time from a utility or an aggregator.

When communication protocols are not conforming to open standards, equipment and vendor interoperability are reduced. The increased cost of integration associated with changing vendors utilizing proprietary systems limits the ability of the customer and/or the utility to explore new DER technologies in the future.

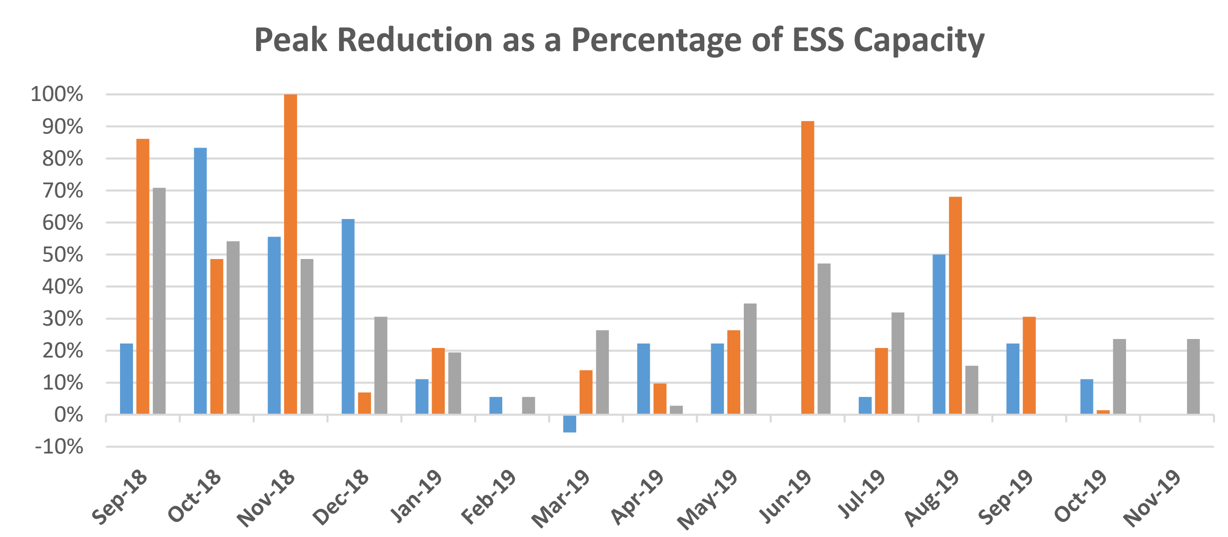
Security issues are an increasing concern with any communication device. Insufficient security can expose customer data, raising liability concerns for both the utility and a third-party. Many aggregators view some of the data as intellectual property, and would be impacted by a security breach. Poor security on any part of the communication path is also a safety issue. Unauthorized access via hacking risks the potential for unsafe operation of the ESS, possibly leading to equipment damage and/or human safety issues, resulting in legal issues, mistrust of ESSs, and/or erosion of trust in the utility.

3.3 Commercial Results

3.3.1 Commercial Functionality Results

The primary control objective was to reduce each customer's peak demand charge through strategic discharge during peak times in each billing cycle, while recharging during times of lower net building demand. This was managed through the partner aggregator, STEM. Secondarily, commands from the DERMS, DERO™ were transmitted to battery storage systems, also deployed by STEM, to each battery and at times when this does not conflict with the primary objective of reducing the customer's peak demand charge. These signals from DERO™ can call for charge or discharge of real power to obtain value through energy arbitrage, real-time pricing, and utility peak demand reduction. STEM algorithms determine the times at which each battery is available to respond to DERO™ signals, based on the anticipated requirements for customer peak demand charge reduction. This prediction is updated every 5 minutes and transmitted to DERO™ as availability. A determination of availability is made by STEM algorithms at each site. This value is a binary choice of either all power installed and active at each site determined available or no power determined available. The aggregated total is transmitted to DERO™ as available power.

Figure 3-3 shows the ESS systems installed in the three commercial sites chosen to participate in the demonstration performed with varying degrees of success with their primary goal of reducing the customers' peak demand. The most successful months of demand charge reduction were the months during 2018. In these months, the ESS's were operating only for this functionality. In 2019, the additional functionalities enabled by DERO were introduced. This initially decreased the demand charge reduction effectiveness, gradually improving to some degree later in the year. Some of this improvement can be attributed to the Stem and DERO control software accumulating historical data to better optimize operations, while summer months also result in higher peak demands with greater reduction potential.



	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19
Site A	22%	83%	56%	61%	11%	6%	-6%	22%	22%	0%	6%	50%	22%	11%	0%
Site B	86%	49%	100%	7%	21%	0%	14%	10%	26%	92%	21%	68%	31%	1%	0%
Site C	71%	54%	49%	31%	19%	6%	26%	3%	35%	47%	32%	15%	0%	24%	24%

Figure 3-3 Commercial Fleet Peak Reduction as a Percentage of ESS Capacity

The impact on demand charge reduction effectiveness by introducing the other functionalities can be seen in the example in Figure 3-4.

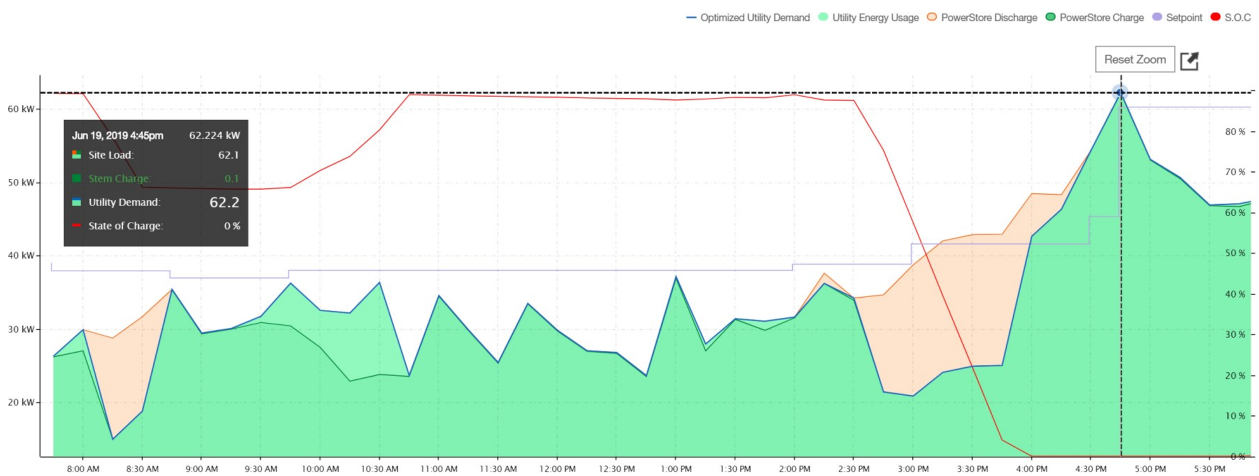


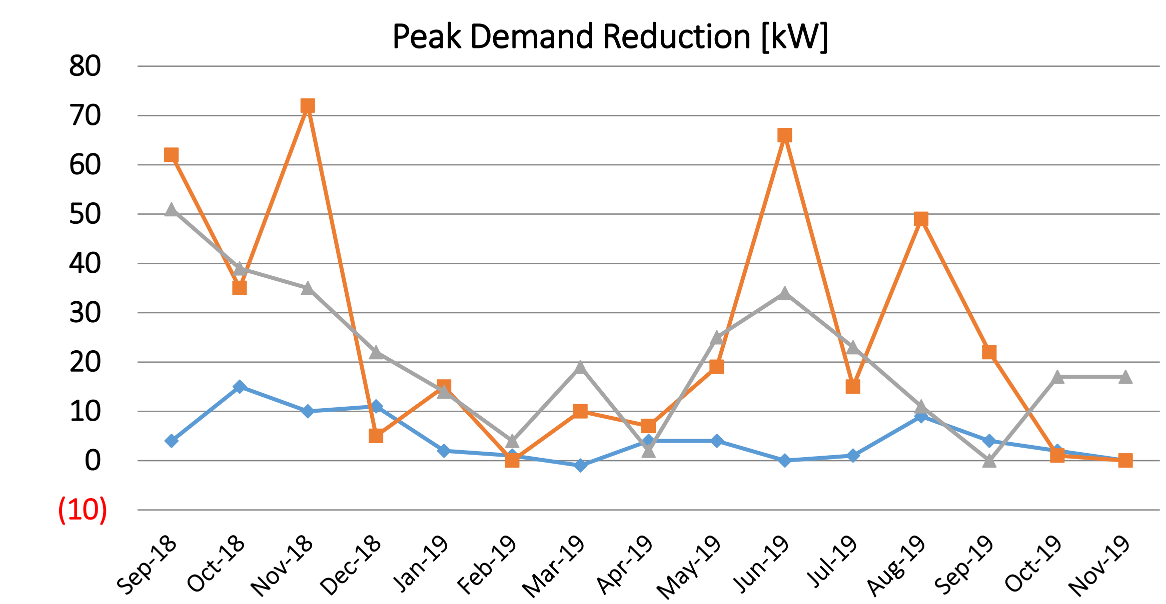
Figure 3-4 Decreased demand charge reduction effectiveness

In this example, the DERO called for discharge (represented by the orange colored portions in the graph) early in the morning at this facility for energy arbitrage. Later that morning, the ESS was able to recharge (represented by the light green portion). Later in the afternoon, DERO called for more discharge near 2:30 pm. However, the building load began to increase within 30 minutes. The ESS continued to discharge until the state of charge (represented by the red line) reached zero after 4 pm, and a new higher peak was set for the facility at 4:45 pm.

3.3.2 Commercial Sizing Results

Sizing in the three locations selected for participation were largely based on budget and space constraints. Two locations, one at an educational campus with an existing 100 kW solar PV system and another at a performing arts center with an existing 60kW solar PV system, have ample space, so each location had a 72 kW/144 kWh ESS installed.

So each location's sum consisted of 4 modules, where a module tower was 18kW/36kWh capacity. Budget was the driving force on sizing for this application, with the largest system financially feasible being installed in each case. The third system was constrained by available space to a single tower installation of 18kW/36kWh in a nonprofit office building having a 57 kW solar PV system. The graph in Figure 3-5 shows the monthly peak demand reduction for each of the 3 sites. Note site B and C, while having the same capacity and power, show significant variations in reduction in some months, due to the different load profiles of each building.



	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19
Site A	4	15	10	11	2	1	(1)	4	4	0	1	9	4	2	0
Site B	62	35	72	5	15	0	10	7	19	66	15	49	22	1	0
Site C	51	39	35	22	14	4	19	2	25	34	23	11	0	17	17

Figure 3-5 Commercial Fleet Peak Demand Reduction

3.3.3 Commercial Siting Results

Siting for the commercial SHINES ESSs was one of the more challenging aspects of the project. Once all of the commercial and institutional sites with existing solar PV systems were identified on the SHINES feeders, site visits revealed barriers at most sites from many different perspectives.

Initial consultation with the Austin Fire Department and other local code officials quickly revealed a reluctance to approve the installation of batteries in any facility, driven by safety concerns and unfamiliarity with the technology. Follow-up meetings and technology knowledge transfer activities resulted in the process of AFD accompanying Austin SHINES staff on site assessments, and arriving at the requirements that installation areas be unoccupied secured areas with limited access, and increased sprinkler flows (approximately 50% greater than otherwise required by code) in 1 hour fire rated rooms for any installations next to occupied space. These requirements eliminated several potential installation sites due to the cost of either constructing a compliant room for the ESS or bringing an existing room's walls/ceilings/floors and/or sprinkler system into compliance. One installation site was a stand-alone unoccupied building housing mechanical/electrical equipment, and therefore did not require a 1 hour fire rating or a sprinkler system. A second site contained a 1 hour fire rated room, and sprinkler calculations revealed the flow was sufficient to meet the AFD requirements. A third site, while meeting the fire rating requirement, required a sprinkler head replacement to meet the flow requirements.

Two of the three installation sites involved rooms with other electrical equipment, which limited the location inside each room to ensure equipment clearances, required by code, would be met. This also necessitated the consideration of environmental conditions that caused by the existing equipment not only in normal operation but also in the event of some type of failure. One room included cooling tower pumps and boilers, so the decision was made to pour a concrete pedestal to increase the protection of the ESS in the event of a spill, an eventuality that did in fact occur during the demonstration period. An unanticipated event in this room during the demonstration period involved the failure of a boiler, releasing steam which filled the room and caused the staff to shut down the ESS for several days until an inspection could be performed until it was determined safe to bring back online.

None of the installation sites were conditioned space, which was of some concern given the long hot weather conditions that are typical of an Austin summer. While the sites each experienced some battery cell failures, it was not possible to definitively determine that excessive heat was the cause. There were times at one site when cell temperatures reached a sufficiently high value to cause the ESS to cease operation as a cautionary measure to protect the system from possible damage.

At one of the sites there was insufficient space in the electrical room which contained the main distribution panel, however an empty room was identified some distance away. The decision was made to move ahead the install but required drilling concrete block walls in running conduit through two other spaces to reach the point of interconnection. This added considerable time to the installation compared to the other two installations.

3.3.4 Commercial Communication Path Results

Each of these installations include the battery itself as well as ancillary equipment, including a STEM Power Monitor, Network Hub, and Site Meter. The Power Monitor tracks the health of battery, including characteristics such as state of charge and temperature, while the Site Meter monitors the net building power demand in time intervals of one minute via CTs that were installed in the main electrical panels at each site. Both components send data back to the Network Hub via cable. The Network Hub transmits the information from the Power Monitor and the Site Meter back to STEM via cellular signal (primarily Verizon, with a backup carrier for redundancy) using a STEM proprietary protocol. The Network Hub also receives signals from STEM via this same proprietary protocol cellular communication and transmits them to the battery.

STEM is also receiving signals from DERO™ for utility value streams. This communication to STEM is through the cloud, but is an open protocol rather than the proprietary protocols used by STEM to communicate with each ESS. The open protocol ADR 2.0 was specified by Austin Energy to avoid vendor lock in as described in previous sections.

Each installation also includes an Austin Energy utility grade research meter collecting one minute data of the battery energy usage in both directions. This information is collected by Austin Energy via a Landis and Gyr solution that includes both wired and wireless components transmitting the data back to Austin Energy utilizing proprietary protocols.

STEM provides each customer with real time performance information via an online portal. The information collected on site by the Site Meter and Power Monitor and sent back through the Network Hub is presented to each customer in graphical form on a near real time basis. Historical information showing 15 minute interval data depicts building load as well as battery charging and discharging events.

Section 4 **Residential**

4.1 Optimized Residential Methodology

Like all ESSs, sizing residential battery energy storage can encompass multiple potential uses, determining capacity. Similar to commercial systems, there exist drivers for both cost and value generation in residential systems. Residential systems may also have size considerations without a distinct monetary value, such as backup power requirements based on a self-sufficiency desire.

4.1.1 Optimal Residential Functionality

For utility usage, the primary functionality of residential energy storage systems would entail providing real and reactive power support. The reactive power support, ideally, would be independent of the real power generation, as it often is for commercial or grid-scale systems. This would allow the battery systems to provide additional grid support services without necessarily running the batteries through charge/discharge cycles, and could be value-added across the existing systems -limited to defining output in terms of power and power factor.

The functionality for the customer would include the ability for the system to offset TOU rates if present, demand charges if present, and reserve a percentage of battery power for backup purposes. Figure 4-1 shows a simple diagram for most single-family residential homes and the technology which can be leveraged. Residential batteries in combination with smart home controllable loads pose utilities the opportunity for sophisticated load management. With coordination, demand response signals can also call on storage discharging, so on the utility side curtailment could be aligned with storage for stand-by storage and customers would not

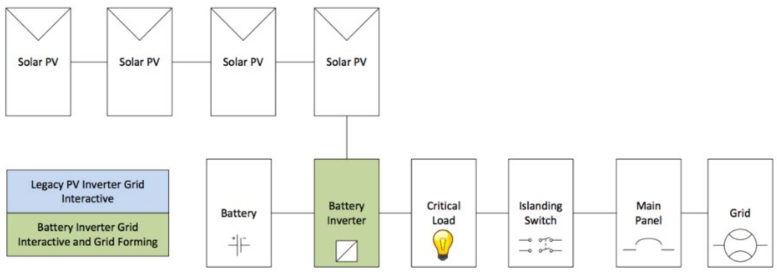


Figure 4-1 Energy Storage System Block Diagram DC-Coupled

4.1.2 Optimal Residential Sizing

For a residential consumer the main application of residential energy storage, in locations where there isn't a financial incentive or regulatory requirement, is emergency backup power. The systems are customarily sized to the intended load, but most consumers do not understand costs associated with the ability to run more than a few critical loads. A load including refrigeration, lighting, and communications electronics can be run with systems between 1.5 and 3kWp. To run HVAC systems and larger numbers of devices, 5kWp or larger systems are typically required due to the inrush currents required for starting the compressor motor.

For utilities, the sizing requirements will vary based on the estimated need for voltage support, reverse power flow prevention, energy arbitrage, peak reduction, and/or several other potential applications. In some states, for example, the energy storage systems are used to ensure no periods of reverse power flow to the grid.

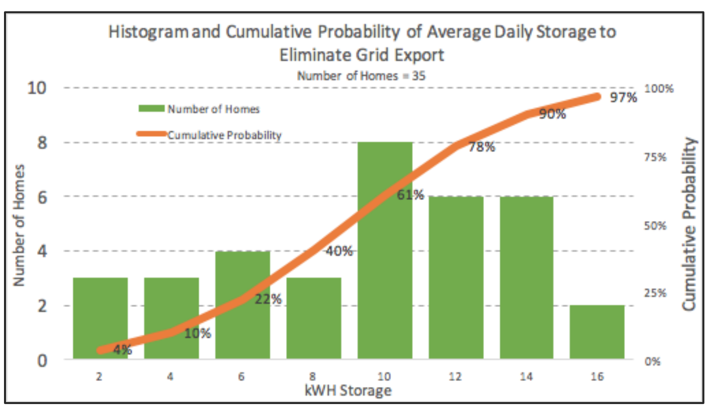


Figure 4-2 Energy Storage System Sizing Histogram

Using data collected from Pecan Street Inc, the project team looked at the solar production and usage from 35 homes for the calendar year 2016. Demonstrated in Figure 4-2, there are many ways to use energy storage to avoid issues like the "duck" curve, one of which is subjecting residential solar systems to a no-net-export rule. In many cases this no export rule means that solar production is curtailed when the energy storage system is full. For this analysis the team looked at avoiding this curtailment. In this case the daily use and generation curves were analyzed to figure out the average daily excess production during solar production hours, 7 AM to 7 PM. This energy could then be

dispatched to the grid at night...which might result in a net export later, but far fewer systems would be simultaneously exporting energy resulting in a net benefit to the grid for fewer dispatched fossil fuel-based generation.
As seen in Figure 4-2, an energy storage system sized at 10kWh would result in 61% of the homes being able to avoid a reverse power flow during the solar production hours. If the utility decided that it needed 90% of the homes to avoid a reverse power flow, the energy storage system would have to store 14kWh. These amounts will vary by geographical location, but serve as a general guideline for residential energy storage.

Pecan Street also analyzed sizing based on residential load profiles. Energy storage systems are typically sold and installed for backup purposes. The average load profile for residential structure in the Mueller neighborhood is illustrated in Figure 4-3.

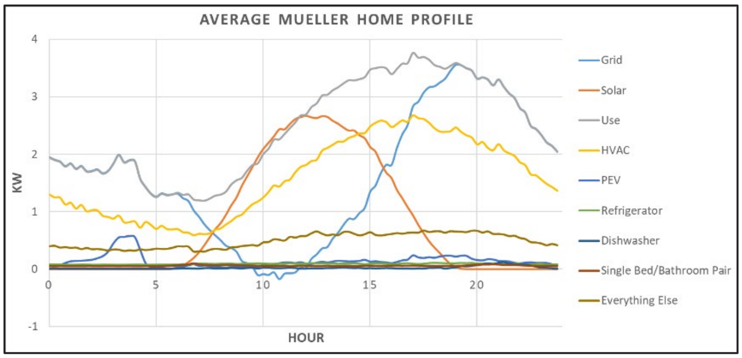


Figure 4-3 Energy profile where N=10 Homes, solar shown as positive (7/1/19-9/1/19)

The plot was generated using ground truth measurement data for 10 homes during a two month window of the SHINES demonstration period. The load profiles indicate the majority of the residential load is HVAC.

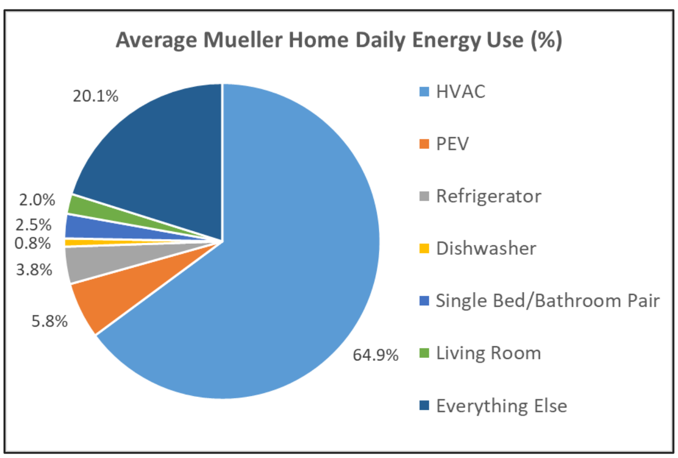


Figure 4-4 Average Mueller home daily energy use

Breaking out the loads by type, the average daily energy use during the period was 64.9% HVAC, 6%PEV and other smaller uses, shown in Figure 4-4.

4.1.3 Optimal Residential Siting

Placement of residential systems is an emerging topic that is continually evolving in safety, code allowance, and sophistication. As precedent for this scale of system has been deployed, inspectors and firefighting agents have not codified acceptable or unacceptable measures, that are site specific, in Austin. Other cities in the United States have begun to write such measures and it would best serve utilities to evaluate these constraints, on behalf of their customers, to understand who and what processes would be entailed to install systems safely. Although it is unlikely residential systems currently deployed indoors (like an attached garage) will need to move, the codes set in other cities are moving towards more cautionary approaches requiring indoor placement be in dedicated or stand-alone units, like detached garages. And given there are not as many fire suppression systems commercially available at the single-family home level, considering expansion of the system and space requirements as related to safety measures can help alleviate distress in the future should this become a standard practice. If siting moves away from the home itself, the cost of interconnection would then need to be valued, as excess conduit and distance from main electrical infrastructure can disrupt a home's layout or impact maintenance needed.

4.1.4 Optimal Residential Communication Paths

Residential broadband communications, utility backhauls, and cellular systems all have the ability to provide functionality for device monitoring and control. However, broadband communications and cellular backhaul systems have highest interoperability with energy storage equipment providers and typically represent the lowest overall deployed cost. In applications where system availability is critical, a backup communication pathway such as broadband + cellular or broadband + backhaul may be a good choice. This provides a primary high-speed low-latency communication pathway, at low cost and a secondary communication pathway for critical applications.

The systems should adhere to an established communications and control standard such as IEEE 2030.5 or equivalent.

4.2 Impact of Alternate Residential Design

As a result of either over or under sizing capacity miscalculations, the utility and/or residential customer will not be able to recover the costs of the system or perform the intended functionality for the installation.

4.2.1 Alternate Residential Functionality

Due to California Rule 21 Phase 1 requirements the majority of currently available residential energy storage system inverters have a minimum functionality that meets the major needs for utility customers. As discussed in the sizing section, the primary concern for residential energy storage customers is sufficient backup power to make the cost of purchase and installation justifiable for the homeowner. One potentially important function of the inverter is that it be able to accept solar as well as battery DC input. Not all storage system inverters have backwards compatibility with existing solar systems. This means the residential structure will have to have two inverters for battery and solar production, doubling the cost of power electronics, demonstrated in Figure 4-5.

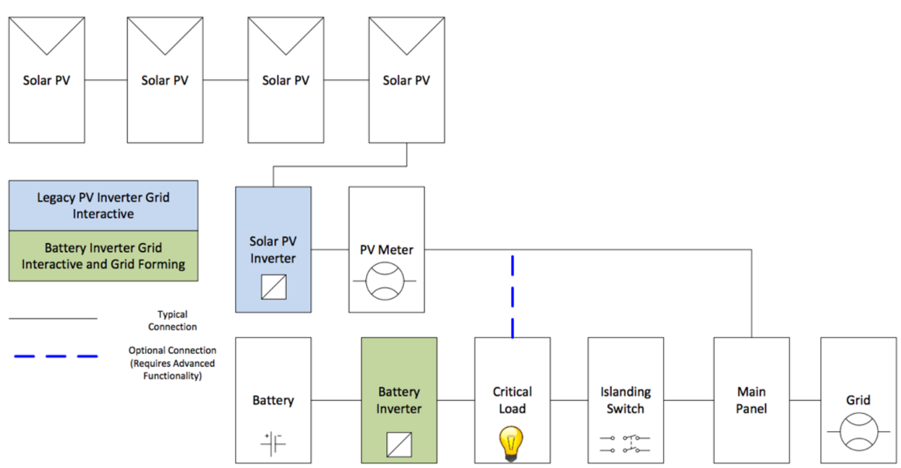


Figure 4-5 AC Coupled Energy Storage System, Dual Inverter Approach

4.2.2 Alternate Residential Sizing

In the case of oversized battery systems, the residential customer or utility may have to pay for infrastructure upgrades. These upgrades consist of either increased requirements on the distribution transformer or the service entrance/main panel sizing for the residential structure.

The energy storage systems installed for the SHINES program triggered service size upgrades for two of the six installed locations. The service entrance panels for both homes were ~100A units. The addition of the energy storage system, although effectively energy neutral in terms of total load, was interpreted under local codes as a load for the sizing calculation. This necessitated upgrading the service to 200A in two residential structures. These structures were built between 2008 and 2010. This represents an added cost that isn't necessary, since it is entirely possible for the systems to add the limiting functionality to ensure they do not exceed the maximum ampacity for a service size. At the time of writing this report it is unknown how many include this feature.

A second potential impact is the need to upgrade service transformers if enough homes on a transformer install storage. In the SHINES study residential neighborhood there are between 6 and 10 homes per 50kVA distribution transformer, with the average being 8 homes with 100-200A service entrances. This means that a transformer with half the homes having energy 5kW class storage may see an additional load of up to 20kVA on the transformer.

If the battery systems are too small then the utility may not be able to perform the necessary voltage control, energy arbitrage, peak shaving, or no-net export functions typically performed by energy storage systems. The customer may not have the backup functionality expected for the system. Early residential designs tested for the SHINES program were incapable of running more than a few small appliances, lighting and computers. Given the cost of the systems, customers may expect to be able to run some portion of their HVAC equipment or larger appliances.

4.2.3 Alternate Residential Siting

Residential systems did not have the limitations seen with some of the commercial or grid-scale systems for physical space. The major limitation was the City of Austin inspections office did not want the systems installed in a garage or driveway path unless protective bollards were installed. For every residential system an acceptable external wall was available for system installation, typically within a few feet of the service entrance. Limitations for external placement included: Visibility, proximity to service entrance, avoiding direct sunlight and water ingress protection.

4.2.4 Alternate Residential Communication Paths

The initial design study of the system implementation used the residential broadband connection with a Wi-Fi link between the storage system gateway. Over the course of the project the residential class Wi-Fi-gateways were replaced with a commercial class wi-fi router.

One of the energy storage systems considered for installation did not adhere to a publicly available communications/control standard. It was eliminated from consideration because of the non-standard nature of the control interface.

4.3 Residential Results

Based on the design and equipment selection studies for the SHINES program the selected residential energy storage system was the LG Chem RESU10H 9.8kWh/5kW (nominal) battery systems combined with the SolarEdge StoreEdge inverter. Other systems were considered but were either not available in enough quantity, short enough time frame or within budget requirements to be selected for deployment.

4.3.1 Residential Functionality Results

The selected power electronics vendor did not include backward compatibility with existing string solar arrays. The solar arrays would have had to be removed from the residential structure, module level maximum power point trackers installed and then the modules re-installed on the structure. At the time of selection there were only two power electronics vendors compatible with the selected battery system. As of writing this report there are 8 compatible brands, several of which include backwards compatibility with string PV arrays reducing overall system costs.

4.3.2 Residential Sizing Results

The battery systems selected are capable of 5kWp charge/discharge output and up to a power factor of .9 Leading/Lagging. The systems are capable of almost 2 hours of charge/discharge at the maximum sustained charge/discharge rate. The inverters are capable of almost 7kW sustained charge/discharge, but utilizing that capacity would require installing a second battery system.

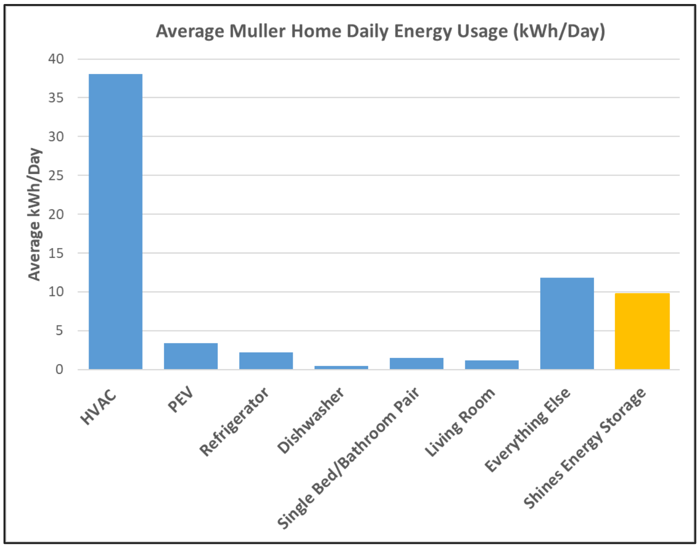


Figure 4-6 Average Mueller Home Daily Energy Usage vs SHINES Residential ESS Capacity

Compared to the average daily energy use in Figure 4-6, the SHINES battery storage systems would provide approximately 4 hours of run time for the central HVAC system based on energy requirements. Other loads such as lighting, food refrigeration for critical backup purposes could be powered for a day or more depending on conservation efforts.

Even though it would be possible for the battery systems to keep a home air conditioned during an outage based on energy, the 5kW discharge limit would prevent them from being used for that purpose. In fact, even though the average load profile would indicate the batteries would be capable of whole home backup, having a high resolution view of the 1 minute demand for a single home shows the 5kW limit for a single LG based battery system would be regularly exceeded, as shown in Figure 4-7.

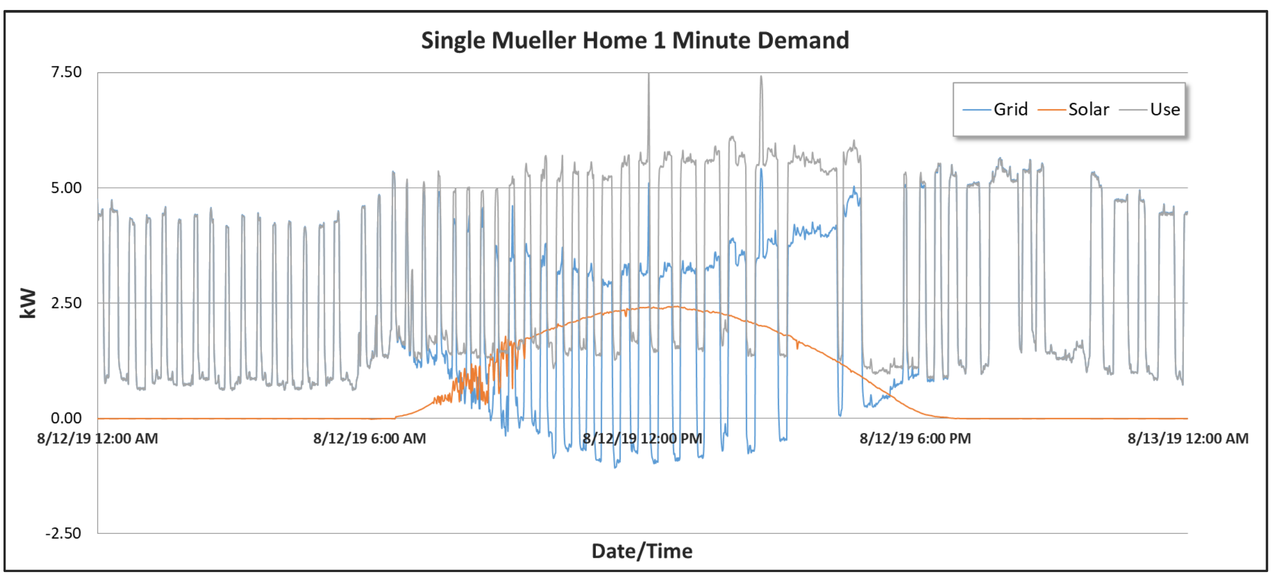


Figure 4-7 Single family residential home 1 minute demand

4.3.3 Residential Siting Results

During the installation and permitting process for the aggregated battery systems, the City of Austin (COA) required that protective bollards installed if the battery systems were located in a garage. Because of the cost of installation, and potentially removal at the end of the program the decision was made to install all systems outside. Every effort was made to install them in accordance with the installation manual. However, during the record high temperatures of August 2019, any of the battery modules that received indirect solar irradiance during the afternoon started to experience functionality issues because of high internal operating temperatures. These temperatures could be elevated based on high usage, cycling energy into and out of the battery for arbitrage or voltage control purposes would raise the temperature during the day and the batteries would typically be too hot for operation during peak hours. Pecan Street recommends full shade and/or installation in conditioned/indoor areas to maximize battery availability and to avoid potential for degradation or safety issues due to temperature.

4.3.4 Residential Communication Path Results

The systems initially communicated to the aggregator through the residential broadband connection. The local gateways communicate to the inverter with a wired Ethernet connection and to the broadband over Wi-Fi. During the period between final design and final acceptance testing Pecan Street discovered the Wi-Fi connection quality varied over a wide range for several of the locations. The broadband connection itself was high quality, but the Wi-Fi link between the broadband modem and gateway was intermittent, yielding lower overall availability to monitor and control the deployed units. To resolve the issue Pecan Street deployed a low-cost business class Wi-Fi router dramatically improving system availability.

Section 5 Conclusion

5.1 Design and Operation Influences

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 Final Deliverable 4 (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.