

Battery Storage Integration Into the Electric Grid

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Abstract - Energy storage is expected to flourish considerably, requiring large investments in tools and instruments that support its integration into the electric grid. This paper addresses the research question: “How can we determine the optimal locations for energy storage for proper integration into the electricity system?” Therefore, we have developed a conceptual framework for decision-making that caters to utilities for it considers the impacts of the energy storage placement on the grid, and the electric circuit capacity constraints. Additionally, we have built a prototype of Geographic Decision Support Systems (GDSS) to aid in the battery storage systems location choices and provide actionable information for utilities and other stakeholders who are concerned about the grid reliability and the urgency of energy storage deployment as a distributed energy resource.

Keywords- battery storage; electric grid; circuit capacity; optimal location; conceptual framework.

I. INTRODUCTION

Electric utilities in the United States face serious challenges, which have raised concerns about the uncertain future for America’s electric grid. The electricity demand is rising while the existing electric infrastructure is deteriorating. Environmental trends force regulators to institute new carbon restraints, and the penetration of distributed energy continues to grow exponentially. To employ the smart grid and resolve these challenges, utilities will need to integrate additional components into the grid. Smart meters, outage management systems, distribution managements systems, sensors, data management systems, and energy storage systems are all examples of the additional components to be incorporated into the grid [1].

Grid reliability is the greatest concern resulting from challenges facing electric utilities. According to the North American Electric Reliability Council (NERC), reliability is “the degree to which the performances of the elements of the electric system result in power being delivered to consumers within accepted standards and in the amount desired” [2]. Osborne and Cornelia [3] view reliability as “the ability of the power system components to deliver electricity to all points of consumption, in the quantity and with the quality demanded by the customer” [3]. Reliability is measured by outage indices as illustrated by the Institute of Electrical and Electronics Engineers (IEEE) Standard 1366. The argument is that today’s

power systems cannot accommodate significant variable distributed energy generation, for instance, without failure [4].

According to the United States Department of Energy, energy storage technology can help contribute to the overall system reliability as wind, solar, and other renewable energy sources continue to be added to the grid. Additionally, storage technology will be an effective tool in managing grid reliability and resiliency by regulating generation fluctuation and improving the grid’s functionality. Storage can provide redundancy options in areas with limited transmission capacity, transmission disruptions, or volatile demand and supply profiles [4]. In addition, the storage market might foster a strong manufacturing base of high-tech electric energy storage devices in the United States, and this capability can enhance America’s export opportunities [4]. Further, storage will help promote America’s energy independence and reduce carbon emissions by enabling more efficient adoption of renewable energy sources.

An August 2013 White House report, written in conjunction with the Office of Electricity Delivery and Energy Reliability, detailed the vital role that energy storage would play in improving grid resiliency and robustness related to weather outages and other potential disruptions [5]. Energy storage is expected to flourish considerably, requiring large investments in tools and instruments that support its integration into the electric grid. Different States have started new policy incentives and processes to address the integration need. The state of California, for example, has adopted a Roadmap which focuses on addressing three main challenges associated with energy storage adoption: “1) Expanding revenue opportunities 2) Reducing costs of integrating and connecting to the grid 3) Streamlining and spelling out policies and processes to increase certainty” [6]. As a result, Energy storage will be beneficial to all parts of the electricity system as shown in Figure 1 [7].

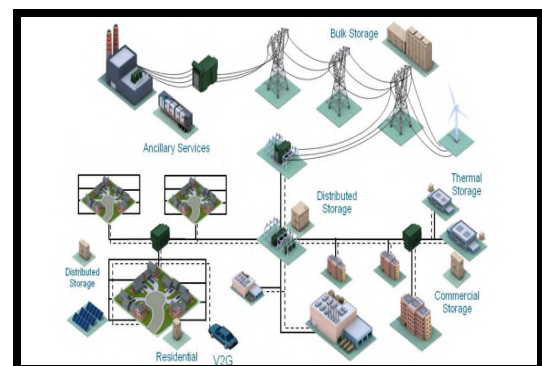


Figure 1. Overview of Energy Storage Roles on the Electric Grid [7]

In this paper, we discuss energy storage systems as previous literature showed insufficient attempts by researchers to provide solutions that can assist in the undertaking of integrating storage systems into the grid. Considering that energy storage is a critical component to be added to the power network and the urgency of energy storage deployment, this paper addresses the research question: “How can we determine the optimal locations for energy storage for proper integration into the electricity system?”

A Geographic Information System (GIS) provides the tools and integration ability to support the smart grid. GIS can be used to highlight optimal locations for different components within the network. With the rollout of a smart grid, utilities need “to determine the right location for sensors, communication-marshaling cabinets, and a host of other devices” [1]. GIS provides the proper instruments to perform these design services, especially as the optimal locations depend greatly on the existing infrastructure. Considering the GIS current role in managing the electric grid and the previous research, we posit GIS will play a strong role in the placement of smart grid components such as battery storage systems. GIS can certainly contribute to the transformation of the grid “from a largely passive and blind system to an interactive, intelligent one” [1].

Hence, the objective of this research is to develop a prototype of GIS-based Decision Support System solution, which is an elegant, interesting, and novel solution to assist with the placement of battery storage systems by finding the optimal locations considering the electric grid constraints, the deployment requirements and the potential benefits to the grid. The paper is based on the process steps in Takeda, et. al.’s design cycle to create an artifact/solution [8]. The authors used the three design science research cycles of relevance, design, and rigor [9] to perform each of the Takeda, et. al., process steps leading to the final framework and prototype in this paper.

Takeda et al. [8] cycle has five main steps/phases, which are the awareness of the problem, suggestion, development, evaluation, and conclusion [8]. This paper is organized based on the five phases. In introduction and literature review section, we discussed the awareness of the problem. In the conceptual framework and prototype sections, we covered the suggestion phase by explaining the decisions that we have made to develop the artifacts. In the research approach section, we have indicated the steps taken to develop and create the artifacts as outlined in the development phase. In the evaluation section of the paper, we evaluated the artifacts. In the last section, we concluded our research and offered future research directions.

II. BACKGROUND LITERATURE REVIEW

This section discusses the recent researches that had been conducted in the field.

A. Energy Storage Technologies and Categories

Energy storage can be defined as the capture of energy produced at one time for use at a later time [10]. It is required to level peak electricity generation. We can divide energy storage technologies into four categories based on discharge times [11]. These categories are useful in conceptualizing the role of storage on the grid. According to the International Electro technical Commission [11], either energy storage technologies can discharge enormous amounts of power, but only for a short time (energy storage with the highest power densities and lower energy densities), or it can discharge energy for a long time, but cannot provide massive amounts of power immediately (technologies with the highest energy densities and lower power densities) [11]. We summarized battery storage technology types in Table I based on their discharge time, use case, and energy-to-power ratio. Additional information about energy storage types can be found in Table A1 in Appendix 1 along with their definitions and examples.

TABLE I. ENREGY STORAGE TECHNOLOGIES [11]

Energy Storage Resources	Use	Discharge Time	Energy-to-Power Ratio (kWh/kW)	Examples
Short Discharge Time	Provide instantaneous frequency regulation services to the grid	Second or minutes	Less than 1	Double layer capacitors (DLCs), superconducting magnetic energy storage (SMES), and flywheels (FES)
Medium Discharge Time	Useful for power quality and reliability, power balancing and load following, reserves, consumer-side time-shifting, and generation-side output smoothing. May be designed so as to optimize for power density or	Minutes to hours	Between 1 and 10	Lead acid (LA), lithium ion (Li-ion), and sodium sulphur (NaS), flywheels may also be used

	energy density.			
Medium-to-Long Discharge Time	Useful primarily for load-following and time-shifting, and can assist RE integration by hedging against weather uncertainties and solving daily mismatch of RE generation and peak loads.	Hours to days	Between 5 to 30	Pumped hydro storage (PHS), compressed air energy storage (CAES), and redox flow batteries (RFBs) which are particularly flexible in their design
Long Discharge Time	Useful for seasonal time shifting (storing excess generation in the summer and converting it back to electricity in the winter).	Days to months	Over 10	Hydrogen and synthetic natural gas (SNG)

B. Types and growth of battery storage market

In the United States, Lithium-ion batteries dominate the energy storage market, accounting for more than 90% of the market share. California, Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia together account for about 81% of U.S. energy storage deployment in MW terms. Researchers expect the U.S. energy storage market in year 2021 to grow by almost eight times its 2016 market size [12]. Because of the market growth, there are many vendors competing in various segments. Figure 2 shows the latest taxonomy of energy storage vendors where Tesla and few other companies play a significant role in the U.S. market.



Figure 2. Energy Storage Vendor Taxonomy [12]

Battery storage can be classified into residential, nonresidential, and utility-scale storage types. There are different energy storage system vendors for different storage types. In this paper, we only focus on the medium and the medium-to-long discharge time technologies in the Utility scale segment. Utility-scale storage has been viewed as the key technology, which will help to bring the nation's utility grid into the 21st century. It will play a significant role in meeting the challenges facing electric utilities by improving the operating capabilities of the grid, lowering cost and ensuring high reliability, as well as deferring and reducing infrastructure investments. Utility-scale storage can be also instrumental for emergency preparedness because of its ability to provide backup power, as well as grid stabilization services [13].

C. Optimal locations

Identifying optimal locations for energy storage is a problem that utility companies currently face. Several studies have tried to solve this problem using different methods. For example, Bose, Gayme, Topcu, and Chandy [14] conducted a study to optimally place large-scale energy storage units in power grids considering both conventional and wind generation [14]. The storage type and size played an important part in determining the optimal distributed storage location. The authors developed and tested an algorithm considering different portfolios of wind and conventional generation resources. The results showed that “changes in optimal storage siting configurations remain reasonably consistent regardless of the generation mix and these results are robust to changes in total storage capacity and transmission line limits” [14].

Other scholars have also discussed the optimal location issue associated with the renewable energy sources. Another example was a study that conducted by Meneses de Quevedo, and Contreras [15]. According to the authors, the renewable energy sources are growing rapidly, which causes a problem in the network operation due to higher network constraints [15]. To solve the problem, an Energy Storage System (ESS) is considered as a solution. The authors in this study discussed the uncertainty associated with the nature of wind, network load, and price of ESS in optimizing distribution system costs. The researchers used a Mixed Integer Linear Programming

(MILP) approach as a method to identify the best locations for storage [15].

Additionally, Fernández-Blanco et al. [16] discussed the problem of energy storage (ES) optimal locations in large transmission grids considering two perspectives: (1) a System Operator and (2) a profit-seeking ES owner [16]. A System Operator has the expertise to determine the locations and sizes of energy storage to minimize the investment and the operational costs. The researchers mainly focused on cost minimization, so they combined “the system costs of the [System Operator] and the profits collected by the ES owner into a single objective function subject to the technical constraints” [16]. The researchers solved the problem by applying MILP. Then, they reengineered the problem into a multi-objective optimization with the perspective from both the system operator and the storage owner [16].

Energy storage can also reduce the variability, shift load time, and control ramping time. Xu [17] discussed and provided a solution to determine the optimal location of energy storage using the simulation tool MATPOWER [17]. This study developed a general procedure to optimize the location with the use of point estimation method in order to have more credible results.

GIS is a catalyst for improving multiple facets of smart grids. For instance, Resch et al. have integrated GIS-based modeling into the energy system to address the renewable energy infrastructure planning [18]. Sultan et al. [19] used GIS to optimize the locations of a distributed energy resource such as solar panels [19]. Similarly, Sultan et al. [20] investigated the power grid reliability incidents/power outages and their correlation with the infrastructure age by using GIS-based modeling [20]. Therefore, GIS enhances the research inquiries in the smart grid domain.

Nazaripouya et al. [21] urged researchers to consider tackling the nascent energy storage optimal location research area [21]. With the versatility of GIS, incorporating GIS to determine optimal locations of energy storage in the grid is essential for enhancing the knowledge base and provide a novel solution. Therefore, our paper employs a GIS-approach as the key research vehicle.

III. THEORY AND RESEARCH APPROACH

The authors followed and used Hevner et al. [9] Design Science Research (DSR) framework to develop the conceptual framework for placement of utility scale energy storage. According to Hevner et al. [9], there are three important cycles in the DSR, which are relevance, design, and rigor cycles, as it shown in Figure 3 [9]. The authors used these cycles to develop the framework by searching the background literature. Moreover, applying the location theory, developing and evaluating the artifacts were the further steps taken by the researchers to determine the optimal locations for placement of utility scale energy storage.

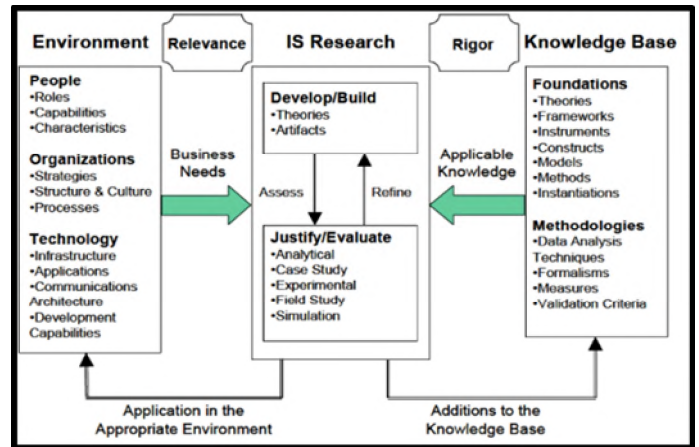


Figure 3. Design Science Research (DSR) Framework in Information Systems Research [8]

Location theory is used to address questions of what economic activities such as energy storage should be located where and why [22]. This theory is based on microeconomics, which studies the behavior of individual and firms in making decisions concerning the allocation of limited resources. Firms, such as utility companies should choose locations that raise their profits and advance the benefits to the grid. Therefore, as is shown in Figure 4, we have chosen the location theory since it considers the firms’ perspective to answer what and where question, which matches our research goal. We have classified the site selection factors and structured the process of the energy storage site selection. Location theory’s key objective is to explain why specific economic activities prefer to establish themselves in particular areas and locations by allocates with what (energy storage) and where (area, location, or regions).

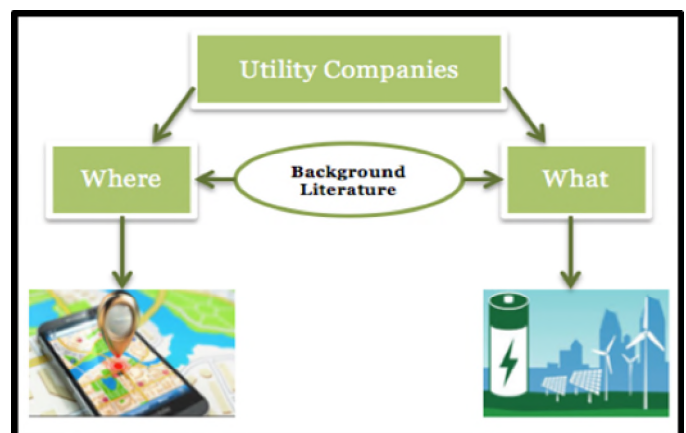


Figure 4. Utility Scale Energy Storage Location Decision Guided by Location Theory

A. Artifact 1: Conceptual Framework

The researchers used and studied the background literature as a research method to develop the conceptual framework for decision-making that caters to utilities, for it considers the impacts of the energy storage placement on the grid, and the electric circuit capacity constraints as is shown in Figure 5.

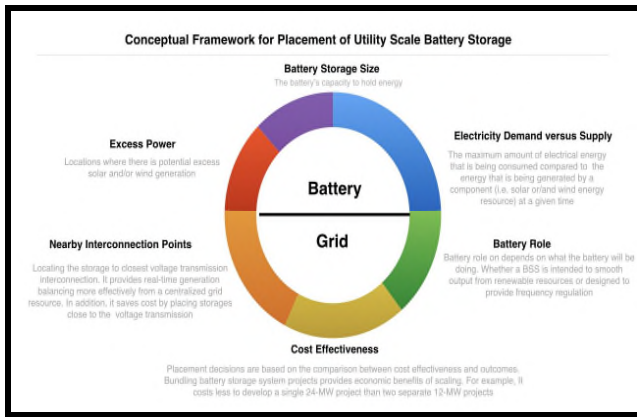


Figure 5. Conceptual Framework For Placement of Utility Scale Battery Storage

Our framework has two main dimensions; the first one is the factors’ characteristic dimension, which has two main values: (1) battery and (2) grid. The second dimension is the factors that help in decision-making for the optimal location of battery storage. First, we searched in the literature, and the literature evaluation produced three factors that related to battery. Then we considered three more factors that related to grid. These factors assist in determining the optimal battery storages location for utilities. All six factors were developed from the background as is shown in Table II.

TABLE II. BATTERY & GRID RELATED FACTOR

Factor	Definition	Tech. Specification	Resource
Battery			
Battery Storage size	The battery’s capacity to hold energy	Large centralized battery systems work better than smaller, distributed systems.	[23] [24]
Excess Power	Locations where there is potential excess solar and/or wind generation	Statistically significant areas using kernel density estimation (KDE) where there is high potential solar and/or wind generation	[25]
Electricity demand versus supply	The maximum amount of electrical energy that is being consumed compared to the energy that is being generated by a component (i.e., solar or/and wind energy	The situation when energy supply is exceeding the demand	[26] [27]

	resource) at a given time		
Grid			
Nearby interconnect on points	Locating the storage to closest voltage transmission interconnection . It provides real-time generation balancing more effectively from a centralized grid resource. In addition, it saves cost by placing storages close to the voltage transmission	Nearby 154-kV or 345-kV substations	[28]
Battery role	Battery role on depends on what the battery will be doing, such as whether a BSS is intended to smooth output from renewable resources or designed to provide frequency regulation.	Based on Table I “Energy Storage Technologies”	[24] [11]
Cost Effectiveness	Placement decisions are based on the comparison between cost effectiveness and outcomes. Bundling battery storage system projects provides economic benefits of scaling. For example, It costs less to develop a single 24-MW project than two separate 12-MW projects.	Single centralized battery storage systems is preferred	[24]

B. Artifact 2: GDSS Prototype

This study proposes a GDSS solution to assist in the placement of battery storage systems by finding the optimal locations considering the electric grid constraints, the deployment requirements, and the potential benefits to the grid. This solution can aid in the battery storage systems location choices and provide actionable information for utilities, state-level decision-makers, and other stakeholders who are concerned about the grid reliability and the urgency of energy storage deployment as a distributed energy resource. Though a GDSS can provide a solution to address the placement of all types of energy storage systems, we chose to focus on Utility-scale storage to instantiate the conceptual framework and to demonstrate how an interactive, computer-based system can assist in decision-making considering the net and the potential benefits to the grid.

1) Data Selection and Acquisition

- SCE's DERiM Circuit Capacity Data: Southern California Edison's distributed energy resource interconnection map includes power electric lines and the capacity analysis in kilowatts by circuit line. The data is retrieved from DERiM [web map](#).
- Solar Parcel Data: LA County is the data source for the solar parcel data. [LA County solar map](#) includes key data elements, such as: total roof area and area suitable for solar, potential solar system size, solar potential annual output, and potential cost savings.
- Electricity Household: Simply map is the source of data. The Electricity Household is in the average of the annual (yearly) consumption in dollar for each geographic region in 2016. Electricity is generally supplied by means of above or underground electric power lines.

2) Data Preparation Steps

- DERiM Circuit Capacity Data was loaded into ArcGis 10.3.1. The first layer was locating the SCE substations (837 stations) across LA County Figure 6.
- Considering the Nearby interconnection points requirement, substations with circuit capacity constraints with less than 150 kilovolts were excluded.

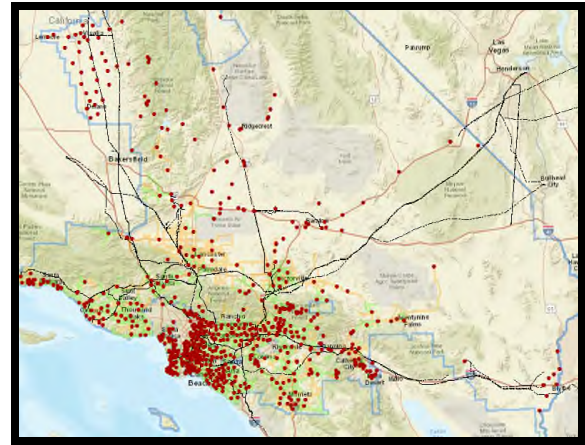


Figure 6. SCE Substations Across LA

- According to Sultan et al. [20], the solar rooftop's potential electricity output was calculated for each parcel by multiplying the rooftop's solar panel area, the solar panel yield, the annual average solar radiation on tilted panels (constant for LA county, equal to 2018.45), and the solar system's performance ratio which is the coefficient for losses (used default value = 0.75). Two fields were added in ArcMap attribute table to perform these calculations. Considering the V2G technology/exploiting excess power factor, these calculations are required to predict areas with potential solar excess generation assuming maximum adoption of solar rooftops in LA County [22].
- The electricity household data was added as an indicator for the electricity consumption level to serve the supply vs. demand factor Figure 7.

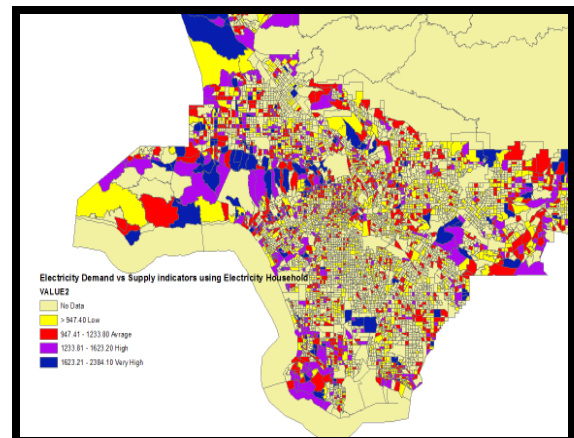


Figure 7. Electricity Consumption in LA County

- Potential Battery Location layer was created by joining the following map layers:
 - The excess parcel level power data based on step 3 to estimate the supply level.
 - The electricity household data to assess the

demand level. The assumption was made that less than 1000 in electricity household spending a year were considered low demand.

- The Substations data with the targeted requirements in step number 3 (more than 150 kilovolts). Then, buffer tool with 500 feet distance from the substations and locations that overlaps with low demand and high supply were identified.

3) Analysis and Findings

Our findings suggested 12 potential location for battery storage in SCE electrical substations based on the three spatial factors in the conceptual framework in Table II: 1) Demand vs. Supply 2) Nearby interconnection points 3) Excess power. The locations are listed in Table III and are shown in Figure 8.

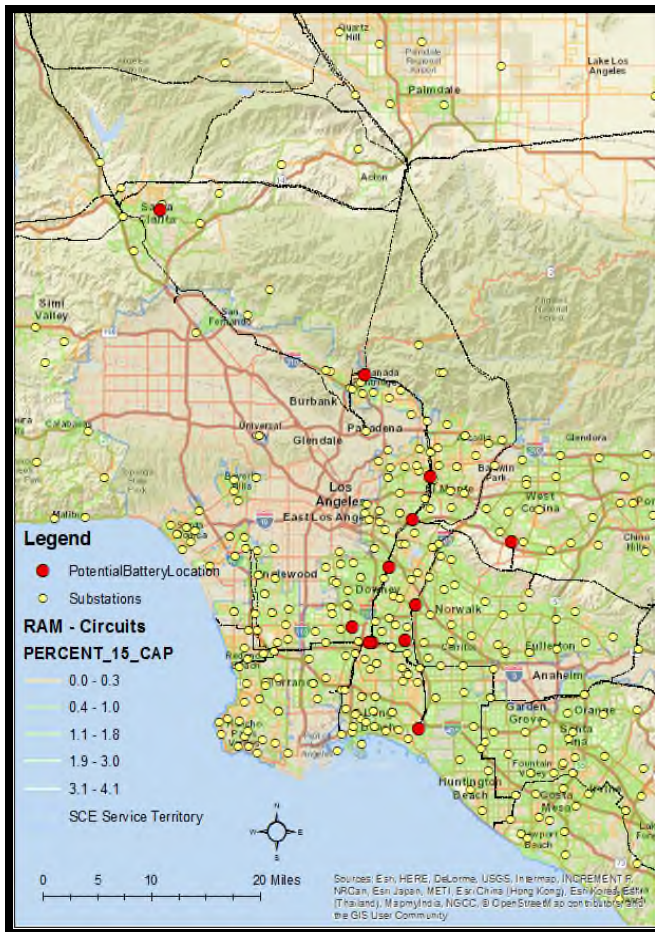


Figure 8. The Suggested Battery Storage Locations

TABLE III. LIST OF LOCATION NAMES

ID	Substation Name	Substation Type
1	WALNUT	S -- Sub-transmission
2	ROSEMEAD	D -- Distribution
3	GOULD	S -- Sub-transmission
4	MESA	S -- Sub-transmission
5	LAGUNA	S -- Sub-transmission

6	BULLIS	D -- Distribution
7	CENTER	S -- Sub-transmission
8	CORNUTA	D -- Distribution
9	LIGHTHIPE	S -- Sub-transmission
10	SUNLIGHT P.T.	A -- District Pole Top
11	HASKELL	D -- Distribution
12	STADIUM	D -- Distribution

According to Jim Horstman, an industry consultant, pole top substation (Sunlight P.T.) included in Table III might not be used for batteries, as these are ‘substation’ built on a platform between poles. Thus, we have a final count of 11 potential locations for battery storage after excluding this one pole top substation.

Figures 9, 10, 11, and 12, show that substations of Stadium, Walnut, Rosemead and Gould are locations for placing battery storages. To illustrate, the yellow circles represent the location of the substation and the red circles represent the suggested location where there is excess power, supply in electricity is actually more than the demand level, and lastly that location is near a substation territory.

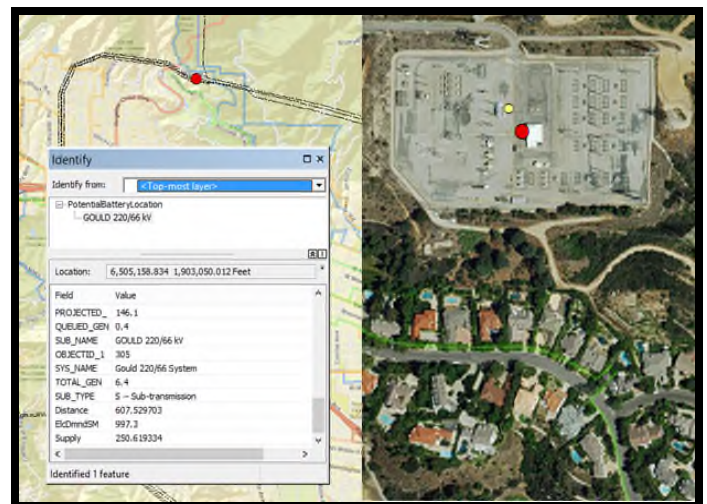


Figure 9. Suggested location of SCE Gould substation

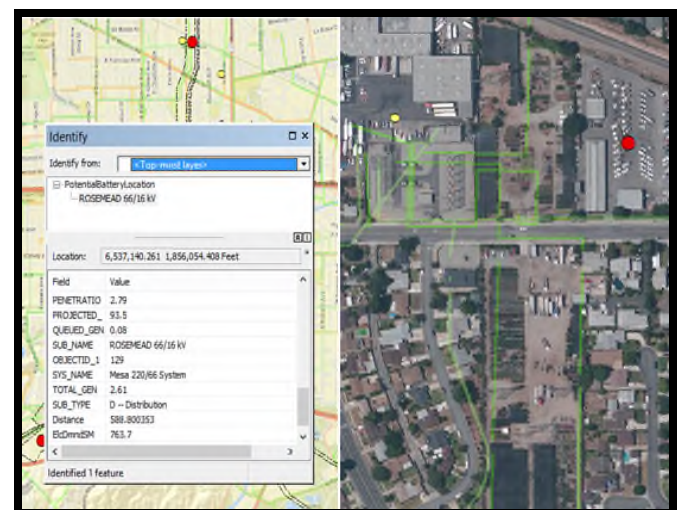


Figure 10. Suggested Location of SCE Rosemead Substation

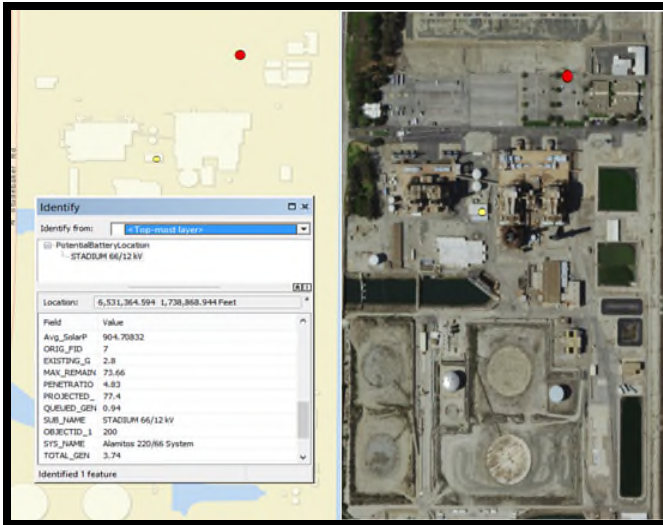


Figure 11. Suggested Location of SCE Stadium Substation

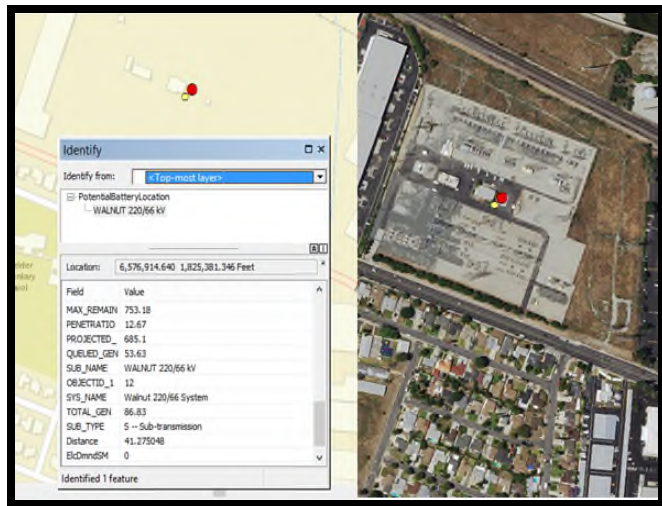


Figure 12. Suggested Location of SCE Walnut Substation

IV. EVALUATION

The project team applied a qualitative interview method to evaluate the prototype using socio-technical technique to assess the following metrics: propriety and utility. The researchers evaluated the different values held by the utilities by sending the following seven interview questions via email:

1. How useful is the conceptual framework (Fig.5.) in your view?
2. Is the framework complete from your perspective?
3. Do you agree with the factors' definitions in Table II?
4. Do you agree with the factors' technical specifications in Table II?
5. Do you see potential solution offered by the GDSS prototype (shown in Fig.8.)?
6. What changes would you recommend for improvement?
7. Do you see the potential in this research direction? In this case, both EV drivers' and utility executives'

perspectives were part of the evaluation process to ensure that their unique stances were understood?

Feedback is currently being solicited from industry consultants and executives who can provide feedback from a utility perspective. Two participants responded with positive feedback and they highlighted the potential offered by the proposed artifact. According to Jim Horstman, a utility industry consultant, the conceptual framework is useful, complete, and it covers the relevant issues. Horstman mostly agree with the factors' definitions. However, he views the framework dimensions to be causing some confusion. For example, "the battery role is under grid rather than battery and the excess power and supply & demand are under battery when they would seem more appropriate to grid. Further Excess Power is a function of Supply and Demand (i.e., $\text{Excess Power} = \text{Supply} > \text{Demand}$) so not clear that is a separate issue" Horstman said. The industry consultant suggested another consideration relative to the nearby interconnection points, which is the space available for the battery storage. "While many substations might have ample space for the batteries others may have restraints" he said.

Horstman agreed with the technical specifications with the exception of including specific voltages (154 KV, 345 KV) as "those are utility specific e.g., SCE could be 220/500 KV for high voltage subs where it is stepped down to 133 KV, 66KV, etc.," The industry consultant recommended something more appropriate like high, medium voltage substations. In looking at the list in Table III, Jim Horstman saw that it includes sub-transmission and distribution substation that he believes would be categorized as medium and/or low voltage.

V. LIMITATION AND FUTURE WORK

The artifacts proposed in this paper aimed at providing a solution for decision-making to assist with the placement of battery storage systems by finding the optimal locations considering the electric grid constraints, the deployment requirements and the potential benefits to the grid. This could potentially save time and resources for developers and utility companies who are interested in the identification of optimal locations for the placement of storage systems.

Potential locations for battery storage can thus be prioritized in locations with excess power, where supply in electricity is actually more than the demand level, and where there is nearby a substation territory. However, a limitation of the GDSS prototype proposed in this paper is that it only deliberated three of the six factors of the suggested framework. Due to time and data availability constraints, the project team have chosen to build an artifact that addresses the placement of Utility-scale storage systems considering three of the six factors of the framework: 1) Demand vs. Supply 2) Nearby interconnection points 3) Excess power factor. We didn't address the battery size, the cost effectiveness and the battery role factors of the decision-making framework.

Another limitation is in the evaluation phase. It is important to recognize that the time constraint imposed limitations on the evaluation and what these limitations are.

The project team doesn't have the time to complete the evaluation phase and address the interviewees' comments after the solution delivery. The researchers don't have an opportunity to perform further iterations to improve the prototype. The project team needs to get and address the interviewees' suggestions to complete the research.

The utility and novelty of the solution is important to emphasize as the driving factors for this project. By developing a conceptual framework for decision-making that previously didn't exist, a great amount of time is reduced for utilities/grid operators who are interested in finding the optimal locations and the undertaking of integrating storage systems into the grid. The GDSS prototype can be regarded as an instantiation (to provide an instance of or concrete evidence in support) of the conceptual framework. So, it is important to realize that this prototype is only meant to serve as a good starting point for the illustration of how an interactive, computer-based system can assist in decision-making considering the net and the potential benefits to the grid.

In future DSR cycles, the project team will address all of the suggestions from interviewees after they get their feedback. The project team will evaluate the GDSS prototype many times through multiple iterations to improve its utility. The next iteration will offer a custom tool for developers/utilities, so that they are better able to evaluate the results. The prototype will run on a public server to give the research participants access to the application.

Moreover, the project team will add quantitative methods in the evaluation such as System Usability Scale (SUS) and cognitive walkthrough. The usability of this prototype will increase since both methods measure the usability of any application. The SUS and cognitive walkthrough will be administered to all research participants. In this case, the evaluation will involve more participants who will be given access to the application to ensure the validity of the evaluation results.

VI. CONCLUSION

This study aimed at addressing "How can we determine the optimal locations for energy storage for proper integration into the electricity system?" To answer the research question, we have developed a conceptual framework for decision-making that caters to utilities for it considers the impacts of the energy storage placement on the grid, and the electric circuit capacity constraints. The framework we offer in this paper is the first, to date, to address the research question. In addition, we have built a prototype of Geographic Decision Support Systems (GDSS), which is an elegant, interesting, and novel solution, to aid in the battery storage systems location choices and provide actionable information for utilities, state-level decision-makers, and other stakeholders who are concerned about the grid reliability and the urgency of energy storage deployment as a distributed energy resource.

From this research, we conclude that Battery Storage locations can be assessed geographically to minimize potential increases to overall electric system costs while still meeting

customers' needs. Our solution provides evidence that GIS can play an integral role in the problem resolution.

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