Northern Arizona University
NAU Capstone Team
New Mexico State University
5.A. Optimization Strategy Narrative

1 Summary of Team Structure

The NAU Capstone team consists of four mechanical engineering seniors and one electrical engineering senior. The mechanical engineering students are Corey Burke, Elizabeth Griffith, Grant Hale, and Daniel McConnell. The electrical engineering student is Jack Viola. Most of team members are expected to graduate this May and are participating in the competition to fulfil their senior capstone requirement for graduation. The mechanical portion of the team worked on the conceptual system design, financial analysis, and development plan, while Jack completed the distribution system impact analysis using OpenDSS.

2 Summary of Final Solution

The final solution presented by the team consists of three different subsystems: the Geothermal Substation Ground Mount system (GSGM), the Pan American Center Solar Parking Awnings, and the Hadley Hall Spanish Solar Tiles. The Geothermal substation is the largest subsystem at 3 MW and is a ground mount system that is south facing with a 30 degree tilt. The Parking structure is a 2 MW system with a 10 degree tilt, the parking structure also doubles as shaded parking spots that can raise extra revenue. The Spanish Solar tiles subsystem is the creative idea that doesn't have high production but provides great public relations. The Battery storage system will have saltwater batteries which are almost as efficient as lithium ion but are completely recyclable. In total the NMSU system will create 577 shaded parking spots and be 5.1 MW with a 220KW battery storage capacity. Details about each system are shown in Table 1.

Table 1: Individual system details

System	Size (kW)	Energy Offset	System NPV	Customer NPV
Geothermal Substation Ground Mount	2,999	19%	($100,433)	($3,531,408)
Pan American Center Solar Parking Awnings	1,950	11%	+$194,079	($2,107,310)
Hadley Hall Spanish Solar Tiles	164	1%	($26,689)	($203,486)
Battery Storage Using REopt Lite	-	-	($65,048)	-
Net Values	5,113	31%	$1,909	($5,842,204)

The final design for the battery storage system is a system of Greenrock salt water batteries that have a capacity of 580 kWh and a system power of 341 kW. This design proved to be the most financially viable while still providing resilience.

The final power purchase agreement price used in the financial models is $0.023. This PPA price resulted in the IRR values displayed in Table 2.

Table 2: IRR values for each system

System	Internal Rate of Return (IRR)
Geothermal Substation Ground Mount	19.65%
PanAmerican Center Solar Parking Awnings	270.15%
Hadley Hall Spanish Solar Tiles	25.40%
Battery Storage using ReOpt Lite	-4.67%

3 Strategy for Optimization

The strategy the team took to optimize the OpenDSS model first involved becoming familiar with and analyzing the distribution system model the team received at the beginning of the competition. This included configuring the simulation workspace and working directory to handle all the load profiles and various circuit elements. Once the team had a working base model, the team could then integrate the subsystem designs and simulate the systems response to these new elements. Upon viewing the working base model, the team quickly noticed that the system could be further optimized with power factor correction, as many of the three phase transmissions had mismatched values. However, realizing that the elements the team would be adding contained intrinsic impedances and capacitance, the team thought it best to tackle this issue at the back end of the design.

Once the team had working designs for the photovoltaic sub-systems, the panels, inverters, controllers and storage elements were modeled in OpenDSS and incorporated into the base distribution system. As other software analysis and simulation tools were used to generate the values that inform these models, the majority of this stage's optimization came down to how the team chose to model various circuit elements. For example, the initial design only contained one PV system, which the team modeled as a 'generator' object in OpenDSS. After receiving feedback on the first competition deliverable, the team converted this sub-system to a 'PV system' object and used this object type for the additional sub-systems. After all three sub-systems were implemented in the distribution system model, the team ran a few simulations to verify that the values obtained were within an expected and acceptable range. This took a few iterations to get each sub-systems' various parameters properly assigned and pointing to their respective source files.

The approach to the battery design was to input the original design the team made from the first deliverables into REopt lite and then modify that design in order to maximize the financial savings while keeping the design resilient. The team found as many inputs as possible for REopt lite but for all design inputs that were not know the team used either the suggested inputs from REopt lite or other highly conservative values. This strategy makes the simulation a “worst case scenario” which means that the value is a very safe to trust for the university because the system will likely save them more money than hypothesized. When designing the battery size the team decided that the critical load factor for the campus is 16%, this came from taking one fourth of the energy usage for cooling, computing, all of the refrigeration, and adding a 1.5% of miscellaneous uses as essential taking average data from the mountain area [1]. The team chose to use salt water batteries because they are the most environmentally friendly battery and they are a new and innovative technology which provides a creative appeal. Another input that was very important is the load profile, because the energy consumption data for most buildings given was not complete. The team found that the hospital model in REopt light most accurately replicated the energy consumption of the buildings given. This was determined by using Aurora Solar to find the peak load and smallest load daily for each building and then summing those for each building giving the total daily peak load and smallest load. This was then compared to each model in REopt lite and the hospital had the profile that most accurately represented that load

The Approach to Optimizing the SAM models was to first optimize the Geothermal substation because it is the largest subsystem. The Cost Projections for Utility-Scale Battery storage PDF [2] was extremely helpful for estimating some of the cost like Model cost per watt, BOS cost per watt and many others. SAM made it easy to find the optimal amount of Inverters and DC to AC ratio of each subsystem. Arrays were created to the desired voltage and Inverters were chosen based off their capacity. The Geothermal substation had the potential to be an 8 MW but the analysis in REopt lite determined the team would be wasted too much energy. After all components of the Geothermal substation were finalized in SAM they were applied to the other subsystems. All of the parameters about design were different but similar values were used on the financial aspects of the design.

4 Approach to System Design & Operation

The teams Approach to designing a PV generation and storage system for the NMSU district case was to offset as much energy consumption as possible for the lowest price possible. The Geothermal substation was the first section of interest because it is the largest area given and the land is flat. The team wanted the Geothermal substation to be the most efficient and largest system, Monocrystalline modules where chosen because of the high irradiance in New Mexico. The parking structure was designed with the idea of charging a parking premium because the campus currently has 10 shaded parking spaces. The Spanish Solar tiles were designed to aesthetically amplify the Horseshoe quad, which is a common campus tour area. The PV system design was chosen to be 5.113MW because after running simulations with the original design of 8 MW there were times that the PV system would have to export to the grid, have a very large battery system, or dump the energy as a complete loss. The battery storage loses the most money in the system so the team prioritized making that system as small as possible while still providing essential systems power in case of a grid power outage, therefore the 8 MW system that would provide excess power would not be as financially efficient as a smaller, 5MW system.

The decision to incorporate saltwater batteries into the system design offered various potential benefits over traditional alkaline cells, including a substantially better depth of discharge and round trip efficiency while being significantly safer. However, this decision required a few design considerations. First, this emerging technology inherently has less statistical and field performance data, so a lot of the information the team worked with related to ideal values and conditions. These batteries also have a much slower charging rate, potentially affecting their ability to perform their intended peak-shaving operations. Finally, saltwater batteries use different chemical mechanics than traditional alternatives, so the team was unable to use industry standards for sizing the storage sub-system. Anticipating that this would affect the accuracy of REOpt Lite's internal algorithms, the team also used a sizing table provided by the manufacturer to gauge how much storage the system would need [3].

5 Optimization & Performance Strategy

The battery performance was optimized for performance in REopt lite. REopt lite uses energy consumption data with the current PV system and implements the optimal battery storage and outputs the performance strategy that best fits the needs input. One of the main inputs that affects how the performance estimated in REopt lite is whether the system is to be resilient or financial. With the need of resilience, the performance of the battery storage both maximizes the resilience while still making the design provide financial help through peak shaving. The design will help the university critical systems survive 31% of all potential outages throughout the year simulated in REopt lite.

OpenDSS provides a range of tools and features that helped the team assess the performance of the distribution system model throughout the course of this project. The team was able to analyze losses from mechanics such as impedance mismatching, line drops, and power conversion in the inverters and batteries. A large majority of the system losses can be linked to phase differences in the power signal transition. These losses are caused by an imbalance in the three-phase lines, where a balanced signal will have a difference of ±120° between each of its phases. A straightforward fix for these losses is the addition of capacitor banks at each inverter. While these elements will dissipate some power due to their properties as a passive circuit element, the proportion of real power (as opposed to reactive power) delivered to the load will increase. Losses due to line impedance and power conversion are much more difficult to mitigate, and the best the team could do was to properly size each subsystem in accordance to its individual elements as well as the larger distribution system it will be servicing.

The first step to optimizing the performance of the Geothermal substation in SAM was to find the optimal GCR and determine how much land the team could use without shading losses. The GCR was determined using the solar altitude of New Mexico then using right triangle rules to determine the spacing of .95m. Next was to create the optimal Array size and find the best inverter for the specific situation. SAM can estimate the desired Array size based on the Voltage, so the voltage was set to 800 Vdc which is generally the voltage of the grid which gave an array of 12 modules. Once the voltage and array size were determined the team picked the largest Inverter found on SAM to determine the DC to AC ratio. Most losses such as wire losses, module mismatch, etc. were determined using OpenDSS. The degradation of the system could be assumed at 5% annually which is given in the competition rules. All values for the system cost were based off the size of the system determined from the system cost estimations [2] . The only incentives used in SAM is the 26% Federal ITC [4] and the contingency of the project was 3% of the total cost.

6 Alignment with District Needs & Interests

The NMSU Master Plan established a goal to achieve “zero emissions” by 2050 in 2007 when President Michael Martin signed the American College and University Presidents’ Climate Commitment. The Master Plan also discusses sustainable design guidelines that mentions implementing solar and renewable energy systems. These interests are met through the innovative design selections. The Pan American Parking Structure and Geothermal Substation Ground Mounted system collectively produce a large amount of renewable energy bringing them one step closer to becoming a “zero emissions” campus.

Throughout the provided District Master Plan the University stresses its desire to preserve the campus’ history by reflecting the Spanish Renaissance style as much as possible throughout campus. The Hadley Hall building in the Horseshoe Quad is a great representation of this style, but also houses the campus administration. This makes it an important building on campus not only historically, but from a PR perspective as well. In order to comply with the university’s goals for 2050, the team decided to utilize Spanish solar tiles on this building. In addition to preserving the Spanish Renaissance style, the building reflects the university’s goal to move towards renewable energy whenever visitors see the building.

Another effort the team took towards ensuring the district’s needs were met was making sure none of the implemented designs were on buildings the University might remodel, replace, or destroy in the next 20 years. This ensured each subsystem would last the entire lifespan of the project.

7 Innovation

One area of the final design that demonstrates innovation within the scope of the project is the use of solar parking awnings in the Pan American Center parking lot. Turning the spots into covered parking allows for an increase in price for the parking passes. This increase in parking pass revenue can be used to pay off the initial installation costs of the system and is really useful in making the solar parking awnings financially viable for the university. The initial concern with the parking awnings was that, currently, the rows of spots run north to south. In order to allow for the parking awnings to be tilted towards the south, the lot would need to be repainted with the rows of spots running east to west instead of north to south. The team determined an increase in price for each spot of $78 with 2% inflation each year. After 20 years, the covered parking spots have the potential to generate roughly 1.1 million dollars.

An additional area the team used an innovative design was in the Horseshoe Quad. The University stressed the importance of not putting any ground mount systems within the quad. The team must develop something else creative that could showcase the university's move towards renewable energy. By using the Spanish solar tiles, the university would be displaying their shift, but in a less obtrusive way than had the team used walkway awnings or other solar installations within the quad. The Spanish solar tiles fit in with the current architecture theme and information regarding their use and purpose could be placed somewhere within the quad or near the building to bring more positive attention to the installation.

The design incorporates salt water batteries as energy storage for the PV system. Salt water batteries are innovative due to being a very new technology and are completely recyclable. The other batteries on the market are difficult to recycle which is one of the main selling points of salt water batteries along with the wide charge/discharge rating for the saltwater batteries.

8 Works Cited

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