Solar District Cup

Preliminary Proposal

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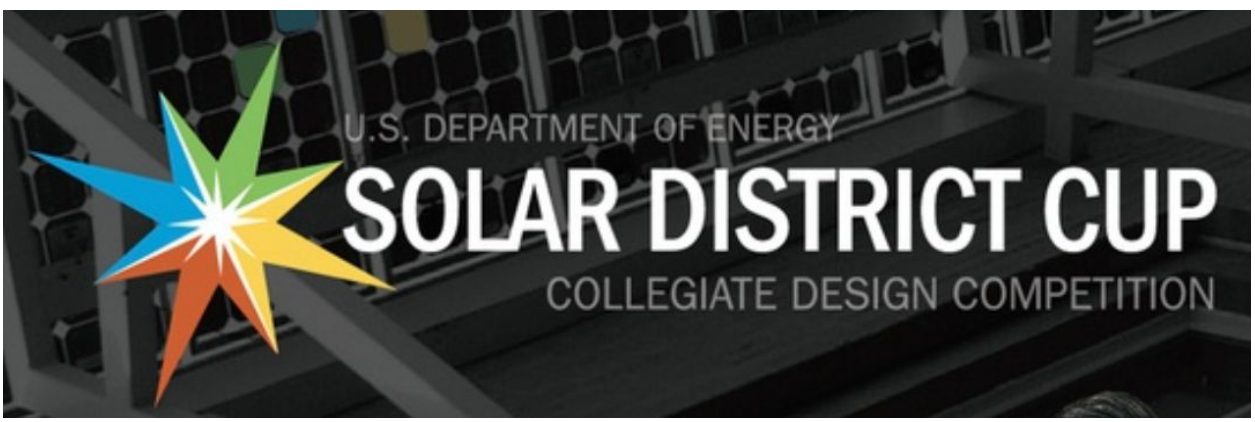

Figure 1: Solar District Cup Collegiate Design Competition

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DISCLAIMER

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1 BACKGROUND

1.1 Introduction

The Solar District Cup is a new competition proposed, conducted, and evaluated by the U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL). The basic premise of this project is to design and model a solar powered network for an assigned area and evaluate this design for both financial viability and financial savings for the district over a twenty year timespan.

This project is of interest to the sponsors because with the increasing advancements in solar energy and battery storage technology, employers have found an increasing lack of experience and technical capabilities of new graduates entering the renewable energy sector. Additionally, solar energy is a more sustainable long term source of energy than natural gas and coal, and has the capability to provide more benefits to utility companies and homeowners than they might currently have. By forming teams of individuals doing research in solar radiation and learning how the solar industry works, the sponsors are bringing more minds into the field that could help progress the technology involved in the energy process.

This project is of high importance because growing research in global warming and the ozone layer has shown that the world's current sources of energy are damaging the planet and the ozone layer. These damages are considered irreversible and unless a change to the energy sources used is made, the problems associated with global warming and the ozone layer will increase in magnitude. Knowing this, the United States is making a push to move more towards renewable energy sources as opposed to the current sources being used. With the need for more renewable sources of energy, however, more research needs to be done in these fields and these fields have not had as large of employment numbers compared to other, more established fields of non-renewable energy in the past. By encouraging people to work on this project, the DOE and NREL are increasing the preparedness and skills of potential graduates entering the field, as well as potentially introducing students to a field they had not considered pursuing previously.

1.2 Project Description

Following is the original project description provided by the sponsor.

> "The Solar District Cup challenges multidisciplinary student teams to design and model optimized distributed energy systems for a campus or urban district. These systems integrate solar, storage, and other distributed energy capabilities across mixed-use districts, or groups of buildings served by a common electrical distribution feeder. The competition engages students across the engineering, urban planning, and finance disciplines to reimagine how energy is generated, managed, and used in a district.
>
> Teams compete in one of multiple divisions, each structured around a distinct district use case. A winner is selected for each division, based on the quality of their solar energy system design. The strongest designs provide the highest

offset of annual energy and greatest financial savings. This will be determined by a techno-economic analysis conducted by students and evaluated by judges. The goal is to design, model, and present the most reliable, resilient, and cost-effective system possible.

Students will present their solutions to judges at the 2020 Solar Power Southeast conference in Atlanta, where the winners will be selected and announced."

2 REQUIREMENTS

The team's goal is to design a photovoltaic solar energy and storage system for New Mexico State University that maximizes energy offset and financial savings over a 20 year time period. With this goal in mind the team determined specific requirements from the customer, the competition guidelines, and Dr. Oman. The given Customer Requirements (CRs) need to be fulfilled in order to ensure the project is completed successfully. The CRs were then used to create Engineering Requirements (ERs). Turning the CRs into ERs gives the team a quantifiable measurement that helps the team meet and optimize the client's CRs. The ERs and CRs were then put into a House of Quality (HoQ). The HoQ relates the CRs to ERs giving the team the relative importance of each requirement compared to the others. The initial goal for gathering these requirements is interpreting our competition guidelines to gather the Customer Requirements.

2.1 Customer Requirements (CRs)

After reviewing the competition guidelines listed in Table 1A in Appendix A the team created a goal statement that summarizes the purpose of this competition. The overall goal is to design a photovoltaic solar energy and storage system for New Mexico State University that maximizes energy offset and financial savings over a 20 year time period. Using this statement along with other given data we gathered our Customer Requirements. CRs are a particular characteristic and/or specification of a product determined by the customer or client. Table 1 below provides the CRs gathered from the Solar District Cup Rules 2020.

Table 1: Generated Customer Requirements

Customer Requirements	
offset annual energy and power consumption	**maximizes financial savings over 20 years**
aestheticly pleasing	energy output based on a reasonable yield factor
optimized distributed energy system	voltage within expected bandwidth
includes solar photovoltaic generation	all network elements satisfy loading and voltage constraints
has battery electric storage	active elements have realistic settings, responses, and dead times
power purchase agreement	optimal battery use
financial viability	cost within budget
reasonable PV location	durable & robust design
reliable design	

The first row in Table 1 provides the most important CRs according to the guidelines set by the DOE and NREL. To distinguish the relative importance of the customer requirements, each CR was given a weight between 1 and 5, with 5 carrying the most weight. A summary of the weighted customer requirements are shown in the House of Quality in Table 2A.

Four customer requirements were determined to be the most important: the system offsetting the annual energy and power consumption, the system containing battery electric storage, financial viability of the system, and total cost with respect to the budget. In the proposal given to the team by NMSU, the university established and explained in their proposal for solar panels that they wish to become a completely sustainable campus by the year 2050. The four customer requirements mentioned have been weighted the highest because of their impact and potential solution for the university's goal.

Another goal of the system is to maximize financial savings over a 20 year time period. If the system is not optimized it may not provide enough energy which would in turn increase the University's expenditures. The counterpart to this being that the system generates too much energy and currency is lost through unused energy. Neither of these situations will maximize the financial savings. The financial savings over a 20 year time period is weighted at a 2 because it depends greatly on offsetting the energy and power consumption, which has been determined to be a 5.

As with any design being interacted with by the general public, the design needs to be aesthetically pleasing. The way the system looks will be very dependent on its location, so being aesthetically pleasing will only really apply to the sections of the system that the students and faculty will interact with in their day to day activities on the campus. Any solar placement on/or around the Horseshoe Quad cannot take away from the aesthetics of the area because it has high visibility to the university leadership and campus visitors. Since this is only a small portion of the campus, its given weight is a 3.

To offset the annual energy and power consumption, the team wants to maximize energy output based on a reasonable yield factor. This means eliminating as much energy loss as possible. Optimizing the amount of energy the system can yield as well as minimizing energy losses was given a weight of 4 due to its direct relationship with offsetting annual energy and power consumption.

Another CR is optimizing the distributed energy system. This CR is weighted at a 2 because the system will connect directly to the campus energy grid resulting in optimized energy distribution. The next CR is that the voltage must be within the expected bandwidth. This is weighted as a 3 because if the voltage is not sufficient enough for the bandwidth, unnecessary energy losses are created that will have to be compensated for in another area of the system.

Photovoltaic generation is the most efficient type of solar panel to date which is why including this type of system is weighted at a 4, although it is not necessary it is highly encouraged. It is extremely important that all network elements satisfy loading and voltage constraints. If the grid is overloaded it may fail and if it is underloaded the system will not have its optimum energy output so its weight is a 4.

The systems can only generate energy when the sun is present, however, energy is consumed continuously. This brings us to the importance of electric battery storage. Without battery storage the system would not be able to supply energy when the sun is not present (e.g. at night and on cloudy days) which in turn would make it impossible to offset the annual energy and power consumption. With battery storage the system can harvest the excess energy generated during the day and supply the campus with energy/power when the sun is absent. This gives electrical battery storage a weight of 5.

A power purchase agreement is a legal contract between an electricity generator, the proposed solar energy system, and a power purchaser. The power purchase agreement is weighted as a 3. It is an important aspect of the financial savings but since New Mexico has a specific range of agreements there will not be much flexibility within the contract. Optimal battery use is weighted heavily. Without this, the university would lose money and waste energy, giving it a weight of 4.

The next CR is financial viability with a weight of 5. If the system is overloaded or underloaded the project will not offset the energy and power consumption and will cost money instead of saving it. Reasonable photovoltaic location is weighted a 4 because the solar panels' placement directly affects the efficiency of the system.

Durable and robust design was given a weight of 3. Although, this is an important aspect of many design solutions, we were given a 20 year time period and solar energy systems have a lifespan much greater than that. Our final CR states our system must have a reliable design with a weight of 4. If the system is not reliable, none of the CRs will be met and the system will fail.

The determined customer requirements listed were analyzed and turned into quantifiable measurements the team could use as targets toward creating a successful final design. These quantifiable measurements are the engineering requirements, also displayed in the House of Quality in Table 2A.

2.2 Engineering Requirements (ERs)

As stated previously, engineering requirements give the team a quantifiable measurement that helps the team meet and optimize the customer requirements for the client.

The first ER is power generated and will be measured in kilowatts hours. The target value for power generated is 50% of the total power used during peak energy usage hours. The reasoning behind this is because low energy usage hours and peak energy production hours are at the same time, collecting 166% more energy than what is being used and offsetting the total energy and power consumption. The tolerance is set at anything greater than 50% because any excess energy can and will be sold through the power purchase agreement.

Placement is another ER being measured and is measured in hours of sun per day. The target value for this is 11 hours of sun per day with a tolerance of plus one hour. In order to optimize our system our photovoltaic solar panels need to be receiving sunlight at least 11 hours of the day. This tolerance was given because there is only a total of 12 hours of sunlight in a day.

Energy loss will be measured in kilowatt hours. The target value for this is 20% which may seem high but with a large-scale system is minimal. With a 20% energy loss the team will still have enough energy stored in the batteries to offset power consumption. The tolerance will be plus or minus 5%. If the percentage decreases, it allows the team to increase the amount of energy available to sell through the PPA. If it increases, the batteries with still have excess energy to offset power consumption.

Cost will be measured in dollars. Since this system has no budget there is no specific target value or tolerance for this ER. The goal is to minimize the overall cost of the project in order to optimize financial savings. Additionally, the competition asked that the team hold off on financial aspects until the next deliverable in March.

Battery storage capacity is the next ER and will be measured in kilowatt hours. This portion of the project, just like cost, will not be considered until next semester, which is why there is not a target value or tolerance.

Reliability and durability are encompassed by the life cycle of the system and will be measured in years. In order for the system to maximize financial savings it must last 20 years giving the target value. The tolerance for this 0% because solar energy systems have a lifespan 30 years and greater, which extends past the requirement given.

Replacement parts will be measured in dollars. To minimize financial expenditures, it is desired that the system lasts its entire lifespan without needing any replacement parts. The target value for this is $0 because of this and the tolerance is 0%.

Energy savings per year will be the next ER and is measured in dollars per year. At this point the team is unsure of the amount of energy the campus consumes so it is difficult to predict the energy that needs to be created. In order to come up with a target value and tolerance, the team will have to wait two more weeks when the energy data is scheduled to be given.

The incident angle will be measured in degrees. Since the roofs vary from being completely flat to 45 degrees and solar tracking is being considered, there is not a set target value or tolerance for the incident angle considering the different roof types and rotating solar panels. The main goal with each incident angle is to optimize the amount of solar energy the panels receive.

Safety is another important ER that is measured on a 1-10 scale. The target value is a 9 to ensure that the system does not pose a threat to human/wildlife safety. The tolerance is plus one because of engineering ethics. The team does not want to implement a system that could potentially threaten any type of species.

2.3 House of Quality (HoQ)

A house of quality is a diagram used for defining the relationship between customer requirements and engineering requirements. This helps the team interpret the top engineering requirements in relation with each other, designating specific ERs to focus on. Using the house of quality template provided by Dr. Oman, the team came up with the most important engineering requirements. As seen in Table 2A in Appendix A, the primary ERs are placement, energy loss, life cycle, and energy generated in comparison to the energy needed per year.

The most important engineering requirement provided by the HoQ is minimizing energy loss, which is measured in kilowatt hours. As stated in the previous section, the target value for the amount of energy loss is 20% energy loss with a tolerance of plus or minus 5%. This is why the team decided to incorporate a solar tracking system that follows the sun throughout the day in order to optimize the amount of sun each panel receives. Energy can also be lost when translating over some distance so keeping the system as close to the grid as possible is crucial.

Placement is the second most important engineering requirement according to the HoQ. It is measured in hours of sun per day. The target value for this requirement is 11 hours and it has a tolerance of plus one hour. With this in mind, the team made sure to only incorporate buildings and parking structures that do not have any solar obstructions into the potential final design.

3 DESIGN SPACE RESEARCH

To start the project, the team conducted research to get a better understanding of the current state of solar. The team then looked at current designs of solar panels and other subcomponents as a benchmark for creating designs. With the knowledge gained from research the team then created a black box model and functional decomposition of the system that the team will design.

3.1 Literature Review

The team conducted research on many aspects of designing a solar array, including equations and basic concepts of PV solar panels, battery storage, how to model these solar projects using online tools, solar tracking devices, and the rules and regulations for the competition and district given.

3.1.1 Daniel McConnell

Daniel focused on researching basic concepts of PV solar cells along with battery storage. The first source found was a book on sustainable energy [1]. This book provides information on how solar panels work and how to optimize the energy produced by them. It also provides equations for the incident angle which is a very important equation the team will need to create the most efficient solar distribution. The next source found was a website on basic info on PV cells [2]. The website explains the composition of the different PV cells. After a basic understanding of the PV cells, a deeper understanding of how to analyze the PV cells was looked into using a book on solar energy engineering [3]. This book provides specific equations that validate how to set up PV cells to achieve the greatest efficiency. With a good understanding of PV cells and how to optimize them, the next topic investigated was the electrical engineering aspect of the design. A book on electrical engineering of renewable energy was found [4]. This book provides information on how to wire systems of solar panels depending on the arrangement of the panels [4]. Lastly, Daniel looked into battery storage and found an article explaining the efficiencies of battery storage which will help the team design a battery storage system that minimizes losses and maximizes energy offset [5].

3.1.2 Corey Burke

Corey investigated the different resources that are available to the team. SAM, an open-source modeling tool to analyze the energy production and cost of the system, was the first tool researched [6]. This tool will provide useful information on the yearly energy production and cost of the potential designs we create. Another tool researched was Aurora Solar. Like SAM it is a tool for creating systems of solar panels and power purchase agreements (PPAs) [7]. The next tool researched was ReOPT lite [8]. ReOPT lite is a tool that optimizes the battery usage based on the data is provided. This tool will help the team find the optimal battery placement and usage once the solar panels are arranged [8]. Then Corey researched OpenDSS which is a program that optimizes the electrical components of the solar array with respect to the grid that is input [9]. Finally, Corey investigated the webinar provided on how to create a financial model in excel [10]. This will help the team create the required financial model for the competition.

3.1.3 Elizabeth Griffith

Elizabeth was tasked with researching sun tracking devices for PV solar panels. First, Elizabeth researched into the benefits of solar tracking devices and it was found that solar tracking devices increase the power generation of solar panels by 30% [11]. It was also found that on sunny days the potential power generation is increased by about 63% for solar tracking panels [12]. Next, the usage of active and passive solar tracking devices, finding that active solar tracking devices are most commonly used. Around 76% of solar tracking devices implemented use active solar tracking as they provide more power generation than passive systems [13]. Then two solar tracking devices were researched. The first system analyzed was an article on a new dual axis sun tracking device [14]. This article explains a solar tracking device that should minimize energy consumption of the tracker but is a bit more expensive than the competition [14]. Another solar tracking device was found that works for small solar panel applications. As the team must offset annual power consumption for the entire campus, large scale solar farms will be needed and this will not be an option for the team [15].

3.1.4 Grant Hale

Grant Hale researched in depth the different city, state, and district regulations. The first source Grant used was the data provided by Herox [10]. This data outlined the regulations that come from the competition itself relating to the areas on campus provided for design [10]. The next source looked into was the rules provided by Herox which gave the team regulations on the type of solar panels allowed and the voltage required to connect to the grid [10]. Grant then researched the incentives for solar energy use in the state, this data was found from DSIRE [16]. The incentives will help the team create a PPA that is required for the competition. Grant then used a development plan that was provided on New Mexico State University to learn how the district plans to expand or use the current land differently in the next eight years just in case this might influence how the team designs the system. Lastly, permits and regulations on solar in Las Cruces were researched. A document from las-cruces.org was to see what permits would be required to set up the system that is suggested [17]. The competition requires that the design team find all permits required by the county, which is why this was researched.

3.2 Benchmarking

The team then did some benchmarking of current designs for the project. The benchmarking process was not completed to see how to improve current designs but instead to see some of the current designs that the team may be using in the project. The team is not allowed to design any new technology which is why the benchmarking was done to see what products the team would like to use. The team researched subsystem level designs that may be used in the project that include solar panels, inverters, and sun tracking devices.

3.2.1 Subsystem #1: Thin Film PV Solar Panel

The thin film PV solar panel made by Jiang is a very cheap solar panel, being only about $17, but the tradeoff for that is it has a very low efficiency [18]. This product could be helpful to the team because it offers a flexible design that can be put virtually anywhere on the campus however, the lack of efficiency makes the product undesirable because the campus uses so much energy and the small amount of power produced by the thin film solar panel would not offset the energy required by the competition.

3.2.2 Subsystem #2: Polycrystalline Solar Panel

A polycrystalline solar panel sold by AIMS Power is another PV cell option for the team [19]. This product provides a decent efficiency but is more expensive than the thin film panels being priced at about $311. The team will likely choose polycrystalline panels as the type of panels because the efficiency is high enough that with the square footage available the team will be able to design a system that offsets the annual energy consumption without costing all that much. This particular panel is not necessarily the panel that will be used because the competition holders have not sent out a list of usable panels.

3.2.3 Subsystem #3: Monocrystalline Solar Panel

Monocrystalline solar panels are another option for the team to consider. The product found for a monocrystalline solar cell is sold by Trina, being more expensive than polycrystalline panels but usually having a bit more efficiency and increased endurance [20]. Monocrystalline panels will be considered for applications where there might be high heat as monocrystalline cells have a higher heat tolerance than polycrystalline cells and should last longer in those instances. Again, the competition holders have not given a list of possible solar panels to use so the team does not know if this specific panel will be used.

3.2.4 Subsystem #4: Solar Tracking

Solar tracking is something the faculty advisor for this project has tasked the team with researching because of the potential benefits of solar production. After extensive research, finding a full solar tracking system is very difficult but one was found. A large solar tracking device made by Missouri Wind and Solar costs about $3,700 and holds up to 6 solar panels. That is a total of about $600 per solar panel to implement solar tracking [21]. This increase in cost may be too large to justify using the solar tracking if they only produce at most 30% more power. First, the team needs to get approval from the competition holders before using any specific solar tracking devices.

3.3 Functional Decomposition

To develop a plan for solar panel layout, the team constructed a black box model and functional model of the system. The system being analyzed in both of these diagrams is the entire campus of New Mexico State University that has been approved for solar panel placement.

3.3.1 Black Box Model

The inputs and outputs of the system have been characterized into three separate groups: materials, types of energy, and signals. The primary material components that will be interacting with the system are people, animals, and dust. These three materials can impact the system by shading the panels or potentially adjusting the incident angles of the panels. The most active types of energy flowing through the system are heat energy and solar radiation energy. The primary signal flows are shaded and dirty panels. These are the most important signals because the amount of shade or dust on the panel will directly affect the efficiency of the individual panels. The entire Black Box Model is shown in Figure 2.

Figure 2: Black Box Model of NMSU solar panel system

The Black Box Model was used by the team to create a functional model, as well as to analyze the system for potential barriers to efficiency and sources of unsafe environments.

3.3.2 Functional Model

To fully understand the connections between the solar panels, transformers, and the grid, the team created a Functional Model. This allowed the team to better analyze the parts that comprised the whole system. The final Functional Model is shown below in Figure 3.

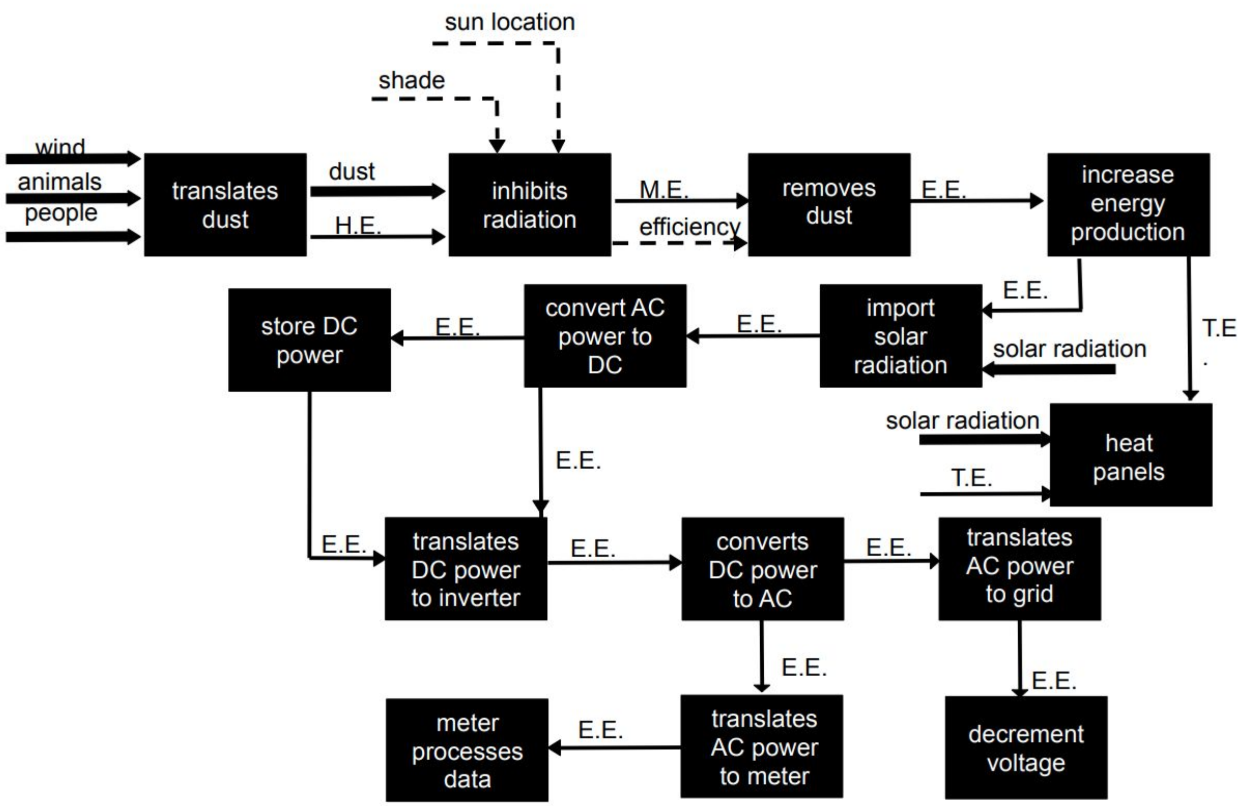

Figure 3: Functional Model of New Mexico State University solar panel system

Although this model shows how the entire system interacts, the mechanical team will only be focused on a portion of the system. This includes accounting for dust, people, and animals, increasing energy production, and determining optimum incident angles for each panel. Although these will be the mechanical team's primary focus in the functional model, the team will still need to be cognizant of the other working parts such as the distance each panel is from the center of the grid--the Tortugas building--and the battery storage connected to specific panels.

4 CONCEPT GENERATION

The team has come up with several concepts considered for final selection of the design.

4.1 Full System Concepts

The Solar District Cup is a competition where the teams have to optimize a PV system. The team must account for power generation, excess power, losses, aesthetics and the financial viability. Due to all these factors, the team will only have one final design which will implement many of these concepts. The team's full system concepts can be broken down into three concepts that will be used in the final design. These three concepts are what the team believes will have the largest financial savings over 20 years.

4.1.1 Full System Design #1: Solar Parking Structure

The first design is a solar parking structure. These structures are very widely used by schools and private businesses. The parking structures double as a parking shade and can turn a parking lot into a PV solar generation field. The team plans to call solar companies that install these structures to get an accurate estimate on how much they cost and produce. The primary disadvantage to utilizing a system like this is paying for the structure to hold the panels in place. Although the structures themselves will not be cheap, the amount of energy the team can harvest from them will likely offset the cost.

4.1.2 Full System Design #2: American Center

The American center is the largest building on the NMSU campus and is also a white building, which helps reflect more sunlight to the solar panels. This building has a huge flat roof that would be perfect for rooftop solar because there are not many obstructions to consider along its surface. The American Center is used for college sporting events and concerts. Some of the energy generated could be used to make these events more eco-friendly. A con to utilizing this building for solar panel placement would be that the building would house so many solar panels, the team would need an area for inverters inside the building.

4.1.3 Full System Design #3: Solar Tracking Dirt Lot

The Dirt lot is an extremely large area in the desert located 3 miles east of campus. This will provide most of the power generation due to the extremely large open area. The team will most likely need to create a grid connection to allow the power generated to reach campus and allow excess generation to net meter. Another con is that parts of the area may need to be leveled because the land has not been used for anything previously.

4.2 Subsystem Concepts

In addition to the full-scale concepts developed, the team came up with several subsystem concepts within the three different sections of campus.

4.2.1 Subsystem #1: Main Campus
The subsystems are divided into three different areas distinguished in the competition: the main campus, Horseshoe quad, and the dirt lot 3 miles from campus. The main campus is the largest area but is filled with buildings and parking lots, meaning the primary source of solar power would be panels installed on rooftops and parking structures.

4.2.1.1 Design #1: Jett Hall building
Jett Hall building has a very large flat roof that is all on the same level. This will decrease the losses as a result of shade on the panels. The Jett Hall is located close to the Tortuga building which is the central hub of all the electricity supply and demand needs because it is connected directly to El Paso Electric Company. The only risk associated with using the Jett Hall roof is the chance of it collapsing from too much weight. The team will have to conduct structural analysis of the roof once a finalized design has been determined.

4.2.1.2 Design #2: Parking structure
A solar parking structure is a great way to generate solar energy while also providing shaded parking for students and staff. The con of the parking structure is that the university would have to pay for and construct the metal structure that holds the panels in place. The panels would also be difficult to clean because they would separated by parking spots.

4.2.1.3 Design #3: American Center
The American Center is a very large flat building that is used to house sporting events and concerts. This building is white and the largest building on campus which gives plenty of space to place panels and make sure they're not shading each other. Cons would be cleaning such a large array of panels as well as finding somewhere to house the inverters.

4.2.1.4 Design #4: Zuhl Library
The Zuhl Library is a large flat building similar to the size of the Jett Hall building. The library is also in the center of campus. This building has a large flat roof with plenty of area for solar panels. The cons are that the roof has several levels which would increase shading significantly. The different levels also make it harder for maintenance and cleaning.

4.2.2 Subsystem #2: Dirt Lot
Subsystem two is the dirt lot located 3 miles east of campus which is an extremely large and open area. This area is where we predict most of the energy will come from due to its extremely large open area. The downside of building here would be creating a grid connection as well as maintenance because the desert is dirty.

4.2.2.1 Design #1: Fixed Solar Field
The first idea for the Dirt Lot is to create a fixed PV generation field where the panels would be pointing south and the angle is only changed seasonally. This is the cheapest option but also the least efficient because fixed pv cells generate around 30% less energy than solar tracking.

4.2.2.2 Design #2: Concentrated Solar Field
Concentrated solar is similar to fixed panels but there are mirrors that reflect even more solar radiation into the panels. This was found to be more expensive and less efficient than solar tracking.

4.2.2.3 Design #3: Solar Tracking

Solar tracking is when a light sensor tells the solar panel where to move to follow the incident angle. Following the incident angle increases power generation by up to 30% [???]. This is a huge pro because this is the largest area available to generate solar energy.

4.2.3 Subsystem #3: Horseshoe Quad

The last area provided is the Horseshoe Quad. This area cannot have ground mounted solar panels which forces the team to get creative. The team came up with 3 innovative designs to have solar generation in this quad. The quad is also a very popular place to show to visitors so NMSU wants something that stands out and is aesthetically pleasing.

4.2.3.1 Design #1: Solar Trash Can

The first concept is to have solar trash cans like the ones at NAU. These look good and every campus needs lots of trash cans to accommodate the large amounts of people interacting with the campus. These solar trash cans will not produce much power because they have very small solar panels but should produce enough to power lights or other small electronics like phone chargers.

4.2.3.2 Design #2: Solar Street Lights

The second concept developed is solar powered streetlights. Ideally these lights would produce and store enough power to stay lit all night. These lights would be perfect for the quad because at night it is a large dark field and the panels will be almost unnoticeable. The cons would be having to install these in existing fixtures, rewire the lights, and install a battery to store energy if viable.

4.2.3.3 Design #3: Solar Awning

The final design is a solar awning or gazebo. This design would be very aesthetically pleasing as well as generate the most power. It could provide some shade for tables or just add to the overall beauty of the quad. The con would be building the structure, this would make it less cost effective than many options.

5 DESIGNS SELECTED – First Semester

The designs selected were determined using a decision matrix, pugh chart and financial viability. The three designs that were selected are what the team believes to be the most financially beneficial over 20 years.

5.1 Technical Selection Criteria

The technical criteria used to evaluate the designs were the customer needs and engineering requirements previously defined in the house of quality (Figure 2A). The customer needs were used in a pugh chart shown in appendix B (Figure 1B) to evaluate the use of different buildings for the system. The team learned from the pugh chart that the buildings with slanted roofs would not perform as well as those with flat roofs. The team then used a decision matrix to further reduce the ideas that will be used in the system by comparing them to the engineering requirements. The decision matrix created is shown in appendix B (Figure 2B) and revealed that the designs that will be used in the system will be the American Center and solar tracking in the dirt lot.

5.2 Rationale for Design Selection

The top two design selections are the solar tracking dirt lot and the American Center building with rooftop solar. These are the two largest areas given and will generate the most energy from two areas instead of a couple small PV arrays. The Dirt Lot will produce a large percent of the energy production due to it having the largest area for a solar field. The disadvantages of the dirt lot is the lack of infrastructure already there. Grid connections would need to be built to connect the energy generated to the grid.

The American Center is the largest building on campus with a white, flat roof which maximizes the energy that can be produced. The disadvantage of the American Center is having such a large PV array. This will require an area for the inverters that would preferably be inside the building to protect them from the elements. In the pugh chart, the American Center scored a lower score only because of the size of the array which would increase cos. In the long run, however, the American Center will be more beneficial because of the amount of power it can generate. The team used SAM to analyze part of the Dirt Lot with solar tracking and could scale it up as necessary. It was found that 2,000 square meters of area, or half an acre, would produce around 60,000 kwh a month. The Dirt Lot is over 23 acres. so the team could theoretically produce 2,760 Mwh a month from just the Dirt Lot alone. The Dirt Lot could be used as the entire source of power if it is found to be the most financially viable decision.

6 REFERENCES

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7 APPENDICES

7.1 Appendix A: Progress Deliverables and House of Quality

Table 1A: Progress Deliverable Package Content and Evaluation Statement

Content	Evaluation Statement
1. Conceptual System Design	
A. Layout and specifications for the solar electric PV systems proposed within the district on one or more rooftops, parking lots, or ground areas [PDF].	A. Conceptual system design is complete and reasonable for PV system location and specifications.
B. Average hourly energy production output for each system over annual period [Excel spreadsheet].	B. Energy output is complete, based on a reasonable yield factor, and accounts for climatic variables.
2. Distribution System Impact Analysis	
A. Descriptive approach to power flow model [PDF], including: i. Irradiance profiles for the proposed PV systems ii. Load profiles for the connected buildings iii. Size of PV systems to comply with utility code iii. Control settings for the PV systems, capacitor banks, and voltage regulators.	A. Approach document provides clear explanation of input choices.
B. Power flow model [OpenDSS[1] input and output]: i. Demonstrating all network elements satisfy loading and voltage constraints ii. Demonstrating active elements have realistic settings, responses, and dead times.	B. Power flow model voltage analysis shows operation within expected bandwidth and with reasonable inputs.
3. Financial Analysis	
A. A project financial model that uses the production data and other inputs to generate a PPA price for a 20-year term and that achieves a net present value of $0 [Excel spreadsheet].	A. Financial model has a complete set of reasonable inputs, models cash flows competently, and has a PPA price output that conforms to market benchmarks.
4. Development Plan	
A. Building and site plan for conceptual system design, including applicable local ordinances [PDF].	A. Building and site plan demonstrates compliance with district master plan, zoning, and other land use building restrictions.
B. Construction plan to procure necessary permits and comply with local codes [PDF].	B. Development plan demonstrates compliance with permitting and relevant codes.

Table 2A: House of Quality

House of Quality (HoQ)													
Customer Requirement	**Weight/Engineering Requirement**	Power generated (KWh)	placement (hrs sun/day)	Energy loss (KWh)	cost ($)	battery storage capacity (KWh)	life cycle (years)	maintenance/labor cost ($)	replacement parts ($)	electricity savings/year ($/yr)	incident angle (deg)	energy generated/energy needed per year	Safety (1-10)
offset annual energy and power consumption	5	9	9	9	9	9	9	3	3	9	9	9	3
aesthetically pleasing	3		9		3		9	9	9		1		9
optimized distributed energy system	2	3	9	9		9	9	3	3	1	9	9	9
includes solar photovoltaic generation	4	9	9	3	9	1	9	3	3	9	9	9	3
has battery electric storage	5	3	9	9	9	9	9	3	3	9		9	9
maximizes financial savings over 20 years	2	9	9	9	9	9	9	9	9	9	9	9	9
power purchase agreement	3	9	9	9	9	9	9	3	3	9	3	9	9
financial viability	5	9		9	9	3	9	3	3	9	3	9	3
reasonable PV location	4	9	9	9	3	3	9	9	3	9	9	3	9
energy output based on a reasonable yield factor	4	9	9	9	3	9	3	3	3	3	9	9	
voltage within expected bandwidth	3	9	9	9	3	9	3			3	9	9	3
all network elements satisfy loading and voltage constraints	4	9	9	9	3	9	3	3	3	9	9	9	9
active elements have realistic settings, responses, and dead times	3	9	9	9	3	3	3	3	3	9	9	9	3
optimal battery use	4	3	3	9		9	9	9	9	9	3	9	1
cost within budget	5	3	3	3	9	3	3	9	9	3	3	3	3
durable & robust design	3	3	3	3	3	3	3	9	3	3	3	3	9
Reliable design	4	3	9	9	3	3	9	9	3	3	9	3	3
Absolute Technical Importance (ATI)		402	450	468	345	364	435	330	264	410	378	444	325
Relative Technical Importance (RTI)		6	2	1	9	8	4	10	12	5	7	3	11
Target ER values		0.5 needed	11	20%	D		20		0			50%	9
Tolerances of Ers		+	+	5%			0	-	0	+	=	+	+

7.2 Appendix B: Design Selection

Table 1B: Pugh Chart

PUGH CHART								
Customer Requirement	Jett Hall	American Center	Dominici Hall	Zuhl Library	Branson Hall Library	Regents Residence Center	Hadley Hall	Science Hall
offset annual energy and power consumption	-	+	D	+	+	-	-	+
aesthetically pleasing	S	+		+	+	-	+	+
optimized distributed energy system	-	-		+	+	S	+	+
includes solar photovoltaic generation	S	S		S	S	S	S	S
has battery electric storage	S	S	A	S	S	S	S	S
maximizes financial savings over 20 years	+	+		+	+	-	+	+
power purchase agreement	S	S		S	S	S	S	S
financial viability	+	-	T	-	S	S	S	-
reasonable PV location	+	+		+	+	-	S	+
energy output based on a reasonable yield factor	S	S		S	S	S	S	S
voltage within expected bandwidth	S	S	U	S	S	S	S	S
all network elements satisfy loading and voltage constraints	S	S		S	S	S	S	S
active elements have realistic settings, responses, and dead times	S	S		S	S	S	S	S
optimal battery use	S	S		S	S	S	S	S
cost within budget	+	-	M	-	S	-	S	-
durable & robust design	S	S		S	S	S	S	S
Reliable design	S	S		S	S	S	S	S
TOTAL SUM	2	1	0	3	5	-5	2	3

Table 2B: Decision Matrix

	Weight	Jett Hall	American Center	Science Hall	Zuhl Library	Parking Shade	Streetlight	Trash Can	Bench Awning	Dirt Lot - Fixed	Dirt Lot - Solar Tracking	Dirt Lot - Concentrated	Branson Hall Library
Intallation Price	4	3	1	3	4	1	4	1	3	2	2	1	3
Net Energy Produced (kWh)	5	4	5	2	1	3	1	1	1	4	5	5	2
Aesthetics	2	5	5	5	5	5	4	5	5	2	2	2	5
Safety	4	3	3	3	3	4	5	5	4	4	4	1	3
Maintenance	3	2	1	3	4	2	3	5	4	2	2	1	3
Accessibility	3	4	4	3	4	3	1	5	4	5	5	5	5
Ethics	3	5	5	5	5	5	5	5	5	3	3	3	5
Lifespan	3	5	5	5	5	5	4	4	5	5	5	5	5
Distance from Distribution	2	3	3	5	5	3	3	3	3	2	2	2	4
Dust Accumulation	2	4	5	4	4	3	5	3	3	1	1	1	4
Weighted Sum > 100		116	112	110	115	102	104	108	109	99	104	85	114