115kV / 34.5kV Solar Power Plant Substation Design

DESIGN DOCUMENT

Team 26

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ILR: Inverter load ratio, the ratio between DC input capacity and the inverter AC output capacity.

PV: Acronym for photovoltaic

Combiner Box: A device that combines the output of multiple strings of PV module to connect to the inverter.

Inverter: A device that converts direct current (DC) voltage to alternative current (AC) voltage.

String: A series connection of solar panels

Array: Made up of rows of multiple rack, with inverter and combiner boxes

Rack: Made up of strings

MW: MegaWatts

kV: KiloVolts

NEC: National Electrical Code

1. INTRODUCTION

1.1 ACKNOWLEDGEMENT

The senior design team would like to thank Cole Beaulieu and Emily Neumann, employees of Black & Veatch, for their time and willingness to oversee the project and providing the team with the tools necessary and essential for the design aspects of the project. The team would also like to thank Dr. Ajjarapu for his time and expertise, serving them as the faculty advisor. This project has been a great learning experience, and the team would like to thank the Department of Electrical and Computer Engineering at Iowa State University for this wonderful opportunity.

1.2 PROBLEM AND PROJECT STATEMENT

Due to increasing renewable energy standards set by the RES Group (Renewables Energy Systems), which promoted companies to push more toward renewable energy, Black & Veatch is sponsoring a senior design project that utilize solar to generate power. The senior design team will take charge of designing a 60 MW solar power plant and a 115 kV/34.5 kV substation and will integrate both parts of the project by first establishing the solar power plant according to the specifications given by Black & Veatch. Upon completion of the solar power plant design, the team will design the substation based on the Arcadia single-line diagram provided by Black & Veatch. Deliverables include:

- Solar plant layout drawings and conductor sizing
- AutoCAD drawings of schematics for plant and substation
- Component connections for plant and substation
- Key protection diagram
- Substation one-line diagram
- Substation three-line diagram
- Man-hour budget, schedule and cost estimates

In the first semester, the focus of the project will be the solar plant layout, sizing and budget. The substation one-line diagram will also be completed in the first semester. In the second semester, the substation design will be the priority and the final solar designs will be optimized in preparation for the final presentation.

1.3 OPERATIONAL ENVIRONMENT

If Black & Veatch decides to build the solar power plant, it will be located in Estancia, New Mexico. This location was chosen after extensive research and comparison with other locations. Weather conditions and solar radiation were big factors. Estancia is environmentally and geographically almost perfect for solar generation. It is sunny most of the year, and the only form of precipitation it experiences is rainfall. Estancia averages about 15 inches of rain while the rest of the United States averages about 39 inches. Rainfall is an important factor as it indicates how much cloud coverage, and thus lack of sunshine, a location receives.

1.4 INTENDED USERS AND USES

Because the team is designing a utility-scale solar power plant and a substation for a company and not the end users, who are those that are connected to the opposite end of the grid, the team will utilize all the specifications that have been provided by the client. The team understands that the electrical power generated could be used directly and indirectly. The appropriate way to ensure that the project is successful is by doing extensive research on the subject matter, accurate calculations, and following the specifications set by the client.

1.5 ASSUMPTIONS AND LIMITATIONS

Assumptions

An assumption is that the end product will provide electrical energy up to 9,000 homes in the United States. Another assumption is that the end product is designed to meet all the standards and code in the U.S., and therefore, the possibility of integrating such a system in other parts of the world is possible as long as it meets the standards set by those places.

Limitations:

The end product will produce no more than 60 MW of AC power according to client specification. The total cost of the project so far is 64.5 million excluding the cost of labor, which is quite expensive. However, the design of the project will be reviewed as the project continues in order to reduce the total cost.

1.6 EXPECTED END PRODUCT AND DELIVERABLES

The team will have a list of deliverables to fulfill by the end of each semester. These deliverables are the footprints of the project. Deliverable dates are shown in the Gantt charts.

First Semester Deliverables:

1. Solar Power Plan layouts

This includes finding the perfect location for the project and using the array parameter tool provided by the client to calculate the number of solar panels, inverter, combiner boxes, and land size. Through this deliverable, we will have a complete solar layout design for the power plant.

2. Solar layout drawing

The team will utilize the solar plant drawings that have been provided by Black and Veatch and use AutoCAD in order to have a full design of the power plant.

3. Substation one-line

The team will also have a complete AutoCAD design of the Substation one-line. The design will include every component of the substation (feeder, collector, 34.5 KV bus, protection relays, step-up transformer, and 115 KV bus).

4. conductor sizing

There will be a lot of wiring in this project and in order to decrease the power loss, the team is going gather all the data needed to come up with the conductor sizing for the Solar Power plant. The size will depend on the area temperature, the amount of current going through it, and the size of the plant.

5. Engineering man-hour budget

The team will develop a Gantt-chart to track the progress of the project and record the time spent on tasks.

Second Semester Deliverables:

1. Substation three-line drawings.

In the second semester, the team will dive deeper on the substation and manage the bridge between the solar power plant components and substation components.

2. Revise/improve last semester's drawing

There will be a lot of revision to the quality, cost, and optimization of the project. As mention, the second semester is mainly about the substation, therefore, the revision is done to work accordingly with the substation.

3. Finalize the project requirements

This more like a test state. the team will try to finalize everything about the project before the end of the semester. Also, the team will test the functionality before the final project presentation to make the project is accomplished successfully.

2. SPECIFICATIONS AND ANALYSIS

This section describes and explains the designs of the solar power plant and substation proposed by the student team. As of now, the main focus of this section is on the design of the solar plant since the student team has yet to start the substation aspect of the project.

2.1 PROPOSED DESIGN

The student team decided to approach the design problem by splitting it into two phases; Phase 1 focuses on the design of the 60 MW power plant, and Phase 2 focuses on the design of the 115kV/34.5kV substation. **Figure 2.1** is the block diagram of the design project, and it shows the power flow from generation all the way to transmission.

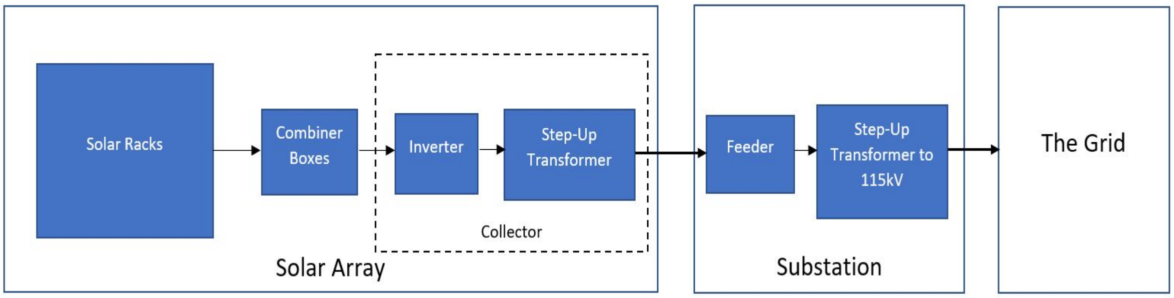
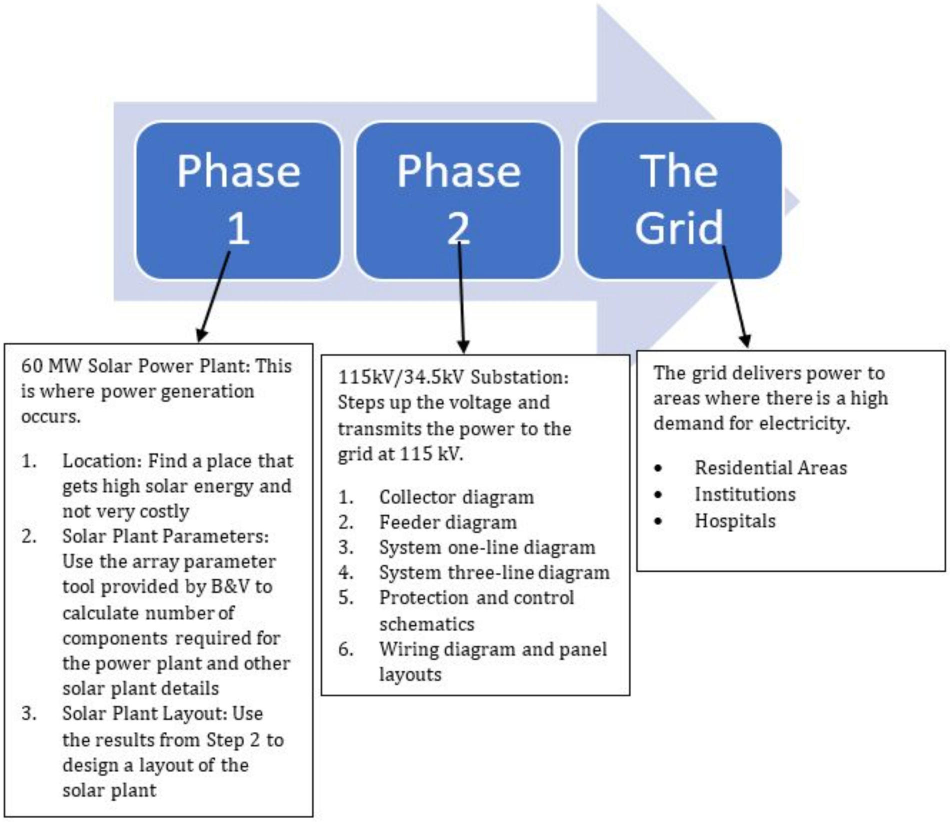


Figure 2.1: Project Block Diagram

Solar racks consist of solar panels that generate DC power from the Sun's solar radiation. The panels are connected in series, and a series connection of panels is called a string. The strings are connected to the combiner boxes, which will combine the voltages of all the strings together. Then, the combined voltage is input into inverters to convert the DC power into AC power with a DC-to-AC ratio of 1.3 to 1. Since the goal is to output an AC power of 60 MW, this means that the panels need to generate a DC power of 78 MW. After the conversion to AC power, the output of the inverters is stepped-up by a transformer and fed into the substation through the collector and feeder components of the substation. Finally, the substation will transmit the power to the grid at a voltage of 115kV.

In **Figure 2.2**, it outlines the tasks that need to be done in order to complete each phase of the project.



60 MW Solar Power Plant: This is where power generation occurs.

1. Location: Find a place that gets high solar energy and not very costly
2. Solar Plant Parameters: Use the array parameter tool provided by B&V to calculate number of components required for the power plant and other solar plant details
3. Solar Plant Layout: Use the results from Step 2 to design a layout of the solar plant

115kV/34.5kV Substation: Steps up the voltage and transmits the power to the grid at 115 kV.

1. Collector diagram
2. Feeder diagram
3. System one-line diagram
4. System three-line diagram
5. Protection and control schematics
6. Wiring diagram and panel layouts

The grid delivers power to areas where there is a high demand for electricity.

- Residential Areas
- Institutions
- Hospitals

Figure 2.2: Solar Power Plant to Substation Design Connection

2.1.1 Phase 1: 60 MW Solar Power Plant Design

To assist the student team with the design of the power plant, Black & Veatch has provided the following tools:

- Array Parameter Tool: Excel sheets used to determine the parameters and details of the solar plant.
- Voltage Drop Tool: Excel sheets used to calculate voltage drops across cables to determine the placement of combiner boxes.
- NREL SAM: A software that models the solar plant design based on the specifications of the power plant.

In addition to the tools given by the client, the student has also used the following tools to simulate the power plant design:

- Helioscope: A website that models solar power plants based on the specifications of the power plant

2.1.1.1 Location Selection

The very first step of designing the power plant is to select an optimal location for it. It is also a very important step as it determines how much solar radiation the solar power plant will receive and what type of solar rack system will be used in order to meet the requirements set by the client.

Initially, the team selected six locations: two in California, two in New Mexico, and two in Texas. These states are ideal for solar power generation because they get high solar radiation all-year long, and the weather in those states do not receive much precipitation throughout the year. The team then chose one location in each state, with the choices being Millville in California, Alpine in Texas, and Estancia in New Mexico. To narrow down on the optimal location, the team came up with a list of factors. Most of the factors were considered because they affect how much solar radiation the solar panels get and the total cost of the project, while others were considered for possible future solar plant expansions and the public's safety or concerns. The table below shows the factors that were considered, along with a description for each. Since Estancia wins the most categories compared to the other two locations, the team decided that Estancia would be the best location compared to Alpine and Millville.

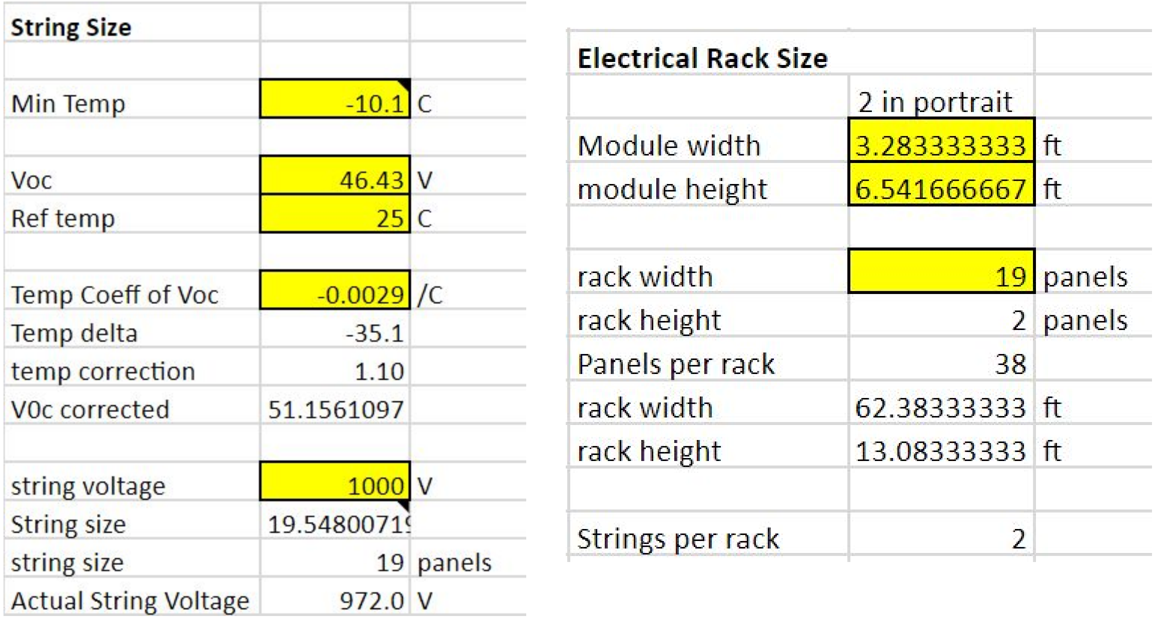
Categories	**Description**	**Millville, CA**	**Alpine, TX**	**Estancia, NM**	**Who Wins?**
Average Solar Radiation (kWh/m^2/day)	How much solar radiation a location gets per day. Higher solar radiation is better.	5.67	6.49	6.41	Alpine, TX
Land Size and Price	The size and price of each location. More land for a cheap price is what we want.	440 acres for $375,000	280 acres for $147,000	560 acres for $195,000	Estancia, NM
Sunny Days/Year (Days)	An average of how many sunny days each location gets per year. More sunny days is better.	249	247	280	Estancia, NM
Higher Than Average Sunshine Compared to the Rest of the Nation	How much higher than average sunshine each location gets. Higher percentage is better.	19.1%	33.1%	33.8%	Estancia, NM
Elevation (ft)	How high the location is from sea level. UV increases at higher altitudes as the atmosphere has less chance to absorb the incoming UV. Higher elevation is better.	600	4514	6103	Estancia, NM

Categories	**Description**	**Millville, CA**	**Alpine, TX**	**Estancia, NM**	**Who Wins?**
State Financial Incentives Ranking (Out of 50)	The ranking of states giving loans or grants. #1 is the best and #50 is the worst.	#28	#27	#8	Estancia, NM
Total Cost of Solar Plant (Million $)	How much the solar plant would cost in each location. Less cost is better.	64.72	65.02	64.58 (5x35 version)	Estancia, NM
How Much Land Left For Substation/ Expansion(acres)	How much land is left for the substation and future expansions. More land is better.	252.7	30.8	211.7 (5x35 version)	Millville, CA
More Cost-Effective Than the Rest of the Nation	How much more cost-effective each location is compared to the rest of the nation. Higher percentage is better.	38.1%	21.6%	22.0%	Millville, CA
Distance To Nearest City/Town (m)	How far the nearest town is to the location. The further the better, considering the dangers of having a large scale plant close to people.	Palo Cedro (6,343)	Alpine (50,291)	Estancia (7,893)	Alpine, TX

Table 2.1: Location Comparison

2.1.1.2 Solar Power Plant Parameters and Layouts

After selecting the optimal location for the solar power plant, the student team proceeded with the project by using the Array Parameter Tool to determine the parameters of the solar power plant, including its cost and size. The Excel images below show the output of the tool for designing a single rack of solar panels. The minimum temperature refers to the lowest temperature in Estancia, and the rest of the values in the yellow cells were obtained from the solar panel datasheet.



String Size		
Min Temp	-10.1	C
Voc	46.43	V
Ref temp	25	C
Temp Coeff of Voc	-0.0029	/C
Temp delta	-35.1	
temp correction	1.10	
V0c corrected	51.1561097	
string voltage	1000	V
String size	19.5480071	
string size	19	panels
Actual String Voltage	972.0	V

Electrical Rack Size		
	2 in portrait	
Module width	3.283333333	ft
module height	6.541666667	ft
rack width	19	panels
rack height	2	panels
Panels per rack	38	
rack width	62.38333333	ft
rack height	13.08333333	ft
Strings per rack	2	

Figure 2.3: Parameter Tool Location and Solar Panel Inputs

The minimum temperature of a location is an important factor when designing a solar power plant because temperature affects the voltage generated by the solar panels; voltage seems to be higher at lower temperatures. By implementing the minimum temperature into the design, the student team was able to calculate the corrected open circuit voltage of each solar panel and determine how many panels are in a string. There are 19 panels connected in a string, and the actual string voltage is 972 V, which is the closest value the team could get to the desired value of 1000 V, without exceeding it.

Since the client wants a single solar rack to have two strings of panels, the student team designed their solar rack to be that way. As shown in the figure below, a single solar rack is made up of two strings of nineteen solar panels. Therefore, there are thirty-eight panels in a single rack. Its height is 13.1 ft, and its width is 62.4 ft. The team arranged the solar panels in portrait because this arrangement would take up less space than if the panels were arranged horizontally.

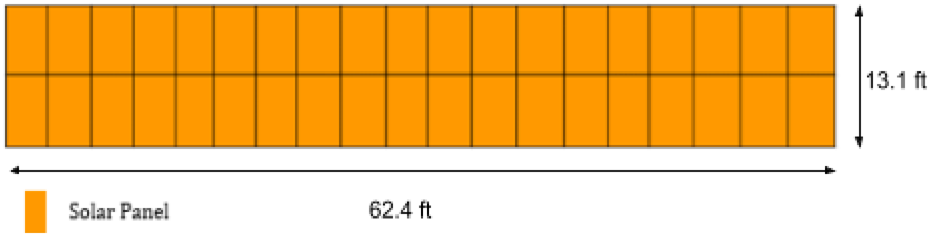
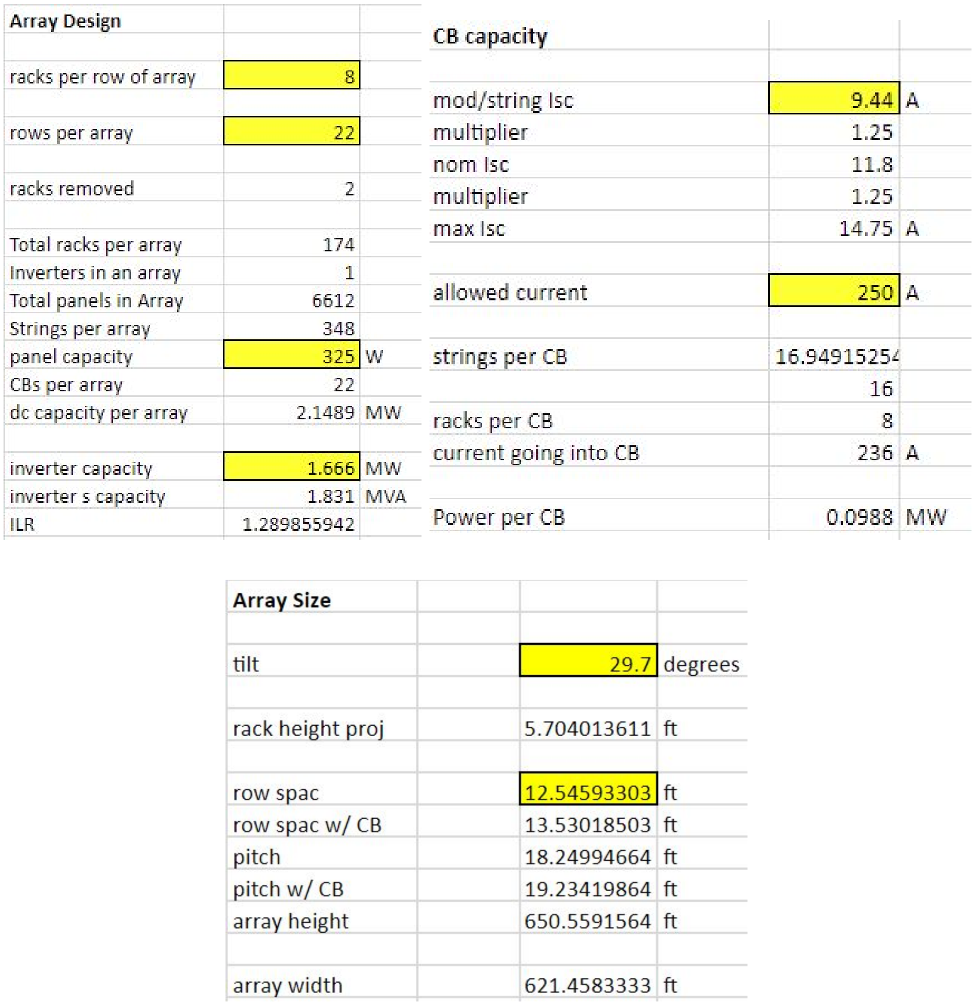


Figure 2.4: Single Rack Layout

After designing the layout of a single rack, the team designed the layout of a single solar array, which is made up of racks, combiner boxes, and an inverter. To do this, the team tried different combinations of "racks per row of array" and "rows per array" to get an ILR value as close to 1.3 as possible. By doing this, the team concluded that the best design for the array is to have 22 rows of 8 racks, with two racks removed to make space for an inverter. Then, the team calculated how many racks a combiner box of an allowed current of 250 A can handle, which turned out to be 8. This means that in a single array, there has to be 22 combiner boxes.

The Excel images below show the output of the array parameter tool for designing a single array. "Allowed current" refers to the maximum current a combiner box can handle, and "tilt" refers to the tilt angle of the racks, which was determined by the latitude of Estancia. The space between the rows in an array was determined by adding the vertical height of a tilted rack and the tangent of the tilt angle together. By including the vertical height of a tilted rack, the team eliminated the chance of a rack being shielded by the rack in front of it.



Array Design		
racks per row of array	8	
rows per array	22	
racks removed	2	
Total racks per array	174	
Inverters in an array	1	
Total panels in Array	6612	
Strings per array	348	
panel capacity	325	W
CBs per array	22	
dc capacity per array	2.1489	MW
inverter capacity	1.666	MW
inverter s capacity	1.831	MVA
ILR	1.289855942	

CB capacity		
mod/string Isc	9.44	A
multiplier	1.25	
nom Isc	11.8	
multiplier	1.25	
max Isc	14.75	A
allowed current	250	A
strings per CB	16.94915254	
	16	
racks per CB	8	
current going into CB	236	A
Power per CB	0.0988	MW

Array Size			
tilt		29.7	degrees
rack height proj		5.704013611	ft
row spac		12.54593303	ft
row spac w/ CB		13.53018503	ft
pitch		18.24994664	ft
pitch w/ CB		19.23419864	ft
array height		650.5591564	ft
array width		621.4583333	ft

Figure 2.5: Parameter Tool Single Array Outputs

After getting an idea of how a single array should look like, the student team used the values that were previously calculated to design the layout of a single array, as shown in the image below. A single array is made up of 22 rows of racks, and each row consists of 8 racks, with 2 removed for one of the rows. Therefore, a single array consists of 174 racks, 22 combiner boxes, and an inverter. The arrangement of the combiner boxes and inverter was determined by the voltage drop calculations across the cables connecting the racks to the combiner boxes and the cables connecting the combiner boxes to the inverter. The length of an array is 527.7 ft and its width is 499.1 ft.

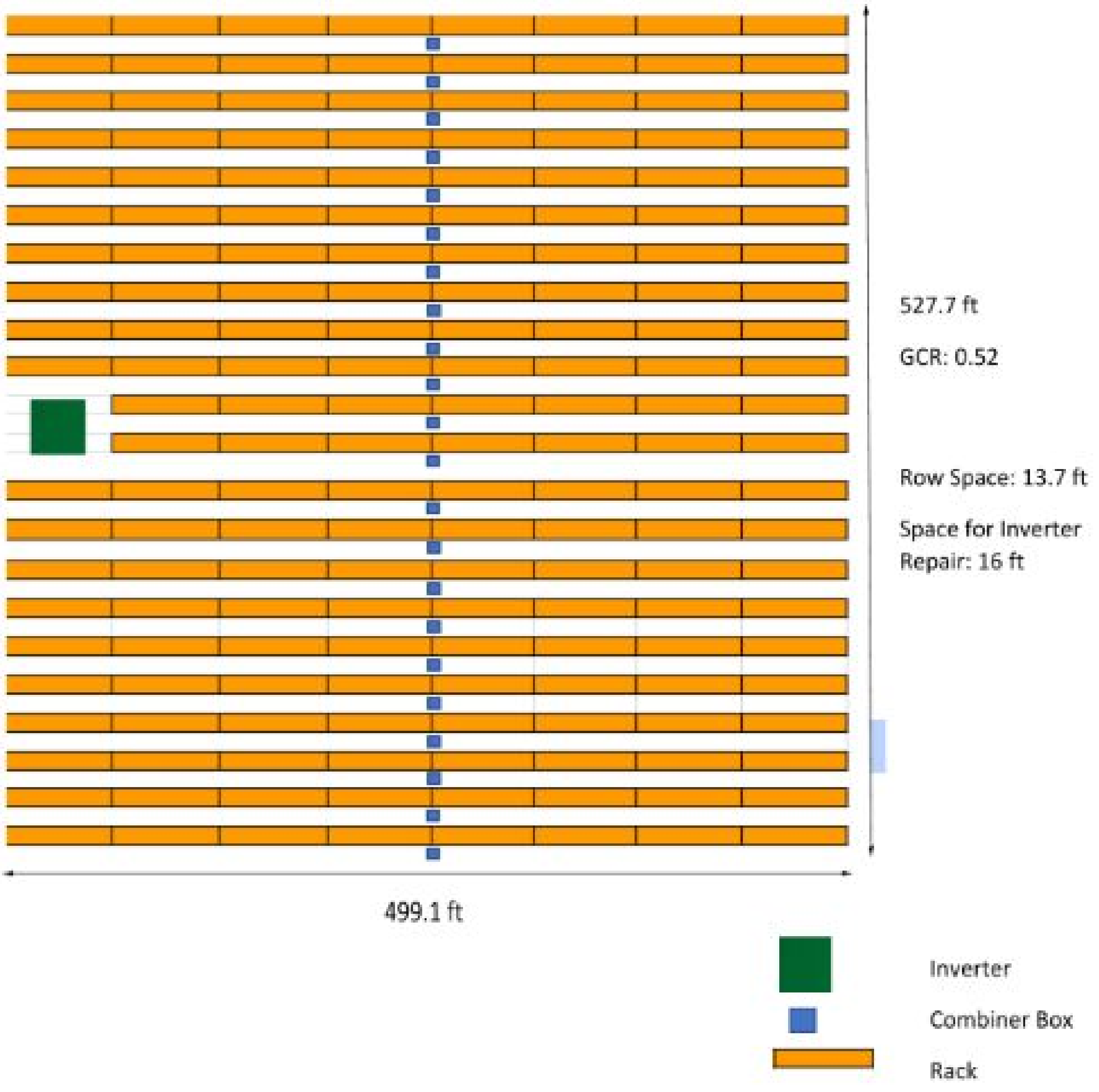
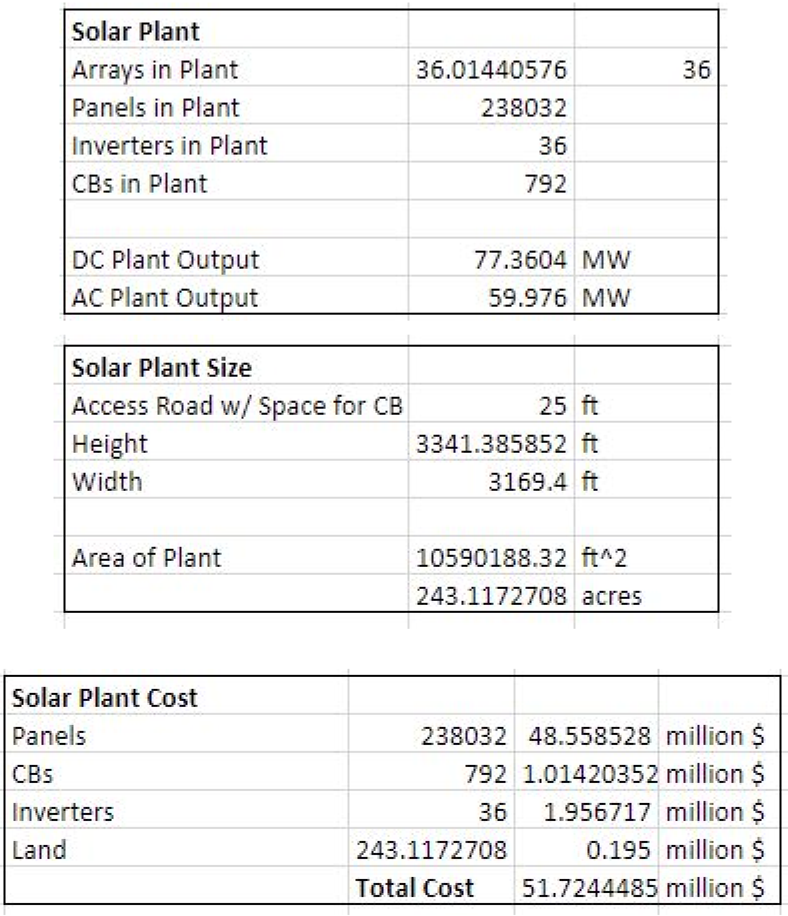


Figure 2.6: Array Layout

The Excel images below show the actual AC power output of the solar plant, and its size and cost, along with the number of solar plant components needed to build the plant. Note that the total cost of the solar plant is solely the total cost of solar panels, combiner boxes, inverters, and land; it does not include the cost of labor and other costs.



Solar Plant		
Arrays in Plant	36.01440576	36
Panels in Plant	238032	
Inverters in Plant	36	
CBs in Plant	792	
DC Plant Output	77.3604	MW
AC Plant Output	59.976	MW

Solar Plant Size		
Access Road w/ Space for CB	25	ft
Height	3341.385852	ft
Width	3169.4	ft
Area of Plant	10590188.32	ft^2
	243.1172708	acres

Solar Plant Cost			
Panels	238032	48.558528	million $
CBs	792	1.01420352	million $
Inverters	36	1.956717	million $
Land	243.1172708	0.195	million $
	Total Cost	51.7244485	million $

Figure 2.7: Parameter Tool Solar Plant Outputs

The image below shows the layout of the entire solar power plant, which consists of thirty-six arrays. The length of the solar plant is 3278.4 ft, and its width is 3106.4 ft. The distance between each array is 16 ft to comply with the standards set by the National Electrical Code (NEC). The space between each array also acts as roads for vehicles, which allows easy access for solar plant maintenance.

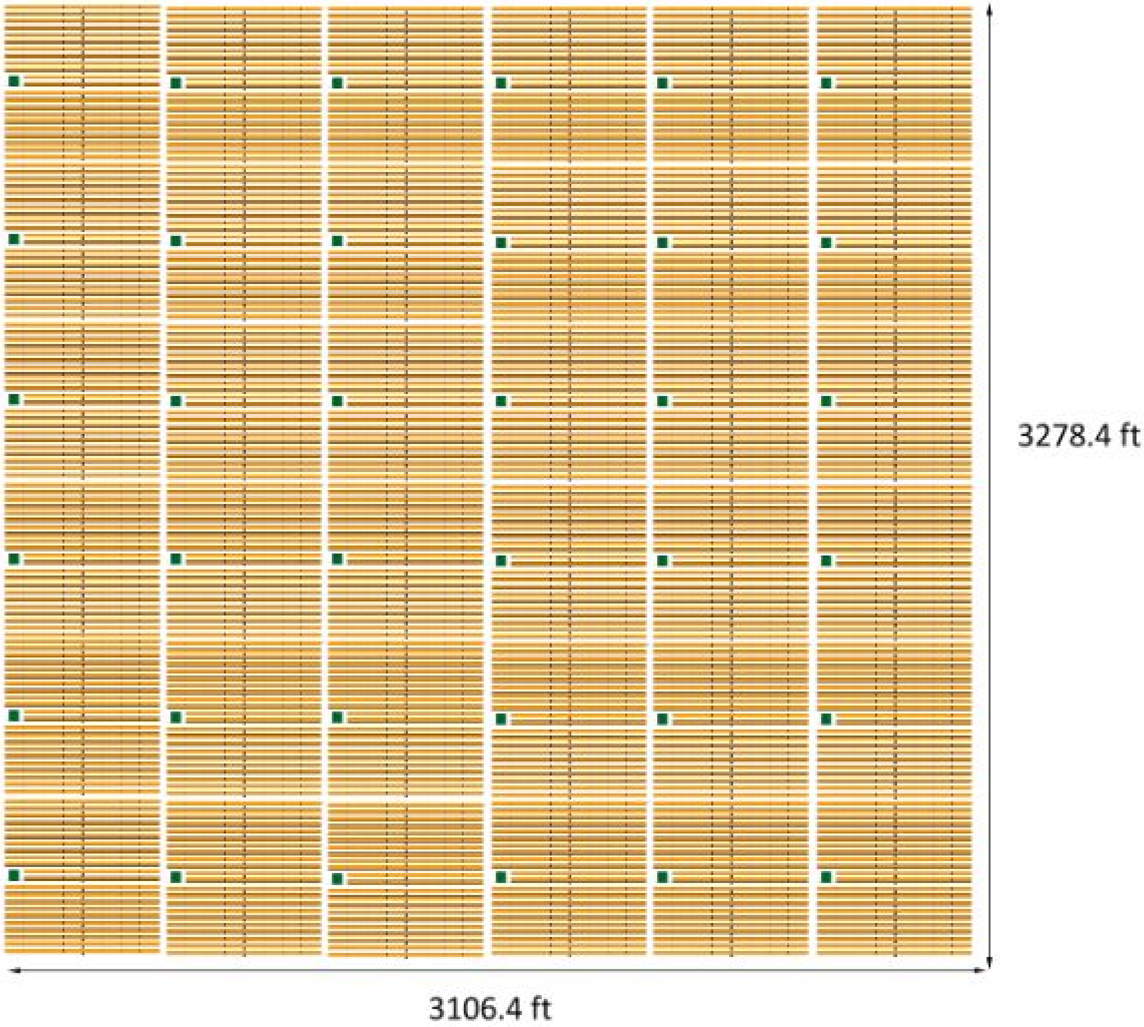


Figure 2.8: Solar Power Plant Layout

2.1.2 Phase 2: 115kv/34.5kv Substation Design

The most important components of the substation are the collectors and feeders, key protection diagram, and one- and three-line diagrams. More information will be added to the sub-sections once the student team begins the substation component of the project.

2.1.2.1 Collectors

A collector system is made up of three inverter skids, each of which contains an inverter and a step-up transformer. The inverter skid takes in the the DC power generated from the solar panels, convert it into AC power, and step up the voltage. A collector system then collects the total power generator from three inverter skids and feeds it into the substation via a feeder. There are three feeders, and each feeder is connected to four collectors. This means that there are a total of twelve collectors that are connected to the substation viz the three feeders.

2.1.2.2 Feeders

Feeders take the output of the collectors and feed it to the 34.5 kV bus of the substation. There are a total of three feeders that are connected to the substation, and each feeder is connected to a circuit breaker and relay for control and protection purposes in case of fault currents.

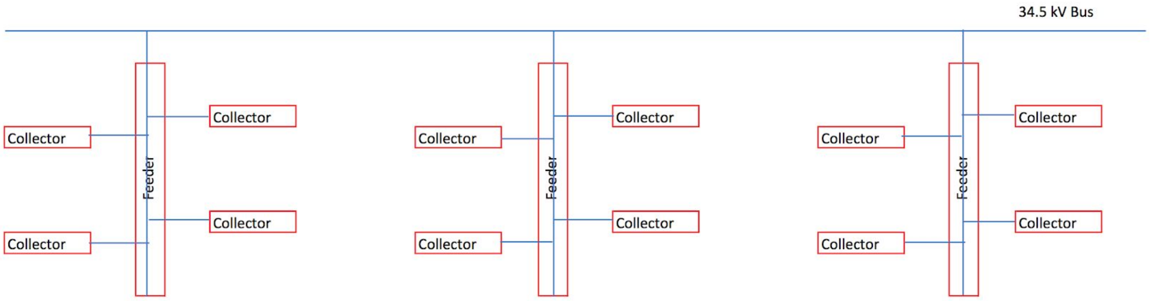


Figure 2.9: Feeders

2.2 DESIGN ANALYSIS

The approach the student team has taken thus far has worked in their favor to a degree. By breaking the project down into phases and then subcomponents, the students have been able to gain a better understanding of project requirements and learn about substation and power plant design. This has allowed the team to take designing the product on a step by step basis and allowed for testing of smaller parts of the project at a time. For a group of students with little to no knowledge of substation design, this has been a great approach.

There is a bit of difficulty in the testing of phase one as there is a limit to the power flow analysis of the solar power plant. To work around this, the team uses different solar power plant development tools such as NREL SAM, the array parameter tool, the voltage drop calculator and Helioscope to compare system outputs once the same input factors are introduced. So far, this test method has proved successful but there is always a chance that it will fail future tests. The student team has also considered using PSS/E by modeling the power plant as a generator but this would mainly support the substation testing phase.

Some of the constraints of the system that the student team designed include the use of a fixed rack system for the power plant. Although this racking system is cheaper than the rotating racks available for use, using it reduces the productivity of the plant as some solar radiation that could have been used in power generation is missed once the sun moves from the optimal position. To make up for this loss, the student team chose a location with a very high solar radiation thus reaching their goal of 60MW power produced. Even with this idea, during months of bad weather system efficiency is expected to be reduced as the panels will not be able to rotate with the sun.

A common misconception in the design of systems that make use of a DC/AC conversion is that the Inverter Load Ratio (ILR) should be 1.2 at most. In reality, the ILR should be 1.3 as systems rarely perform at optimal conditions, and clipping usually should not be an issue at this ILR. However, clipping is a concern at optimal conditions as it increases system losses due to heat and lowers efficiency of the plant.

The use of a 250A combiner box versus a 400A combiner box means an increase in the number of combiner boxes used in the system. An increase in the number of combiner boxes means that the cost of the whole solar plant goes up

One of the main issues that the team has encountered thus far is the final array layout. Finding a good arrangement for the solar array to make a symmetric solar power plant in compliance with IEEE and NEC standards proved difficult as not enough research was done on this. The voltage drop tool provided by the client will hopefully aid in making the solar plant more symmetric.

3. TESTING AND IMPLEMENTATION

3.1 INTERFACE SPECIFICATIONS

Power System Simulator for Engineering (PSS®E—often written as PSS/E) is a software tool used by power system engineers to simulate electrical power transmission networks in steady-state conditions as well as over timescales of a few seconds to tens of seconds. This software will be useful in testing the substation.

3.2 HARDWARE AND SOFTWARE

Array Parameter Tool is a spreadsheet provided by the client, and it calculates the area and cost of the solar power plant, as well as ILR (Inverter Load Ratio) value. This tool will help with the selection of a suitable location and the best shape of the solar power plant.

The System Advisor Model (SAM) is a software of National Renewable Energy Laboratory. This software is recommended by the client, and it makes performance predictions and cost of energy estimates for grid-connected power projects based on installation and operating costs and system design parameters that you specify as inputs to the model. Therefore, this software is useful to choose suitable locations for the project.

3.3 FUNCTIONAL TESTING

Designing the solar power plant is tested by the array parameter tool that was given from Black and Veatch. Input of the array parameter tool are the specifications of the inverter, combiner box, and the shape of the plant. Then, it will calculate the number of solar panels (also the number of the rack), power from each rack, currents collected from each rack, number of combination boxes needed, Inverter Load Ratio (ILR), the size and the cost of the plant. This tool is used to test the handwritten calculations and the shapes decision of the project team.

The System Advisor Model (SAM) consider annual solar radiation, shading, conductor losses, statistical component mismatch, inverter clipping and soiling base on latitude and weather of the locations. Therefore, SAM is a good software to test the efficiency of the location for the project.

To test the voltage drop and current calculations, the spreadsheet that is given from the client will let the team know what are the correct voltage drops and currents from the conductor. From that, the project team can compare to their handwritten calculations and make the best decision.

National Electrical Code (NEC) is a resources to test the suitability of the conductors for each connections. The project team need to choose the conductors based on the currents that are approved by Black and Veatch. Then, the project team can use NEC to see whether their conductors are suitable.

3.4 NON-FUNCTIONAL TESTING

There's no specific testing process that could be done because it is not within the scope of the project but there are several non-functional considerations that need to be done, such as the products that we choose to build the solar power plant:

3.4.1 Determine the Types of Solar Panels

Choosing between monocrystalline or polycrystalline is very crucial. This does not cause functional issue to the solar power plant but it could increase the cost of building the power plant as it changes the power output of each solar panel. With the power output of each panel different, the design might require either more or less solar panels.

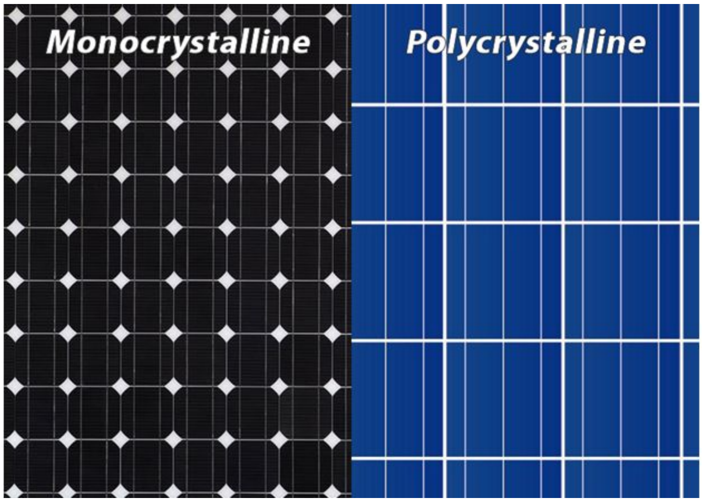
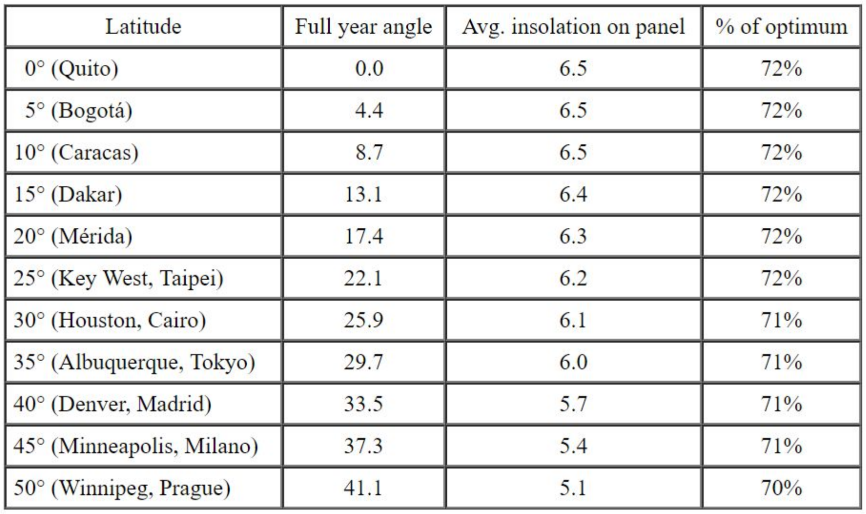


Figure 3.1: Two types of Solar Panels

Figure above shown is the comparison between the appearance of monocrystalline and polycrystalline solar panel. Monocrystalline solar panel has greater ability on receiving heat than polycrystalline solar panel because it has higher purity value. But based on the market research, polycrystalline solar panels are cheaper than the monocrystalline solar panels as close as half of its price.

3.4.2 Determine the Solar Racks

The types of solar racks refer to the types of rack system that we are implementing. There are two common types of rack systems: *fixed rack system* and *variable rack system*. The types of racks that we use could affect the performance of the solar panels on receiving sunlight as it affects the amount of sunlight that the solar panels will exposed to throughout the year. To use fixed rack system, we refer to **Table 3.1** for mounting the rack at the most optimum angle based on the latitude of the location.



Latitude	Full year angle	Avg. insolation on panel	% of optimum
0° (Quito)	0.0	6.5	72%
5° (Bogotá)	4.4	6.5	72%
10° (Caracas)	8.7	6.5	72%
15° (Dakar)	13.1	6.4	72%
20° (Mérida)	17.4	6.3	72%
25° (Key West, Taipei)	22.1	6.2	72%
30° (Houston, Cairo)	25.9	6.1	71%
35° (Albuquerque, Tokyo)	29.7	6.0	71%
40° (Denver, Madrid)	33.5	5.7	71%
45° (Minneapolis, Milano)	37.3	5.4	71%
50° (Winnipeg, Prague)	41.1	5.1	70%

Table 3.1: Solar Racks Mounting Angle based on Latitude

3.5 PROCESS

In order to come out with a better location that could receive high solar radiation yearly and at the same time cheaper in price, we run through the follow process of simulation and testing:

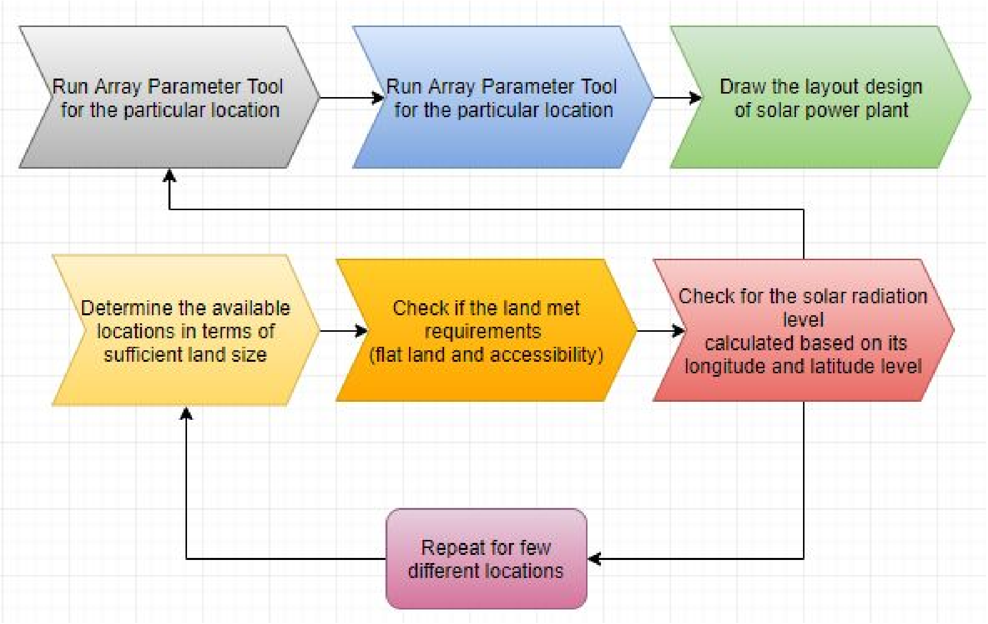


Figure 3.2: Testing Process of Solar Power Plant Layout

The figure above shown is the flow diagram of the construction of the solar power plant layout. The first three steps mainly illustrates the process on researching a suitable location. It should be repeated several times until the location satisfy all the requirements and cheaper in cost.

3.6 RESULTS

The results from the SAM simulations are recorded as below:

Solar Radiation Level:

Location	Solar Radiation Level (kWh/m^2/day)
Millville, CA	5.67
Barstow, CA	6.76
Sabinoso, NM	6.27
Estancia, NM	6.41
Plains, Texas	6.54
Alpine, Texas	6.49

Table 3.2: Location Solar Radiation Level

The amount of sunlight the solar power plant design can provide will be determined fully based on its average solar radiation level throughout a year.

4. CLOSURE MATERIALS

4.1 CONCLUSION

Conclusively in order to design utility-scale 60 MW Solar Power Plant and 115/34.5 kV, the team will work side-by-side with Black & Veatch to achieve the goal. The project is splitted into two phases. First the power generation, which is the solar plant that contain all the solar arrays and inverters. The second phase is the substation, which contains all the necessary components (transformer, protection relays, monitoring equipment, and capacitor bank). So far we have been able to accomplish all the deliverable for the first semester. after extensive research in order to find the optimal location with higher solar radiation, optimal weather condition, and cheaper land, we choose Estancia, NM. Based on those parameter, we were able to determine the amount of solar modules, string size, combiner boxes, and inverters needed as well as calculating the solar power plant cost. In the second semester, will dive deeper into the substation design and utilize AutoCAD to optimize the one-line diagram, three-line diagram, protection, and control schematic.

4.2 WORKS CITED

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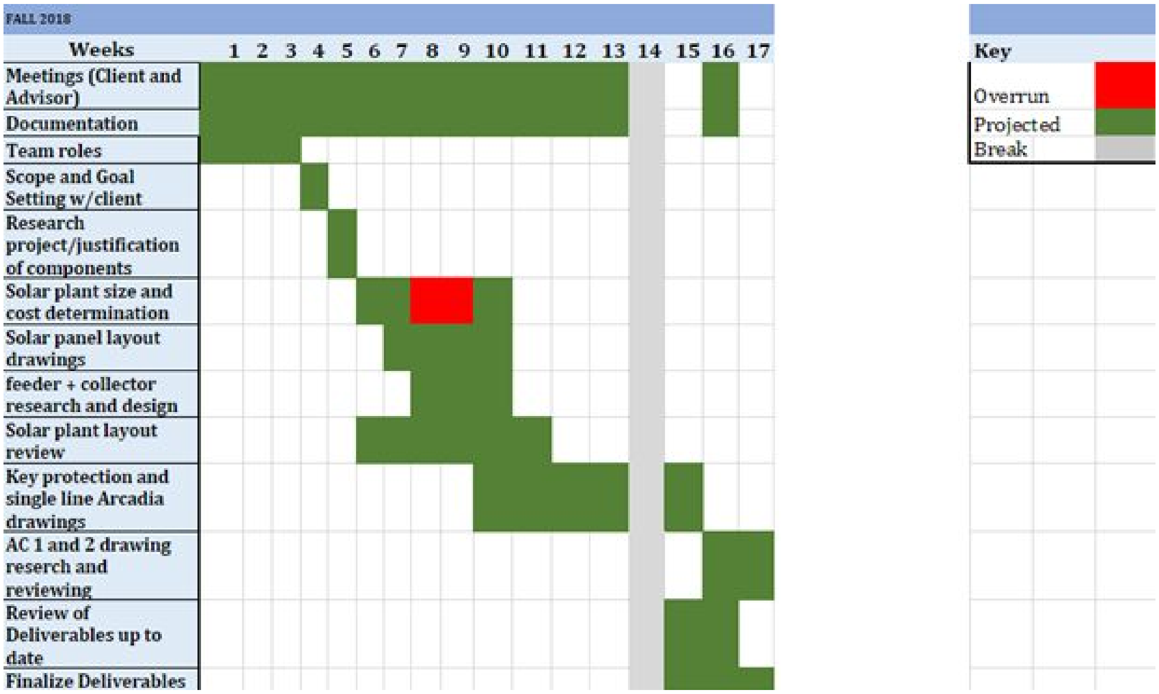
4.3 APPENDIX

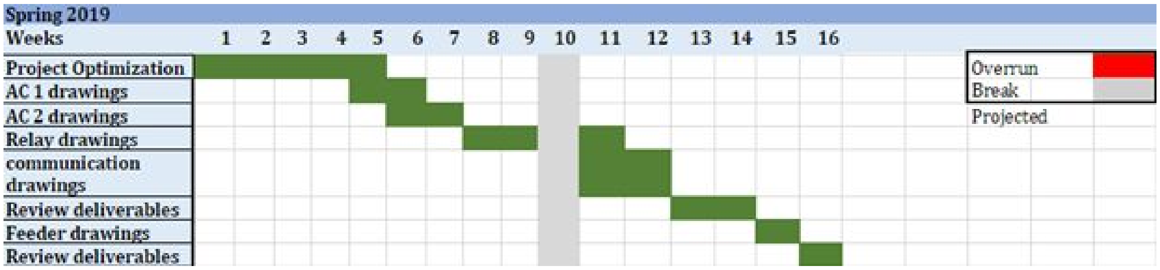


FALL 2018

Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Meetings (Client and Advisor)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	▨		🟩	
Documentation	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	▨		🟩	
Team roles	🟩	🟩	🟩											▨			
Scope and Goal Setting w/client				🟩										▨			
Research project/justification of components					🟩									▨			
Solar plant size and cost determination						🟩	🟩	🟥	🟥	🟩				▨			
Solar panel layout drawings							🟩	🟩	🟩	🟩				▨			
feeder + collector research and design								🟩	🟩	🟩				▨			
Solar plant layout review						🟩	🟩	🟩	🟩	🟩	🟩			▨			
Key protection and single line Arcadia drawings										🟩	🟩	🟩	🟩	▨	🟩		
AC 1 and 2 drawing reserch and reviewing														▨		🟩	🟩
Review of Deliverables up to date														▨	🟩	🟩	
Finalize Deliverables														▨	🟩	🟩	🟩

Key	
Overrun	🟥
Projected	🟩
Break	▨

Figure 4.1: Fall 2018 Gantt Chart



Spring 2019

Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Project Optimization	🟩	🟩	🟩	🟩	🟩					▨						
AC 1 drawings					🟩	🟩				▨						
AC 2 drawings						🟩	🟩			▨						
Relay drawings								🟩	🟩	▨	🟩					
communication drawings										▨	🟩	🟩				
Review deliverables										▨			🟩	🟩		
Feeder drawings										▨					🟩	
Review deliverables										▨						🟩

Overrun	🟥
Break	▨
Projected	

Figure 4.2: Spring 2019 Gantt Chart

Arcadia one-line diagram: