115kV / 34.5kV Solar Power Plant Substation Design

FINAL PROJECT REPORT

EE 492 (Senior Design II)
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List of Definitions

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, Emily Neumann and Patrick Kester, employees of Black & Veatch, for their time and willingness to oversee the project and provide the team with the tools necessary for the design aspects of the project. The team would also like to thank Dr. Ajjarapu for his time and expertise while acting as the faculty advisor. This project has been a great learning experience, and the team would like to express gratitude to the Department of Electrical and Computer Engineering at Iowa State University for this wonderful opportunity.

1.2 PROBLEM AND PROJECT STATEMENT

Black & Veatch wanted to provide clean energy for a grid that is shifting towards renewables in order to decrease its dependence on fossil fuels. Because of this, the senior design team was assigned to design a 60 MW solar power plant that feeds a 115kV/34.5kV substation based on various specifications and requirements set by Black & Veatch. Deliverables for this design project include:

- Location specification
- Solar power plant layout drawings
- Conductor sizing
- Voltage drop calculations
- Collector and feeder drawings
- Substation protection and controls schematics
- Substation grounding grid design
- Man-hour budget, schedule and cost estimates

1.3 INTENDED USERS AND USES

Since the team is acting as a consulting company, the solar power plant and substation are designed for a utility company and not the end users, who are those that are connected to the opposite end of the grid.

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.

1.4 ASSUMPTIONS AND LIMITATIONS

Assumptions

Assuming that the average home in the United States consumes approximately 5kW of power. Under this assumption, the design would provide power to roughly 12,000 homes. Another assumption is that the end product is designed to meet all the standards and codes 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 was found to be approximately 73.7 million USD excluding the cost of labor. The team worked to reduce the cost of the project throughout the year.

1.5 EXPECTED END PRODUCT AND DELIVERABLES

The team separated the project into two phases, one carried out in the Fall 2018 semester and the other in the Spring 2019.

First Semester Deliverables:

1. Solar power plant layouts

This included 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. The total cost of designing the product was calculated and a complete solar plant layout created based on this information.

2. Solar plant wiring diagrams

After carrying out array parameter calculations and going through system evaluation, the team determined how different components of the solar power plant would be wired. To do this, the team placed components in suitable locations to wire the plant efficiently and minimize voltage drop across the conductors.

3. Conductor sizing

Conductor sizing is the selection of conductors used in system wiring based on the Maximum Power Current or IMP, which is multiplied by a safety factor of 1.25. This information is used in the voltage drop calculation for validation and verification of the system.

4. Engineering man-hour budget

The team developed a Gantt Chart to track the actual hours spent on activities related to the completion of the project. This information was then used to create a man-hour budget, which shows the amount of work performed by a worker in one hour.

Second Semester Deliverables:

1. Protection and Controls Schematics

The second semester involved working on substation protection and controls schematics, which can be split into AC schematics, DC schematics and substation grounding.

AC schematics are drawings that show all three phases of the primary system. The location of all the important equipment is shown in these, as well as detailed connections and terminal numbers for the system.

DC schematics are primary drawings that show the protection and controls functions of equipment in the substation. Although some control functions utilise AC power, they are included in the primary wiring diagrams.

Substation grounding is a necessary protection process that ensures that humans in physical contact with the substation are not harmed by high voltages in the system.

2. Revise/improve last semester's drawing

One of the main focuses of the second semester was reviewing and justifying designs created in the first semester to add improvements are refresh the memory of team members.

3. Finalize the project requirements

This included carrying out system tests and preparing documentation so that deliverables can be provided to the client in a timely and clear manner.

2. System Design and Development

This section describes and explains the designs of the solar power plant and substation designs. Section 2.1 explains the final design of the project and section 2.2 explains the analysis of the design.

2.1 Proposed Design

We are breaking down the design into two main separate phases: *2.1.1 Phase 1: 60MW Solar Power Plant* and *2.1.2 Phase 2: 115kV/34.5kV Substation Design*. ***Figure 2.1*** is the block diagram of the design project, and it shows the power flow from generation all the way to transmission.

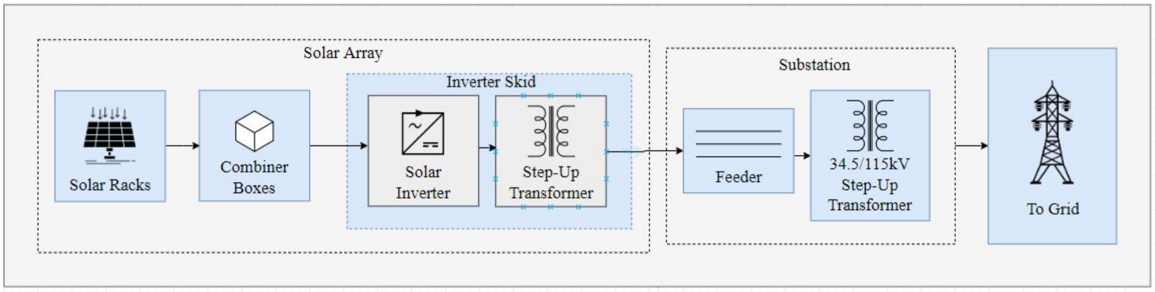
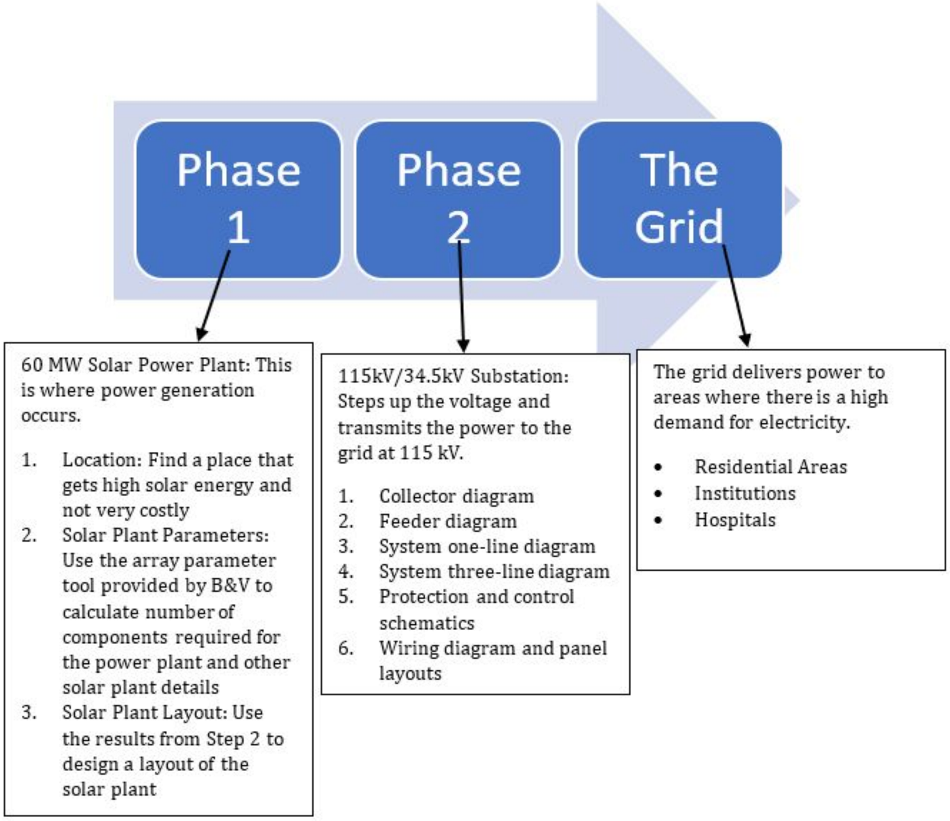


Figure 2.1: Project Block Diagram

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 in a parallel connection. Then, the combined voltage (1000V) is input into inverters to convert the DC power into AC power with a DC-to-AC ratio, also known as Inverter Load Ratio (ILR) 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. The reason of having an ILR of 1.3 is to provide stability in the generated power because the solar power plant might not always generate power at its nominal condition. Therefore, having a higher ILR ratio might cause a little more power loss as heat under nominal condition but it provides a more consistent power throughout the year. 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.

Figure 2.2 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 spreadsheet used to determine the parameters and details of the solar plant.
- Voltage Drop Tool: Excel spreadsheet 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. Will be used for testing of our solar power plant design.

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 do not receive much cloud coverage 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.

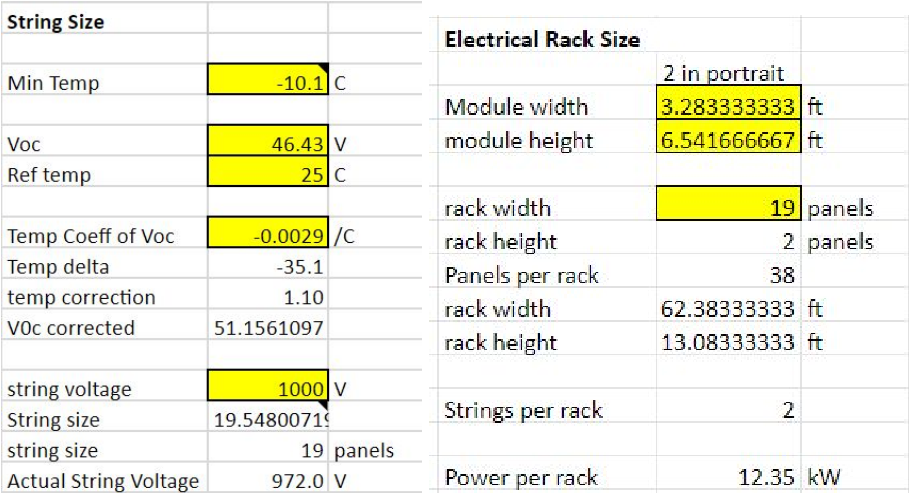
Categories	Description	Millville, CA	Alpine, TX	Estancia, NM	Who Wins?
Average Solar Radiation Per Day (kWh/m^2/day)	How much solar radiation a location gets per day. Higher solar radiation is better.	5.67	6.49	6.41	Alpine, TX
Land Size and Price	The size and price of each location. More land for a cheap 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 Per Year	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.. Higher elevation is better.	600	4514	6103	Estancia, NM
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. ***Figure 2.3*** shows 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	
Power per rack	12.35	kW

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. 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 2.4***, 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.

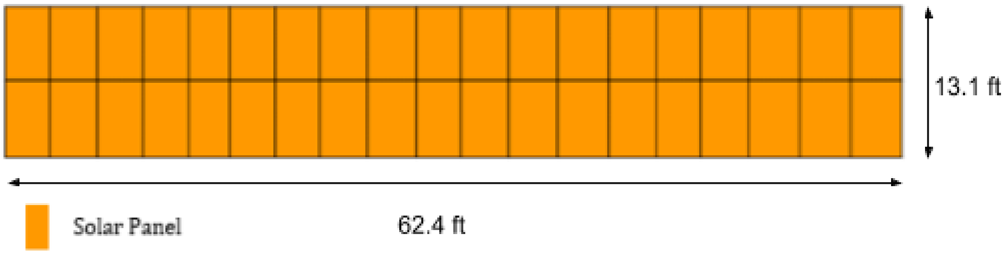
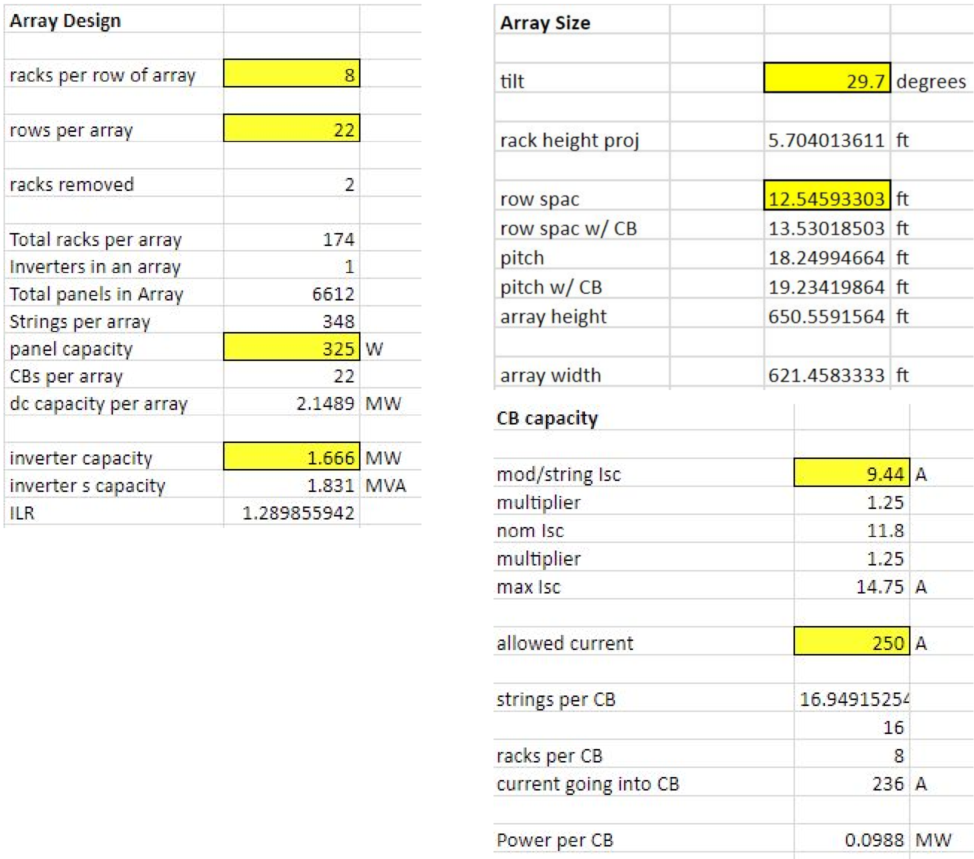


Figure 2.4: Single Rack Layout

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, are 22 combiner boxes.

Figure 2.5 shows 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 tilt angle is also a very important factor when designing a power plant because the tilt angle of solar panels determine how much solar energy is being generated. Therefore, the design team chose the tilt angle that would allow the most power generation. 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	

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

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

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 ***Figure 2.6***. 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. Also, there is a distance of 16 ft between the inverter and the row of racks below it to reserve enough space for inverter maintenance and repair. As shown in the figure below, the length of an array is 527.7 ft and its width is 499.1 ft.

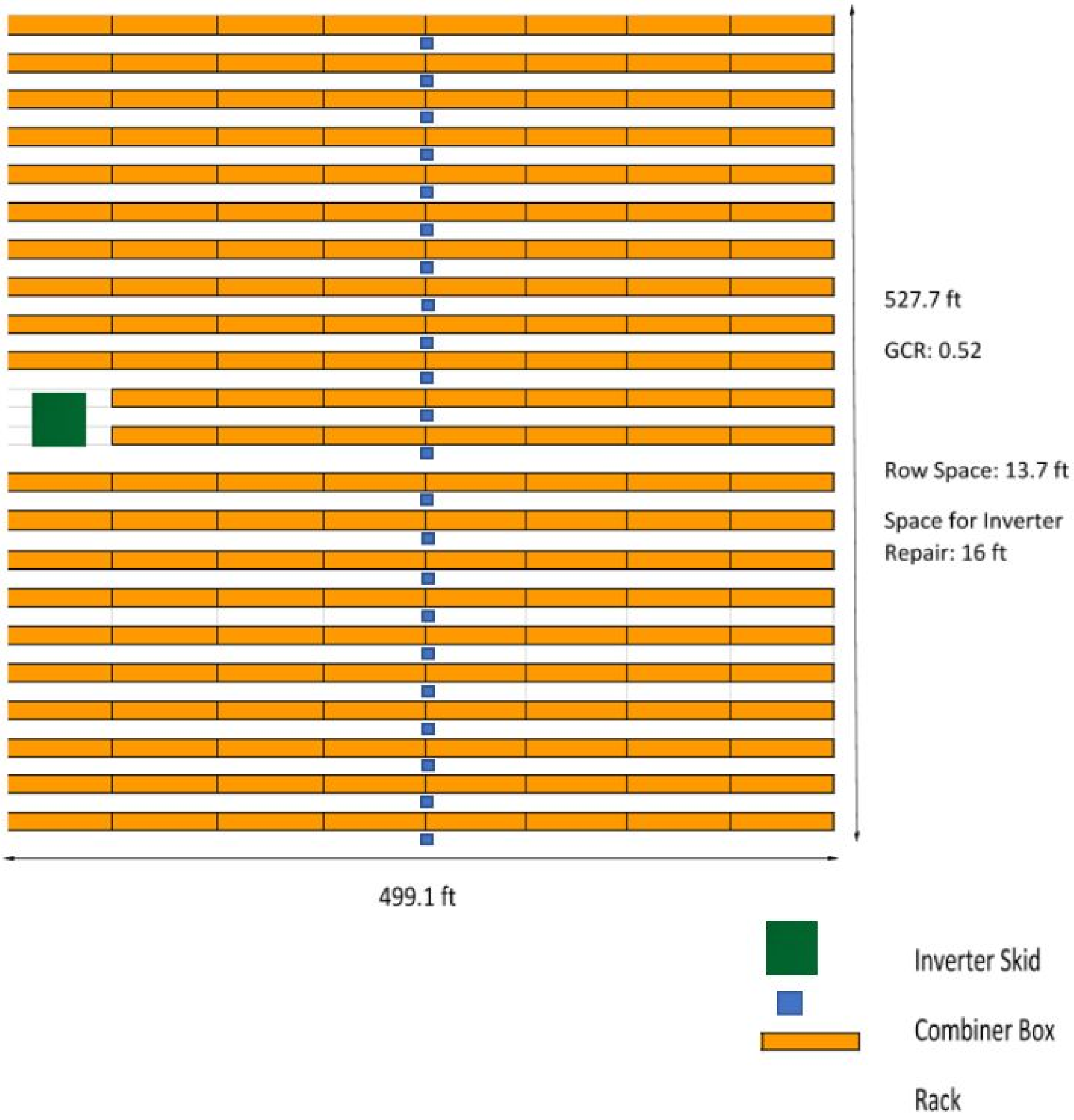
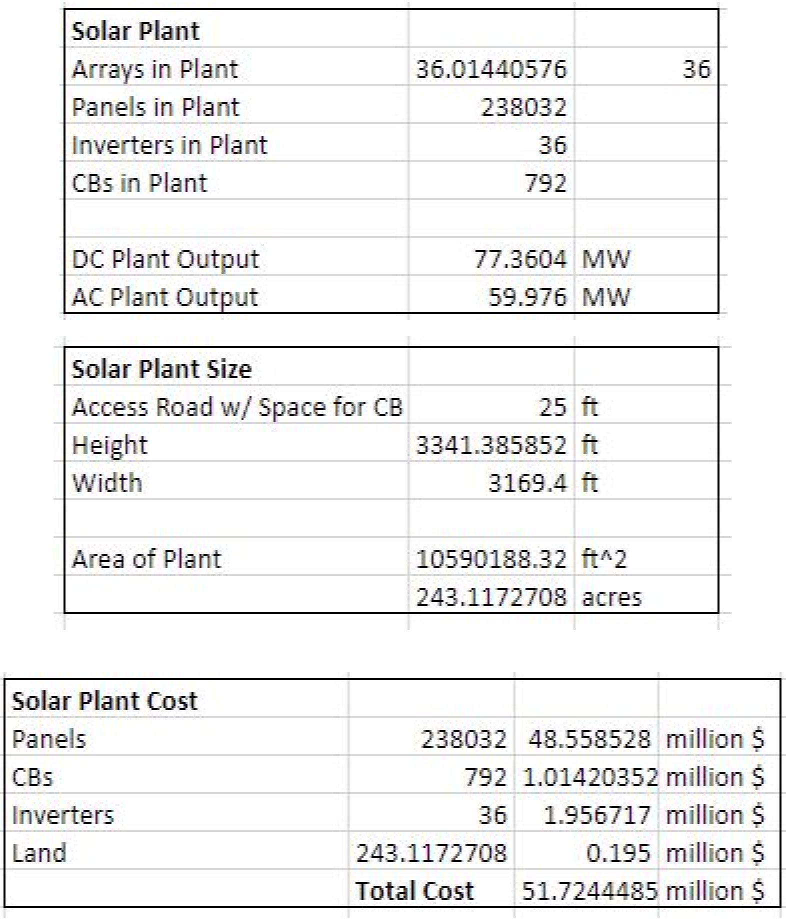


Figure 2.6: Array Layout

Figure 2.7 shows 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

Figure 2.8 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.

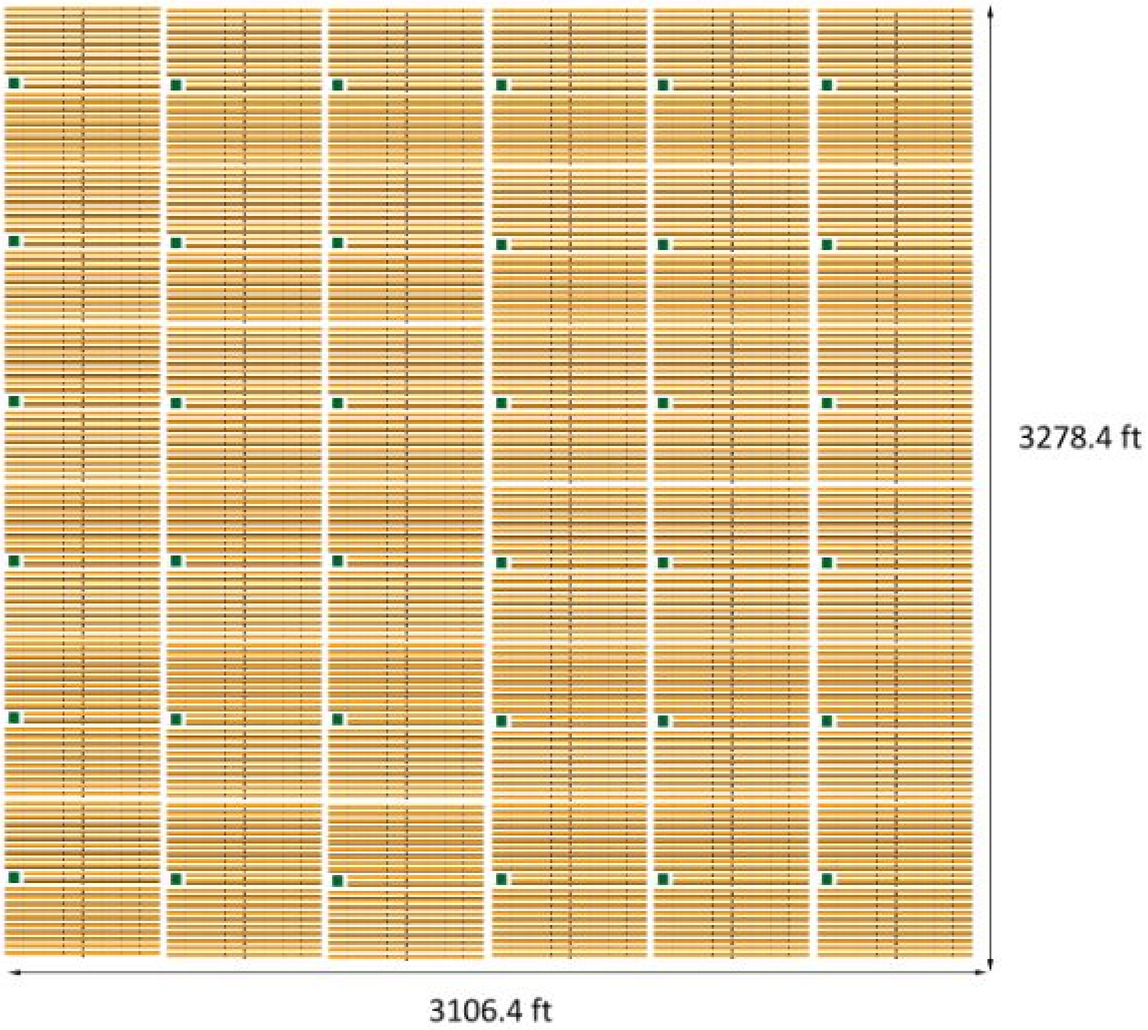
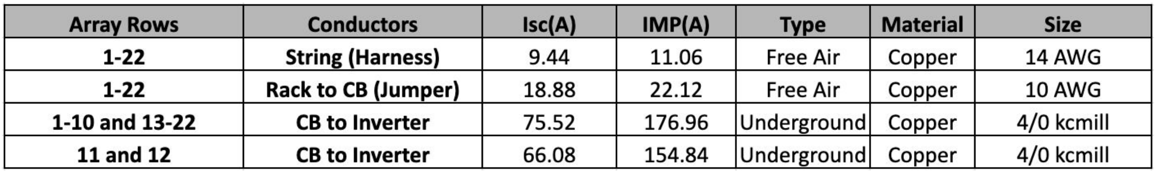


Figure 2.8: Solar Power Plant Layout

2.1.1.3 Conductors Sizing and Voltage Drop Calculation

The final step for designing solar power plan was to calculate the current go through each connection to choose appropriate conductors and to consider about the voltage drop in each conductor.

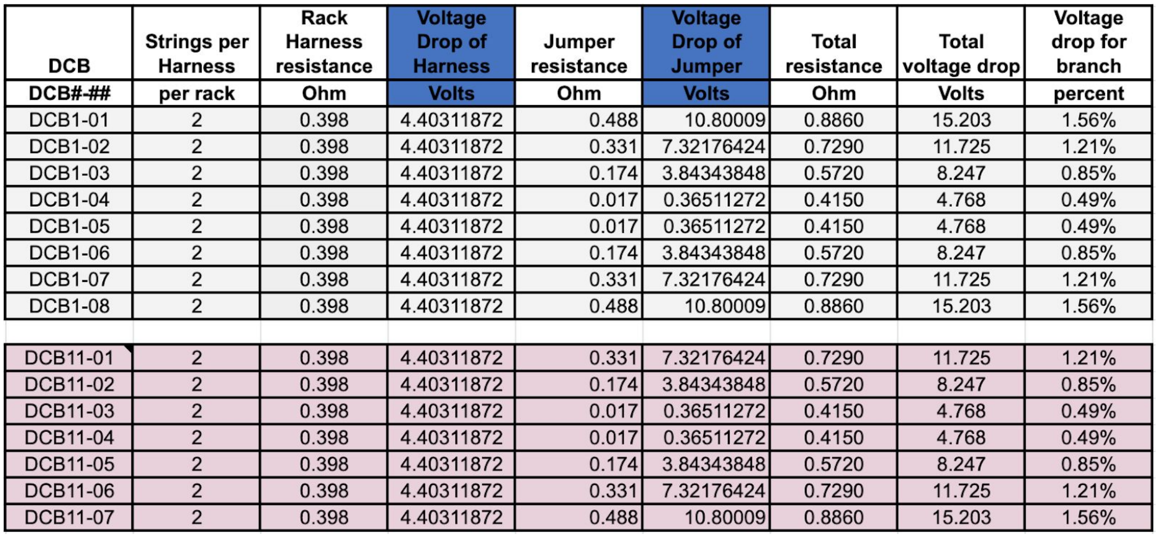
STEP 1: Determining the conductors size. The table below shows the amount of each current that will go in different connections of an array. It includes the current between the string, the current from the racks to the combiner boxes, and the currents from the combiner boxes to the inverter. Then, from the safety factor (additional 25%) and the National Electrical Code (NEC), determining the conductor size for each connection.



Array Rows	Conductors	Isc(A)	IMP(A)	Type	Material	Size
1-22	**String (Harness)**	9.44	11.06	Free Air	Copper	14 AWG
1-22	**Rack to CB (Jumper)**	18.88	22.12	Free Air	Copper	10 AWG
1-10 and 13-22	**CB to Inverter**	75.52	176.96	Underground	Copper	4/0 kcmill
11 and 12	**CB to Inverter**	66.08	154.84	Underground	Copper	4/0 kcmill

Table 2.2: Conductors Sizing

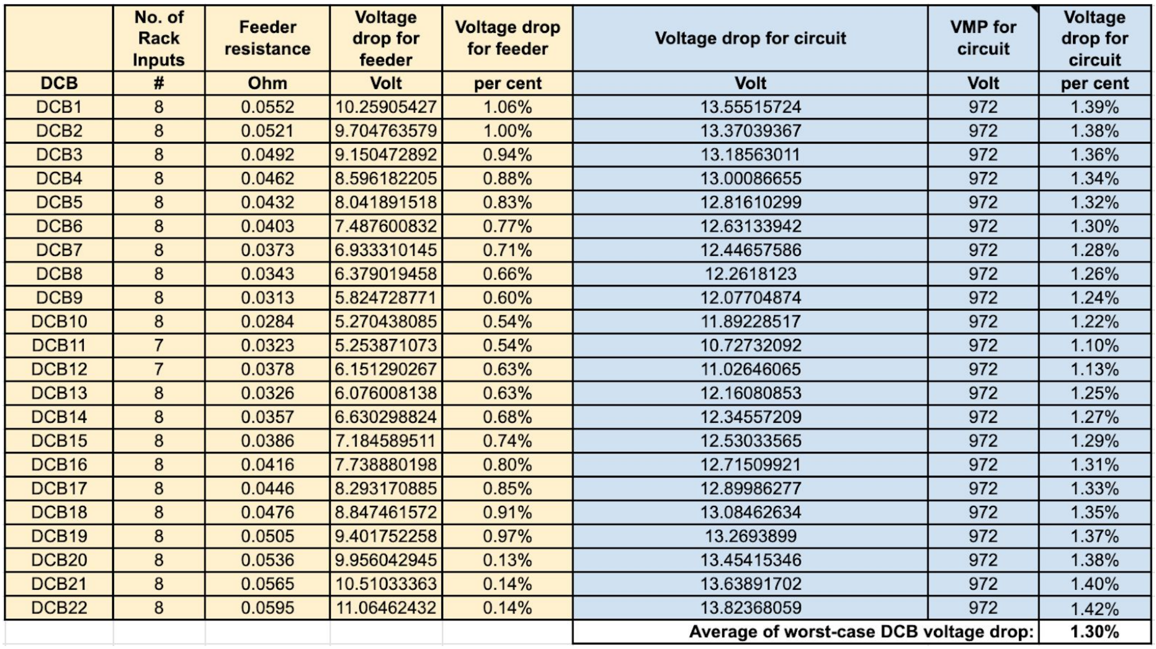
STEP 2: Determining the voltage drop from solar panels to combiner boxes. The table below shows the resistances in each string of solar panels and in each connection from the racks to the combiner boxes. From that, the voltage drops from the solar panels to combiner boxes were calculated.



DCB	Strings per Harness	Rack Harness resistance	Voltage Drop of Harness	Jumper resistance	Voltage Drop of Jumper	Total resistance	Total voltage drop	Voltage drop for branch
DCB#-##	**per rack**	**Ohm**	**Volts**	**Ohm**	**Volts**	**Ohm**	**Volts**	**percent**
DCB1-01	2	0.398	4.40311872	0.488	10.80009	0.8860	15.203	1.56%
DCB1-02	2	0.398	4.40311872	0.331	7.32176424	0.7290	11.725	1.21%
DCB1-03	2	0.398	4.40311872	0.174	3.84343848	0.5720	8.247	0.85%
DCB1-04	2	0.398	4.40311872	0.017	0.36511272	0.4150	4.768	0.49%
DCB1-05	2	0.398	4.40311872	0.017	0.36511272	0.4150	4.768	0.49%
DCB1-06	2	0.398	4.40311872	0.174	3.84343848	0.5720	8.247	0.85%
DCB1-07	2	0.398	4.40311872	0.331	7.32176424	0.7290	11.725	1.21%
DCB1-08	2	0.398	4.40311872	0.488	10.80009	0.8860	15.203	1.56%
DCB11-01	2	0.398	4.40311872	0.331	7.32176424	0.7290	11.725	1.21%
DCB11-02	2	0.398	4.40311872	0.174	3.84343848	0.5720	8.247	0.85%
DCB11-03	2	0.398	4.40311872	0.017	0.36511272	0.4150	4.768	0.49%
DCB11-04	2	0.398	4.40311872	0.017	0.36511272	0.4150	4.768	0.49%
DCB11-05	2	0.398	4.40311872	0.174	3.84343848	0.5720	8.247	0.85%
DCB11-06	2	0.398	4.40311872	0.331	7.32176424	0.7290	11.725	1.21%
DCB11-07	2	0.398	4.40311872	0.488	10.80009	0.8860	15.203	1.56%

Table 2.3: Solar Panels to Combiner Boxes Voltage Drops

STEP 3: The final step was to determine the voltage drops from combiner boxes to the inverters, then from that, determining the voltage drops of the whole solar power plant. The table shows the voltage drops from the combiner boxes to the inverters (yellow side). Sames as the last step, these voltage drops were calculated from the resistance of the conductors that connect the combiner boxes with the inverter (called feeder on the table). From that, the voltage drops for the whole solar power plant were calculated, and the average worst voltage drop would be 1.30%.



	No. of Rack Inputs	Feeder resistance	Voltage drop for feeder	Voltage drop for feeder	Voltage drop for circuit	VMP for circuit	Voltage drop for circuit
DCB	#	Ohm	Volt	per cent	Volt	Volt	per cent
DCB1	8	0.0552	10.25905427	1.06%	13.55515724	972	1.39%
DCB2	8	0.0521	9.704763579	1.00%	13.37039367	972	1.38%
DCB3	8	0.0492	9.150472892	0.94%	13.18563011	972	1.36%
DCB4	8	0.0462	8.596182205	0.88%	13.00086655	972	1.34%
DCB5	8	0.0432	8.041891518	0.83%	12.81610299	972	1.32%
DCB6	8	0.0403	7.487600832	0.77%	12.63133942	972	1.30%
DCB7	8	0.0373	6.933310145	0.71%	12.44657586	972	1.28%
DCB8	8	0.0343	6.379019458	0.66%	12.2618123	972	1.26%
DCB9	8	0.0313	5.824728771	0.60%	12.07704874	972	1.24%
DCB10	8	0.0284	5.270438085	0.54%	11.89228517	972	1.22%
DCB11	7	0.0323	5.253871073	0.54%	10.72732092	972	1.10%
DCB12	7	0.0378	6.151290267	0.63%	11.02646065	972	1.13%
DCB13	8	0.0326	6.076008138	0.63%	12.16080853	972	1.25%
DCB14	8	0.0357	6.630298824	0.68%	12.34557209	972	1.27%
DCB15	8	0.0386	7.184589511	0.74%	12.53033565	972	1.29%
DCB16	8	0.0416	7.738880198	0.80%	12.71509921	972	1.31%
DCB17	8	0.0446	8.293170885	0.85%	12.89986277	972	1.33%
DCB18	8	0.0476	8.847461572	0.91%	13.08462634	972	1.35%
DCB19	8	0.0505	9.401752258	0.97%	13.2693899	972	1.37%
DCB20	8	0.0536	9.956042945	0.13%	13.45415346	972	1.38%
DCB21	8	0.0565	10.51033363	0.14%	13.63891702	972	1.40%
DCB22	8	0.0595	11.06462432	0.14%	13.82368059	972	1.42%
					Average of worst-case DCB voltage drop:		**1.30%**

Table 2.4: Combiner Boxes to Inverters Voltage Drops

2.1.2 Phase 2: 115kV/34.5kV Substation Design

The substation components can be broken down into *inverter skids, collectors, feeders, key protection diagram/one-line diagram, dc schematic,, ac schematic/three-line diagrams* and *substation grounding*. *Collectors* and *feeders* act as wiring connections to integrate solar power plant design into substation design through inverter skids. *Key Protection Diagram* is the first substation design drawing that was designed based on Arcadia one-line diagram. Therefore, all the rest of our drawings will be designed based on the *Key Protection Diagram*. ***Figure 2.9*** shows the hierarchy of substation design drawings that are included in our project scope.

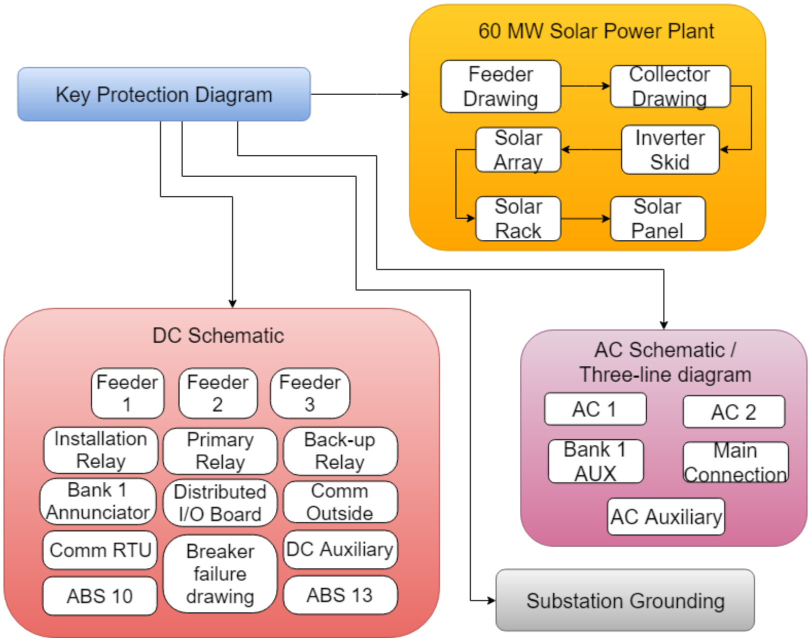


Figure 2.9: Protection and Control Drawings Hierarchy

2.1.2.1 Inverter Skids

Inverter skid is the combination of both solar inverter and 357V/34.5kV Step-Up Transformer. Based on the requirement of client, we will be using Eaton 1831kVA Solar Inverter in our design. From earlier, we know that each solar array has one inverter skid, since we have 36 solar arrays, we will be having a total number of 36 inverter skids. Inverter skids are all connected to the substation design by the combinations of collectors and feeders. ***Figure 2.10*** shows the inverter skid layout design with its connections and parameters.

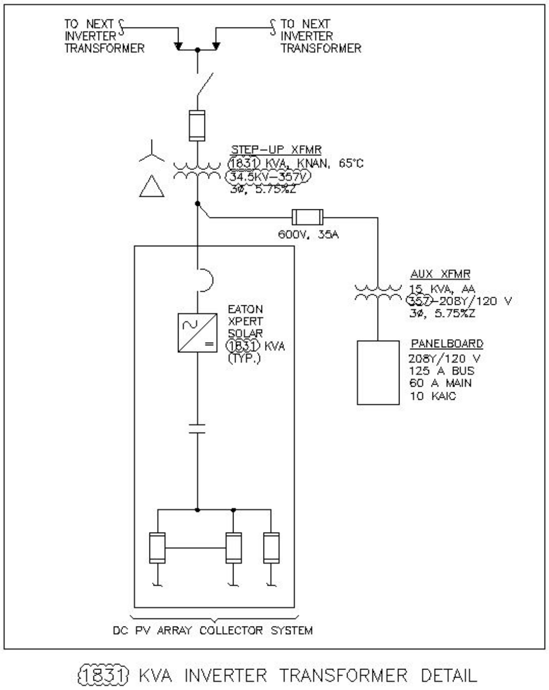


Figure 2.10: Inverter Skid Layout

2.1.2.2 Collectors

A collector 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. ***Figure 2.11*** shows the collector layout design of one collector that contains three inverter skids and a surge arrester.

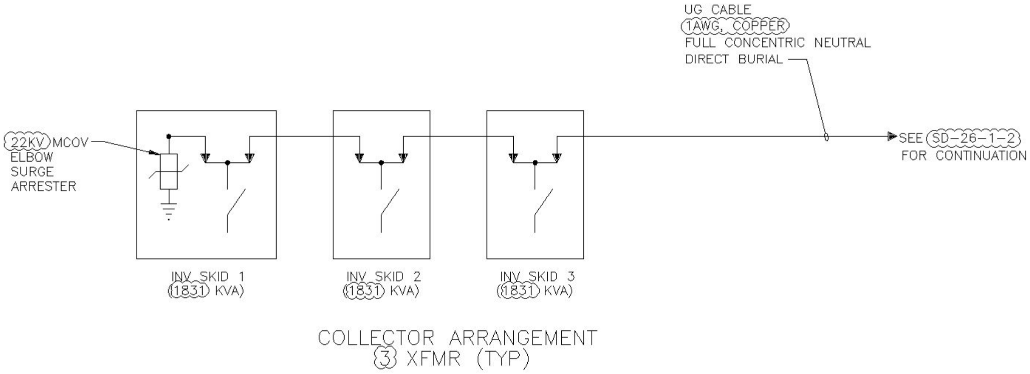


Figure 2.11: Collector Layout

2.1.2.3 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 2.12*** shows the feeder layout design of feeder that contains 4 collectors and 4 surge arrestors.

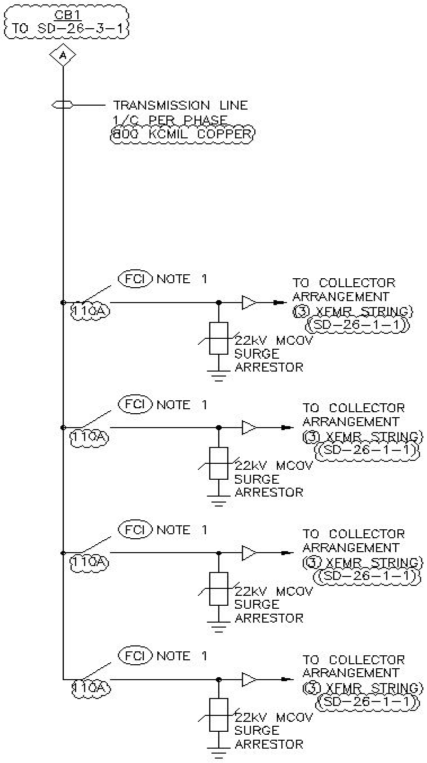


Figure 2.12: Feeder Layout

2.1.2.4 Key Protection/One-Line Diagram

The key protection diagram consists of 4 combiner boxes (CB1, CB2, CB3, CB4) and 6 relays(CB1 RELAY, CB2 RELAY, CB3 RELAY, CB4 RELAY, BANK 1 PRI RELAY, BANK 1 BU RELAY). CB1-4 RELAYs are connected to be tripped by CB1-4 while BANK 1 PRI RELAY is the primary relay and BANK 1 BU RELAY is the backup relay.

CB1-3 relays are connected to feeders 1-3 on one side and 34.5kV BUS 1 on the other side. ***Figure 2.13*** illustrates the design of CB1, CB2, and CB3 relays and protections drawings.

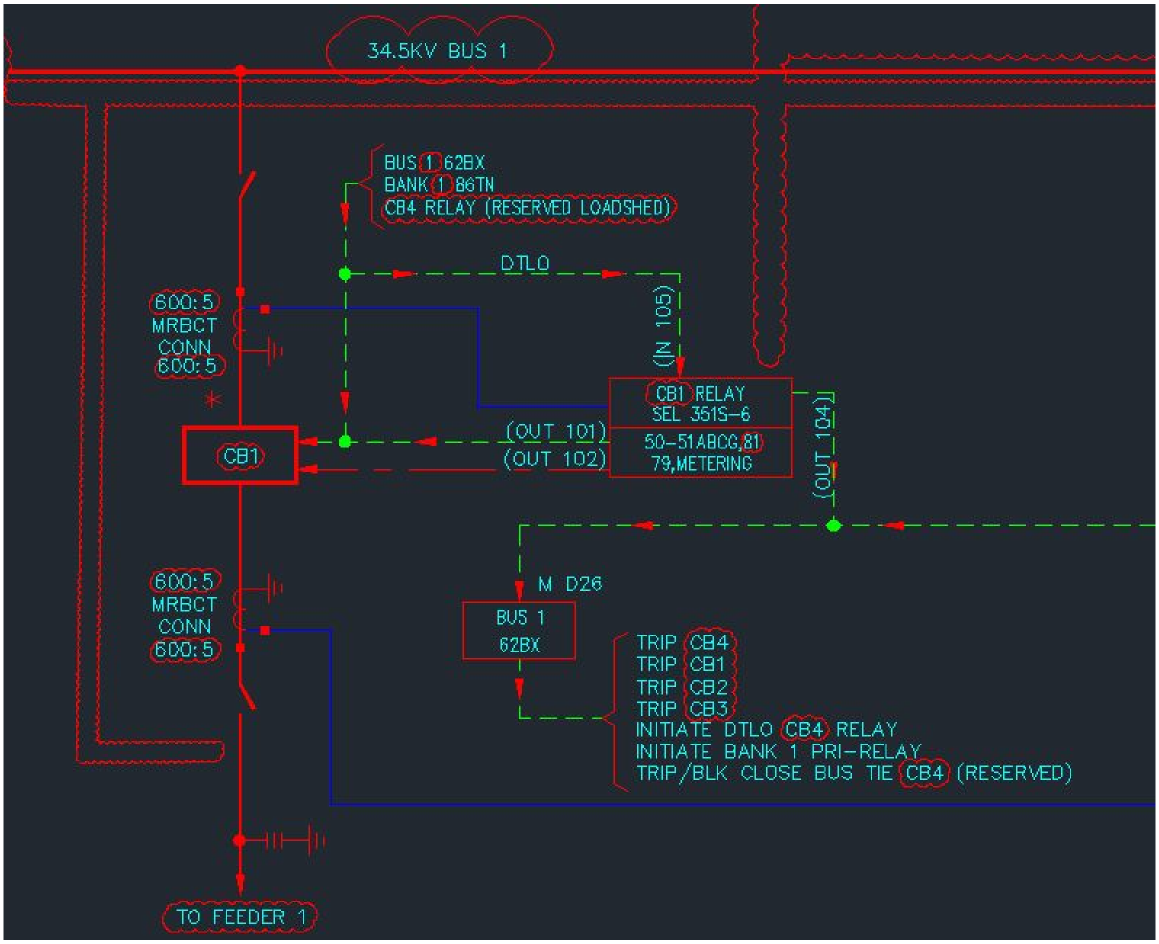


Figure 2.13: Key Protection Diagram (CB1)

CB4 is located in between the 34.5kV bus and 115kV bus. ***Figure 2.14*** shows the design of CB4 relay and protection drawings.

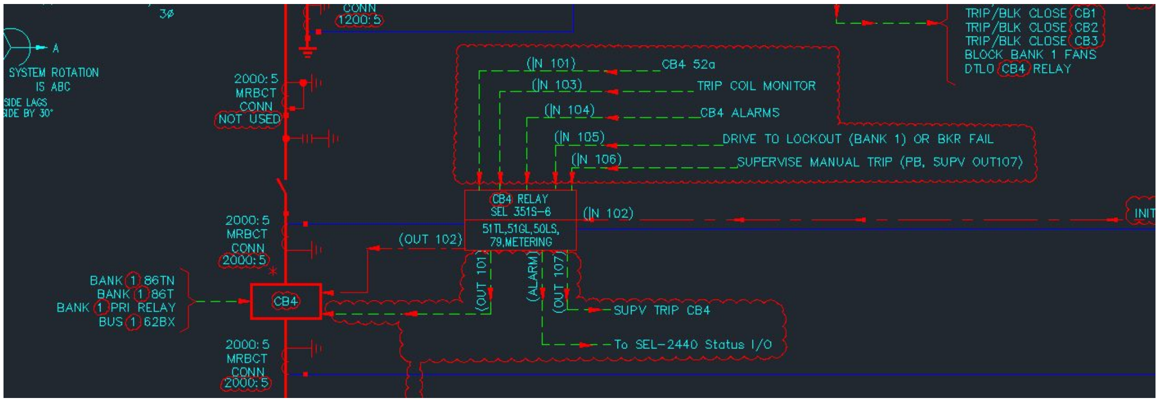


Figure 2.14: Key Protection Diagram (CB4)

Figure 2.15 shows the design BANK 1 BU RELAY and its I/O connections in layout drawings.

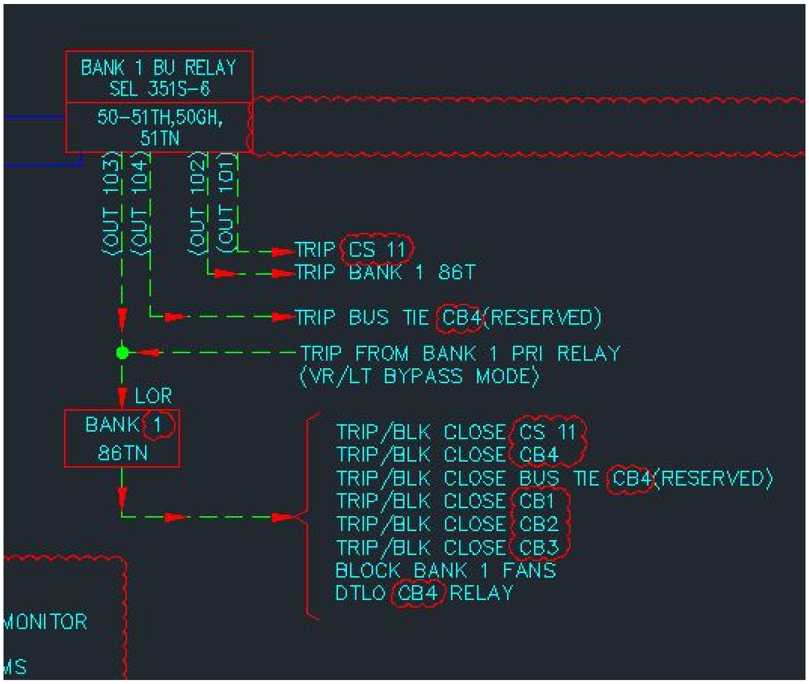


Figure 2.15: Key Protection Diagram (BANK 1 BU RELAY)

Figure 2.16 shows the design BANK 1 PRI RELAY and its I/O connections in layout drawings.

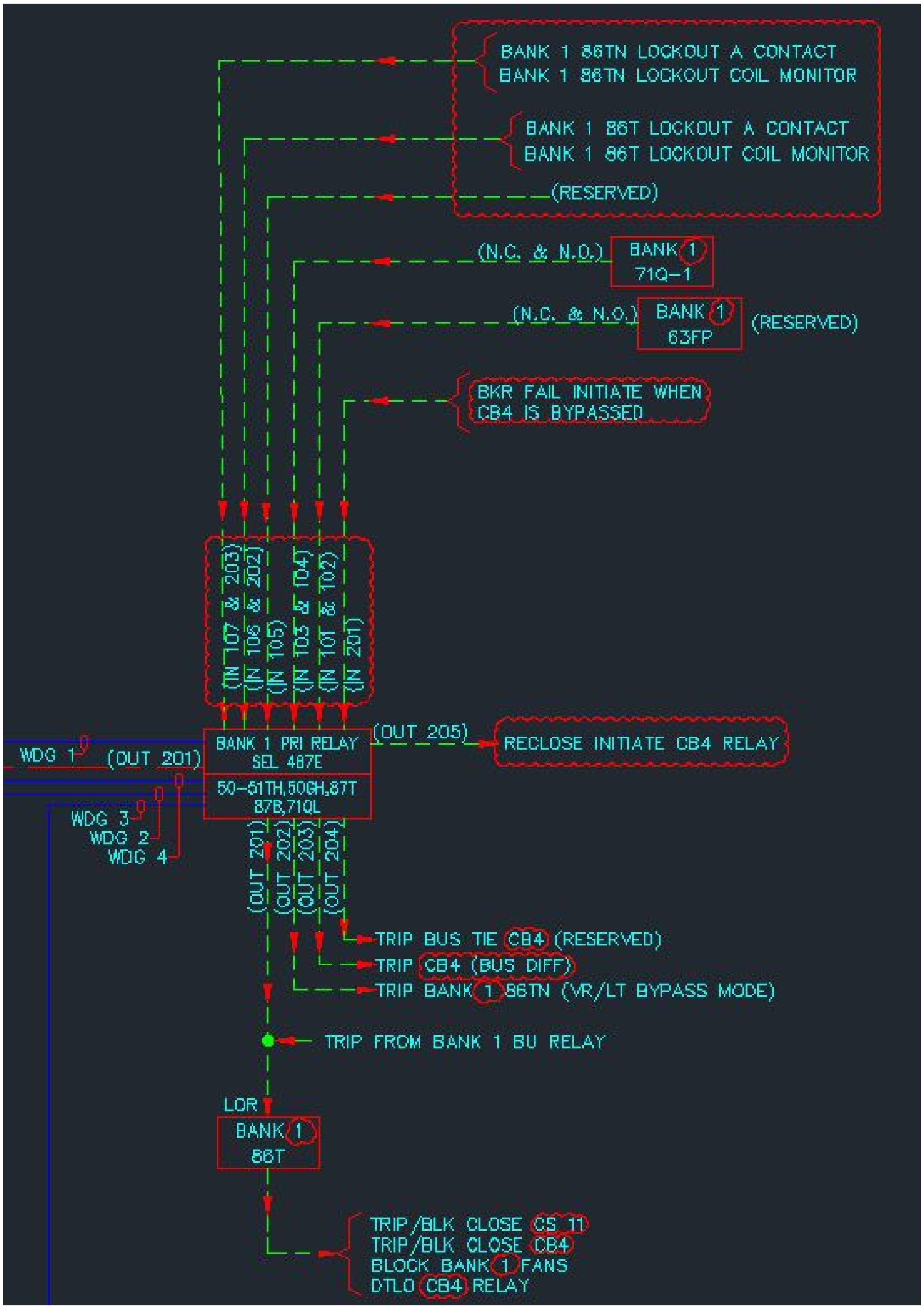


Figure 2.16: Key Protection Diagram (BANK 1 PRI RELAY)

2.1.2.5 Three-Line Drawings

The three-line diagrams that are in the scope of our project includes:

1. AC 1
2. AC 2
3. BANK 1 AUX
4. Main Connection
5. AC Auxiliary

The three-line diagrams illustrates the actual connections of the substation in three-phase, it shows an overview of the substation design connections. These drawings are designed mainly based on the key protection/one-line diagram.

2.1.2.6 DC Schematic Drawings

The DC schematic drawings that are in the scope of our project includes:

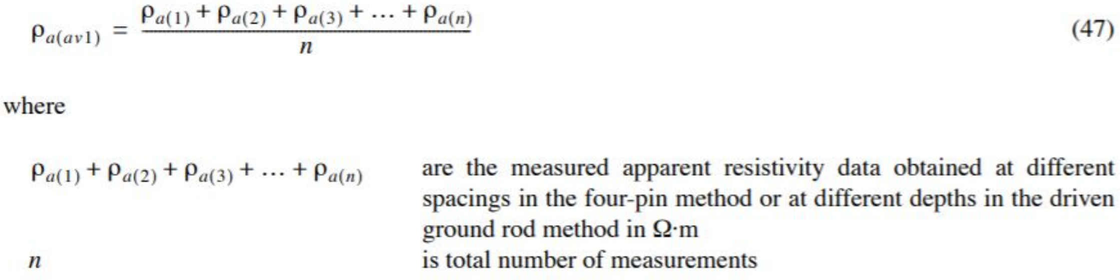
1. Feeder 1-3
2. Installation Relay
3. Primary Relay
4. Backup Relay
5. Bank 1 Annunciator
6. Distributed I/O Board
7. Comm Outside
8. Comm RTU
9. ABS 10
10. ABS 13
11. Breaker failure drawing
12. DC Auxiliary

The DC Schematic drawings are detailed circuit drawings on substation relatable electric components that take charge of the circuit breaking and communication signals. The designs are mainly based on standard drawings except some hardware changes on connections are needed to be compatible with our substation design.

2.1.2.7 Substation Grounding

The purpose of Substation Grounding Design is to design the layout of the ground grid and determine the number of rods and conductors to ensure the substation area has appropriate maximum step and touch voltage. The steps needed to fulfill the purposes will be described below:

STEP 1: Calculating the uniform resistivity (ρ_a) in ohm-m using the given soil resistivity measurements. The equation below, which was found in 13.4.1 of the IEEE Std 80-2000 document, was applied to calculate the soil resistivity.



$$\rho_{a(av1)} = \frac{\rho_{a(1)} + \rho_{a(2)} + \rho_{a(3)} + \dots + \rho_{a(n)}}{n} \qquad (47)$$

where

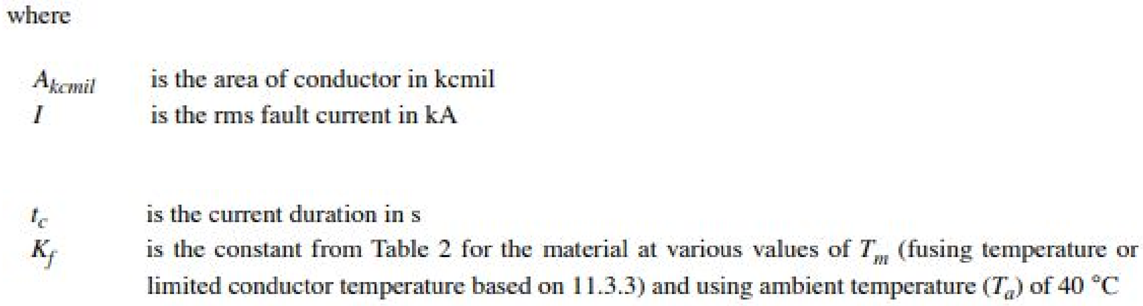
$\rho_{a(1)} + \rho_{a(2)} + \rho_{a(3)} + \dots + \rho_{a(n)}$	are the measured apparent resistivity data obtained at different spacings in the four-pin method or at different depths in the driven ground rod method in Ω·m
n	is total number of measurements

The calculated resistivity was:

$$\rho_a = \frac{120 + 85 + 65 + 48 + 32 + 24 + 20}{7} = \frac{394}{7} = 56.286\ \Omega m$$

STEP 2: Determining the minimum conductor size in kcmil for a copper, soft-drawn grounding conductor using the equation below, which was found in chapter 11.3.1.2 of the IEEE document.

$$A_{kcmil} = I \cdot K_f \sqrt{t_c} \qquad Equation\ (42)$$



where

A_{kcmil}	is the area of conductor in kcmil
I	is the rms fault current in kA
t_c	is the current duration in s
K_f	is the constant from Table 2 for the material at various values of T_m (fusing temperature or limited conductor temperature based on 11.3.3) and using ambient temperature (T_a) of 40 °C

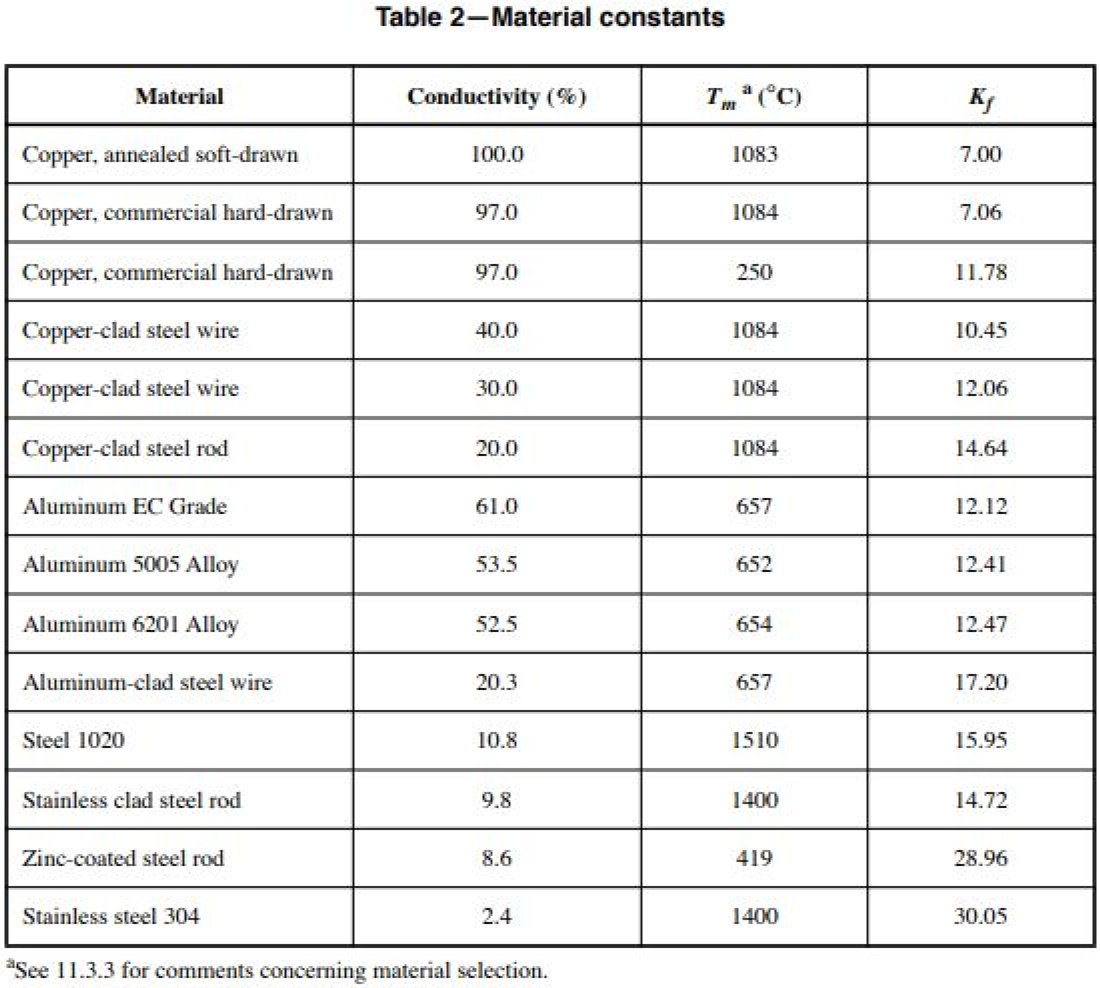


Table 2—Material constants

Material	Conductivity (%)	T_m [a] (°C)	K_f
Copper, annealed soft-drawn	100.0	1083	7.00
Copper, commercial hard-drawn	97.0	1084	7.06
Copper, commercial hard-drawn	97.0	250	11.78
Copper-clad steel wire	40.0	1084	10.45
Copper-clad steel wire	30.0	1084	12.06
Copper-clad steel rod	20.0	1084	14.64
Aluminum EC Grade	61.0	657	12.12
Aluminum 5005 Alloy	53.5	652	12.41
Aluminum 6201 Alloy	52.5	654	12.47
Aluminum-clad steel wire	20.3	657	17.20
Steel 1020	10.8	1510	15.95
Stainless clad steel rod	9.8	1400	14.72
Zinc-coated steel rod	8.6	419	28.96
Stainless steel 304	2.4	1400	30.05

[a] See 11.3.3 for comments concerning material selection.

The K_f value of 7 was chosen since the conductor was a soft-drawn copper.

$$A_{kcmil} = 32 \times 7 \times \sqrt{1} = 224\ kcmil$$

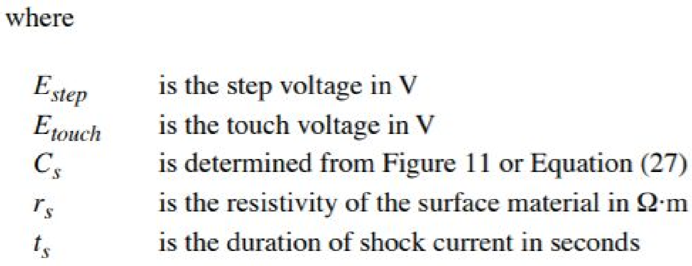
$$Actual\ Cable\ Size = 250\ kcmil$$

The calculated conductor size was 224 kcmil. However, the next available size was 250 kcmil, so the chosen size would be 250 kcmil.

STEP 3: Finding the tolerable Step (E_{STEP}) and Touch (E_{TOUCH}) voltages with a surface layer derating factor C_S = 0.8 using the equations found in 8.3, as shown below.

$$E_{step50} = (1000 + 6C_s \cdot \rho_s)\frac{0.116}{\sqrt{t_s}} \qquad Equation\ (29)$$

$$E_{touch50} = (1000 + 1.5C_s \cdot \rho_s)\frac{0.116}{\sqrt{t_s}} \qquad Equation\ (32)$$



where

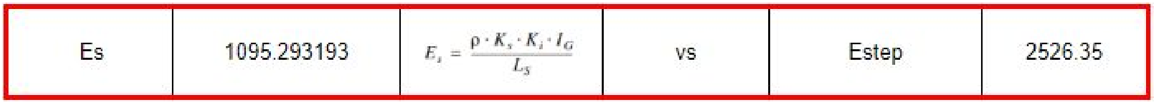
E_{step}	is the step voltage in V
E_{touch}	is the touch voltage in V
C_s	is determined from Figure 11 or Equation (27)
r_s	is the resistivity of the surface material in Ω·m
t_s	is the duration of shock current in seconds

$$E_{step50} = (1000 + 6(0.8) \cdot 3000)\frac{0.116}{\sqrt{0.5}} = 2526.35\ V$$

$$E_{touch50} = (1000 + 1.5(0.8) \cdot 3000)\frac{0.116}{\sqrt{0.5}} = 754.624\ V$$

The calculated tolerable E_{STEP} was 2526.35 V and calculated tolerable E_{TOUCH} was 754.624 V for a body weight of 50 kg.

STEP 4: Calculating the maximum step (E_S) and maximum touch (E_m) voltages using the given equations from the IEEE Std 80-2000 document. Then, adjusting the number of rods to ensure the maximum step and touch voltages are less than the tolerable step and touch voltages from the last step. The calculations were shown below:



Es	1095.293193	$E_s = \frac{\rho \cdot K_s \cdot K_i \cdot I_G}{L_S}$	vs	Estep	2526.35

Figure 2.17: Maximum Step Voltage Calculation

Em	752.2751266	$E_m = \frac{\rho \cdot K_m \cdot K_i \cdot I_G}{L_M}$	vs	E touch	754.624

Figure 2.18: Maximum Mesh/Touch Voltage Calculation

With the use of 149 ground rods, the value of the maximum Step and Touch Voltages were smaller than tolerable ones, which is appropriate with the requirement.

STEP 5: Designing the grounding grid based on the yard size of our substation, including the 3 ft extension on all sides.

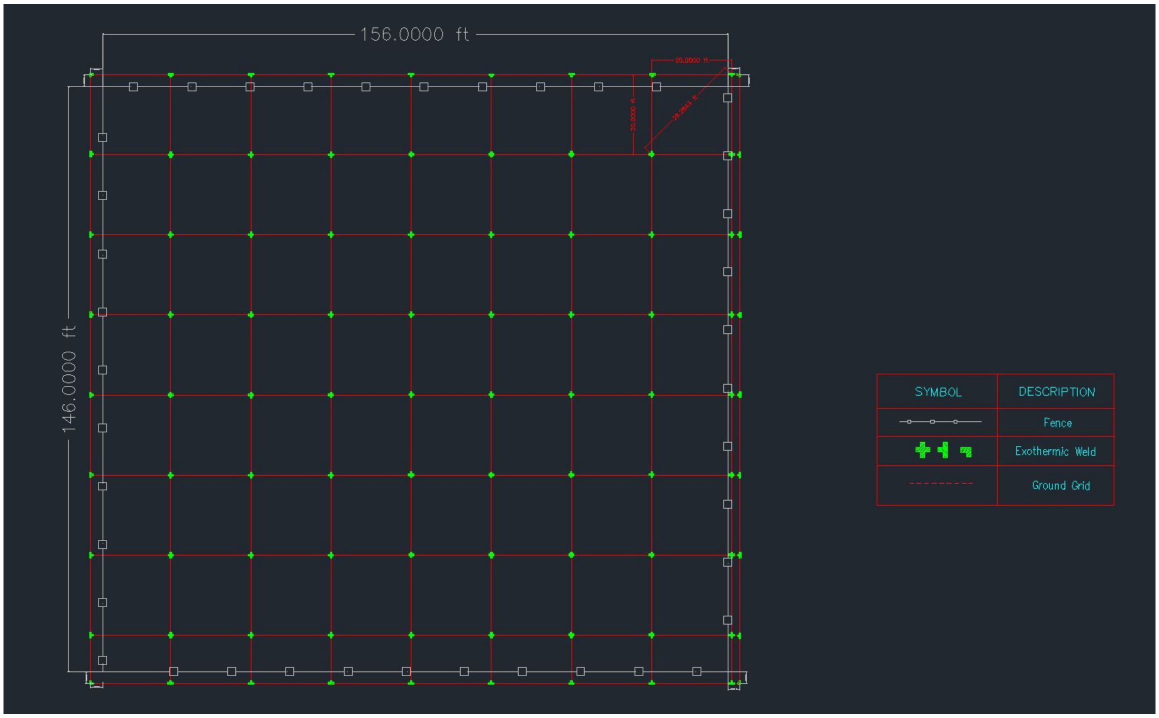


Figure 2.19: Substation Grounding Layout

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 TESTING AND EVALUATION PLAN

National Renewable Energy Lab System Advisor Model (NREL SAM) is a renewable energy cost and performance simulation program that was used to simulate the proposed solar power plant design to predict the amount of power that would be generated by the power plant.

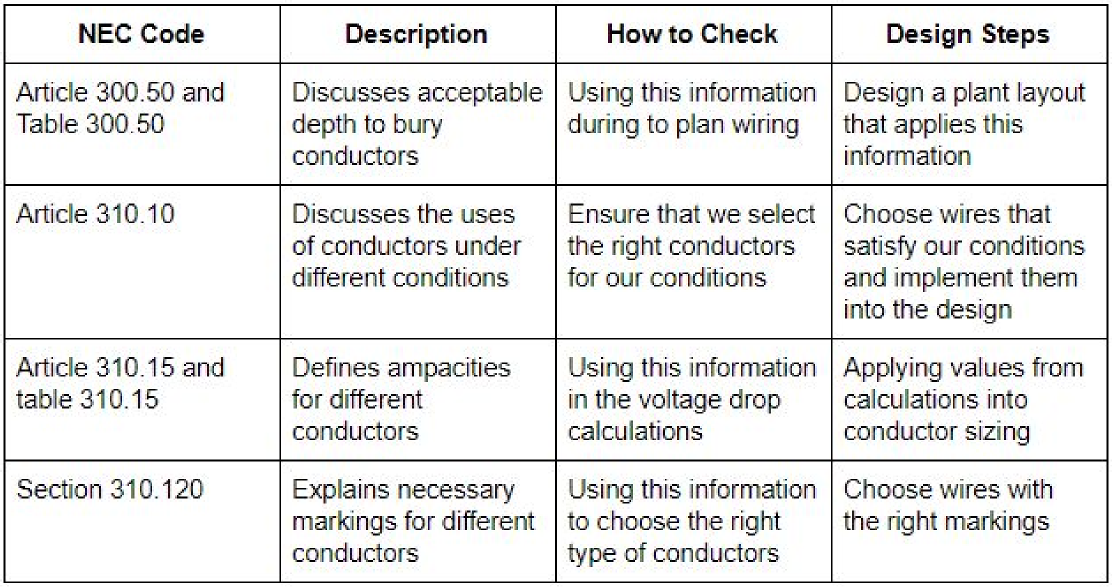
Array Parameter Tool is an Excel spreadsheet provided by the client that consisted of a series of calculations that were used to determine the parameters of the solar power plant, such as the number of components needed in the design and the area and cost of the solar power plant. The tool was also used to verify that the ILR value of the solar plant was approximately 1.3, as desired by the client. This tool helped with the selection of a suitable location, based on the total estimated cost of the project in different locations. A desirable shape and layout of the solar plant was based off of the array parameter tool output as well.

Using codes like the National Electrical Code (NEC) and Institute of Electrical and Electronics Engineers Substation Grounding Code (IEEE 80-2000) the team was able to validate parameters and calculated values used in the design of the system.

3.2 VALIDATION AND VERIFICATION

Since both the array parameter tool and NREL SAM provide similar data in terms of the number of components needed and cost of project, the team was able to compare these results to ensure that the data obtained from the array parameter tool looked like the data obtained from NREL SAM. The team was able to compare costs, analyze system losses and generate energy estimations based on the data entered in the simulator.

The NEC was implemented when doing conductor sizing and voltage drop calculations. After creating the solar power plant layouts, the team carried out conductor sizing which is the selection of conductors for solar plant wiring. This is where the NEC codes were implemented for verification. The following NEC codes were used to select the type of wires, wiring conditions and necessary material to be used. It is important to note that the 125% safety factor required in the NEC was applied to all currents flowing through conductors.

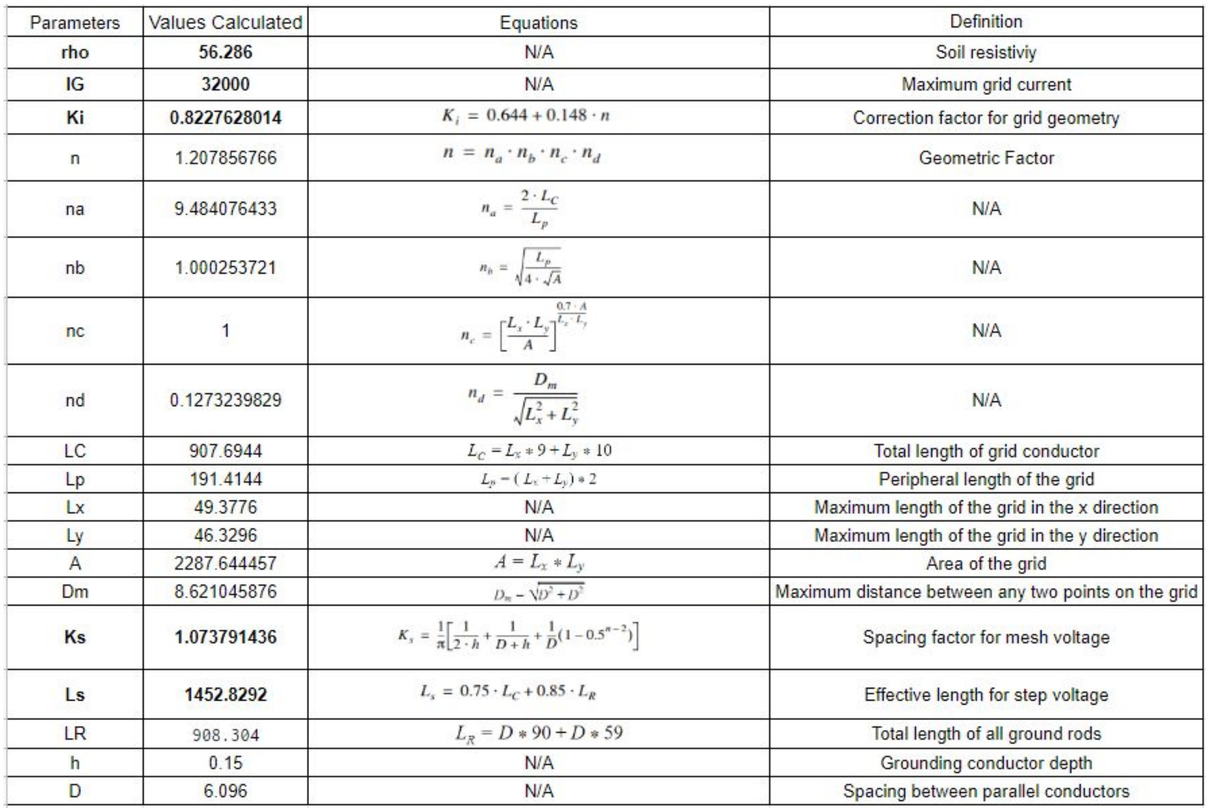


NEC Code	Description	How to Check	Design Steps
Article 300.50 and Table 300.50	Discusses acceptable depth to bury conductors	Using this information during to plan wiring	Design a plant layout that applies this information
Article 310.10	Discusses the uses of conductors under different conditions	Ensure that we select the right conductors for our conditions	Choose wires that satisfy our conditions and implement them into the design
Article 310.15 and table 310.15	Defines ampacities for different conductors	Using this information in the voltage drop calculations	Applying values from calculations into conductor sizing
Section 310.120	Explains necessary markings for different conductors	Using this information to choose the right type of conductors	Choose wires with the right markings

Figure 3.1: NEC Codes Applied to Design

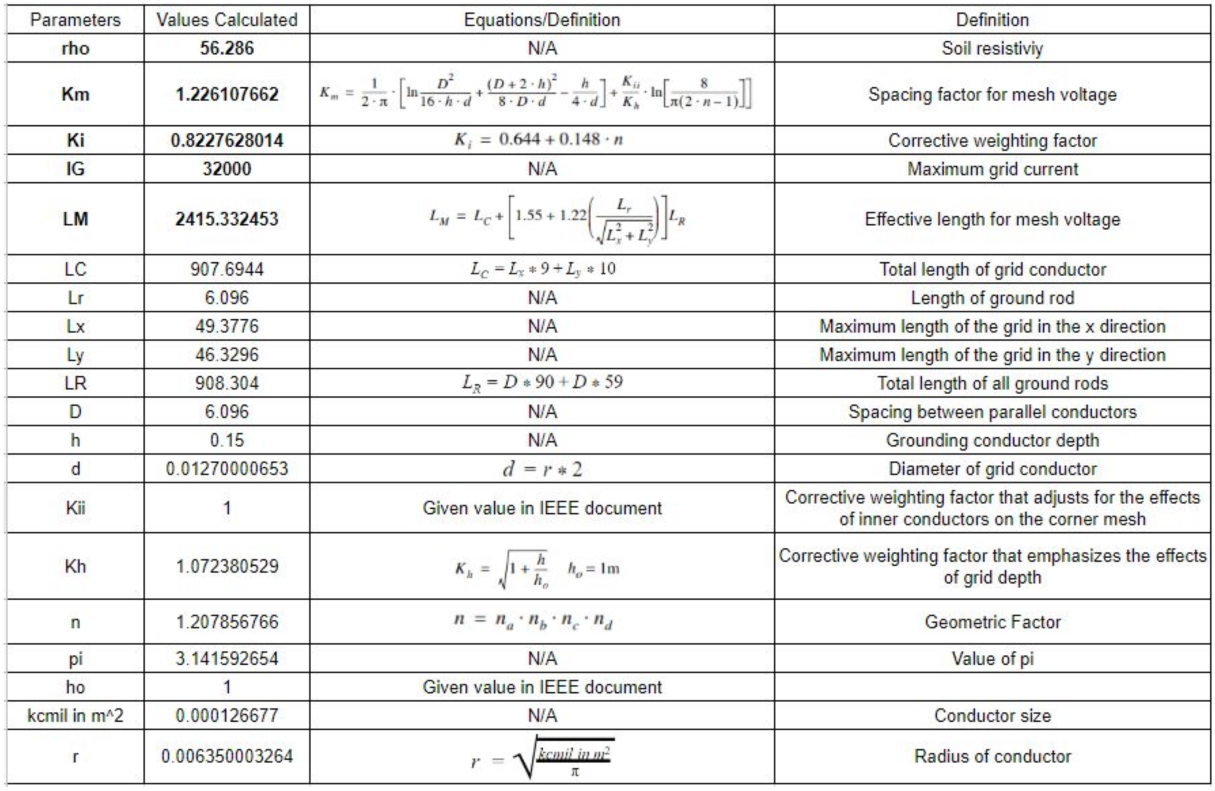
After determining the sizes of the conductors used in the solar power plant wiring, the team carried out the voltage drop calculations. As verification, the team was required to keep the total voltage drop percentage across the conductors from the solar panels to the combiner boxes at 3% or less. The actual voltage drop of the system up until this point was at most 1.56% which was excellent. The average worst case voltage drop across the conductors from the solar panels to the inverter was required to be no more that 5%, and the team achieved an average worst-case drop of 1.30%, thus meeting the safety requirement set by the NEC.

The IEEE 80-2000 was used as verification for the substation grounding phase by utilising the equations and theory highlighted in this document for the design of the substation grounding grid. The equations shown in the following tables were used as validation for values calculated.



Parameters	Values Calculated	Equations	Definition
rho	**56.286**	N/A	Soil resistiviy
IG	**32000**	N/A	Maximum grid current
Ki	**0.8227628014**	$K_i = 0.644 + 0.148 \cdot n$	Correction factor for grid geometry
n	1.207856766	$n = n_a \cdot n_b \cdot n_c \cdot n_d$	Geometric Factor
na	9.484076433	$n_a = \frac{2 \cdot L_C}{L_p}$	N/A
nb	1.000253721	$n_b = \sqrt{\frac{L_p}{4 \cdot \sqrt{A}}}$	N/A
nc	1	$n_c = \left[\frac{L_x \cdot L_y}{A}\right]^{\frac{0.7 \cdot A}{L_x \cdot L_y}}$	N/A
nd	0.1273239829	$n_d = \frac{D_m}{\sqrt{L_x^2 + L_y^2}}$	N/A
LC	907.6944	$L_C = L_x * 9 + L_y * 10$	Total length of grid conductor
Lp	191.4144	$L_p = (L_x + L_y) * 2$	Peripheral length of the grid
Lx	49.3776	N/A	Maximum length of the grid in the x direction
Ly	46.3296	N/A	Maximum length of the grid in the y direction
A	2287.644457	$A = L_x * L_y$	Area of the grid
Dm	8.621045876	$D_m = \sqrt{D^2 + D^2}$	Maximum distance between any two points on the grid
Ks	**1.073791436**	$K_s = \frac{1}{\pi}\left[\frac{1}{2 \cdot h} + \frac{1}{D + h} + \frac{1}{D}(1 - 0.5^{n-2})\right]$	Spacing factor for mesh voltage
Ls	**1452.8292**	$L_s = 0.75 \cdot L_C + 0.85 \cdot L_R$	Effective length for step voltage
LR	908.304	$L_R = D * 90 + D * 59$	Total length of all ground rods
h	0.15	N/A	Grounding conductor depth
D	6.096	N/A	Spacing between parallel conductors

Figure 3.2.1: Substation Grounding Equations



Parameters	Values Calculated	Equations/Definition	Definition
rho	**56.286**	N/A	Soil resistiviy
Km	**1.226107662**	$K_m = \frac{1}{2 \cdot \pi} \cdot \left[\ln\frac{D^2}{16 \cdot h \cdot d} + \frac{(D + 2 \cdot h)^2}{8 \cdot D \cdot d} - \frac{h}{4 \cdot d}\right] + \frac{K_{ii}}{K_h} \cdot \ln\left[\frac{8}{\pi(2 \cdot n - 1)}\right]]$	Spacing factor for mesh voltage
Ki	**0.8227628014**	$K_i = 0.644 + 0.148 \cdot n$	Corrective weighting factor
IG	**32000**	N/A	Maximum grid current
LM	**2415.332453**	$L_M = L_C + \left[1.55 + 1.22\left(\frac{L_r}{\sqrt{L_x^2 + L_y^2}}\right)\right]L_R$	Effective length for mesh voltage
LC	907.6944	$L_C = L_x * 9 + L_y * 10$	Total length of grid conductor
Lr	6.096	N/A	Length of ground rod
Lx	49.3776	N/A	Maximum length of the grid in the x direction
Ly	46.3296	N/A	Maximum length of the grid in the y direction
LR	908.304	$L_R = D * 90 + D * 59$	Total length of all ground rods
D	6.096	N/A	Spacing between parallel conductors
h	0.15	N/A	Grounding conductor depth
d	0.01270000653	$d = r * 2$	Diameter of grid conductor
Kii	1	Given value in IEEE document	Corrective weighting factor that adjusts for the effects of inner conductors on the corner mesh
Kh	1.072380529	$K_h = \sqrt{1 + \frac{h}{h_o}} \quad h_o = 1\text{m}$	Corrective weighting factor that emphasizes the effects of grid depth
n	1.207856766	$n = n_a \cdot n_b \cdot n_c \cdot n_d$	Geometric Factor
pi	3.141592654	N/A	Value of pi
ho	1	Given value in IEEE document	
kcmil in m^2	0.000126677	N/A	Conductor size
r	0.006350003264	$r = \sqrt{\frac{kcmil\ in\ m^2}{\pi}}$	Radius of conductor

Figure 3.2.2: Substation Grounding Equations

3.3 EVALUATION

System evaluation is done using NREL SAM, as stated in previous sections. NREL SAM takes in inverter and solar panel specifications and weather information for the desired location. It then calculates the number of solar panels (also the number of racks), 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 plan. The process of using this software for evaluation is detailed in the section below.

3.4 PROCESS

The steps of using the Array Parameter Tool have been explained in the design section of this report. The steps of using NREL SAM to simulate the proposed solar power plant are:

1. Location and Resource
2. Module
3. Inverter
4. System Design

3.4.1 Step 1: Location and Resource

To use NREL SAM, the team selected the weather profile of the desired location which contains information solar irradiation, latitude and longitude of the system as well as elevation and minimum temperature.

3.4.2 Step 2: Module

The next step was to select the exact solar module or panel that will be utilised in the design of the system. NREL SAM had a library of solar panels the team could select from, so attention to detail was a necessary trait for this step. The team then compared module information, such as temperature coefficients and nominal information from the datasheet of the module to the information of NREL SAM for verification.

3.4.3 Step 3: Inverter

Similarly, the team selected the exact inverter information from the system library and compared datasheet parameters as a proofing mechanism.

3.4.4 Step 4: System Design

After entering this information, the team was able to input the number of inverters in the system and evaluated a new ILR of 1.29, which is the exact value obtained in the array parameter tool. The team then compared the total AC capacity of the system obtained by NREL SAM to the one that was calculated in the array parameter tool and noticed that the two values matched.

3.4.5 Step 5: Shading and Layout

The team ignored "Shading and Layout" tab because the proposed solar plant layout was designed specifically to prevent the shading of solar panels on other panels. For the "Losses" tab, the team entered the DC power losses caused by the voltage drop across each conductor, which was determined by various calculations done in the Voltage Drop Tool.

3.4.6 Step 6: Lifetime

The results of this simulation include system performance degradation which is a value of 0.6% per annum for the solar plant. This degradation is applied to the total kilowatt hour output for the previous year from year two.

3.5 SIMULATION & RESULTS

The figure below shows the estimated kWh per month for the first year of operation of the solar power plant. It is important to note that the system evaluation results were constrained by input parameters, as the team could not select 36 separate arrays in the design. As a result, the team simulated the plant as one large solar array instead of 36 separate arrays. By doing this the team affected the total land area of the system but not the AC or DC power generated by the plant.

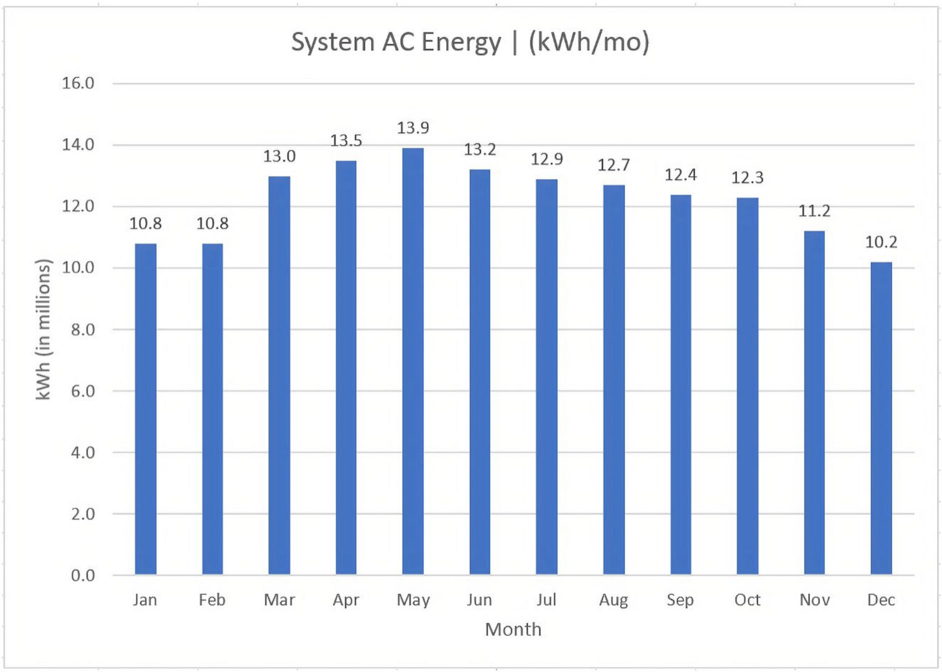


Figure 3.5: System Output in kWh per Month

4. Project Risk and Management

4.1 TASK DECOMPOSITION

Task decomposition can be separated according to the two phases of the senior design project. The tables below outline the contribution of members and the tasks performed by members.

4.1.1 Phase One: Solar Plant Design

Task	Person
Location Selection	Everyone
Parameter Tool	Everyone
Solar Power Plant Layout	CZ
Singe Array Wiring Diagram	NS
Solar Plant Wiring Diagram	NS

Task	Person
Conductor Sizing and Voltage Drop Calculation	KK

Table 4.1: Phase 1 Task Decomposition

4.1.2 Phase Two: Substation Design

Task	Person
Collector One-Line	TN
Feeder One-Line	TN
Substation Key Protection (One Line)	YC
AC 1 Three-Line	CZ, YC
AC 2 Three-Line	NS
AC Main Connection	NS
Bank 1 AUX	CZ
AC Auxiliary	KK
DC Schematic Feeder 1	KK
DC Schematic Feeder 2	TN
DC Schematic Feeder 3	KK
Breaker Failure	TN
Back-Up Protection	KK
DC Auxiliary	NS
Primary Relay	NS
Installation Relay	YC
Distributed I/O Board	CZ
Communication Outside	YC
Communication RTU	YC
Bank 1 Annunciator	TN
ABS 10	NS
ABS 13	KK

Task	Person
W01	TN
W02	CZ
W03	YC
W04	NS
W05	CZ
W06	TN
Grounding Grid	YC

Table 4.2: Phase 2 Task Decomposition

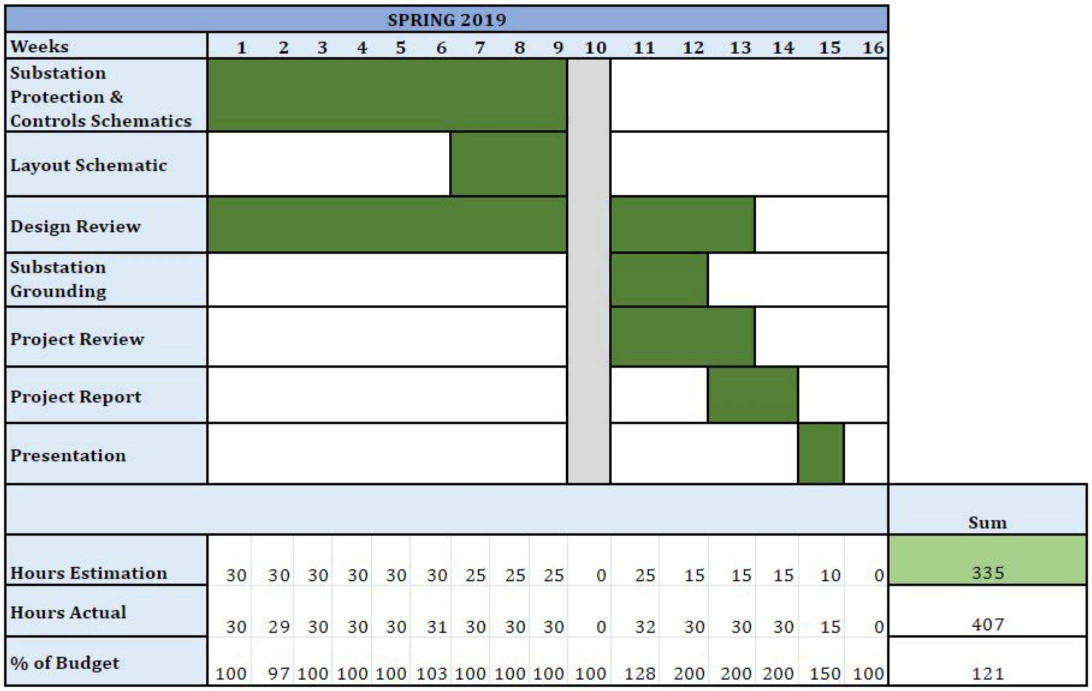
4.2 PROJECT SCHEDULE

The Fall 2018 Gantt chart is shown in the figure below. The main focus of the first semester was to work on the solar power plant aspect of the design project. Some of the deliverables include solar plant layouts, feeder and collector drawings, conductor sizing, and voltage drop calculations. Towards the end of the semester, the team started working on the substation design by editing and reviewing the key protection diagram and the AC1 & AC2 schematics.

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	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	▨	🟩	🟩		
Solar Plant Size & Cost Determination				🟩	🟩	🟩	🟩	🟥	🟥	🟩				▨				
Solar Plant Layout Drawings							🟩	🟩	🟩	🟩				▨				
Feeder & Collector Design								🟩	🟩	🟩				▨				
Conductor Sizing and Voltage Drop								🟩	🟩	🟩	🟩			▨				
Key Protection Schematic										🟩	🟩	🟩	🟩	▨	🟩			
AC 1 and 2 Schematics														▨		🟩	🟩	
Review Deliverables														▨	🟩	🟩		
																		Sum
Hours Estimation	0	3	15	30	60	60	60	60	60	60	35	35	24	0	15	15	2	534
Hours Actual	0	3	14	46	78	90	58	94	64	88	84	39	15	0	14	6	6	699
% of Budget	100	100	93	153	130	150	97	157	107	147	240	111	63	0	93	40	300	131

Key	
Overrun	🟥
Projected	🟩
Break	▨
Billable Hours	🟩

Figure 4.2.1: Man Hour Budget for Fall 2018



SPRING 2019																	
Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Substation Protection & Controls Schematics	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	▨							
Layout Schematic							🟩	🟩	🟩	▨							
Design Review	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	▨	🟩	🟩	🟩				
Substation Grounding										▨	🟩	🟩					
Project Review										▨	🟩	🟩	🟩				
Project Report										▨			🟩	🟩			
Presentation										▨					🟩		
																	Sum
Hours Estimation	30	30	30	30	30	30	25	25	25	0	25	15	15	15	10	0	335
Hours Actual	30	29	30	30	30	31	30	30	30	0	32	30	30	30	15	0	407
% of Budget	100	97	100	100	100	103	100	100	100	100	128	200	200	200	150	100	121

Figure 4.2.2: Man Hour Budget for Spring 2019

4.3 RISKS AND MITIGATION

4.3.1 The Natural Environment Risk

Natural environmental risks refer to risks caused by changes in the natural environment that may be encountered during substation construction, including severe weather conditions and adverse geographical conditions. In general, natural environmental risks have a great impact on substation construction. We should rationally arrange the construction period and plan, and adopt the risk-retaining and risk-controlled disposal methods.

4.3.2 Technical Risk

As substation designers, we face no real risks during our design stage. A risk that could be faced during the implementation of our design is component defect. This risk is of a high rank because it could lead to damage of the system and even death in extreme cases.

To mitigate this risk, the design team recommends system testing which involves a component by component assessment to ensure that each piece of the design can function on its own, then testing they system as components are connected to reduce risk.

4.4 LESSONS LEARNED

Throughout the senior design project, not only did the team learn about the working principle of substations, but also substation design that meets the customer's requirements as well as NEC and IEEE 80-2000 codes. In the process, the team learned how of solar power plants operate and learned about designing protection and controls systems for substations.

Participating in this course has showed the team the importance of working on a team and how to work as engineers in real situations. The team also learned the importance of having a design process and proper documentation techniques.

5. Closure Materials

5.1 Conclusion

In order to design a utility-scale 60 MW Solar Power Plant and a 115/34.5 kV substation, the team worked closely with Black & Veatch representatives to successfully complete the design project. To make the design process easier, the project was split into two phases. The first phase was to design the solar power plant, which is where power generation and conversion from DC to AC power happen. To meet the safety requirements set by the NEC, the team did conductor sizing and voltage drop calculations across each conductor. The second phase was to design the substation, which steps up the voltage from 34.5 kV to 115 kV and transmits it to the grid. The bulk of this phase was to create the protection and controls schematics on AutoCAD based on the key protection diagram and project scope document given by the client. The team also worked on the substation layout drawings which were based on the protection and control schematics. To ensure the safety of the people inside the substation, the team designed the grounding grid based on the guidelines set by the IEEE.

Overall, the project was a success because all the design aspects of the project were submitted on time and received satisfaction from the client. The project was also a success because of the extensive amount of knowledge and valuable design experience the team acquired throughout the two semesters.

5.2 Future Work

It is now up to the client to implement the project themselves or modify the design to utilize it in similar projects. By implementing the project, not only would it make the grid less dependent on fossil fuels, but it would also decrease the effect of greenhouse gases on the environment.

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TEAM MEMBER INFORMATION

Katayi Katanga: Katayi is an international student from Lusaka, Zambia and a senior in Electrical Engineering with a focus on power systems and controls. She has always dreamed of being an engineer and is excited to jump into the power industry after graduation. Her hobbies include reading, eating, painting and practicing the performing arts. She is an active member in several student organizations on campus as she values building community and making friends.

Nur Sabrina Shuazlan: Nur is a senior in Electrical Engineering with an interest in Power Systems and Control Systems. She is from Malaysia and started attending Iowa State University in Fall 2015 as a freshman student. Nur has been involved in many student organizations, such as archery club, badminton club, and Ames Student Association for Malaysians (ASAM). She enjoys playing sports, particularly basketball and badminton. She also likes eating, sleeping, and watching tv shows.

Chufu Zhou: Chufu is a senior at ISU in the Electrical and Computer Engineering Department, working towards his degree in Electrical Engineering with an emphasis on semiconductor devices. Having experience working with a semiconductor devices company, Chufu is currently using this knowledge to finish an additional project on silicon wafer. Chufu has participated in a group publication for food safety, and the journal will be out soon.

Yao Jiang Cheah: Yao Jiang is an international undergraduate senior in Electrical Engineering from Malaysia. He transferred to Iowa State University (College of Electrical and Computer Engineering) as a sophomore in 2017. He worked as a teaching assistant for the classes Signal Processing II (EE324) and Digital Logic (CprE 281). He will be working with Automed, an agriculture tech company as a firmware engineer after he graduates.

Tam Nguyen: Tam Nguyen is a Senior Electrical Engineering student. He came from Vietnam and started his United States academic journey in North High School. After graduating high school, he attended Des Moines Area Community College (DMACC) for two and a half years. Then, in Spring 2017, he transferred to Iowa State University as a Junior. He has followed the Power Systems sequence that has been his dream since childhood.