115kV / 34.5kV Solar Power Plant & Substation Design Project Document

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Executive Summary

Development Standards & Practices Used

In the scope of this project we adhere to NEC guidelines and practices, specifically with regards to conductor sizing requirements and loading factors. Throughout the design process we followed Black and Veatch standards in regards to safety tolerances, company-specific design tools, and project design flow.

Summary of Requirements

- Equipment sizing calculations
- Solar layout drawings
- Solar panel string sizing design
- Electrical layout drawings (substation equipment)
- Protection and Control schematics based on project scope document
- Grounding analysis and ground-grid developed with IEEE 80
- Possibility of additional calculations (DC battery bank, Lightning protection, etc.)

Applicable Courses from Iowa State University Curriculum

- EE 303
- EE 311
- EE 456
- Engl 314

New Skills/Knowledge acquired that was not taught in courses

- Solar array layouts
- Array parameter tool calculations and how they are applicable to the process
- Subsystem design
- Voltage drop calculations
- How to set up and run professional meetings
- An understanding of inverter boxes, strings, arrays, and modules involved in creating the solar panel layout.

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Tables and Datasheets:

1. JA Solar Datasheet
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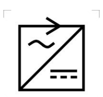
5. Solar Inverters ABB Central Inverters Datasheet
6. NFPA 70 -NEC Table
7. Voltage Drop Calculation tables
8. Array Parameter Tool Table

Symbols and Definitions:

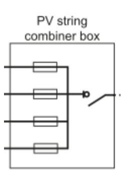
Module: Also called solar panels, a solar module is a single photovoltaic panel that is an assembly of connected solar cells. The solar cells absorb sunlight as a source of energy to generate electricity.

String: A series-connected set of solar cells or modules.

Inverters: A type of electrical converter which converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network.



Combiner boxes: A device that combines the output of multiple strings of PV modules for connection to the inverter.



Array: A group of solar panels arranged into rows with the goal of capturing sunlight to turn into electricity.

Figure 1.0 below illustrates the components that were considered in this project.

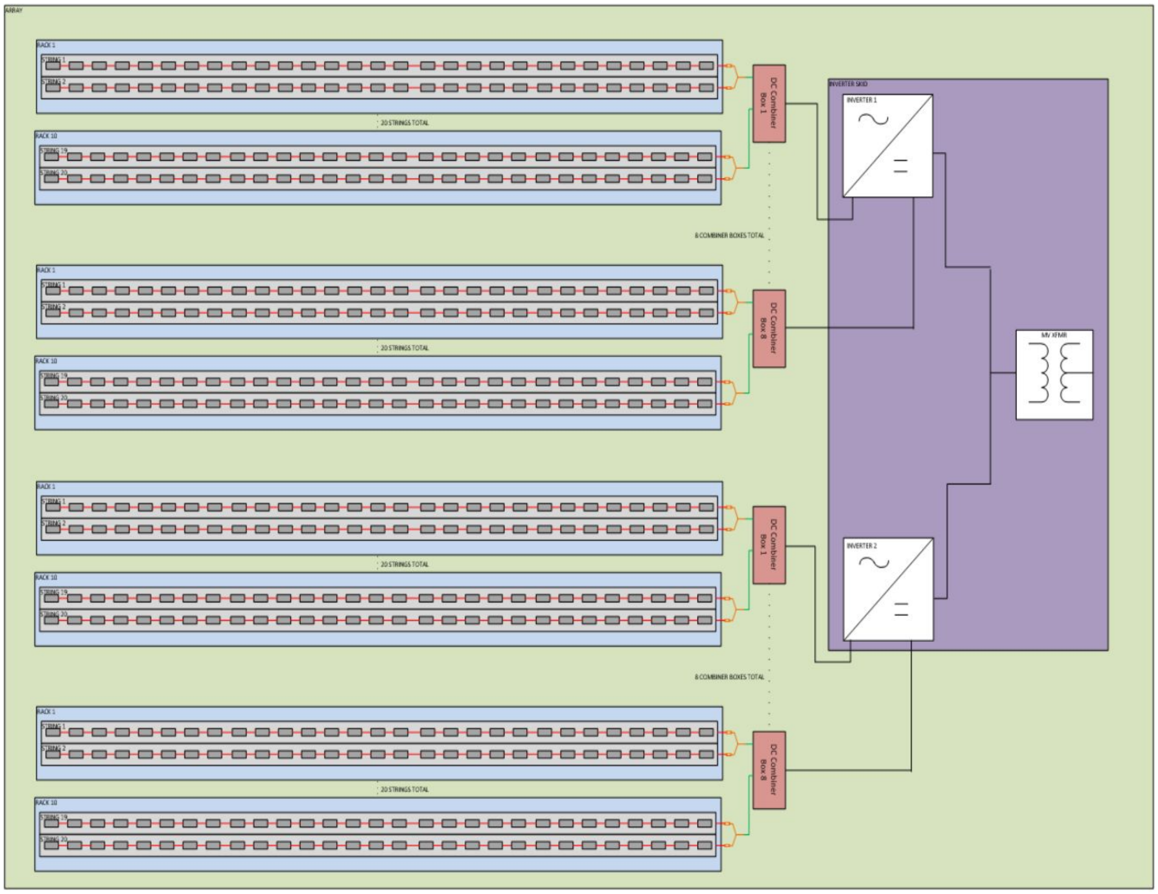


Figure 1.0: Illustration of possible component layout

1 Introduction

1.1 Acknowledgement

We would like to thank Black and Veatch for their guidance during this project. They supplied us with the information, suggestions, and support that allowed us to produce the best result possible. We would also like to thank our advisor, Mr. Venkataramana, for taking the time to meet with our team and help us get a deeper understanding in the background theory of our project.

1.2 Problem and Project Statement

Due to the huge changes in the grid energy market that lead to a big change in the electricity system, traditional energy sources such as coal and nuclear are being significantly replaced with renewable energy sources (RES) such as wind and solar. As team we believe security climate change is a real issue that threatens our globe in many ways and it's our responsibility to take positive actions to reduce its impact. After intensive research and discussion, we decided if we could design a 60 MW solar power plant and tied to the general grid that it would be a great contribution to making the grid more flexible by incorporating renewable energy. This project is extremely important in today's climate as renewable energy solutions are becoming increasingly needed for large scale power. Our focus for the first semester will be the solar power plant design including: selecting the budget, location, equipment layout, sizing, array tool parameters, single line diagram, and the control and protection design. The second semester we will be working on the design of the substation and and optimized solar design.

1.3 Requirements

The technical requirements that our group will work to achieve is to create a 115kV/34.5kV distribution substation and 60MW solar power plant. This will include the completed design of the solar layout, protection and control design, electrical layout, and associated construction deliverables. We will also be required to perform various calculations required of a typical substation. In addition to these calculations, we will also be tasked with researching the environment in which this substation will be implemented, which includes many factors that we needed to consider. One of the most important criteria that we compared was the different irradiance levels in different possible locations of this substation. Irradiance, or energy per unit area, directly corresponds to the power output of solar panels, so choosing an area with high irradiance is key. The next important aspect was the cost, which is affected by the community's stance on renewable energy as well as the cost per acre of the specific location. For any end product other than simply a calculation or simulation, it is essential to know the environment in which the end product will be used or to which it is expected to be exposed or experience. For example, will the end product be exposed to dusty conditions, extreme temperatures, or rain or other weather elements? This information is necessary in order to design an end product that can withstand the hazards that it is expected to encounter.

1.4 Intended Users and Uses

Although this project is through our client, the electricity generated from the solar plant would be sold to local people. This means our primary client is the people buying the electricity. Knowing that the average U.S. household consumes about 1,000 kWh each month, and 12 MWh per year, our 60 MW solar farm would produce enough energy to power close to 10,000 homes.

1.5 Assumptions and Limitations

Assumptions

This project will meet all safety and reliability requirements by NERC for supplying the nominal voltages, frequencies that meets the specifications in order to be connected to the general grid. Second assumption is that the 60MW produced from our solar plant will provide a reliable energy source that can power up to 1000 homes. This project is specifically designed for the United States, for any use outside of the United States, other environmental and economical factors should be taken into consideration.

Limitations

Our energy generation is dependent upon sunlight availability at our location. As a result, the power generated will vary according to the light intensity and irradiance of the area. Moreover the biggest limitation with solar generation is required battery storage within the power plant. The initial cost of installing, purchasing of solar cell panels, combiners, inverters are very high which is considered to be a disadvantage in the solar generation field.

1.6 Expected End Product and Deliverables

Throughout the semester our team has worked on different PV design tasks to finish the project on time. A list of deliverables will be fulfilled by the end of each semester as determined from our client. Below are all of the required deliverables for the project, it includes all the dates and the sub tasks we will carry out in this project.

First semester deliverables:

- Solar Power Plan Design

  This task includes researching and choosing the most efficient location for the project, filling out and analysing the array parameter tool for calculating our component choices, calculating the amount of area that will be required, creating man hour budget deliverables, and calculating the pricing and comparing it with our scheduled budget. We will also be working on creating a completed schematic, one line diagram voltage drop calculations, and protect and control schematic. we will have deliverable for the material used in the project toward the end of the next semester will have our project review, final report and the presentation deliverable as well this will be next semester

Deliverable timeline:

Task	Deliverable date	Hours taken in the task
Man Hour Budget		
protection plan		
one line diagram		
protection & control circuit		
Material list		
Project Review		
presentation document		
Final report		

2. Specifications and Analysis

2.1 Proposed Design

As noted above, our team has a lot of tasks that we are working to accomplish. Some of the work needs to be submitted to our clients at Black and Veach, the rest will is for our advisor to help guide our progress. These documents and deliverables can be found in section (). The deliverables consists of the layout of the entire project, single line diagrams, land selection, man hourly budget which we did with the support of Black & Veatch, the array parameter tool, voltage drop calculations, protection and the control plan for both the Pv and the substation design that ensures reliability for our project.AC, DC schematic , rack layout, panel characteristics and combiner box as well.

each of the tasks will be checked and approved by Black & Veatch and Dr Ajarpu to help with any technical or analysis information required. these tasks will be carried out in the order of design process.

As of now we have completed some of the document such as ,land requirements and selection array tool parameters, voltage drop calculation almost all of these documents get checked and approved by our client and advisor as well. we expect to work on more documents as the proceed more likely it will be about the substation components, and how the substation operates as whole for power delivery.

2.2 Development Process

While Agile is typically used for software development, our group has been following a similar development process in order to efficiently complete our project. We chose to model our development process after Agile because we think that having a lot of interactions within our team, as well as having a lot of collaboration with our customer, will allow us to work efficiently and produce the best solutions to our problems.

2.3 Design Plan

The design plan for our project is mainly divided between the two semesters of the class. The first semester we will be focusing mainly on creating the solar panel design layout. This will involve first picking a suitable location for our plant, which depends upon various factors that we had to research. Next we then had to fill out an array parameter tool that was provided to us by our client; this tool allowed us to pick the correct components for our design. After this, we then had to actually design the layout in Autocad. The final design criteria that we had to accomplish the first semester is computing the voltage drop of our design. For the second semester, we will be looking at our design at a larger scale as we begin to design the substation for our solar plant.

3. Statement of Work

3.1 Previous Work And Literature

Solar panels have existed in the market for a while now; today we know how to maximize the amount of power we utilize from the sun. Using the information gathered from the internet and the Black and Veatch representative, our team has acquired a solid foundation of what makes a good solar panel lay out. We have been given templates from Black and Veatch that previous teams have used in order to gain a deeper understanding of the overall project. While these templates are beneficial in completing many different calculations, we also work with our advisor to make sure that we fully understand what each template is doing. In addition to this, our advisor has given our team some example deliverables from a previous team that was also working on this project. While we feel that these examples are beneficial for gaining a preliminary reference, our team has chosen to complete the project using a different design that we feel will produce an even better result than previous teams, especially considering solar panel technology increases substantially from year to year.

3.2 Technology Considerations

When creating our design, we initially had to research many different types of hardware components that had the necessary specifications. Considering solar technology has been increasing tremendously in recent years, there were countless components that we had to consider with all different benefits and drawbacks. In the end we chose to use components that worked more efficiently, although costing more. Alternatively, we could have chosen to use more panels that produced less power that cost less per individual solar panel, this however, would have needed a larger land area to lay out the solar array.

3.3 Task Decomposition

As previously stated in our design plan, the overall task of completing the 60MW solar plant is divided into two key smaller tasks between each of the two semesters. The first semester is focusing on designing the solar panel layout (location, hardware choices, and Autocad layout). The second semester involves researching and designing the substation that connects to our solar plant.

3.4 Possible Risks And Risk Management

During the design phase of our project, because we are only using the software Excel to work on calculations, there really is one possible risk that we could face. This risk is due to using improper values in calculations that would need to be addressed. Fixing these calculations could potentially lead to missing a time deadline.

3.5 Project Proposed Milestones and Evaluation Criteria

There have been three key milestones within the project:

1) Fill out the Array Parameter tool and figure out which solar panel to use, JA Solar or the Eagle 72
2) Researching the best place for the substation to be located.
3) Fill out the Voltage Drop Calculation Sheets

In the next semester we will reach the following milestone:

4) Finalizing the substation design

3.6 Project Tracking Procedures

Working with a large group on a complicated tasks can easily become disorganized throughout the semester so it was very important to our group to make sure we were staying on task. In order to do this, our group created a detailed Gantt chart using Microsoft Project that allowed us to break down tasks and track their progress. In addition to this, our team created weekly reports that summarized our teams progress that week. This allowed us to easily see which tasks we were going to complete on time and also identify tasks that needed more time dedicated to them in order to complete them efficiently.

3.7 Expected Results and Validation

Our desired outcome for this project is to create the most cost effective and highest output solar plant as possible. In order to make sure that the project will be successful, we have different tools such as our array parameter tool, and our voltage drop calculator that allow us to make sure our values are reasonable with real world outcomes. By using these tools, we are able to see how certain parameters change the outputs of each system and therefore can ensure that our project will be successful at the highest ability.

4. Project Timeline, Estimated Resources, and Challenges

4.1 Project Timeline

****Gantt chart will be input into the document for the final version****

4.2 Feasibility Assessment

For this project, we are expecting to design a solar farm and substation that will generate 60MW. While our client didn't give us a budget, it is important for us to keep cost in mind so that our substation will be financially beneficial. While there are many costs we can't accurately account for, such as the construction timeline, degradation of panels, and maintenance, we can do our best to estimate these potential costs. Generally it has been stated that is costs approximately $1/watt for installation, and since our farm is 60 MW, we can assume it will roughly cost $60 million

4.3 Personnel Effort Requirements

4.4 Other Resource Requirements

Since we do not require any financial aid from our clients, the only other resource that we are required to have to complete our project is software that has been made available through Iowa State University. This software we will be using is AutoCad, which will be used for our solar plant layout. In addition to this, Black and Veatch have provided us with all the necessary datasheets to figure out the required calculations.

4.5 Financial Requirements

Currently, our team does not have any financial constraints while working on the project. We will however, consider many different design choices that will affect the overall cost of the project, considering we would like it to be as low as possible without compromising efficiency.

5. Testing and Implementation

During this semester the "testing" of the project would only be based on completing the provided excel sheets (array parameter tool and voltage drop calculations) and making sure that the values are viable. During the next semester we will begin creating a design of the substation, in which we will most likely run into more “testing” and the implementation phase of our project.

5.1 Interface Specifications

Considering we are working on a very large-scale project, our team will not work directly with any hardware. Instead, Black and Veatch has provided us with different software solutions that we are able to use for designing and testing. The software that we used was mainly Autocad for the actual layout design, and excel for the calculations and testing to ensure our values would work.

5.2 Hardware and software

As previously stated above, due to the nature of our project we will not be working directly with any hardware. The only interaction we had with “hardware” is during our design phase when we had to research different hardware components that we could use in our design. In terms of software, we have used excel templates to figure out the necessary calculations as well as CAD to create a view of the layout we will use for the solar panels.

5.3 Functional Testing

Testing can be seen by the math done within the voltage drop calculations and the array parameter tool. Figure 2.0 below shows the excel sheets we commonly use throughout the project:

		String Size		
	Location	Min Temp	-6.6	C
	Datasheet	Voc	48.81	V
	Datasheet	Ref temp	25	C
	Datasheet	Temp Coeff of Voc	-0.003	/C
		Temp delta	-31.6	
		temp correction	1.09	
		V0c corrected	53.43718	
Confirm possible with Panel type chosen	Designer Choice: 600, 1000, 1500, 2000V	string voltage	1500	V
		String size	28.07033	
		string size	28	
		Actual String Voltage	1496.2	
		Input Information =		

	Electrical Rack Size		
Designer		potrait	
Datasheet	Module width	3.2	ft
Datasheet	module height	6.57	ft
Designer	Rack width	28	modules
Designer	Rack height	2	modules
	Modules per rack		
	Rack width	89.6	ft
	Rack height	13.14	ft

	CB capacity		
Datasheet	mod/string Isc	10.03	A
NEC sectio	multiplier	1.25	
	nom Isc	12.5375	
Irr.	multiplier	1.25	
	max Isc	15.67187	A
Designer Choice: 200, 400A etc.	allowed current	275	A
	strings per CB	17.54735	
	Round down:	16	

	Array Design		
Designer	Racks per row	8	
Designer	rows per Array	23	
Designer	Racks removed	2	
	Total Racks/Array	182	
	Total modules	10192	
Datasheet	module capacity	380	W
	dc capacity	3.87296	MW
Designer	inverter capacity	3	MW
			MVA
Provided: Industry standard 1.3	ILR	1.290986	

	Array Size		
Designer	tilt	35	
	table height proj	10.76365	ft
Designer	row spac	15	ft
	pitch	25.76365	ft
	Space for Inverter Maintenance	15	ft
	Array height	592.5641	ft
	Array width	716.8	ft
	Ground Coverage Ratio	0.510020	

Figure 2.0: Excel sheet from the array parameter tool

5.4 Non-Functional Testing

Our non-functional testing can be defined as the team sending the values calculated to Black and Veatch and discussing them to make sure that they seem reasonable. If any discrepancies are found during our discussion, we go back and revise them until they are satisfactory.

5.5 Process

5.6 Results

From this semester our results have been positive and approved by Black & Veatch's representatives. We were able to obtain these results after many updates and changes we made. The changes were primarily to the array parameter tool and voltage drop calculations. Although we have encountered many challenges and difficulties of understanding various new topics that are necessary for the project, we are able to overcome these obstacles with the help of Black & Veatch, as well as our advisor Dr. AjJarapu.

6. Closing Material

6.1 Conclusion

This semester our design team has worked to finalize a 60 Megawatt solar plant. As a team, we have:

- Utilized the provided Array Parameter Tool to determine the quantities of equipment needed.
- Performed voltage drop calculations to determine the size of conductors needed in order to meet NEC guidelines.
- Determined a suitable location for our solar plant with considerations to irradiance, cost of land, and weather patterns.
- Designed a layout in tandem with our voltage drop calculations that minimizes power loss by reducing conductor lengths.

Our goals moving forward pertain mostly to the design of the substation that will be responsible for integrating our solar plant with the grid. We aim to provide a final design that adheres to all relevant professional standards and codes. We also strive to continue working closely with our contacts at Black and Veatch to maintain an open line of communication, which benefits both parties.

The best course of action to reach these goals will be to continue our weekly meetings with Black and Veatch. It is through these meetings that we can clearly establish what professional standards are considered through each phase of design. They also give us key training that we need in order to utilize the templates they provide for us. It is our time to ask questions, brainstorm possible design solutions, and take the next iterative step towards a final design.

6.2 References

6.3 Appendices