115kV/34.5kV Solar Power Plant and Substation Design

DESIGN DOCUMENT

Team Number: 27
Client: Black and Veatch
Advisers: Professor Ajjarupa
Team Members/Roles:
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Executive Summary

Development Standards & Practices Used

- Engineering Standards
  - NFPA 70 - National Electrical Code 2020
  - International Fire Code 2021
  - UL1741 - Ensures equipment safety with distributed energy resources
  - UL1703 - Standard for flat-plate photovoltaic modules and panels
  - UL61730 - Provides construction requirements and testing for photovoltaic modules

Summary of Requirements

- Function requirements
  - The design of a 60 MW solar plant and a 115/34.5 kV distribution substation that takes into consideration things like:
  - An Electric Panel with Sufficient Capacity
  - Energy Information to Size the Solar
- Physical Requirements
  - Solar plant: hundred acres of land, flat & dry land, close to a substation, fence and maintenance
  - Substation: central, elevated, flat, large, easy to access land
- Environmental Requirements
  - High irradiance, low humidity, low cloud coverage, stable ground material
- Resource Requirements
  - BlueBeam, AutoCAD, Array Parameter Analysis Tool, Google Drive
- Aesthetic Requirements
  - Clear layout for diagrams (string, rack, array, yard), concise agenda and minutes for each client meeting, color coded Gantt chart
- User Experiential Requirements
  - clear and concise design diagrams, budget-friendly design, weekly meeting report updates

Applicable Courses from Iowa State University Curriculum

Within the Electrical Engineering Department, EE 303, EE 351, EE 456, and EE 457 have content applicable to our Solar Farm and Substation project. Outside of the Electrical Engineering Department, Industrial Engineering 305 and English 314 are also applicable to our project.

New Skills/Knowledge acquired that was not taught in courses

- Software
  - Bluebeam
  - AutoCAD
- Solar array design and calculations
  - Voltage Drop Calculations
  - Trench Fill Calculations
  - Economic Estimates
  - Array Parameter

Glossary

Alternating Current (AC) - current that reverses its direction over regular intervals.

Array - a combination of solar modules.

Combiner Box - a device that combines multiple strings together.

Conductor - a means of transporting current from one location to another.

Direct Current (DC) - current that flows in a constant direction.

Feeder - a conductor that connects a combiner box to an inverter.

Inverter - a device that converts electricity into different forms such as DC to AC.

Jumper - a conductor that connects a string to a combiner box.

MW - megawatt is a measurement of power.

Rack - a parallel connection of multiple strings in a singular row.

Renewable Energy - energy sources that are naturally replenished on a human timescale.

Solar Panel - an array of photovoltaic cells that converts sunlight into electricity.

String - a single, series connection of individual panels.

Voltage Drop - a decrease in voltage of a conductor over a specific distance.

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1 Team

1.1 Team Members

Madison Lakomek, Brooke Nelson, Ashton Randolph, Jacob Miller, Jenna Runge, Madissen Lawrence, Zachary Zimmerman, Omer Karar

1.2 Required Skill Sets for Your Project

- Familiarity with Substation Components, Solar Technologies, Power Flow, and Circuit Schematics
- AutoCAD

1.3 Skill Sets covered by the Team

- Familiarity with Substation Components, Solar Technologies, Power Flow, and Circuit Schematics
  - All
- AutoCAD
  - Previous Experience: Zachary Zimmerman
  - Learning: All other team members

1.4 Project Management Style Adopted by the team

Our team employs both waterfall and agile project management techniques. This is because we have regular interactions with the group and the client that are strictly planned out each week. We are also working in a linear way as we complete one aspect of the project each week, slowly working towards the final solar field and substation design.

1.5 Initial Project Management Roles

As outlined in the team contract in 8.4.1, since all team members are electrical engineers with a power systems focus, we have split work throughout the project as seen fit. Managerial roles such as organizing meetings and taking minutes are rotated weekly.

2 Introduction

2.1 Problem Statement

The United States has increasingly become more aware of its carbon footprint and has been taking measures to minimize its emissions. Local utilities have contracted Black & Veatch to implement more ways to generate renewable energy into their electrical systems, specifically solar power plants. Although this issue is continuous across the United States, our project will focus on Roswell, New Mexico, to implement a new generation and transmission system.

One step towards solving this problem is that a large-scale 60 MW utility solar power plant must be designed along with a 115/34.5 kW substation to provide more clean energy to neighboring areas.

2.2 Intended Users and Uses

Our product will be tied into the existing National Grid and will be available to anyone connected to the utility grid. Specific users of this system would be anyone who uses electricity, such as homeowners, renters, and small businesses, utility companies, and Black & Veatch as they are the main clients.

Utilities value clean and reliable energy and therefore need a substation and solar field that consistently produces electricity and sustains the current and future loads produced. There is also a desire for minimal maintenance throughout the years. The utility also requires that the solar field is built in a location with high sunlight, low humidity, low land value cost, and flat ground to ensure the optimum energy is produced. This user may be motivated by money and are encouraged to increase renewable energy sources for more clean energy and a potential tax credit.

Another intended user would be the common person living near the substation and using the electricity produced by the solar field. This user values reliable and affordable electricity to power the devices within their home. The common electricity user in the area also hopes for quick construction so the renewable energy can be implemented in a timely manner. These users will benefit from the solar field and substation because it will bring more clean energy to their residences, and therefore decrease their utility bills overall.

2.3 Requirements and Constraints

- Function requirements
    - The design of a 60 MW solar plant and a 115/34.5 kV distribution substation that takes into consideration things like:
    - An Electric Panel with Sufficient Capacity
    - Energy Information to Size the Solar
- Physical Requirements
    - Solar plant: hundred acres of land, flat & dry land, close to a substation, fence and maintenance
    - Substation: central, elevated, flat, large, easy to access land
- Environmental Requirements
    - High irradiance, low humidity, low cloud coverage, stable ground material
- Resource Requirements
    - BlueBeam, AutoCAD, Array Parameter Analysis Tool, Google Drive

- Aesthetic Requirements
    - Clear layout for diagrams (string, rack, array, yard), concise agenda and minutes for each client meeting, color coded Gantt chart
- User Experiential Requirements
    - Presentations on a weekly basis. We are also working in a linear way as we complete one aspect of the project each week, slowly working towards the final solar field and substation design.

To assist with managing the project, we track our progress weekly through the meeting agenda and minutes. In these documents, we have what has already been done and what needs to be accomplished in the following week. We also keep a list of questions on the agenda to clear up any uncertainties we have with the client and keep track of what is being done.

2.4 Task Decomposition

Because we use an agile approach to managing our project, our group has decomposed the overall project into several parts. This task decomposition was vital because it ensured we progressed throughout the semester to ensure all requirements were met.

- Create a high-level model to help you see the finished product better.
- Farm layout should take accessibility and space requirements into account.
- According to part ratings, cost, and power efficiency, create component attachments.
- Analysis of economic efficiency
- Calculations of voltage drop
- Analysis of trench fill

For our project, we will be taking two semesters to design a solar farm and substation. In the first semester, we'll concentrate mostly on developing the solar panel design layout. To do this, we must first choose an appropriate place for our plant, which will depend on several design variables that we must examine. We then had to use an array parameter tool that our customer had given us, which enabled us to select the appropriate components for our design. We will then use AutoCAD and Bluebeam to design the arrangement. Calculating our system's voltage drop was also considered one of the design criteria we have to complete this semester. Next semester, we will start to design the 60 MW substation for our solar farm, which will require us to also take a larger-scale look at our overall design.

2.5 Project Proposed Milestones, Metrics, and Evaluation Criteria

The substation design portion of the project had key milestones that needed to be met as we progressed throughout the semester. Those key milestones are listed below.

- Plant must have a DC input of 80 MW with an AC output of 60 MW

- The location chosen will maximize sunlight and have enough space to fit the 60 MW solar plant and the substation that must go along with it.
- The voltage drop throughout the solar field will be 5%.
- Complete each stage of the engineering design document (in CAD).
    - Create a title block/cover page
    - Solar plant layout details
    - Racking details
    - Electrical details
    - Wire schedule
    - Code calculations page
    - Cutsheet page
- The panel, converter, and inverter combination chosen must have an inverter loading ratio of < 1.3.

2.6 Project Timeline/Schedule

SOLAR DESIGN						09/14	09/21	09/28	10/05	10/12	10/19	10/26	11/02	11/09	11/16	11/23	11/30
Task Name	*START DATE*	*END DATE*	*DURATION (WORK HOURS)*	*TEAM MEMBER*	*PERCENT COMPLETE*	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8	WEEK 9	WEEK 10	WEEK 11	WEEK 12
Research																	
Solar Panels	09/14	09/21	3	Jacob, Zach & Omer	100%												
Combiner Boxes	09/14	09/21	2	Madissen and Jenna	100%												
Inverter Skid	09/14	09/21	2	Ashton and Brooke	100%												
Bill of Materials (BOM) - Phase I	10/05	10/12	2	Ashton adn Maddy	100%												
Bill of Materials (BOM) - Phase II	11/2	11/9	2	Ashton And Maddy	100%												
DESIGN																	
High Level Model for Visualizaton	09/14	9/21	2	Whole team	100%												
Array Parameter Tool	09/21	10/05	5	Whole team	100%												
AutoCAD Design	10/05	10/26		Zach	100%												
Title Block/template	10/05	10/12	8	Zach	100%												
Array layout	10/05	10/12	10	Zach	100%												
Stringing	10/05	10/12	8	Zach	100%												
Racking	10/12	10/19	10	Zach	100%												
Electrical Diagram	10/12	10/26	15	Zach	100%												
Wiring Schedule	10/12	10/26	15	Zach	100%												
Full plant characteristics	10/19	10/26	10	Whole team	100%												
Calculations																	
Economic Estimates	10/26	11/2	10	Ashton and Maddy	100%												
Voltage Drop	10/26	11/2	10	dissen, Jenna, Omer, Z	100%												
Trench Fill	11/2	11/9	10	rooke, Madissen, Jen	100%												
Class Schedule																	
Design Document - User Needs	09/21	09/30		All/Rotate	100%												
Design Document - Project Requirements	10/03	10/07		All/Rotate	100%												
Lightning Talk	09/21	09/29		All/Rotate	100%												
Design Document - Project Plan	10/10	10/14		All/Rotate	100%												
Design Document - Module 7	10/17	10/21		All/Rotate	100%												
Design Document - Module 8	10/24	10/28		All/Rotate	100%												
Design Document - Module 9	10/31	11/4		All/Rotate	100%												
Design Document Module 10	11/7	11/11		All/Rotate	100%												
Design Document Module 11	11/14	11/18		All/Rotate	100%												
Design Document Module 12	11/28	12/2		All/Rotate	100%												
Weekly Reports	9/26	12/9		All/Rotate	100%												
		Man-Hours	124														
		complete															
		future															
	Key	break															

Figure 1: Gantt Chart for Solar Farm

Above is a photo of the Gantt chart we created for this semester's work schedule. It includes all of the design and documentation work for the solar farm, and then, in spring 2023, it includes all of the design and documentation work for the substation. It is broken down into categories of research, design, calculations, and class schedule. Research includes tasks such as deciding which parts to use and calculating the bill of materials. The design process primarily involves laying out the solar farm in CAD and deciding on all of the associated specifications. The calculations are the voltage drop, trench fill, and economic approximation calculations. Finally, the class schedule lays out when the team assignments for EE 491 were made throughout the semester.

2.7 Risks And Risk Management/Mitigation

There is little risk that coincides with the substation design project. A risk found, though, was potentially misreading the component datasheet. If we misread the datasheet, we will enter incorrect values into the array parameter tool, causing our calculations for the number of arrays, inverters, and so on to be incorrect. This is not a high risk, as we all worked on the array parameter tool together, and if it is incorrect, it is only an Excel sheet that can be easily changed. Our work gets checked weekly by Black & Veatch as well, so this risk is extremely low.

2.8 Personnel Effort Requirements

Tasks	**Explanation of Tasks**	**Man-hours Required**
Complete Array Parameter Tool	Using the different solar panels, inverters, and combiner boxes, create five spreadsheets comparing the combination of the different devices, ensuring the ILR is about 1.3.	10 hours
Research and finalize location for solar field	To determine which land would be the most viable to build a solar field on, the irradiance, cost, and type of land available in Ames and New Mexico had to be determined. Roswell, NM was ultimately determined as the best place	4 hours
Create CAD model of solar field layout	A CAD drawing document, including a title block, cover page, solar plant layout details, rackiACALetails,details,schedule calculations, and other details,lations,calculations must be designed based on the ideal combination of equipment chosen using the Array Parameter Tool. To ensure that the voltage drop is within 5%, the model may need to be modified based on any calibration results.	60 hours
Complete Calculations	Bus, grounding, AC, DC, voltage drop, lightning, trench fill, cost, and cable tray calculation must be completed using various excel sheets given to us by Black & Veatch	24 hours
Weekly Meetings	We meet as a group with our adviser Ajjarapu on Tuesdays, with Black & Veatch on Wednesdays, and then for group work time on Thursdays	24 man-hours/week

Prepare for next semester substation design	Begin to think about how the solar field will be connected to the substation, where on the land it will go, how it will interact with the solar field and customers	5 hours per person

Table 1: Personnel Effort Requirements

2.9: Other Resource Requirements

Two other resources necessary for this project are AutoCAD and BlueBeam software. We also need various calculation spreadsheets provided to us by Black & Veatch to compare and contrast different potential components, estimate the voltage drop, perform a cost analysis, and analyze other aspects of the project.

3 Design

3.1 Design Context

3.1.1 Broader Context

Our project is intended for utility communities attempting to transition to more environmentally friendly practices. Utilities and the communities connected to them are affected by our design. It addresses the need to be more environmentally friendly and to increase the amount of renewable energy that is used in the power sector.

Adding a system like ours would also increase the reliability of the power grid as much of the infrastructure is approaching its end of life and will be experiencing more power failures in the years to come. Adding more systems like this would increase the reliability of power delivery to the affected communities as well as lessen the environmental impact due to the power generation described above.

Area	Description	Examples
Public health, safety, and welfare	This project affects the general well-being of communities where the solar farm is located. Having a solar farm in a neighborhood instead of a coal power plant helps the welfare of families during natural disasters.	Solar panels reduce exposure to air pollutants because they do not rely on fuel that emits carbon dioxide. Building the solar farm will create job opportunities.

Global, cultural, and social	This project reflects the positive values of green energy and reducing climate change. One consideration is the public perception of solar and the number of people who do not want it in their communities.	The development and design of the solar field and substation will not violate any code of ethics and will not force any of the community users to change their typical practices. It will affect how the community views renewable energy as it will positively affect their utility bill. Public perception of solar is important, as these systems will likely become visible parts of their communities, and many are not open to this becoming a part of their community even if they are not against the idea of clean energy itself. Working with communities is necessary to ensure these projects can get off of the ground and can go into development.
Environmental	This project will increase the amount of renewable energy, therefore creating a more green way of producing electricity.	increasing use of renewable energy, therefore making the electricity production in the area more environmentally friendly. The use of solar power also reduces the amount of oil and natural gas extraction necessary to reach the same power output. Less oil and gas extraction reduces harm to local flora and fauna and lessens disruptions to local wildlife.
Economic	Lower consumer expenses, more affordable energy generation for utilities	The overall design of the solar field and substation must be cost-friendly, as the utility is focused on the cost benefits of adding more renewable energy.

Table 2: Societal, Global, Environmental, and Economic Context

3.1.2 User Needs

As we discussed in 2.2, the users of our solar farm and substation are anyone connected to the electric grid in the region of our project—Roswell, NM. The two main users we are focusing on are the utility companies and the average energy consumer. not to be confused with our client Black & Veatch, which is a consulting company that we are delivering these designs to.

Our utility company users want a clean energy source with a reliable, consistent, and efficient design that can be easily connected to the existing distribution network. Furthermore, they need a location to build the solar plant that has high sunlight, low humidity, a low land value, and flat ground.

Consumers, our other user group, value consistent and dependable electricity to power their homes. Additionally, some of them may want clean energy powering their homes, which would be addressed by our clean energy solar farm.

3.1.3 Prior Work/Solutions

Solar farms are a growing source of renewable energy for the power grid. Our project of creating a utility-scale solar farm has been done before and exists in the market. These projects are 20 MW or larger. The solar farm that we are creating is going to be 60 MW. These renewable energy resources compete in the market by offsetting retail electricity rates.

There are several ways to ensure that a solar farm is successful. Location and orientation are key, as is being able to compete with organized electricity markets that can be traded and sold in order to benefit both consumers and utility companies.

One of the main advantages of solar power is that it is a clean energy source. In addition, it is a reliable source of electricity during daytime hours because the sun is not going anywhere. Unfortunately, the construction of solar farms has associated emissions and is not entirely an emissions-free project. However, the emissions from traditional energy sources are significantly higher than those from solar farm construction projects. Another advantage of solar farms is that they can be used to graze livestock or to grow crops. Agrovoltaics, the practice of co-locating farmland and solar farms, has proven to be very beneficial, according to "innovative solar systems." Another way to increase the positive environmental impact of the solar farms is by restoring the ground cover to natural vegetation within the reasonable limits of maintaining the PV system. One such example of this is the vegetation restoration project seen at the solar farm in Ames.. During the project they decided to also work to restore the ground coverage within the PV system to native grasses. In a study by the Department of Energy in 2012, it was estimated that 37% of that output generated from solar panels could come from rooftop installations, with the rest coming from a more traditional solar farm setup. These projects' estimated landforms would cover 1.8 million acres (Beatty et al.). Setting up PV systems in integrated fashions such as the mixed land use with farmers or land restoration, increases the productive output and positive impact from these projects.

While there are several advantages to solar energy, there are also additional cons to using this type of energy. There are three main issues with solar farms: land use, output, which is based on weather patterns, and cost. The extensive land use can be cut by setting up systems to incorporate agrovoltaic practices to combine land uses. The only way to mitigate the effect of weather on output is to choose a location in which the weather would have a minimal impact, such as an area with minimal rain and cloud coverage throughout the year. Finally, solar farms are very expensive, which is not always feasible. Based on our price analysis calculations, our solar farm is looking at being around $80 million. Many utilities could not justify spending that amount of money on a power generation project that could not operate 24 hours a day.

3.1.4 Technical Complexity

1. Two parts (solar and substation design)
2. Client meetings with agendas and minutes
3. Solar field design
    a. Multiple CAD Designs
        i. Array design
        ii. Rack and string detail
        iii. Array component layout
        iv. Electrical detail and line diagram
    b. Array Parameter Tool calculations
    c. Voltage Drop Calculations
    d. Cost Analysis
    e. Trench Fill calculations
4. Substation Design
    a. One line and three line diagrams, grounding, equipment, and bus layout
    b. Grounding, bus, AC, DC, voltage drop, and lightning calculations
    c. Equipment selection
    d. We looked into these two locations: Roswell, New Mexico and Ames Iowa.
        i. With each location we considered the price of land, hours of sunlight a year, and success stories. This decision is important because location is one of the main factors that goes into whether or not the solar farm is able to compete in the market based on the amount of power and electricity it can make.

The third decision we made as we have been drafting up our CAD drawings is the design layout. Again, the orientation of a solar farm can have major effects on the overall output of the system, making it a very important decision. In addition, certain setups compared to others are limited based on the voltage drop calculations we have been doing simultaneously.

3.2.2 Ideation

In order to make our design decisions, we have had to do a lot of research on the different components within a solar farm. We decided to research three different brands for each of the main components: solar panels, inverters, and combiner boxes. After finding our top three for each of these components, we paired them in different combinations together, creating six different options that we considered.

3.2.3 Decision-Making and Trade-Off

We used a spreadsheet to compare all the data generated for the six different combinations that we came up with. The main thing that we compared was the inverter capacity and the industry standard inverter loading ratio, or ILR. The ILR is the ratio of the installed DC capacity to the inverter's AC power rating. We needed our ILR to be 1.3, as per the rule, so we could immediately rule out decision number three. Next, we will use the highest inverter capacity while still achieving an ILR of 1.3. The design that had the highest inverter capacity of 5000 kW was decision number two, so we decided to go with this one since the other designs' capacities ranged from 3000 kW to 4700 kW.

3.2 Proposed Design

3.2.1 Overview

During the fall semester, we are completely designing the solar array portion of our project. There are several aspects that make up the design: the layout, the specific gear that makes up the layout, and the data that helped us make the design decisions.

Our current solar array layout consists of 144 rows of uniformly placed panels with 4 more rows of irregular-length panel strings (as seen below). Within these rows, there are 148 combiner boxes, 13 inverters, and over 160 thousand panels. We were able to determine the number of components to use as well as the make and model through our use of an Excel spreadsheet called the Array Parameter Tool. The APT takes in data from each component datasheet and outputs component numbers, layout spacing, and solar plant output. All of this information was very useful to us because it confirmed which components would generate our desired output voltage and power,as well as tell us how many components we needed and how far apart we should be spacing our rows.

Another tool that helped us solidify our solar array layout was the Voltage Drop Calculator Excel Spreadsheet. In systems such as these, we need to worry about excess voltage drop because if the outermost panels have too high a voltage drop (greater than 5% overall), the equipment will experience too much wear and tear and will degrade much faster than it should. When we enter incorrectly, To meet this requirement, a few calculations must be performed to ensure that the input voltage level remains below 1500 V even under extreme conditions. The output voltage of the solar panel is linearly affected by temperature. As the temperature drops, so does the voltage of the solar panel, and vice versa. We then find the absolute minimum temperature a solar module might experience and multiply that by the temperature correction coefficient of the solar module, which is provided in the datasheet. The 480-watt solar panels we chose for our design produce an output voltage of 53.61 volts per module and have a temperature correction coefficient of -0.0027 volts per degree

Celsius. The lowest temperature a module could experience in Roswell, NM, is -26.11 °C. We can take -26.11 and multiply that by -0.0027 V/°C to find the total voltage output of the solar module under extreme temperature conditions is 57.4 V. We then found the number of solar modules that we could string together and still meet the 1500-volt requirement of the inverter to be 26 modules. ratio, we know our array must output 6.5 MW of DC power. We found that an array could consist of 22 racks per row and have 12 rows per array, which would output 6.59 MW of DC power.

The next step in our design process was to determine the size of our small array needed to reach 80 MW of DC power. We already know that our 12 arrays output a total of 79.073 MW, so we find that we need a total of 926.72 kW to reach our goal of 80 MW. We also know that each rack outputs 24.960 kW, so we found that we need an additional 37 racks. We chose to have three rows of 12 racks and a single row with only one rack.

Shown below is an outline of our solar plant design, which consists of 12 large arrays that each have 13 thousand modules, 24 combiner boxes, and 1 inverter. The small array has 1 inverter, 4 combiner boxes, and 1924 modules.

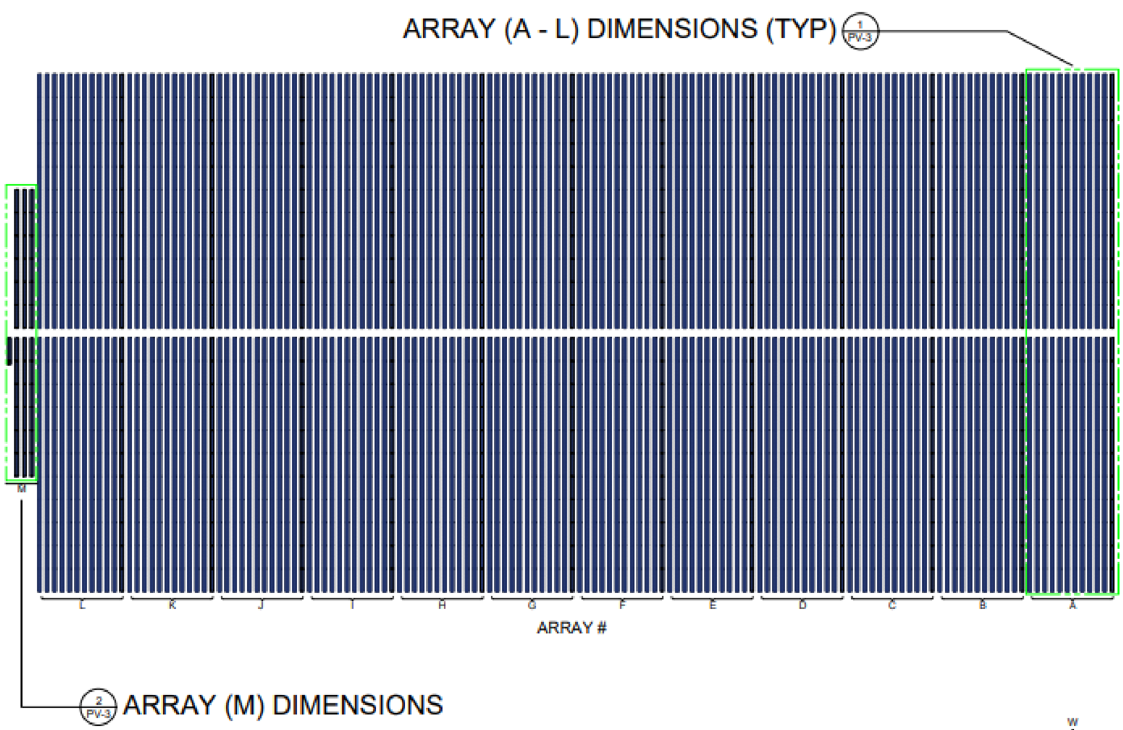

Figure 2: Solar Array Layout

After we completed the APT, we could then begin our design using AutoCAD. As mentioned previously, there are a few different factors that affect the production of the solar farm, such as module orientation, row spacing, array spacing, and the pitch of the solar modules. Here in the United States, it is standard practice to orient the modules facing south in order to maximize production. This orientation has to do with the solar eclipse and the sun's location relative to the solar modules. The spacing between rows of modules is also very important for two reasons. The first reason being that placing the rows too close to each other will cause shading issues and limit the production of the modules. The second reason that row spacing is important is that having the rows too far apart will limit the amount of solar modules since each row would take up more area. Maximizing the spacing between rows allows for our clients to expand in the future and still avoid shading of rows. The spacing of an array is also important. During our design, we wanted to provide easy access to all the components to reduce the costs of maintenance. Creating an access pathway to each of the components in our solar farm will save time and added cost to fix any faulty equipment. Finally, understanding how to position the modules to provide maximum production year round is important. During the summer months, it would be ideal to tilt the modules at a lower angle as the sun travels at a lower path around the United States. In the winter month, the sun travels at a higher angle around the United States, so it would be ideal for the pitch to be at a higher angle. We chose to tilt our modules in relation to the latitude (33 degrees) of Roswell, New Mexico. We chose to use 33 degrees as it provides optimal production year round. Keeping these factors in mind, we began designing our solar farm.

3.2.2 Detailed Design and Visual(s)

Shown below are the final CAD drawing plans for the Solar Farm design. Substation design work will be completed Spring 2023. The images below are grouped into Layout, Wiring, and Voltage Drop Calculations.

3.2.2.1 Layout

Figure 2 above shows the high level overview of the full solar array layout. It is organized so that the system is largely symmetrical, with a small, irregular array on the leftmost side. The irregular section of the design was added to ensure the full system outputs the required DC power output.

Figure 3 below shows a closer view of the array's layout, both a section of the regular array and the small array. The bottom section of this figure explains the more intimate racking detail of both the regular and small array.

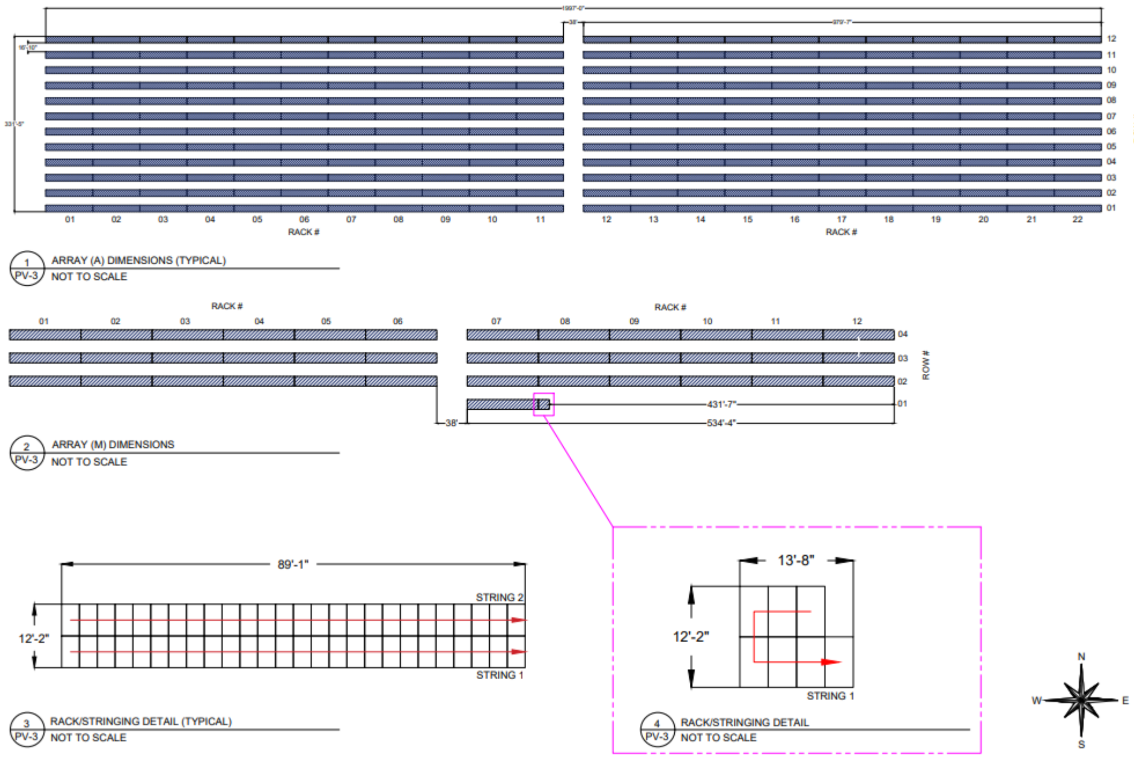

Figure 3: Zoomed in Detailed Array Layout

Figure 4 below details the additional aspects that are necessary within the solar field. These components include the full solar modules, the access pathway, the inverter, as well as the combiner boxes. The top image in the figure is the normal array and the bottom image is the small, irregular array.

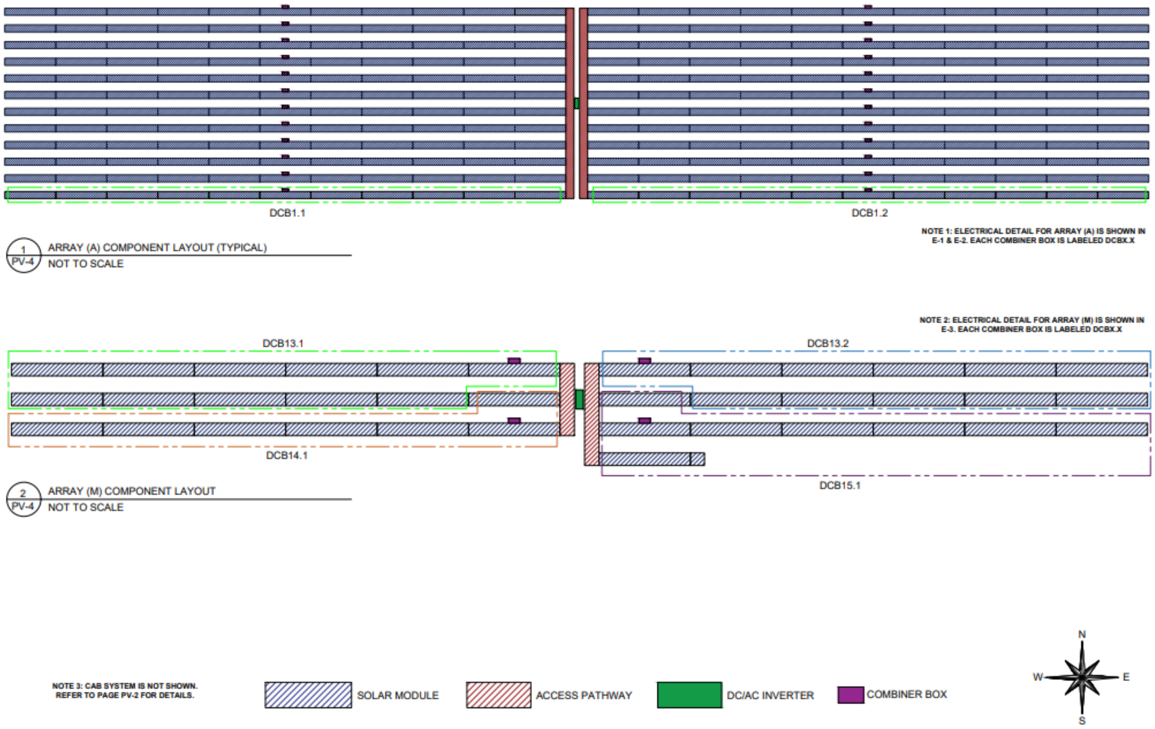

Figure 4: Array Component Layouts

3.2.2.2 Wiring

The wiring is sectioned into three different drawings to show how the solar farm is connected. Figure 5 below shows a complete overview of the wiring from each string to the inverter (for each array). Each rack has two strings that are combined with a junction box where it is then wired into a combiner box. The combiner box connects 22 strings (or 11 racks) together with a total of 24 per array. A wire is then used to connect the combiner box to the inverter.

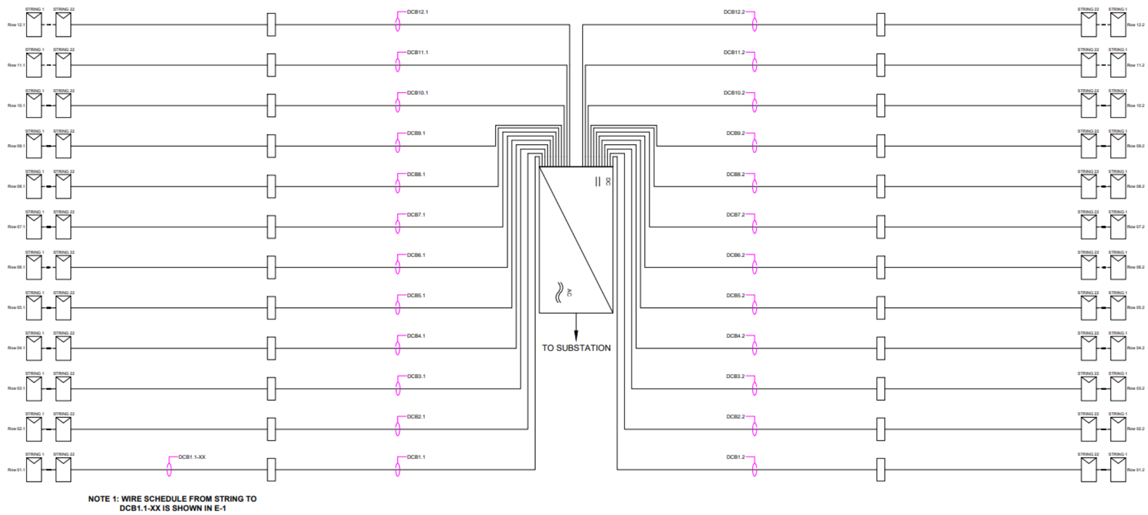

Figure 5: String to Inverter Wiring Overview

Figure 6 goes further into details on how each string is connected to the combiner box and then to the inverter.

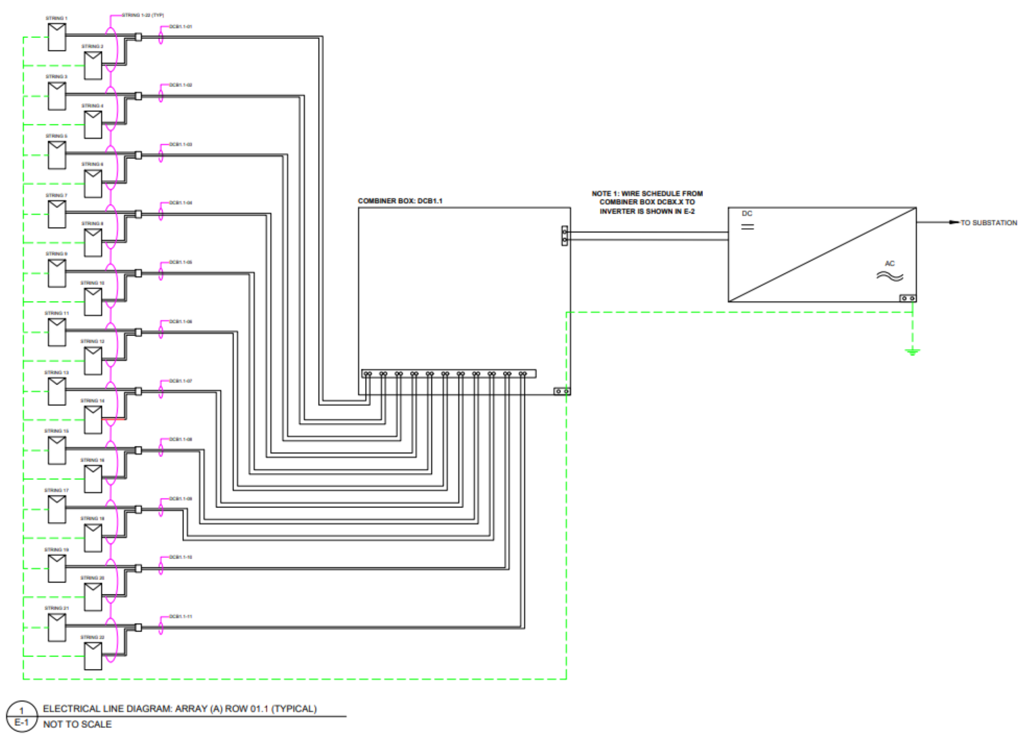

Figure 6: String to Combiner Box to Converter Wiring

Figure 7 shows the wiring schematic for the small array (array 13). Each rack still contains two strings with an exception for the small rack that only contains 7 modules. The two strings for each rack are connected with a junction box and then fed into the combiner box.

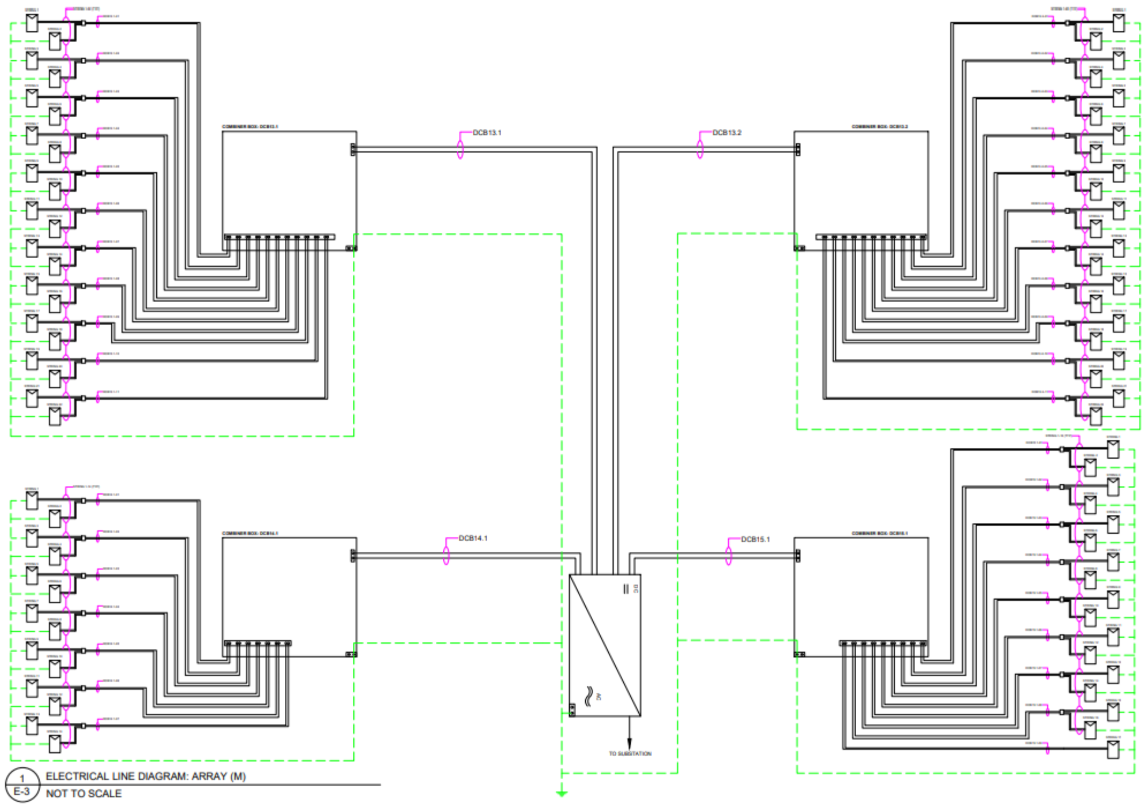

Figure 7: Small Array Wiring Schematic

3.2.2.3 Racking Components

The racking components that are used throughout the solar field are from SnapNrack. There are multiple pieces necessary to complete the racking system, including ground rails, clamps, junction boxes, and much more. The chart below shows the specific species from SnapNrack that our design uses. It also includes the part number found in the catalog as well as how many are needed to construct the entire solar field.

Racking Material	Part #	Qnty
Ground Rail, 172IN, SILVER	232-02542	1489
Ultra Rail MID Clamp, Silver	242-02070	166660
Universal End Clamp	242-02215	333320
Bonding Pipe Clamp Assembly for 1-1/2 IN	242-09004	333320
Ground Rail End Cap, Black	232-01043	333320
Ground Lug Assemply, 6-12 AWG	242-02101	3205
5EXT-8, Single Socket Tee, 1-1/2IN, AL-MG	172-05818	192300
17-8, Single Adjustable Socket Tee, 1-1/2IN, AL-MG	172-05803	192340
62-8, Plug End, 1-1/2IN, AL	172-05808	205120
Junction Box	242-01104	3205

Table 3: Racking Materials

The wiring is also an integral component of the solar field. The designed solar field requires three different wire types. The chart below shows the three types of wires and the length, in feet, required of each wire to create all of the arrays. The first wire listed in the chart are the wires used for the strings within the solar field. The second wire is used for the jumpers and the last wire listed is used for the feeders.

"Wiring" Material	Normal Array(ft)	Small Array (ft)	Total length (ft)
10 AWG Al THWN	90500	8941	99,441.00
6 AWG Al THWN	130488	10430	140,918.00
600kcmil Al THWN	327072	704	327,776.00

Table 4: Wiring Material

3.2.2.4 Voltage Drop Calculations

Shown below are the tables used to calculate the voltage drop. The first table shows the calculations for the strings to a combiner box. The second table calculates the voltage drop from the combiner boxes to the inverters. This organization is repeated for the small array.

For the voltage drop, we started with the combiner boxes along the access roads, near the inverters, to make maintenance and installation easy. This caused the voltage drop to be about 10% for the normal array, which exceeded our max drop of 5%. After some trial and error, the team determined that the large drop was caused by the relative position of the combiner boxes to the inverters and the racks. The large drop was solved by moving the combiner boxes further from the inverters to roughly the middle of the racks due to the large drop occurring. This was due to the long distances between portions of the racks and the combiner boxes and that the distance between the combiner boxes and inverters had a smaller effect on the voltage drop. The final voltage drop was 4.05%

JUMPER VOLTAGE DROP CALCULATIONS: ARRAY A - L (TYP)													
DCB	Strings per Rack	IMP for String	String Length	String wire size	String Conductor resistance	String resistance	Voltage Drop of String	IMP for Jumper	Jumper Length	Jumper wire size	Jumper resistance	Jumper resistance	Voltage Drop of Jumper
DCB#-##	per rack	Amp	feet	AWG	Ohm/kft	Ohm	Volts	Amp	feet	AWG	Ohm/kft	Ohm	Volts
DCB1-01	2	10.7	85.7	10	2.000	0.332	3.668	21.4	490.00	6	0.808	0.766	16.945
DCB1-02	2	10.7	85.7	10	2.000	0.332	3.668	21.4	400.95	6	0.808	0.627	13.866
DCB1-03	2	10.7	85.7	10	2.000	0.332	3.668	21.4	311.90	6	0.808	0.488	10.786
DCB1-04	2	10.7	85.7	10	2.000	0.332	3.668	21.4	222.85	6	0.808	0.348	7.707
DCB1-05	2	10.7	85.7	10	2.000	0.332	3.668	21.4	133.80	6	0.808	0.209	4.627
DCB1-06	2	10.7	85.7	10	2.000	0.332	3.668	21.4	44.75	6	0.808	0.070	1.548
DCB1-07	2	10.7	85.7	10	2.000	0.332	3.668	21.4	44.75	6	0.808	0.070	1.548
DCB1-08	2	10.7	85.7	10	2.000	0.332	3.668	21.4	133.80	6	0.808	0.209	4.627
DCB1-09	2	10.7	85.7	10	2.000	0.332	3.668	21.4	222.85	6	0.808	0.348	7.707
DCB1-10	2	10.7	85.7	10	2.000	0.332	3.668	21.4	311.90	6	0.808	0.488	10.786
DCB1-11	2	10.7	85.7	10	2.000	0.332	3.668	21.4	400.95	6	0.808	0.627	13.866

Table 5: Normal Array Jumper Voltage Drop

DCB	No. of Rack Inputs	IMP for DCB circuit	Feeder length	Feeder wire size	Feeder resistance	Feeder resistance	Voltage drop for feeder	Voltage drop for feeder	Voltage drop for circuit	VMP for circuit	Voltage drop for circuit
DCB#-##	#	Amp	feet	kcmil	Ohm/kft	Ohm	Volt	per cent	Volt	Volt	per cent
DCB1.1	11	235.40	641	600	0.035	0.044	10.653	0.91%	48.338	1165.00	4.15%
DCB1.2	11	235.40	641	600	0.035	0.044	10.653	0.91%	48.338	1165.00	4.15%
DCB2.1	11	235.40	612	600	0.035	0.042	10.171	0.87%	48.177	1165.00	4.14%
DCB2.2	11	235.40	612	600	0.035	0.042	10.171	0.87%	48.177	1165.00	4.14%
DCB3.1	11	235.40	583	600	0.035	0.040	9.689	0.83%	48.016	1165.00	4.12%
DCB3.2	11	235.40	583	600	0.035	0.040	9.689	0.83%	48.016	1165.00	4.12%
DCB4.1	11	235.40	553	600	0.035	0.038	9.190	0.79%	47.850	1165.00	4.11%
DCB4.2	11	235.40	553	600	0.035	0.038	9.190	0.79%	47.850	1165.00	4.11%
DCB5.1	11	235.40	524	600	0.035	0.036	8.708	0.75%	47.689	1165.00	4.09%
DCB5.2	11	235.40	524	600	0.035	0.036	8.708	0.75%	47.689	1165.00	4.09%
DCB6.1	11	235.40	494	600	0.035	0.034	8.210	0.70%	47.523	1165.00	4.08%
DCB6.2	11	235.40	494	600	0.035	0.034	8.210	0.70%	47.523	1165.00	4.08%
DCB7.1	11	235.40	494	600	0.035	0.034	8.210	0.70%	47.523	1165.00	4.08%
DCB7.2	11	235.40	494	600	0.035	0.034	8.210	0.70%	47.523	1165.00	4.08%
DCB8.1	11	235.40	524	600	0.035	0.036	8.708	0.75%	47.689	1165.00	4.09%
DCB8.2	11	235.40	524	600	0.035	0.036	8.708	0.75%	47.689	1165.00	4.09%
DCB9.1	11	235.40	553	600	0.035	0.038	9.190	0.79%	47.850	1165.00	4.11%
DCB9.2	11	235.40	553	600	0.035	0.038	9.190	0.79%	47.850	1165.00	4.11%
DCB10.1	11	235.40	583	600	0.035	0.040	9.689	0.83%	48.016	1165.00	4.12%
DCB10.2	11	235.40	583	600	0.035	0.040	9.689	0.83%	48.016	1165.00	4.12%
DCB11.1	11	235.40	612	600	0.035	0.042	10.171	0.87%	48.177	1165.00	4.14%
DCB11.2	11	235.40	612	600	0.035	0.042	10.171	0.87%	48.177	1165.00	4.14%
DCB12.1	11	235.40	641	600	0.035	0.044	10.653	0.91%	48.338	1165.00	4.15%
DCB12.2	11	235.40	641	600	0.035	0.044	10.653	0.91%	48.338	1165.00	4.15%

Table 6: Normal Array Voltage Drop

The next two tables show the voltage drop for the small array. This voltage drop was also below 5% and led to the ultimate voltage drop of 3.76%..

DCB	Strings per Rack	IMP for String	String Length	String wire size	String Conductor resistance	String resistance	Voltage Drop of String	IMP for Jumper	Jumper Length	Jumper wire size	Jumper resistance	Jumper resistance	Voltage Drop of Jumper
DCB#-##	per rack	Amp	feet	AWG	Ohm/kft	Ohm	Volts	Amp	feet	AWG	Ohm/kft	Ohm	Volts
DCB13.x-01	2	10.7	85.7	10	2.000	0.332	3.668	21.4	396	6	0.808	0.619	13.695
DCB13.x-02	2	10.7	85.7	10	2.000	0.332	3.668	21.4	310	6	0.808	0.485	10.721
DCB13.x-03	2	10.7	85.7	10	2.000	0.332	3.668	21.4	224	6	0.808	0.350	7.746
DCB13.x-04	2	10.7	85.7	10	2.000	0.332	3.668	21.4	138	6	0.808	0.216	4.772
DCB13.x-05	2	10.7	85.7	10	2.000	0.332	3.668	21.4	52	6	0.808	0.081	1.798
DCB13.x-06	2	10.7	85.7	10	2.000	0.332	3.668	21.4	43	6	0.808	0.067	1.487
DCB13.x-07	2	10.7	85.7	10	2.000	0.332	3.668	21.4	468	6	0.808	0.732	16.185
DCB13.x-08	2	10.7	85.7	10	2.000	0.332	3.668	21.4	382	6	0.808	0.597	13.210
DCB13.x-09	2	10.7	85.7	10	2.000	0.332	3.668	21.4	296	6	0.808	0.463	10.236
DCB13.x-10	2	10.7	85.7	10	2.000	0.332	3.668	21.4	210	6	0.808	0.328	7.262
DCB13.x-11	2	10.7	85.7	10	2.000	0.332	3.668	21.4	74	6	0.808	0.116	2.559
DCB14.1-01	2	10.7	85.7	10	2.000	0.332	3.668	21.4	396	6	0.808	0.619	13.695
DCB14.1-02	2	10.7	85.7	10	2.000	0.332	3.668	21.4	310	6	0.808	0.485	10.721
DCB14.1-03	2	10.7	85.7	10	2.000	0.332	3.668	21.4	224	6	0.808	0.350	7.746
DCB14.1-04	2	10.7	85.7	10	2.000	0.332	3.668	21.4	138	6	0.808	0.216	4.772
DCB14.1-05	2	10.7	85.7	10	2.000	0.332	3.668	21.4	52	6	0.808	0.081	1.798
DCB14.1-06	2	10.7	85.7	10	2.000	0.332	3.668	21.4	43	6	0.808	0.067	1.487
DCB14.1-07	2	10.7	85.7	10	2.000	0.332	3.668	21.4	74	6	0.808	0.116	2.559
DCB15.1-01	2	10.7	85.7	10	2.000	0.332	3.668	21.4	396	6	0.808	0.619	13.695
DCB15.1-02	2	10.7	85.7	10	2.000	0.332	3.668	21.4	310	6	0.808	0.485	10.721
DCB15.1-03	2	10.7	85.7	10	2.000	0.332	3.668	21.4	224	6	0.808	0.350	7.746
DCB15.1-04	2	10.7	85.7	10	2.000	0.332	3.668	21.4	138	6	0.808	0.216	4.772
DCB15.1-05	2	10.7	85.7	10	2.000	0.332	3.668	21.4	52	6	0.808	0.081	1.798
DCB15.1-06	2	10.7	85.7	10	2.000	0.332	3.668	21.4	43	6	0.808	0.067	1.487
DCB15.1-07	2	10.7	85.7	10	2.000	0.332	3.668	21.4	74	6	0.808	0.116	2.559
DCB15.1-06	2	10.7	85.7	10	2.000	0.332	3.668	21.4	74	6	0.808	0.116	2.559
DCB15.1-07	1	10.7	13.7	10	2.000	0.053	0.586	10.7	74	6	0.808	0.116	1.280

Table 7: Small Array Jumper Voltage Drop

DCB	No. of Rack Inputs	IMP for DCB circuit	Feeder length	Feeder wire size	Feeder resistance	Feeder resistance	Voltage drop for feeder	Voltage drop for feeder	Voltage drop for circuit	VMP for circuit	Voltage drop for circuit
DCB#-##	#	Amp	feet	kcmil	Ohm/kft	Ohm	Volt	per cent	Volt	Volt	per cent
DCB13.1	11	235.40	106.5	600	0.035	0.007	1.770	0.15%	43.930	1165.00	3.77%
DCB13.2	11	235.40	106.5	600	0.035	0.007	1.770	0.15%	43.930	1165.00	3.77%
DCB14.1	7	235.40	69.5	600	0.035	0.005	1.155	0.10%	23.203	1165.00	1.99%
DCB15.1	9	235.40	69.5	600	0.035	0.005	1.155	0.10%	25.901	1165.00	2.22%

Table 8: Small Array Total Voltage Drop

Below in Figure 8 displays the hand calculations that verify the calculations done in the voltage drop tool given to us by Black & Veatch.

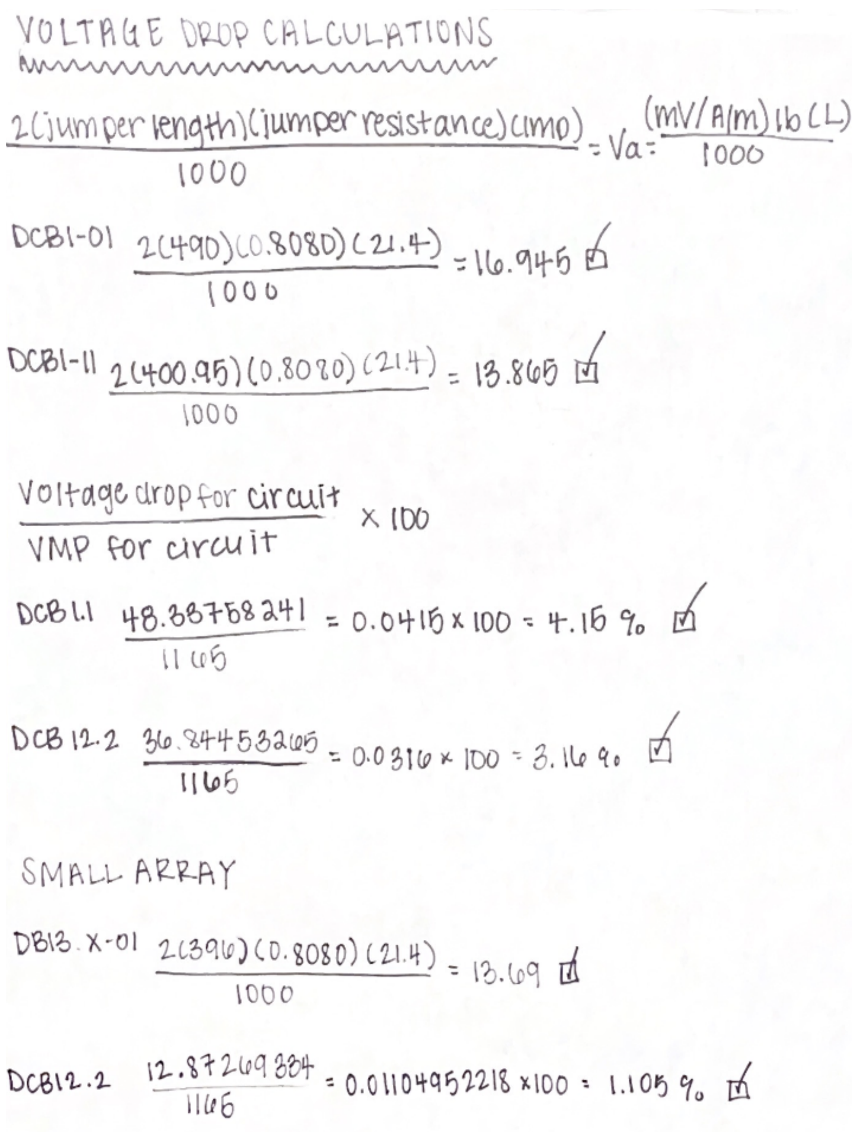

Figure 8: Hand Voltage Drop Calculations

3.2.3 Functionality

Our project design is solely a design. Users will use the design as a template for how to build the physical substation and solar field. It will be used as a print of sorts to show the dimensions and equipment needed when constructing both the solar field and substation. The design drawing will stay the same and be used as a visual to go off of when constructing the solar field and substation.

3.2.4 Areas of Concern and Development

The current design satisfies the requirements and users needs very well because it is a clear documentation that contains all the material, dimensions, and full layout of the solar field and substation. The document includes labels and intimate details that display all aspects of the solar field. The clarity and specifics included in the design documents meet users' needs because they are easily able to understand the design, the material needed, and the cost of everything included.

Our primary concerns are that our design is actually applicable in the real world because everything we are designing is purely hypothetical. Based on our current design the property we are using may have some difficulties implementing the solar field as there is wetland along the edge as well as an incline.

We have reached out to our clients about the water and incline and they did not seem to be worried about it. We plan on doing our own research in order to understand what difficulties that might be run into if our hypothetical solar farm came to fruition.

Describe the Problem, try to gather and examine the data, and Specify and rank the problems at stake. Put a Goal Statement in Each Solution's Heading. Develop Solutions: The Plan of Action Monitor and assess whether to tackle a fresh challenge or hone an existing issue.

3.3 Technology Considerations

AutoCAD: This application is very applicable in the real world. CAD provides engineers with a means of demonstrating all aspects of the project. However, there is no way to collaborate on the same document in CAD. This means that only one person can really work on the CAD designs. Also, not many of us have knowledge of how to work with CAD so it makes it difficult to understand what is going on, therefore leaving a heavy workload for the individual in our group that is doing most of the CAD work.

Array Parameter Tool: This tool is within a google sheet so the whole group can work on it at once, making it easier to keep everyone on the same page. It also already had some equations filled in for it, increasing efficiency for the team when deciding what equipment to use in the solar field. A disadvantage is you cannot compare multiple different scenarios at once, you must create a new page using the parameter tool to display different combinations of components.

Voltage Drop Calculations Tool: This tool is within a google sheet so that the team can collaborate or make changes as necessary from wherever. This tool is set to organize the calculations for voltage drop of the solar field for the lines between the PV and combiner boxes and then the combiner boxes and the inverters. This was used to organize the relevant inputs and streamline the calculations. One disadvantage is that the tool cannot compare different scenarios at the same time, you must create different pages within the sheet to do so. Though this tool is not designed to specifically act as a learning tool, we are using it as such as much as we are for completing the calculations. This falls short in that area as it does not show directly how the calculations are working. As a result one team member calculated the highest voltage and lowest drops by hand to check the work of the tool and use it as a learning exercise.

Solar Cost Analysis Tool: This is another excel tool given to us by Black and Veatch to organize our data. We have this in google sheets as well for increased access and editing ability for team members. This tool is used to organize cost data and project the cost of the project compared to the revenue of the project 10 years after project completion. One advantage of this tool is that it gives the designers and clients an estimate of project cost vs revenue, and where in the project's lifecycle it breaks even. The downside of this tool is that it does not provide as much detail in the cost breakdown of the project, but that will be supplemented by the Bill of Materials we complete later.

BlueBeam: We have not started using this application yet as it will be used next semester for the substation design.

3.4 Design Analysis

We started with the Array Parameter Tool and analyzed different combinations of components within the solar field to find the optimal component combination. We then went through the five different options we had and picked the one that was most optimal based on the values. In this we looked at parameters such as cost, amount of equipment needed for required final output, would the required combination of outputs to reach the power output fit within the land we chose, and other parameters. Some of the parameters we looked at were determined by the standards Black and Veatch worked off of such as putting two strings in a rack and other requirements for the output of the plant. Once we chose the parts to use we worked to lay them out in a logical manner based on the requirements in the array parameter tool and the specifications of the parts (PV, combiner boxes, and inverters) themselves. Such as only connecting so many racks to the combiner boxes and not surpassing the limits on input current and voltage.

A plot of land in Ames and New Mexico were also compared based on cost, irradiance, and other qualities. We decided on a specific plot of land in Roswell, NM to place our substation and solar field. We then started creating CAD designs based on the layout given from the Array Parameter Tool. Our initial design was not correct because we did not take into consideration the total DC wattage, which was 80 MW DC. Because of this, we had to go back and create a small, irregular array that adds a specific amount of voltage to get us to almost exactly 80 MW DC.

Along with this, we did an initial voltage drop calculation, which had a voltage drop of 8.67%. Our total voltage drop needed to be under 5%, so we started by changing the wire sizes to see how that would affect the drop and they had minimal effect with our initial design. Changing the wire gauge from 12 AWG to 6 only brought the drop to 7.89%. We initially worked on the wire gauge to try and make the correct drop, as that would be a simple change to our design before reworking more of the design. Our initial design had the combiner boxes and inverters close together and in the centerline of the arrays along the access road. This was to make it more convenient for repairs and construction. However, with this set up the voltage drop would not go below the 7.89% listed above. From there we went to moving the combiner boxes closer to the arrays as the majority of the drop appeared to be between the array and the combiner boxes rather than combiner boxes and inverters. As a result, we went through and decided to move the combiner boxes to more central locations to each string, therefore decreasing the voltage drop to be within the range. Our current voltage drop of the normal part of the system is 4.05% and the small array is 3.76%. We also were able to decrease the string wire gauge to 10 AWG and the jumper wire size to 6 AWG which is cheaper than our initial plan to use all 6 AWG. The only concern we had initially with this change was that it would make maintenance more difficult as the combiner boxes would be within the arrays and not along the access road with the inverters. However, after making that change it was recognized that the spacing between the rows is approximately 16 ft which can comfortably fit a vehicle for maintenance access as long as it can drive on the terrain.

In the end, the CAD was rearranged to incorporate the new voltage drop combiner box placement along with the small specific array. To strengthen our design, we plan to complete ground calculations and finish the cost analysis to ensure the whole project is not too costly and can be sustained.

4 Testing

4.1 Unit Testing

The testing that we had to complete was more calculator based. We tested which inverter, combiner box, and solar panel combination allowed us to reach 80 MW along with the ILR value of 1.3. With this, we tested different racks and arrays per row, inverter capacities, tilt, row spacing, allowed current, rack width and height, and string voltages and sizes. These were all tested using the Array Parameter tool. We entered the information from the datasheets along with the information we decided as the designers to the spreadsheet and altered the designer choice options until we reached that 1.3 IRL. We continued to test our design to ensure our rack layout had a total voltage drop of under 5 %. We tested this using the voltage drop data sheet given to us by Black & Veatch and reworked our layout until that 5% was reached.

4.2 Interface Testing

The interface testing that we will be doing will be when combining our solar farm with the substation in order to determine whether the designs mesh perfectly to output the maximum possible power out of the solar field. We will have to take this into account when designing and choosing the bus configurations to use. Together we have to review the size and layout of our solar array to make sure the substation protection scheme was set up correctly. All of these considerations had us looking into two different designs: a ring bus as well as a single bus bar system.

4.3 Integration Testing

When creating the substation portion of our project we will be splitting up into two different groups. The protection team and the electrical team. These two teams will be working separately and coming together for cross functional decisions, calculations, and at the end to create the final product.

4.4 System Testing

Our team has to take our voltage drop calculations, cable trench fill, and solar array parameters to make sure that all of the various components interact correctly with each other. We are testing this through our AutoCAD design.

4.5 Regression Testing

Once our team has a new tool that we are using, it is important to look back on old tools that we have used to ensure that all parameters are accurate. For example, we have been adding new solar arrays and this process has made our team go back to the voltage drop calculator and update old functionality, to ensure all implementations are working correctly together.

4.6 Acceptance Testing

Our work in both the spring and the fall semester are hypothetical designs however even so there are still ways for us to test our work. In order to demonstrate our design requirements we will conduct a series of calculations to ensure that our solar farm and substation if taken outside of the hypothetical realm would work in the real world. These calculations include voltage drop calculations that ensure that the voltage drop is below a certain threshold, trench fill calculations where we make sure we can fit within a specific area, and parameter tools to make sure our components will output our desired values. The requirements and standards were given to us by our client and we demonstrated meeting these requirements through our calculations. We look these calculations further by not only using an excel document tool but also verifying them by hand. Aside from our calculations we also kept our clients involved with our design by having a weekly meeting to show them our CAD layout design in which if any requirements were not met feedback would be given for improvement in the following weeks.

4.7 Results

After testing through the array parameter tool, voltage drop calculator, and cable trench fill calculator all numbers are all implemented correctly to successfully create a 60 MW solar farm. Reference section 4.3 Proposed Design for the details of these calculations.

5 Implementation

The solar field design was completed throughout this semester. It is fully implemented. Next semester we will begin the substation design aspect of the project. This part of the project will connect to the solar field design part of the project through understanding trenching and step up transforming. how the output of the solar field must be stepped up to the 115 kV voltage necessary for the substation.

6 Professional Responsibility

This discussion is with respect to the paper titled "Contextualizing Professionalism in Capstone Projects Using the IDEALS Professional Responsibility Assessment", *International Journal of Engineering Education* Vol. 28, No. 2, pp. 416–424, 2012

In the paper referenced above, the table below is used to define different areas of engineering ethical responsibility and then show how they are referenced in the National Society of Professional Engineers' Code of Ethics.

Area of responsibility	Definition	NSPE Canon
Work Competence	Perform work of high quality, integrity, timeliness, and professional competence.	Perform services only in areas of their competence; Avoid deceptive acts.
Financial Responsibility	Deliver products and services of realizable value and at reasonable costs.	Act for each employer or client as faithful agents or trustees.
Communication Honesty	Report work truthfully, without deception, and understandable to stakeholders.	Issue public statements only in an objective and truthful manner; Avoid deceptive acts.
Health, Safety, Well-Being	Minimize risks to safety, health, and well-being of stakeholders.	Hold paramount the safety, health, and welfare of the public.
Property Ownership	Respect property, ideas, and information of clients and others.	Act for each employer or client as faithful agents or trustees.
Sustainability	Protect environment and natural resources locally and globally.	
Social Responsibility	Produce products and services that benefit society and communities.	Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.

The engineering code of ethics our team examined in addition to the NSPE code of ethics, was the Institution of Electrical and Electronics Engineers. Shown below is an addition to the table above, outlining how the IEEE code of ethics references the areas of responsibility mentioned in the table.

- **Work Competence**: IEEE specifies that engineers should look for constructive criticism and give it freely to ensure best quality of work. Should look to understand new technology. Only undertake work if qualified.
- **Financial Responsibility**: Reject bribery. Otherwise, no reference to financials.
- Communication Honesty: IEEE specifies stance on bribery, acting unlawfully, and
- **Health, Safety, Well-Being**: IEEE specifies minimizing
- **Property Ownership**: IEEE's references to act with respect.
- **Sustainability**: IEEE specifies that engineers should act in a manner with sustainability in mind.
- **Social Responsibility**: IEEE also specifies that you should not discriminate against or harass others, specifically minorities. Also to ensure that this code is upheld by coworkers.

Furthermore, as a team we ranked the areas above in terms of importance to our project.

6.1 Importance within our project

Work Competence: *High*. This project would impact the energy reliability of people in the surrounding area, so a reliable system is extremely important.

Financial Responsibility: *High*. This project is extremely high cost (our current estimate is about $80 million) so we want the client to get the best system for their money and to use it wisely especially since the money is the clients.

Communication Honesty: *High*. This is a high cost project, so honesty is very important.

Health, Safety, Well-Being: *High*. The people building these systems and completing maintenance on them are dealing with high voltage so safety is paramount.

Property Ownership: *Medium*. The client is giving us direction and end goals, output scale, and things in that ballpark. Ultimately they are there to guide or progress and we make the decisions based on those

Sustainability: *High*. The goal of a large portion of this project is to decrease the carbon emissions from the energy generation at the utility scale.

Social Responsibility: *Medium*. This project impacts the reliability and access to power for the surrounding community / those within the utility.

6.2 Level of Responsibility within our Project

Work Competence: *High*. We are currently ahead in work and receiving good feedback from clients. Currently set to start transitioning into work we were not planning to start until January.

Financial Responsibility: *Medium*. Since this project is hypothetical we do not have to be as conscious of cost, but this is still an exercise where we can look into those areas where cost can be cut without sacrificing quality.

Communication Honesty: *High*. We have done a good job communicating openly and honestly within our team, with our clients, and with our academic advisor.

Health, Safety, Well-Being: *High*. We're building a fence and designing the system in a way that allows for easy maintenance which will limit injuries during maintenance.

Property Ownership: *High*. Consistent communication back and forth with clients to confirm work is moving in the correct direction.

Sustainability: *High*. Project is centered around integrating solar into the hypothetical utilities generation portfolio.

Social Responsibility: *Medium*. Since this project is hypothetical, the reliability of our project is not as important, but we keep it in mind through choosing reliable equipment and placing the project in a location that will reliably output power.

6.3 Team Discussion of Professional Responsibilities

One thing we disagreed with was the sustainability relevance to our project. One argument was about how our project is about integrating green energy into a grid, but others argued that it is hypothetical and not being implemented and another was that we did not consider the end of life of the parts.

Some other areas we disagreed with were largely in how relevant certain areas are due to the hypothetical nature of our project. Because it is hypothetical we aren't taking every single measure in certain contexts in hand since this will not be implemented, but we are still looking at those measures.

Another thing I had not thought of was in relation to property ownership. We are supposed to sign NDAs about the project, but Black and Veatch still have not gotten them to us so we are unsure what we are able to share within this project or not.

6.4 Important Responsibility with High importance

One area determined to be of high importance for our project is work competence. We are currently a month ahead of schedule and will be able to start work this semester on things we originally weren't supposed to start until January. Black and Veatch seem very impressed with the quality of work and how quickly we can turn things around. One reason this is important (if this were not hypothetical) would be less cost for the client on work time if this was through Black and Veatch for a client.

6.5 Important Responsibility with Low Importance

One area of responsibility that we could work to better integrate into our decisions would be a higher focus on sustainability. Since the nature of the project is to improve the sustainability of the utility's grid, we definitely could spend more time working on improving the sustainability of other aspects of the project such as choosing panels with better end of life disposal methods.

7 Closing Material

7.1 Discussion

This semester, we were able to successfully design a 60 MW solar field. To do so, we needed to choose components that combined to an inverter loading ratio of 1.3. Through trial and error with various array parameter tool combinations, we were able to find the three components that worked best to achieve the 1.3 IRL. Along with this, our design needed to have a total voltage drop of under five percent. Our initial design had a voltage drop slighting higher than that value. After reevaluating and adding a smaller array to our normal array, we were able to get the voltage drop down to 4.05%. The racking material chosen through SnapNrack also allows for the necessary configuration and tilt. The CAD design also showed all the parts of the design, splitting it up into smaller more detailed pieces. Overall, the design successfully met all the requirements given by Black & Veatch and outputted the desired 60 MW of power.

7.2 Conclusion

Overall, this semester we were able to successfully complete a solar array. It has been a good way to get experience applying the knowledge we have learned in our coursework. This semester we wanted to be able to finish the solar array in a way that lived up to our advisor Professor Ajjarapu's standards and our client Black & Veatch's expectations. Throughout the course of the semester we were able to do so and even begin working on the substation part of the project. Furthermore we were able to broaden our understanding of the power industry.

An overview of the semester includes using Excel documents to calculate voltage drop values, determine key components to use, and gather data. We also used software such as AutoCAD to create the solar array document. In order to ensure we were meeting our clients and advisors criteria we had weekly meetings with both of them as well as group work time each week.

Moving forward we will continue to meet weekly with our advisor, team members, and client to ensure a successful final product. In addition we will be working on creating a substation to go along with our solar array. We will start with trench fill calculations in an excel spreadsheet before moving forward with using software such as BlueBeam and AutoCAD to finish creating our substation design.

7.3 References

L. Gaille, "11 Common Solar Farm Pros and Cons," Vittana.org, April 23, 2018. [Online]. Available: https://vittana.org/11-prevailing-solar-farms-pros-and-cons. [Accessed: 20-Oct-2022].

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"Why solar? The benefits of solar farms." *Innovative Solar Systems, LLC*. [online]. Available: https://innovativesolarsystemsllc.com/2019/08/why-solar-benefits-of-solar-farms/. [Accessed: 20-Oct-2022].

7.4 Appendices

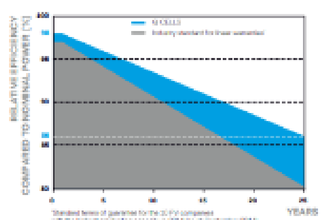
7.4.1 Appendix A - Solar Panel Data Sheet

ELECTRICAL CHARACTERISTICS

POWER CLASS				470	475	480	485	490	495
MINIMUM PERFORMANCE AT STANDARD TEST CONDITIONS, STC[1] (POWER TOLERANCE +5 W / −0 W)									
Minimum	Power at MPP[1]	P_{MPP}	[W]	470	475	480	485	490	495
	Short Circuit Current[1]	I_{SC}	[A]	11.21	11.24	11.26	11.29	11.31	11.34
	Open Circuit Voltage[1]	V_{OC}	[V]	53.54	53.58	53.61	53.64	53.68	53.71
	Current at MPP	I_{MPP}	[A]	10.62	10.66	10.71	10.76	10.81	10.86
	Voltage at MPP	V_{MPP}	[V]	44.27	44.54	44.81	45.07	45.33	45.59
	Efficiency[1]	η	[%]	≥20.3	≥20.5	≥20.7	≥20.9	≥21.2	≥21.4
MINIMUM PERFORMANCE AT NORMAL OPERATING CONDITIONS, NMOT[2]									
Minimum	Power at MPP	P_{MPP}	[W]	352.6	356.4	360.1	363.9	367.6	371.4
	Short Circuit Current	I_{SC}	[A]	9.03	9.05	9.07	9.09	9.12	9.14
	Open Circuit Voltage	V_{OC}	[V]	50.49	50.53	50.56	50.59	50.62	50.65
	Current at MPP	I_{MPP}	[A]	8.34	8.39	8.43	8.47	8.52	8.56
	Voltage at MPP	V_{MPP}	[V]	42.26	42.49	42.72	42.94	43.17	43.39

[1]Measurement tolerances P_{MPP} ±3%; I_{SC}; V_{OC} ±5% at STC: 1000 W/m², 25±2 °C, AM 1.5 according to IEC 60904-3 • [2]800 W/m², NMOT, spectrum AM 1.5

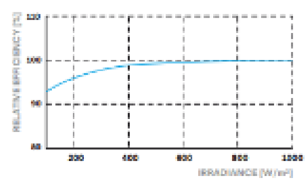
Q CELLS PERFORMANCE WARRANTY



At least 98% of nominal power during first year. Thereafter max. 0.5% degradation per year. At least 93.5% of nominal power up to 10 years. At least 86% of nominal power up to 25 years.

All data within measurement tolerances. Full warranties in accordance with the warranty terms of the Q CELLS sales organisation of your respective country.

PERFORMANCE AT LOW IRRADIANCE



Typical module performance under low irradiance conditions in comparison to STC conditions (25 °C, 1000 W/m²)

TEMPERATURE COEFFICIENTS

Temperature Coefficient of I_{SC}	α	[% / K]	+0.04	Temperature Coefficient of V_{OC}	β	[% / K]	−0.27
Temperature Coefficient of P_{MPP}	γ	[% / K]	−0.34	Nominal Module Operating Temperature	NMOT	[°F]	109±5.4 (43±3 °C)

PROPERTIES FOR SYSTEM DESIGN

Maximum System Voltage V_{SYS}	[V]	1500 (IEC) / 1500 (UL)	PV module classification	Class II
Maximum Series Fuse Rating	[A DC]	20	Fire Rating based on ANSI / UL 61730	TYPE 1
Max. Design Load, Push / Pull[3]	[lbs/ft²]	75 (3600 Pa) / 42 (2000 Pa)	Permitted Module Temperature on Continuous Duty	−40 °F up to +185 °F (−40 °C up to +85 °C)
Max. Test Load, Push / Pull[3]	[lbs/ft²]	113 (5400 Pa) / 63 (3000 Pa)		

[3]See Installation Manual

7.4.2 Appendix B - Combiner Box Data Sheet

TECHNICAL INFORMATION	STG.DCB.xx.C400dCG.BesN[a]	STG.DCB.xx.C400dCC.BesN[a]	STG.DCB.xx.C400dCB.BesN[a]	STG.DCB.xx.C400dCO.BesN[a]
Max. System Voltage	1500 VDC	1500 VDC	1500 VDC	1500 VDC
Rated Output Current	400A	400A	400A	400A
Rated Input Current	25.6A	25.6A	25.6A	25.6A
Max. Overcurrent Protection	32A	32A	32A	32A
Number of Input Circuits	Up to 18	Up to 18	Up to 24	Up to 32
Positive Input Wire Size	6-14 AWG	6-14 AWG	6-14 AWG	6-14 AWG
Negative Input Wire Size	4-14 AWG	4-14 AWG	4-14 AWG	4-14 AWG
Positive Output Wire Size	Up to (1) 600 MCM or (2) 500 MCM	Up to (1) 800 MCM or (2) 700 MCM	Up to (1) 900 MCM or (2) 750 MCM	Up to (1) 1000 MCM or (2) 800 MCM
Negtive Output Wire Size	Up to (1) 600 MCM or (2) 500 MCM	Up to (1) 800 MCM or (2) 700 MCM	Up to (1) 900 MCM or (2) 750 MCM	Up to (1) 1000 MCM or (2) 800 MCM
Ground Wire Size	2/0-14 AWG	2/0-14 AWG	2/0-14 AWG	2/0-14 AWG
Enclosure Rating	NEMA 4X	NEMA 4X	NEMA 4X	NEMA 4X
Max. Ambient Temp. Rating	50°C	50°C	50°C	50°C
Enclosure Size (H x W x D)	24" x 24" x 10"[b]	30" x 24" x 10"[b]	24" x 30" x 10"[b]	30" x 36" x 10"[b]
Approximate Weight	70 lbs	75 lbs	80 lbs	110 lbs

7.4.3 Appendix C - Inverter Data Sheet

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Technical data and types

Product Type designation, PVS980-58	PVS980-58 4.3 MVA -4348kVA-I	PVS980-58 4.6 MVA -4565kVA-J	PVS980-58 4.8 MVA -4782kVA-K	PVS980-58 5.0 MVA -5000kVA-L
Input (DC)				
Maximum recommended input power ($P_{PV,max}$) [1]	8696 kWp	9130 kWp	9564 kWp	10000 kWp
Maximum dc short circuit current	16 kA			
Maximum operational dc current	5700 A			
Maximum operational DC voltage ($U_{max(DC)}$) [2]	1500 V			
DC voltage range for maximum power ($U_{DC, mpp}$) @ -20 to +25 °C	850 to 1350 V	893 to 1350 V	935 to 1350 V	978 to 1350 V
DC voltage range for maximum power ($U_{DC, mpp}$) @ 35 °C	850 to 1250 V	893 to 1250 V	935 to 1250 V	978 to 1250 V
DC voltage range for maximum power ($U_{DC, mpp}$) @ 50 °C	850 to 1100 V	893 to 1100 V	935 to 1100 V	978 to 1100 V
Number of MPPT trackers	1			
Number of protected DC inputs [3]	20-36 (+/-)			
Output (AC)				
Power @ 25 °C	4348 kVA	4565 kVA	4782 kVA	5000 kVA
AC current @ 25 °C	4184 A			
Power @ 35 °C	4229 kVA	4441 kVA	4652 kVA	4864 kVA
AC current @ 35 °C	4070 A			
Power ($S_{N(AC)}$) @ 50 °C	3845 kVA	4037 kVA	4229 kVA	4421 kVA
AC current ($I_{N(AC)}$) @ 50 °C	3700 A			
Nominal output voltage ($U_{N(AC)}$) [4]	600 V	630 V	660 V	690 V
Output frequency [5]	50/60 Hz			
Harmonic distortion, current [6]	< 3%			
Maximum AC short circuit current from network	80 kA (1 s RMS)			
Distribution network type [7]	TN and IT			
Efficiency				
Maximum [8]	98.8%			
Euro-eta [8]	98.6%			
CEC efficiency [8]	98.5%			
Power consumption				
Maximum own consumption in operation	4000 W			
Maximum standby operation consumption	460 W			
Auxiliary voltage type	external [10]			

7.5 Team Contract

Team Members:

1)___Jacob Miller____________________ 2)________Zach Zimmerman__________

3)___Ashton Randolph______________ 4)______Jenna Runge_____________

5)____Madison Lakomek_____________ 6)____Brooke Nelson______________

7)___Omer Karar___________________ 8)____Madissen Lawrence__________

Team Procedures

1. Day, time, and location (face-to-face or virtual) for regular team meetings:

- Every Tuesday at 4 pm in Coover 1016 with Professor Venkataramana
- Every Wednesday at 2 pm via teams with Black & Veatch
- Every Thursday 4-5:30 face to face for group work

2. Preferred method of communication updates, reminders, issues, and scheduling:

- Tuesday face-to-face in Coover 1016, with Professor Ajjarapu
- Wednesday Teams Meeting with Client
- Thursday face-to-face group meeting after class
- Preferred communication method
- Text messages
- Discord
- Email

3. Decision-making policy (e.g., consensus, majority vote):

- Discussion of all the options to talk about benefits/drawbacks to the decisions. Make decisions from consensus after the discussion.

4. Procedures for record keeping (i.e., who will keep meeting minutes, how will minutes be shared/archived):

Meeting minutes taker with B&V and advisor will rotate on a weekly basis. Agenda will be shared via email or teams to Black & Veatch by 2 pm on Tuesdays. Agenda will also be put into google drive. Minutes will be shared via email/team and put into the google drive by 2 pm on Thursday.

The next “minutes” recorder & “ Presenter” will be decided during in person group meetings that take place on Thursdays after class (4-5pm), giving them time to prepare.

Participation Expectations

1. Expected individual attendance, punctuality, and participation at all team meetings:
    a. Attendance is expected but can miss a few meetings as long as they tell team members at least 24 hours in advance
2. Expected level of responsibility for fulfilling team assignments, timelines, and deadlines:
    a. Everyone is responsible for fulfilling assignments by the deadlines that are set. If something occurs where the individual thinks the deadline cannot be met, we can discuss and work together to ensure all the work gets done.

    b. Everyone should be aware of the timelines and deadlines to ensure everything gets completed
3. Expected level of communication with other team members:
    a. Communicate absences before date, struggles with individual responsibilities before they become the groups, tasks working on, and completed tasks
    b. Not compulsively email the professor or client without discussing it with the rest of the group
4. Expected level of commitment to team decisions and tasks:
    a. Strong commitment to team decisions and tasks to ensure all group members are being heard and giving input on the project.

Leadership

1. Leadership roles for each team member (e.g., team organization, client interaction, individual component design, testing, etc.):
    a. A new team leader will be assigned each week. Leadership will primarily be defined by logistical work each week. Ex. sending weekly agenda to client, presenting logistical things in each weekly meeting with B&V.
2. Strategies for supporting and guiding the work of all team members:
    a. Have responsibilities overlap/shared with another group member
3. Strategies for recognizing the contributions of all team members:
    a. Four tasks per week with two team members per task. (Depending on the number of tasks that week)
    b. Everyone should look over the other group members' work to recognize their part in the project

Collaboration and Inclusion

1. Describe the skills, expertise, and unique perspectives each team member brings to the team.

- Jacob: Prior substation experience.
- Zach: Experience creating and reviewing engineering design documents (specifically solar designs) using AutoCAD.
- Maddy: Worked in the field in substations, familiar with substation layout and devices within substations
- Ashton: Worked in relay and protection department, familiar with capacitor banks, and 12kV relay settings, has done some PCB design.
- Brooke: Worked in distribution engineering, familiar with substation design. Has worked with work packets and creating jobs for clients.
- Madissen: Familiar with engineering design - specifically with power, has worked on substation construction before.
- Jenna: Microgrids, research, design, semiconductor info in relation to how solar cells work, charging systems.
- Omer: Work experience with high level switchgear, I have experience with ACB, and SF6 circuit breaker.

2. Strategies for encouraging and support contributions and ideas from all team members:

- Giving everyone a chance to speak by going around in a circle during discussion and actively listening
- Asking all team members what they are comfortable with doing and what they may need help with the ensure they feel supported

3. Procedures for identifying and resolving collaboration or inclusion issues (e.g., how will a team member inform the team that the team environment is obstructing their opportunity or ability to contribute?)

- Confront the team at the team meetings
- If the individual doesn't feel comfortable confronting the team in person, they could message the team via teams and then we can resolve the issue the next time we meet in person

Goal-Setting, Planning, and Execution

1. Team goals for this semester:
    a. Successfully complete the solar array deliverables
2. Strategies for planning and assigning individual and team work:
    a. Create a weekly agenda on Thursday team meetings to list out all objectives for the week
    b. Discuss what everyone is comfortable working on and divide tasks based on that while ensuring everyone has equal workload
3. Strategies for keeping on task:
    a. Use a weekly agenda that is created on Thursdays to know everything that needs to be done that week. (Can be done via shared doc that we update as needed)

Consequences for Not Adhering to Team Contract

1. How will you handle infractions of any of the obligations of this team contract?
    a. Instructor/Advisor/Team intervention when necessary.
    b. Discuss concerns at meetings without sounding like we are attacking the person
2. What will your team do if the infractions continue?
    a. Report to Nicolas & Our Advisor + extra work that week

****

a) I participated in formulating the standards, roles, and procedures as stated in this contract.

b) I understand that I am obligated to abide by these terms and conditions.

c) I understand that if I do not abide by these terms and conditions, I will suffer the

consequences as stated in this contract.

1) Jacob Miller ______________________ DATE 09/15/2022

2) Jenna Runge DATE 09/15/2022

3) Ashton Randolph DATE 09/15/2022

4) Omer Karar DATE 09/15/2022

5) Madison Lakomek DATE 09/15/2022

6) Brooke Nelson DATE 09/15/2022

7) Zachary Zimmerman DATE 09/15/2022

8) Madissen Lawrence DATE 09/15/2022