115kV/34.5kV Solar Power Plant and Substation Design

DESIGN DOCUMENT

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

Development Standards & Practices Used

- Engineering Standards
    - NFPA 70 - National Electrical Code 2020
        - Ensures our design is safe for use
    - International Fire Code 2021
        - Ensures our design is safe for use
    - 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
    - IEEE 80
        - Provides equations necessary for calculating the appropriate grounding grid

Summary of Requirements

- Functional requirements
    - The design of a 60 MW solar plant and a 115/34.5 kV distribution substation that takes into consideration:
    - An Electric Panel with Sufficient Capacity
    - Energy Information to Size the Solar
- Physical Requirements
    - Solar plant: hundreds of 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, ETAP, Array Parameter Analysis Tool, Google Drive, IEEE standards, ANSI standards
- 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 452, EE 455 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
    - ETAP
- Solar array design and calculations
    - Voltage Drop Calculations
    - Trench Fill Calculations
    - Economic Estimates
    - Array Parameter
    - Grounding Grid Calculations
    - DC Battery Calculations
    - Bus Calculations
- Substation design and calculations
    - AC Load Calculations
    - DC Battery Calculations
    - Trench Fill Calculations and Drawing
    - Bus Calculations
    - Lightning Protection Calculations
    - One and Three Line Drawing
    - Key Plan Drawing
    - Conduit Plan Drawing
    - Grounding Grid Calculations and Drawing

Glossary

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

Array - a combination of solar modules

Bus - arrangements of overhead structures that connect switching equipment

Circuit Breaker - a device that opens and closes circuits to control and protect high voltage equipment

Combiner Box - a device that combines multiple strings together

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

Conduit - means in which power cables run from the ground to the electrical equipment

Current Transformer - steps down the currents of the substation for measurement and other auxiliary reasons

Disconnect Switch - provides a point of visual isolation to ensure the power conductors have been opened, usually for maintenance

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

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

Grounding grid - buried grid of conductors to ensure that the ground is not energized for both the safety of personnel and the equipment

Grounding rods - buried conductor rods as a part of the gid

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

Lightning protection - system within the substation designed to protect the station if it were to be struck by lightning

MW - megawatt is a measurement of power

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

Relay - a electromechanical switch that trips the circuit breaker when a fault is detected

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.

Takeoff structure- structure at the end of the substation that combines buses and transfers them into the transmission lines

Transformer - a device that increases or decreases the voltage from the primary to secondary side

Transmission - The bulk transfer of high voltage electricity from generating power plants to electrical substations

Trench - long excavated tunnels that hold the conduit

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
- Bluebeam
- ETAP

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
- Bluebeam
  - Previous Experience: Madissen Lawrence
  - Learning: All other team members
- ETAP
  - Learning: All

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 Array and Substation Components
- 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, ETAP, Voltage Drop Tool, Trench Fill Tool
- Aesthetic Requirements
    - Clear layout for diagrams (string, rack, array, key plan, conduit plan, one line, three line, grounding plan), concise agenda and minutes for each client meeting, color coded Gantt chart
    - Concise ETAP reports
- 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 year to ensure all requirements were met.

Solar Array:

- 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

Substation:

- Create a key plan that will allow for easy visualization of the final layout
- Substation layout should take accessibility and space requirements into account.
- Calculations that help determine layout and equipment specifications
    - Lightning Calculations
    - AC load Calculations

    - DC battery calculations
    - Trench fill calculations
    - Bus calculations
- Economic analysis
- ETAP Simulation
- One line and three line diagrams for layout visualization

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. During the second semester, we designed the full substation. First, we created a one line drawing that laid out our substation, and selected the substation components that we would be using. Then, we did a rough price estimate for the components, although we could not do a full bill of materials for the substation due to the difficulty of getting a quote for our equipment. Once we completed all of this, then we began all of the calculations necessary for this portion of the design. We completed the bus calculations, trench fill calculations, DC battery calculations, lightning calculations, grounding calculations, and AC load calculations. While we were completing the calculations, we began laying out our key plan and working on ETAP simulations that included short circuit analysis, load flow analysis, and arc flash analysis. Finally, once the simulations, calculations, and key plan were completed, we finished our project by creating the three line diagram and conduit diagram.

2.5 Project Proposed Milestones, Metrics, and Evaluation Criteria

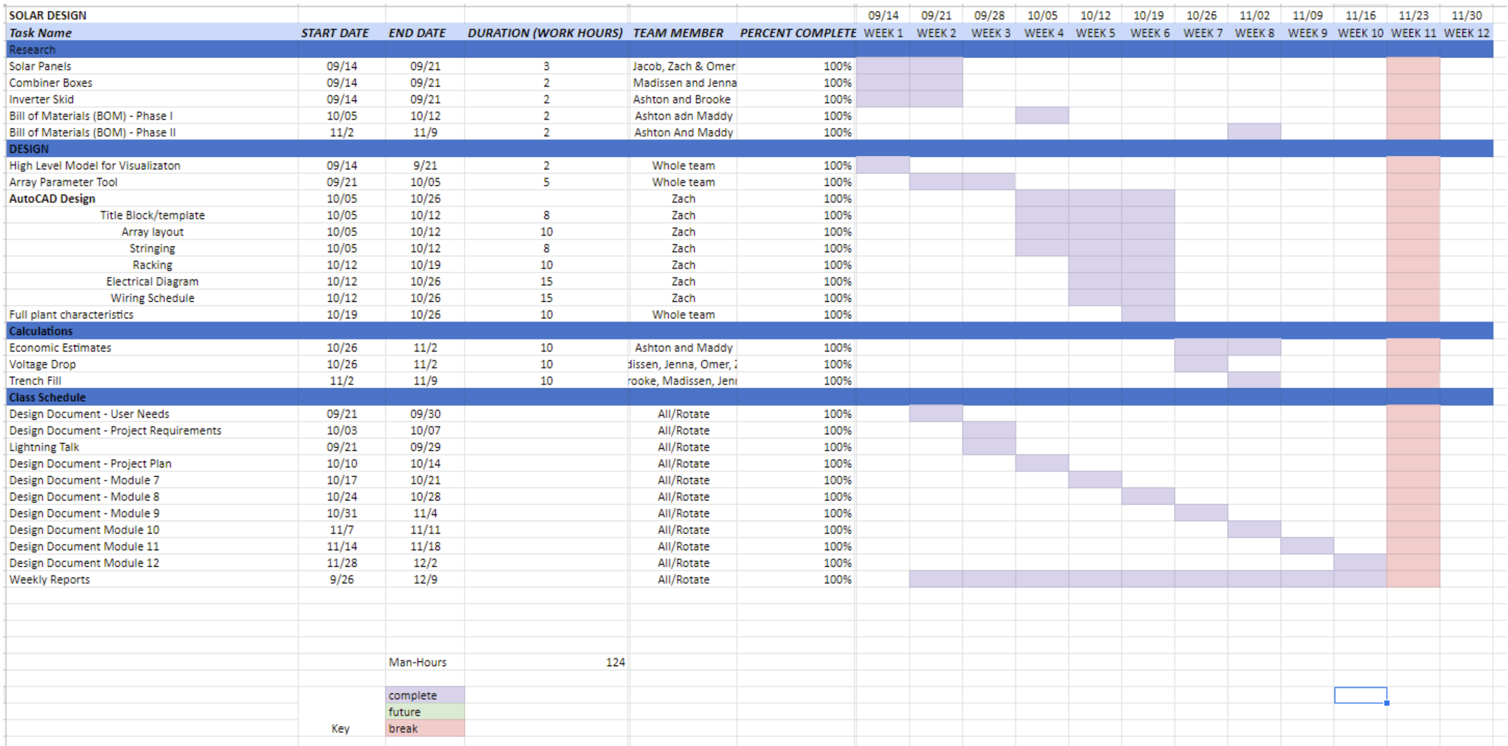
The solar array design portion of the project had key milestones that needed to be met as we progressed throughout the semester. Those key milestones are listed below.

- 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.

The substation portion of the design project milestones are listed below.

- Drawings
    - One line and three line diagrams
    - Grounding grid
    - Conduit diagram
    - Key plan
- Calculations
    - Bus calculations
    - Trench fill calculations
    - DC battery calculations
    - Lightning calculations
    - Grounding calculations
    - AC load calculations
- Component selection and price estimate
- ETAP Simulation
    - Short circuit analysis
    - Load flow analysis
    - Arc flash analysis

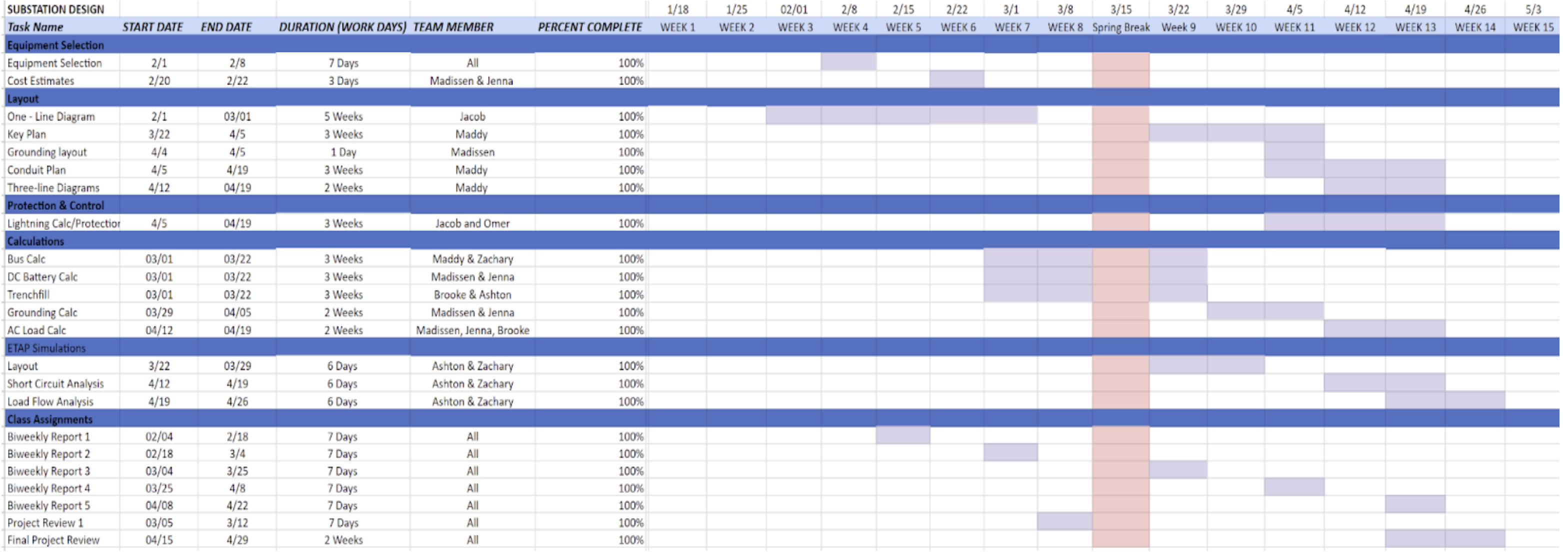
2.6 PROJECT TIMELINE/SCHEDULE



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,	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.



SUBSTATION DESIGN						1/18	1/25	02/01	2/8	2/15	2/22	3/1	3/8	3/15	3/22	3/29	4/5	4/12	4/19	4/26	5/3
Task Name	*START DATE*	*END DATE*	*DURATION (WORK DAYS)*	*TEAM MEMBER*	*PERCENT COMPLETE*	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8	Spring Break	Week 9	WEEK 10	WEEK 11	WEEK 12	WEEK 13	WEEK 14	WEEK 15
Equipment Selection																					
Equipment Selection	2/1	2/8	7 Days	All	100%				▨					🟥							
Cost Estimates	2/20	2/22	3 Days	Madissen & Jenna	100%						▨			🟥							
Layout																					
One - Line Diagram	2/1	03/01	5 Weeks	Jacob	100%			▨	▨	▨	▨	▨		🟥							
Key Plan	3/22	4/5	3 Weeks	Maddy	100%									🟥	▨	▨	▨				
Grounding layout	4/4	4/5	1 Day	Madissen	100%									🟥			▨				
Conduit Plan	4/5	4/19	3 Weeks	Maddy	100%									🟥			▨	▨	▨		
Three-line Diagrams	4/12	04/19	2 Weeks	Maddy	100%									🟥				▨	▨		
Protection & Control																					
Lightning Calc/Protectior	4/5	04/19	3 Weeks	Jacob and Omer	100%									🟥			▨	▨	▨		
Calculations																					
Bus Calc	03/01	03/22	3 Weeks	Maddy & Zachary	100%							▨	▨	🟥	▨						
DC Battery Calc	03/01	03/22	3 Weeks	Madissen & Jenna	100%							▨	▨	🟥	▨						
Trenchfill	03/01	03/22	3 Weeks	Brooke & Ashton	100%							▨	▨	🟥	▨						
Grounding Calc	03/29	04/05	2 Weeks	Madissen & Jenna	100%									🟥		▨	▨				
AC Load Calc	04/12	04/19	2 Weeks	Madissen, Jenna, Brooke	100%									🟥				▨	▨		
ETAP Simulations																					
Layout	3/22	03/29	6 Days	Ashton & Zachary	100%									🟥	▨	▨					
Short Circuit Analysis	4/12	4/19	6 Days	Ashton & Zachary	100%									🟥				▨	▨		
Load Flow Analysis	4/19	4/26	6 Days	Ashton & Zachary	100%									🟥					▨	▨	
Class Assignments																					
Biweekly Report 1	02/04	2/18	7 Days	All	100%					▨				🟥							
Biweekly Report 2	02/18	3/4	7 Days	All	100%							▨		🟥							
Biweekly Report 3	03/04	3/25	7 Days	All	100%									🟥	▨						
Biweekly Report 4	03/25	4/8	7 Days	All	100%									🟥			▨				
Biweekly Report 5	04/08	4/22	7 Days	All	100%									🟥					▨		
Project Review 1	03/05	3/12	7 Days	All	100%								▨	🟥							
Final Project Review	04/15	4/29	2 Weeks	All	100%									🟥					▨	▨	

Figure 2: Gantt Chart for Substation

Above is a photo of the Gantt chart for our substation portion of the design. Initially there were more tasks on it that were seen as "optional" by our clients Black and Veatch, but the shown items are the tasks we were able to complete in the given time. Additionally, the assignments for 492 are also included on our Gantt chart. These items include the biweekly reports, the project review, and the final project deliverables.

2.7 RISKS AND RISK MANAGEMENT/MITIGATION - DESIGN BASED AND SECURITY

There is little risk that coincides with the solar array and 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. Another potential risk is if our protection equipment calculations were wrong. If we sold our designs (which we won't) and our calculations were off, potentially fatal shocks could occur. Our work gets checked weekly by Black & Veatch as well, so these risks are extremely low.

An additional associated risk involves the security of our design. To mitigate our work as well as the tools given to us by Black and Veatch being stolen we all have signed NDAs, and keep our work in a secure folder that can only be accessed by the group members. Further security risks may include (if our design was constructed) civilians or animals being harmed in our solar array and substation. To mitigate this, we have designed a fence to go around the outside of our array and farm to keep people and animals out. There are no cybersecurity risks associated with our project.

2.8: RESOURCE REQUIREMENTS

The resources necessary for this project are AutoCAD, ETAP, and BlueBeam softwares. 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 1: Societal, Global, Environmental, and Economic Context

3.1.2 USER NEEDS

As we discussed in section 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 agro-voltaic 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 had 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 significant amount of research on the different components within a solar farm. Ultimately we researched 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.

A similar process was repeated for the substation design. We researched the different types of parts we would need, found examples, and then laid out the parts for our initial one-line diagram.

3.2.3 Decision-Making and Trade-Off

During the design for the solar farm, 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.

For the substation, our initial one line diagram was considered 'over engineered' and had an extreme amount of protection and redundancies within it in case of faults. However, this design would have been much more expensive due to the amount of equipment used. After going back and forth with Black and Veatch to further define parameters for our design while still ensuring adequate protection, but not creating an excessively expensive system either, we settled on our final design.

3.2.4 Design Evolution

The design of our solar farm was straightforward because the array parameter tool outlined the number and size of an array. We also knew how many components would be needed for the solar plant. The engineering drawings for the solar farm were a continuous process. It took multiple weeks to finish as it was a very complex task. The biggest change that occurred from the initial design to the final design was the location of the combiner boxes that was changed due to the voltage drop exceeding 5% through the circuit branch (circuitry connecting string to inverter) that is recommended by the national electrical code. The initial location for the combiner box was to be located in the maintenance access pathway to provide crews with easy access to the equipment. The issue was that our jumpers wires were using a much smaller wire gauge that has a much higher resistance. The voltage drop relies on multiple factors, but the most important being the voltage drop is proportional to the resistance and distance. Therefore, to decrease the voltage drop we needed to distribute more of the load to the feeder wires. Since the feeder conductors used a larger wire gauge the resistance would be lower, resulting in a reduced voltage drop. The resulting information helped us determine the center of a row as a new location for the combiner boxes. This reduced our voltage drop to under 5% which satisfies the national electrical code requirements.

The initial design of the substation was much more complex than it needed to be. Figure 23 below shows the initial one-line diagram made. That design had SEl-TMU relays as well as SEL-411 relays. This design had too much relaying and was over protected, therefore overcomplicated. It would have been difficult to finish all of the calculations and drawings with this design, therefore it was simplified. The second one line created included SEL-487B relays and did not include the extra protection. This was the ultimate design that we decided to go with.

The key plan, conduit plan, grounding plan, and three lines were all created based on the online. The key plan changed throughout the process because additional requirements, such as an access road and lightning masts, were added later in the semester. These additions forced other pieces of the substation to be moved around to ensure that all spacing requirements were still met. Specifically the fencing was enlarged and the control house was moved further south in the lot. The conduit plan was altered to ensure the least amount of trenching and conduit were used to minimize cost. To do so, the trenching was put at 45 degree angles instead of 90 degree angles and the trench only followed the main horizontal distance of the substation. The conduit was then run to each piece of equipment to demonstrate how they are connected to the control house. Finally, the three line diagram was simplified by removing the relay connections between the CTs. Black and Veatch stated that some clients prefer to not show the specific relay connection in the three lines because it becomes very complicated and messy.. This connection is shown in the one line diagram, so the connection in the three lines is redundant. Therefore the relay connection lines were deleted from the three lines to make it more clear and readable overall.

3.2 PROPOSED DESIGN - SOLAR FARM

3.2.1 Overview

During the fall semester, we completely designed the solar array portion of our project. There are several aspects that made up the design: the layout, the specific equipment that within 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. An important aspect of the solar farm is the series and parallel combinations our solar panel makes up. These characteristics help us determine the voltage and current levels at different points of our solar farm. Each rack consists of 26 modules in series, which is equivalent to one string. A rack contains two strings in parallel; therefore, the voltage and current add up to 1500 (V) and 10.7 (A), respectively. This was the key starting point used in determining the voltage drop, which will be discussed later. Each combiner box is fed by 22 strings which are in parallel; therefore, the current sums up to 235.4 (A), which can be seen in the voltage drop calculations when determining the drop across the feeders. Finally, the input to our inverter consists of 24 combiner boxes, also in parallel, so the DC current input to one inverter is 5,650 (A). The DC current input of the ABB inverter that we chose for our project is rated at 5,700 (A); therefore, we can confirm our inverter will operate under normal conditions. 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 (APT). 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 found 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.

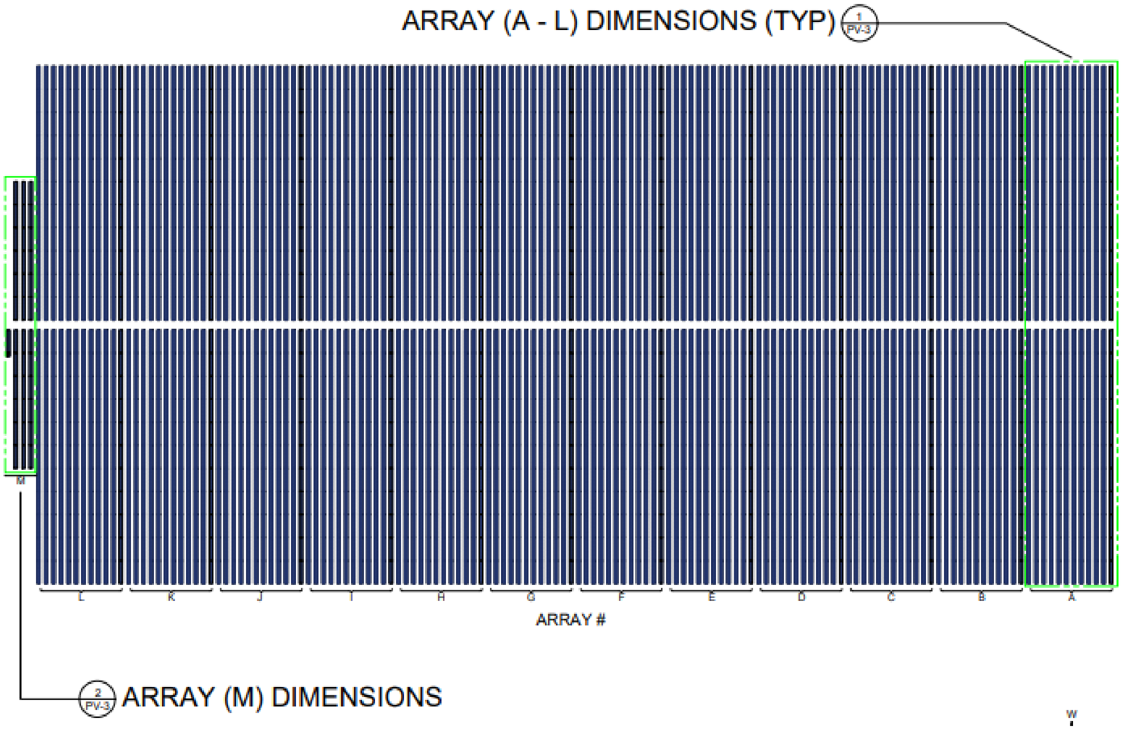


Figure 3: Solar Array Layout

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 3 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 4 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.

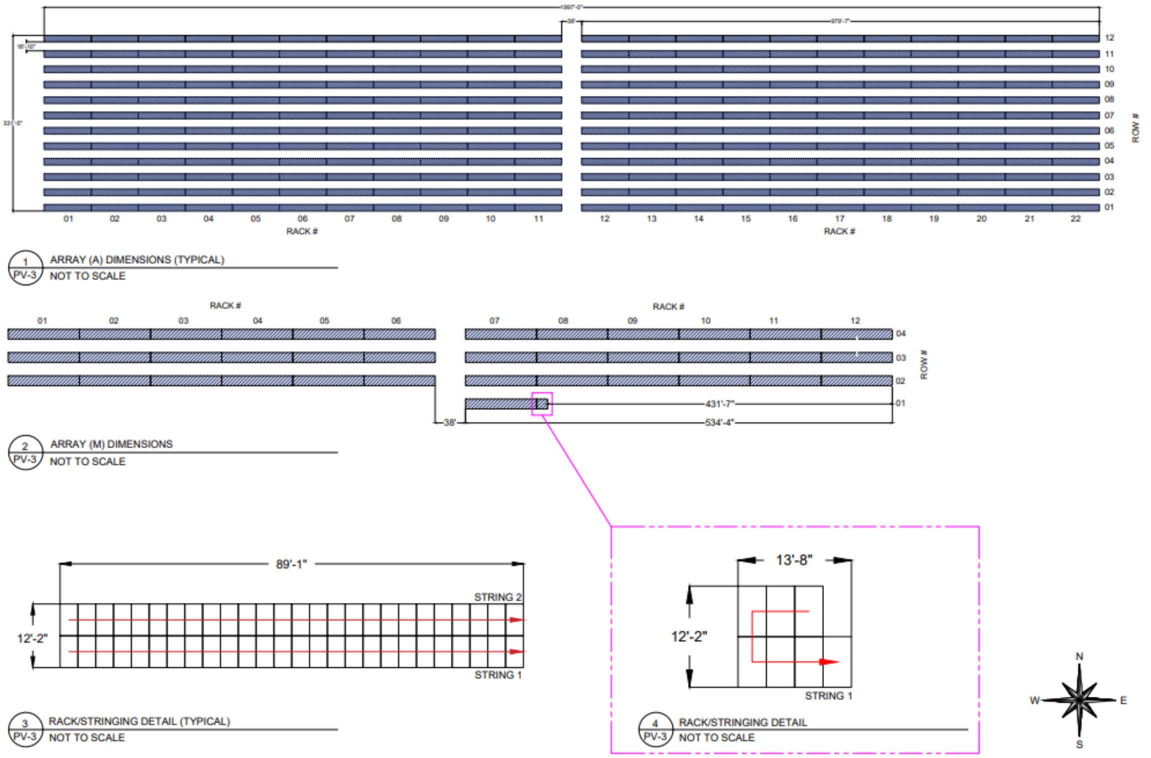


Figure 4: Zoomed in Detailed Array Layout

Figure 5 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.

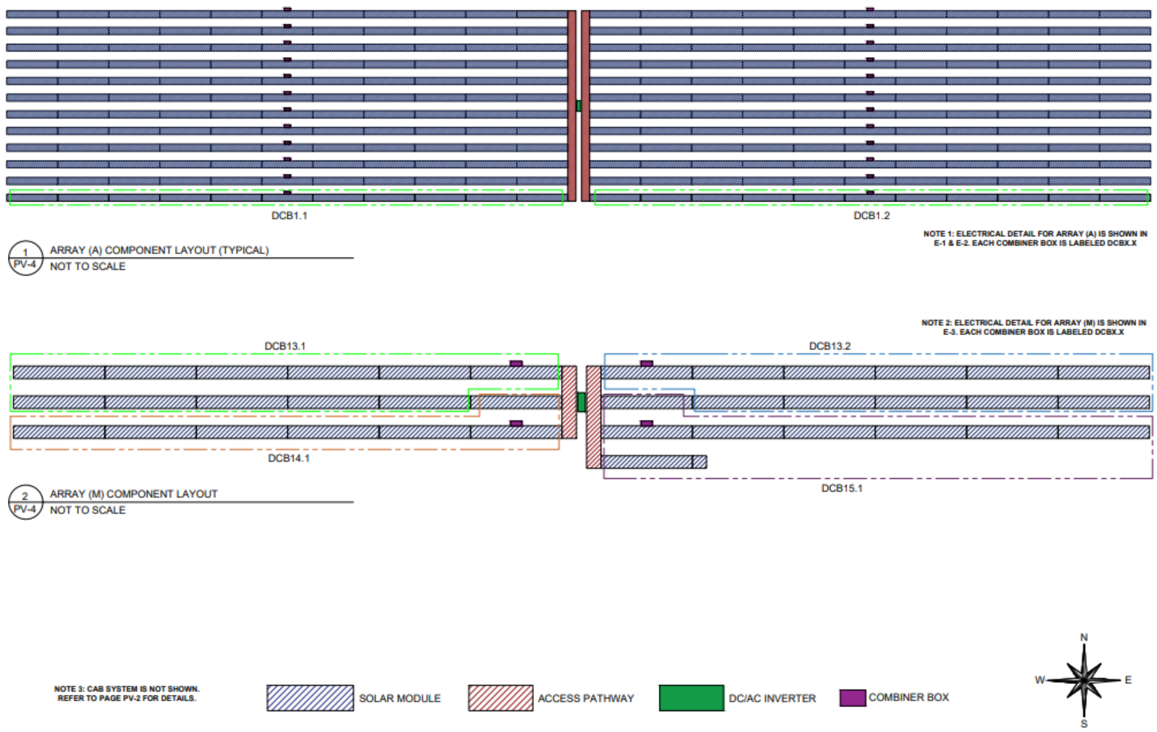


Figure 5: Array Component Layouts

3.2.2.2 Wiring

The wiring is sectioned into three different drawings to show how the solar farm is connected. Figure 6 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.

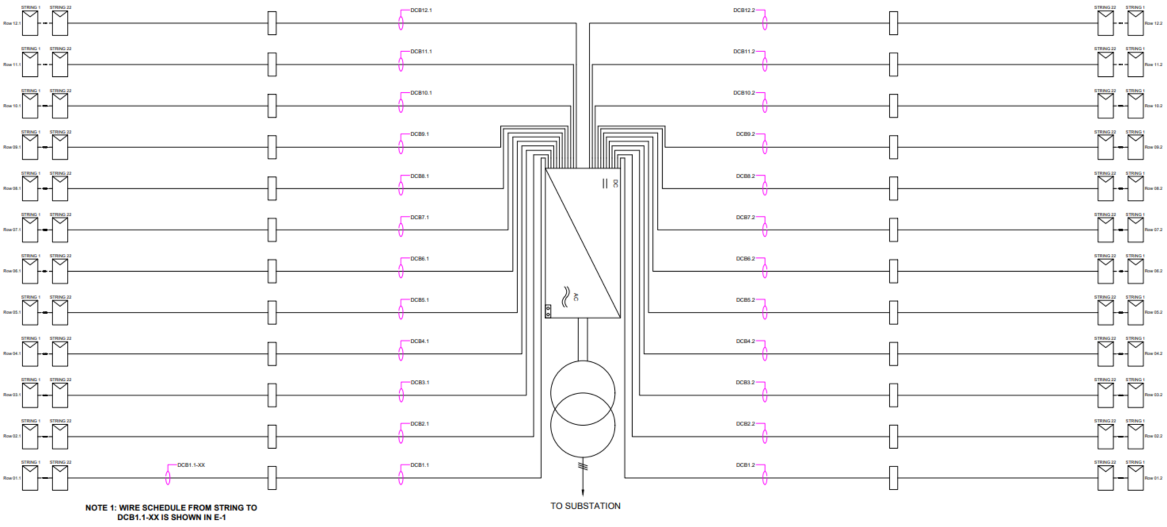


Figure 6: String to Inverter Wiring Overview

Figure 7 goes further into details on how each string is connected to the combiner box and then to the inverter.

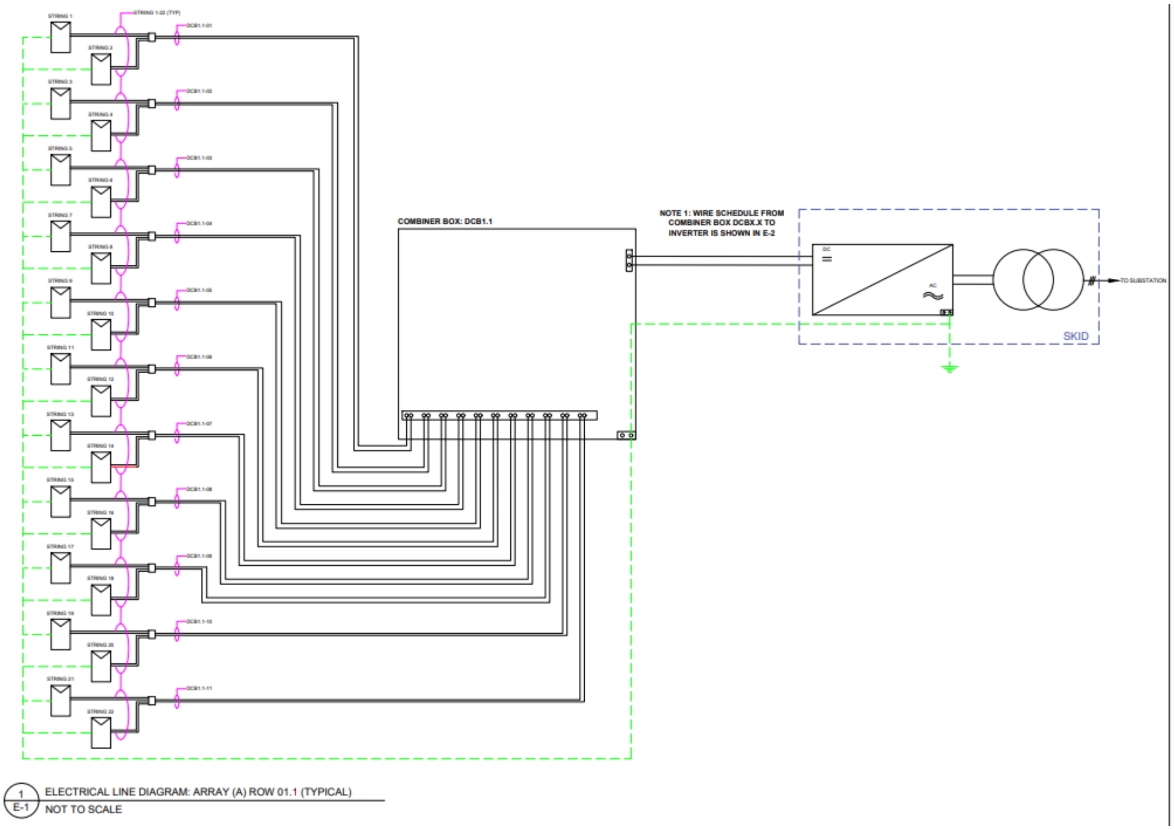


Figure 7: String to Combiner Box to Converter Wiring

Figure 8 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.

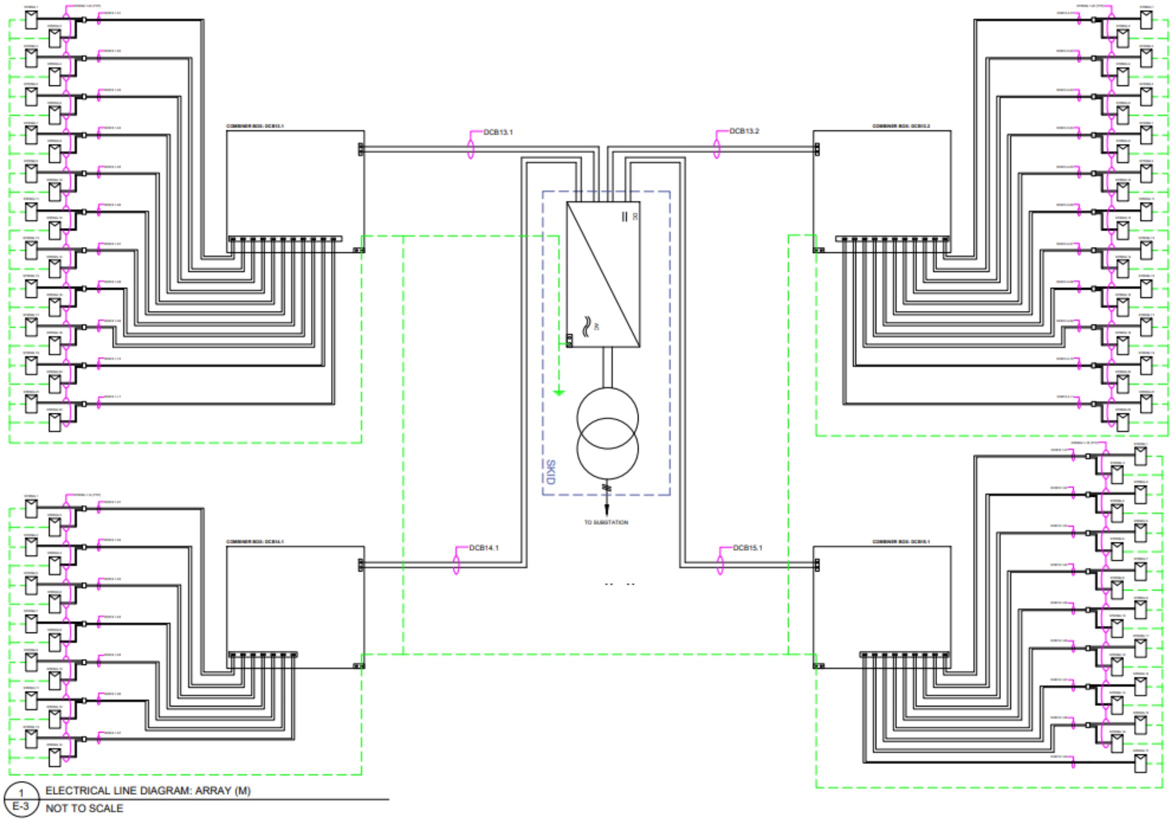
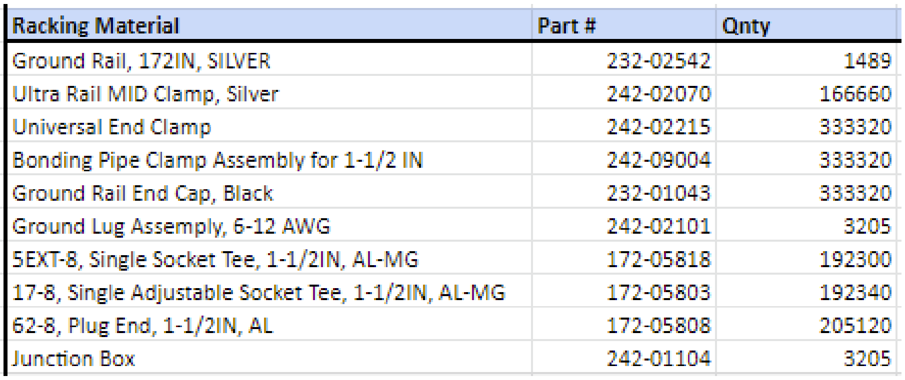


Figure 8: Small Array Wiring Schematic

3.2.2.3 Racking Components

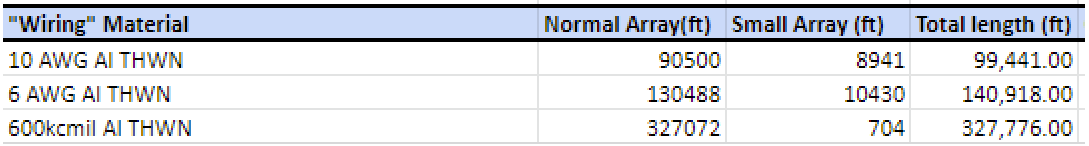
The racking components that are used throughout the solar field are from SnapNrack. There are multiple pieces necessary to complete the racking system, including ground rails, clamps, junction boxes, and much more. The chart below shows the specific species from SnapNrack that our design uses. It also 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 2: 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.



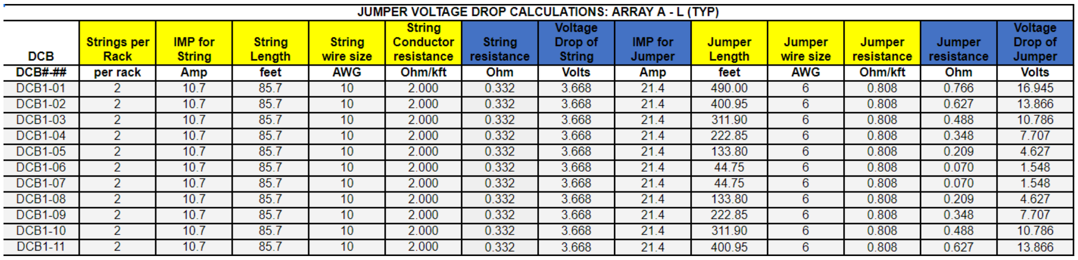
"Wiring" Material	Normal Array(ft)	Small Array (ft)	Total length (ft)
10 AWG Al THWN	90500	8941	99,441.00
6 AWG Al THWN	130488	10430	140,918.00
600kcmil Al THWN	327072	704	327,776.00

Table 3: 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.

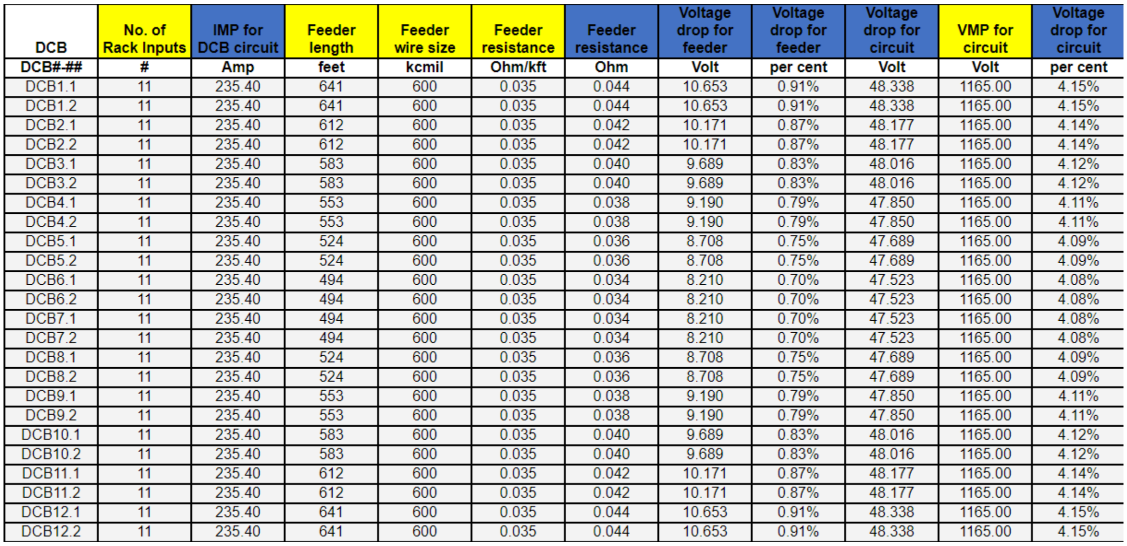
For the voltage drop, we started with the combiner boxes along the access roads, near the inverters, to make maintenance and installation easy. This caused the voltage drop to be about 10% for the normal array, which exceeded our max drop of 5%. After some trial and error, the team determined that the 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

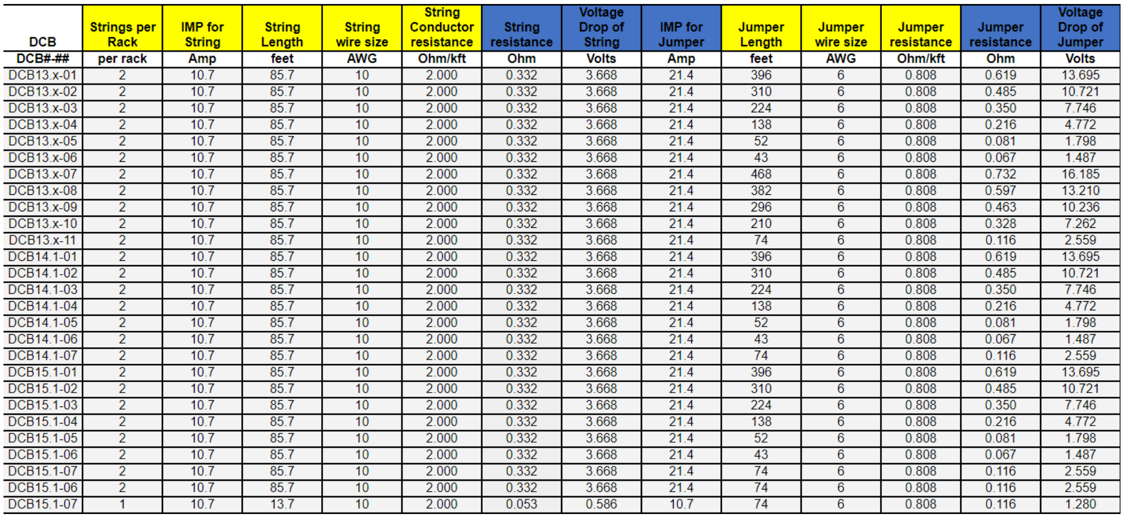
Table 4: Normal Array Jumper Voltage Drop



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%

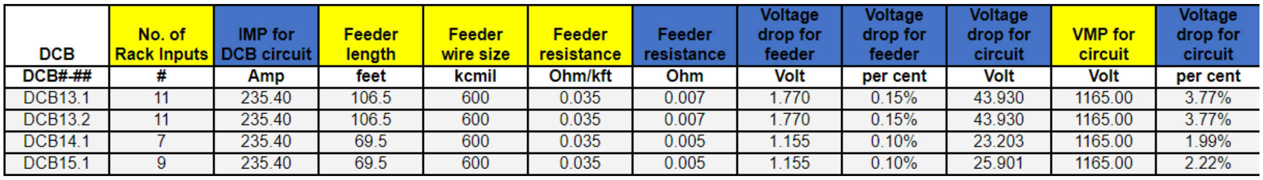
Table 5: Normal Array Voltage Drop

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

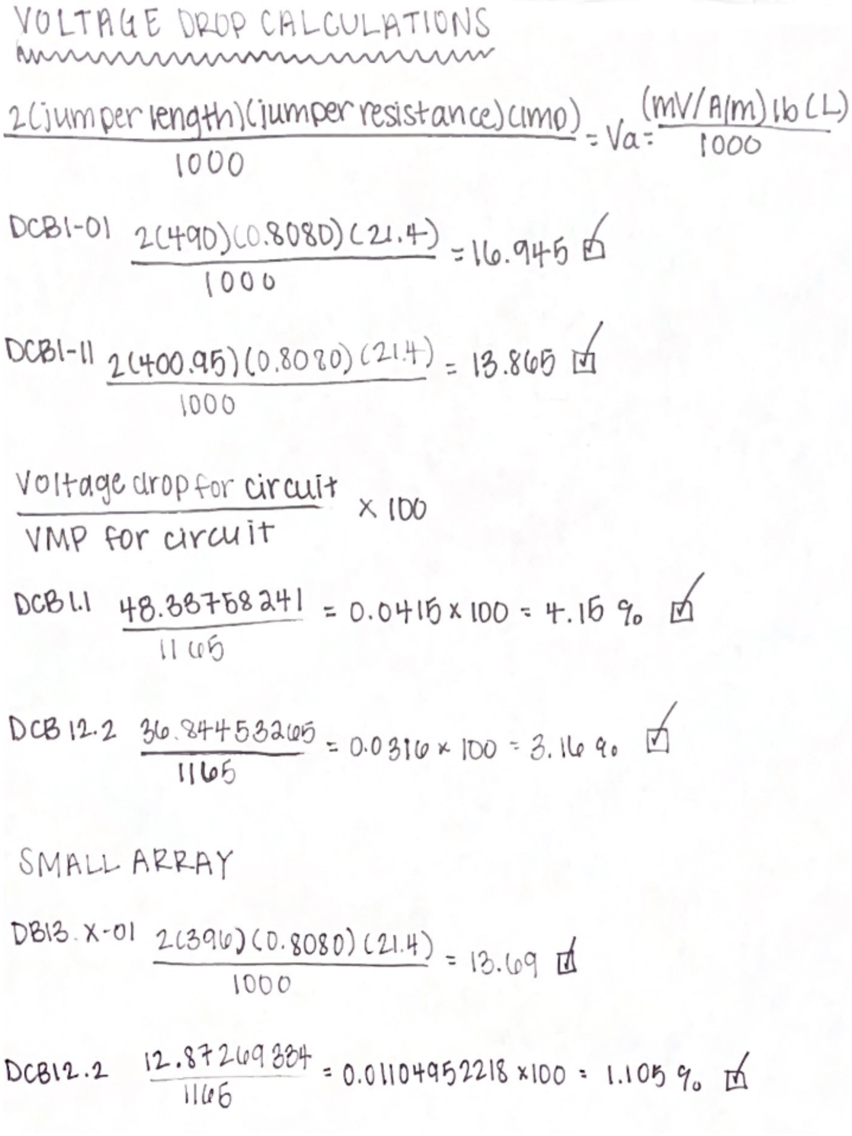
Table 6: Small Array Jumper Voltage Drop



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 7: Small Array Total Voltage Drop

Below in Figure 9 displays the hand calculations that verify the calculations done in the voltage drop tool given to us by Black & Veatch.



VOLTAGE DROP CALCULATIONS

$$\frac{2(\text{jumper length})(\text{jumper resistance})(\text{imo})}{1000} = Va = \frac{(mV/A/m)\,Ib\,(L)}{1000}$$

DCB1-01 $\frac{2(490)(0.8080)(21.4)}{1000} = 16.945$ ☑

DCB1-11 $\frac{2(400.95)(0.8080)(21.4)}{1000} = 13.865$ ☑

$$\frac{\text{Voltage drop for circuit}}{\text{VMP for circuit}} \times 100$$

DCB1.1 $\frac{48.33758241}{1165} = 0.0415 \times 100 = 4.15\%$ ☑

DCB12.2 $\frac{36.84453265}{1165} = 0.0316 \times 100 = 3.16\%$ ☑

SMALL ARRAY

DB13.X-01 $\frac{2(396)(0.8080)(21.4)}{1000} = 13.69$ ☑

DCB12.2 $\frac{12.87269334}{1166} = 0.01104952218 \times 100 = 1.105\%$ ☑

Figure 9: 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.

3.3 Proposed Design - Substation

The most important step in designing a substation is to find a layout which accomplishes your users needs at a reasonable price. We need to design a substation that is capable of handling a combined load of 1,730 A and stepping up the 34.5kV supplied by the solar farm to 115kV for long-distance transmission. In our case we chose a single bus styled configuration as it's cheap, straightforward, and uses less components than most other layouts that accomplish the same task.

3.3.1 Detailed Design Layout and Visuals

Shown below are the final BlueBeam drawing plans for the substation.

3.3.1.1 One Line

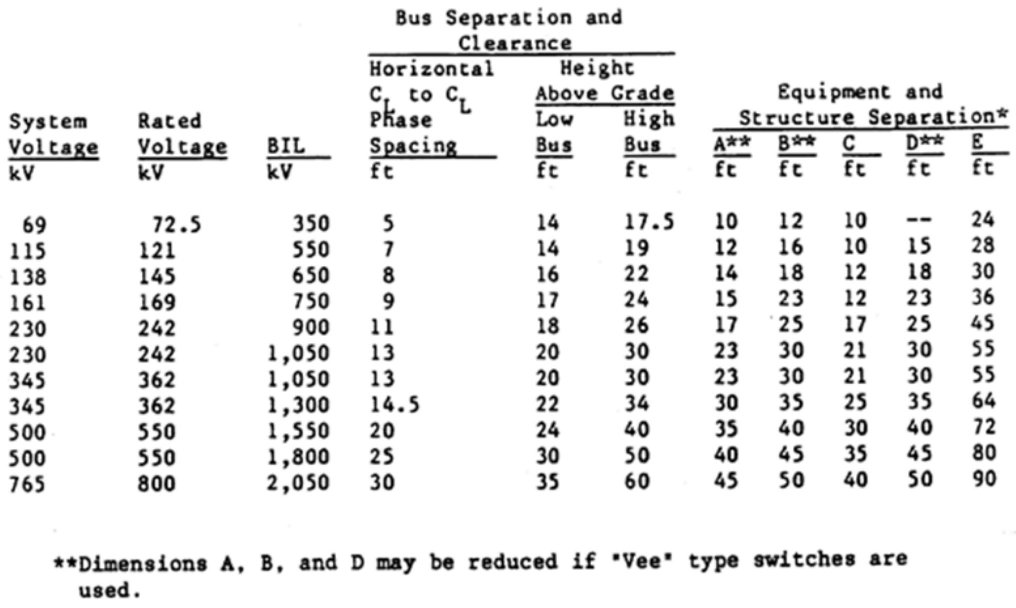
In our final design we have each of our three feeder lines from the solar farm run into their own 34.5kV vacuum circuit breaker, they then come together and connect to a larger main bus capable of handling 1,000 amps, then it is ran through one final 34.5kV vacuum circuit breaker before reaching the transformer. All of these 34.5kV vacuum circuit breakers are capable of being racked out, which is useful for safety during maintenance and repair, and it also saves us from needing an additional disconnect switch on the lowside. Along our highside we have one 115kV SF6 circuit breaker and one motor operated disconnect switch before connecting to the transmission system. The one line can be found in Appendix 4.

3.3.1.2 Three Line

The three line diagram demonstrates all three phases within the substation. It includes the positive, negative, and ground cables in more detail compared to the one line diagram. It is typically used to show relay setting connection, phase sequence design, circuit control and metering connection. It is based exactly on the one line diagram. Our three line diagram, however, did not show the CT relay connection because it became very complex and difficult to read. Based on our client's feedback, we found it most beneficial to keep the three line simple without every CT relay connection. The three line can be found in Appendix 4.

3.3.1.3 Key Plan

The key plan is an integral part of substation design because it clearly demonstrates where each component is physically going to be laid out and connected. This plan includes all the distances between each component, the fence, as well as the access road around the station. It is based on the one line diagram. The spacing between the equipment is not based on IEEE standards, rather varies from client to client. Because of this, the spacing for our substation was based on Black & Veatch internal values. The table below explains the spacing requirements we used. The figure below the spacing table shows the complete key plan for our substation design. The key plan can be found in Appendix 4.



			Bus Separation and Clearance			Equipment and Structure Separation*				
			Horizontal C_L to C_L Phase Spacing	Height Above Grade						
System Voltage kV	Rated Voltage kV	BIL kV	ft	Low Bus ft	High Bus ft	A** ft	B** ft	C ft	D** ft	E ft
69	72.5	350	5	14	17.5	10	12	10	--	24
115	121	550	7	14	19	12	16	10	15	28
138	145	650	8	16	22	14	18	12	18	30
161	169	750	9	17	24	15	23	12	23	36
230	242	900	11	18	26	17	25	17	25	45
230	242	1,050	13	20	30	23	30	21	30	55
345	362	1,050	13	20	30	23	30	21	30	55
345	362	1,300	14.5	22	34	30	35	25	35	64
500	550	1,550	20	24	40	35	40	30	40	72
500	550	1,800	25	30	50	40	45	35	45	80
765	800	2,050	30	35	60	45	50	40	50	90

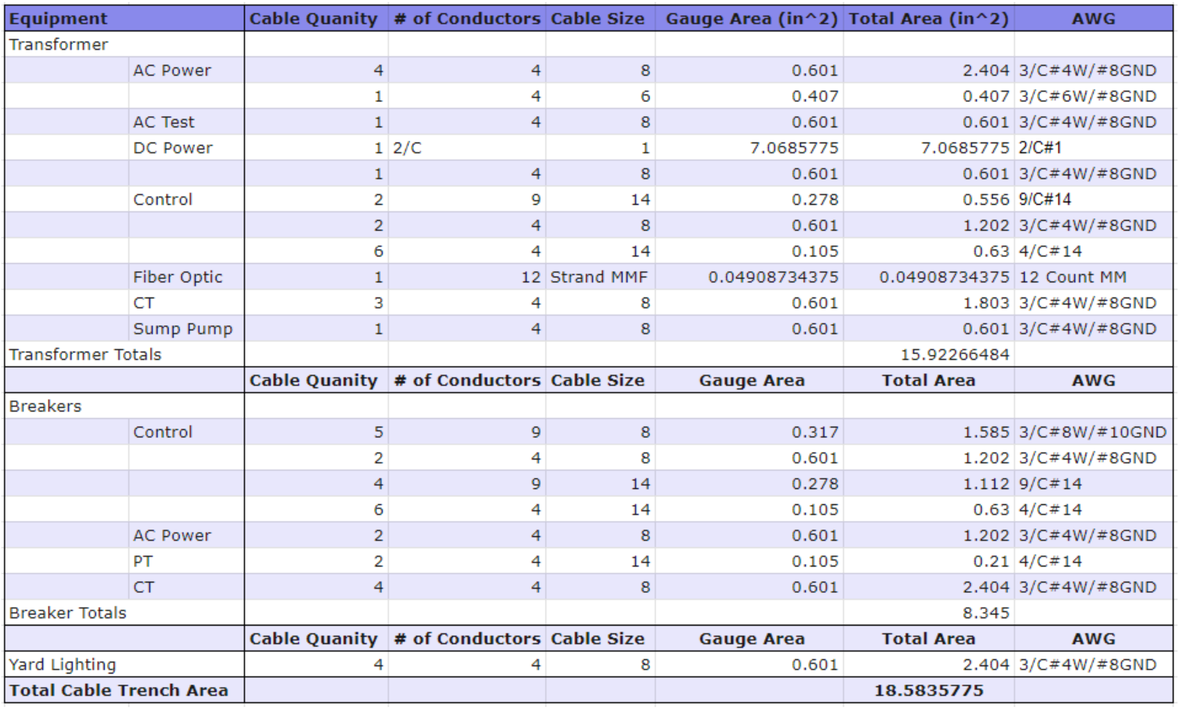
**Dimensions A, B, and D may be reduced if "Vee" type switches are used.

Figure 10: Equipment Distance Reference Table

3.3.1.4 Conduit and Trench Plan

The trench fill calculations helped us determine the conduit plan. In order to complete these calculations we had to have knowledge of the quantity of tables, number of conductors per cable and the cable size. Based on these values we were able to determine the American wire gauges (AWG) standard sizes. Based on the AWG size we could determine the trench area needed for each piece of equipment. In order to complete these calculations we created a table with each of these quantities and multiplied the general gauge area that was determined by the AWG by the cable quantity and summed all the total area values.

These calculations were then used to create the conduit diagram in BlueBeam. The conduit plan shows the underground trenching that holds the cables as well as the PVC that connects the underground trenching to each piece of equipment. The initial trenching was put at ninety degree angles starting at the control house and continuing until the 115 kV disconnect switch. This initial plan was altered after further consideration to be at forty-five degree angles in order to decrease the total amount of trenching that needs to be used. The quantity of cables, number of conductors, and size of cable used in each PVC pipe was determined based on the conduit calculation below. The size of the PVC pipe used was determined by a percentage of the total area in square inches used for the cable size. Reference conduit drawing in Appendix 4.



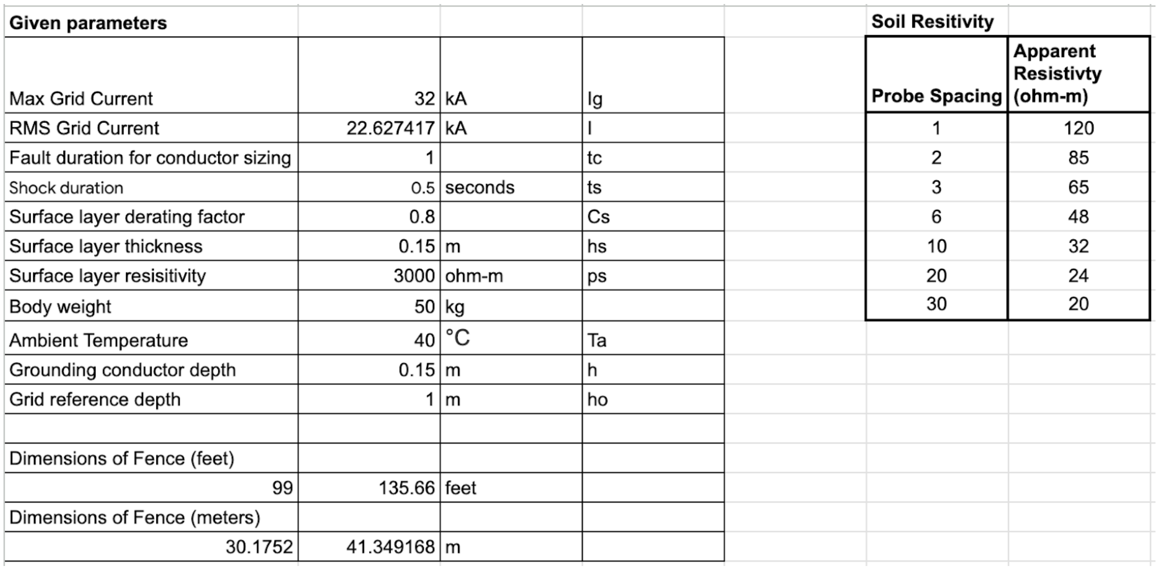
Equipment		**Cable Quanity**	**# of Conductors**	**Cable Size**	**Gauge Area (in^2)**	**Total Area (in^2)**	**AWG**
Transformer							
	AC Power	4	4	8	0.601	2.404	3/C#4W/#8GND
		1	4	6	0.407	0.407	3/C#6W/#8GND
	AC Test	1	4	8	0.601	0.601	3/C#4W/#8GND
	DC Power	1	2/C	1	7.0685775	7.0685775	2/C#1
		1	4	8	0.601	0.601	3/C#4W/#8GND
	Control	2	9	14	0.278	0.556	9/C#14
		2	4	8	0.601	1.202	3/C#4W/#8GND
		6	4	14	0.105	0.63	4/C#14
	Fiber Optic	1	12	Strand MMF	0.04908734375	0.04908734375	12 Count MM
	CT	3	4	8	0.601	1.803	3/C#4W/#8GND
	Sump Pump	1	4	8	0.601	0.601	3/C#4W/#8GND
Transformer Totals						15.92266484	
		Cable Quanity	**# of Conductors**	**Cable Size**	**Gauge Area**	**Total Area**	**AWG**
Breakers							
	Control	5	9	8	0.317	1.585	3/C#8W/#10GND
		2	4	8	0.601	1.202	3/C#4W/#8GND
		4	9	14	0.278	1.112	9/C#14
		6	4	14	0.105	0.63	4/C#14
	AC Power	2	4	8	0.601	1.202	3/C#4W/#8GND
	PT	2	4	14	0.105	0.21	4/C#14
	CT	4	4	8	0.601	2.404	3/C#4W/#8GND
Breaker Totals						8.345	
		Cable Quanity	**# of Conductors**	**Cable Size**	**Gauge Area**	**Total Area**	**AWG**
Yard Lighting		4	4	8	0.601	2.404	3/C#4W/#8GND
Total Cable Trench Area						**18.5835775**	

Figure 11: Trench Fill Calculations

3.3.1.5 Grounding Grid

The grounding grid is an important aspect in the safety of those working on the substation as well as for the equipment in the event of a fault. The grounding grid is a buried grid made of bare copper spread throughout the substation and extends just past the fence to ensure everything in the system is grounded properly.

All the calculations shown below are based on IEEE Standard 80, chapters 11,12, and 16.

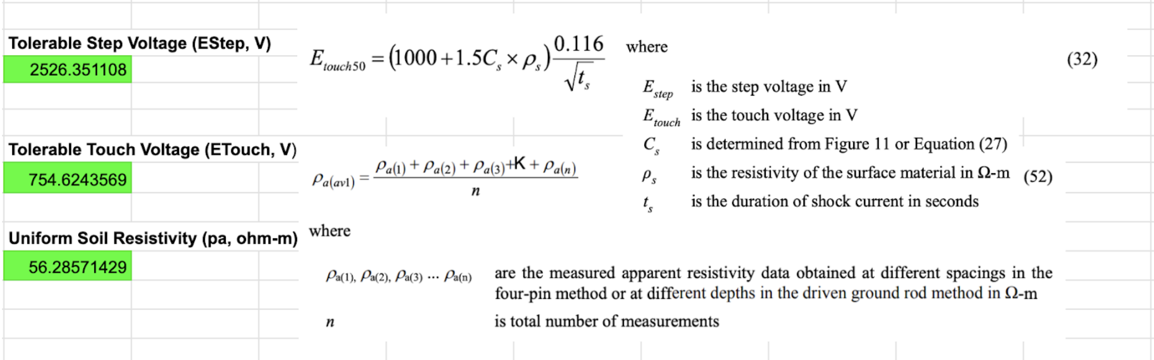


Given parameters			
Max Grid Current	32	kA	Ig
RMS Grid Current	22.627417	kA	I
Fault duration for conductor sizing	1		tc
Shock duration	0.5	seconds	ts
Surface layer derating factor	0.8		Cs
Surface layer thickness	0.15	m	hs
Surface layer resisitivity	3000	ohm-m	ps
Body weight	50	kg	
Ambient Temperature	40	°C	Ta
Grounding conductor depth	0.15	m	h
Grid reference depth	1	m	ho
Dimensions of Fence (feet)			
99	135.66	feet	
Dimensions of Fence (meters)			
30.1752	41.349168	m	

Soil Resitivity

Probe Spacing	**Apparent Resistivty (ohm-m)**
1	120
2	85
3	65
6	48
10	32
20	24
30	20

Figure 12: Starting Parameters for Grounding Grid



Tolerable Step Voltage (EStep, V)
2526.351108

Tolerable Touch Voltage (ETouch, V)
754.6243569

Uniform Soil Resistivity (pa, ohm-m)
56.28571429

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

where

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

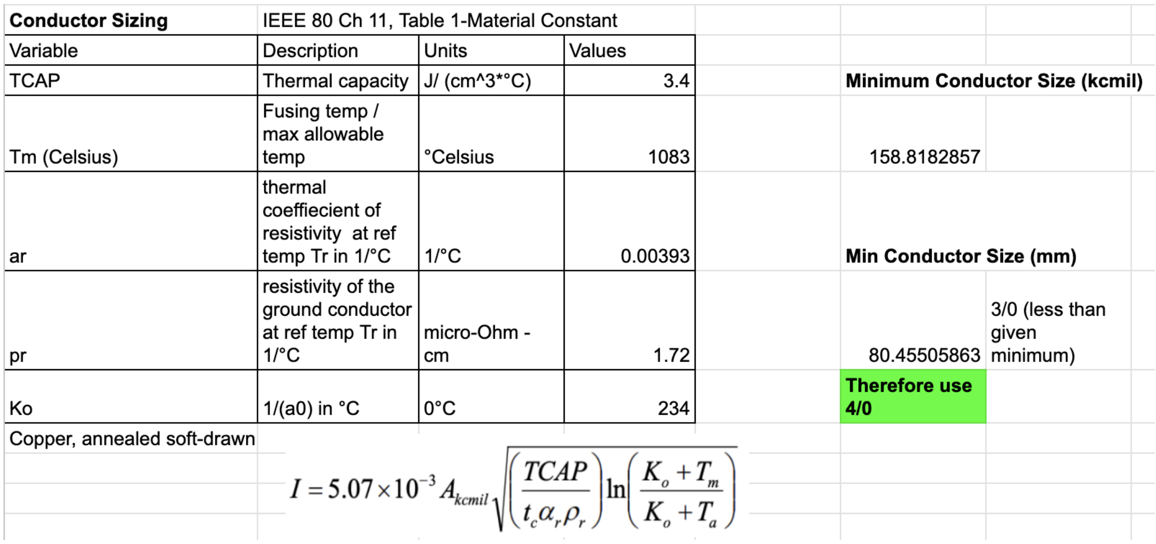
$$\rho_{a(av1)} = \frac{\rho_{a(1)} + \rho_{a(2)} + \rho_{a(3)} + K + \rho_{a(n)}}{n} \qquad (52)$$

where

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

Figure 13: Calculations for Tolerable Step Voltage, Tolerable Touch Voltage, and Uniform Soil Resistivity

The figure above calculates the tolerable step and touch voltage as well as the uniform soil resistivity. The touch and step voltage calculated below must be equal to or less than the values calculated here to ensure that the grounding grid is effective. In order to be cost effective, it is best to keep the final value in a similar range as copper is costly.



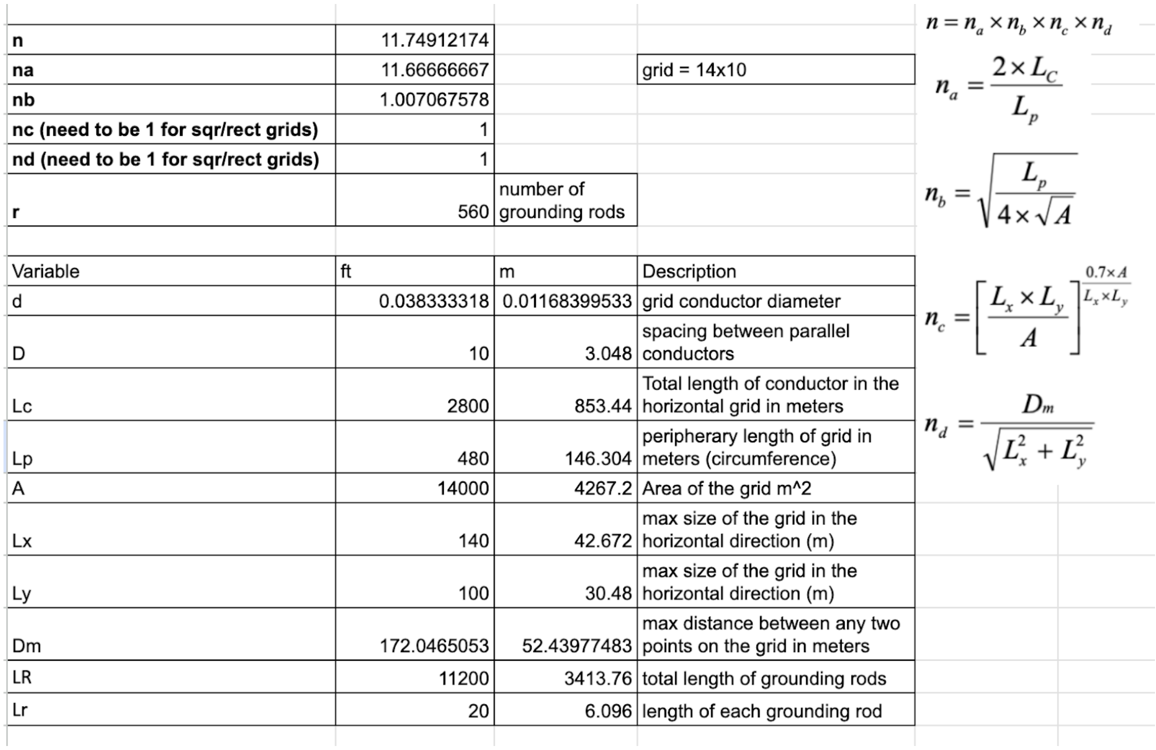
Conductor Sizing	IEEE 80 Ch 11, Table 1-Material Constant					
Variable	Description	Units	Values			
TCAP	Thermal capacity	J/ (cm^3*°C)	3.4		**Minimum Conductor Size (kcmil)**	
Tm (Celsius)	Fusing temp / max allowable temp	°Celsius	1083		158.8182857	
ar	thermal coeffiecient of resistivity at ref temp Tr in 1/°C	1/°C	0.00393		**Min Conductor Size (mm)**	
pr	resistivity of the ground conductor at ref temp Tr in 1/°C	micro-Ohm - cm	1.72		80.45505863	3/0 (less than given minimum)
Ko	1/(a0) in °C	0°C	234		**Therefore use 4/0**	
Copper, annealed soft-drawn						

$$I = 5.07 \times 10^{-3} A_{kcmil} \sqrt{\left(\frac{TCAP}{t_c \alpha_r \rho_r}\right) \ln\left(\frac{K_o + T_m}{K_o + T_a}\right)}$$

Figure 14: Calculations for Minimum Conductor Size

The table above shows the data retrieved from IEEE 80 Chapter 11 Table 1 - Material Constant specifically for the Copper, annealed soft drawn as this is the material that will be used for the grounding conductor.

The equation at the bottom was solved for A_kcmil in order to calculate the minimum conductor value. This was then converted to millimeters to size.For the minimum conductor size, the smallest conductor used based on industry standard is 4/0. This is why, even though our calculations say that 3/0 is an acceptable value, it is smaller than what is used across the industry, therefore we use 4/0 gauge wiring for the grounding grid.



n	11.74912174		
na	11.66666667		grid = 14x10
nb	1.007067578		
nc (need to be 1 for sqr/rect grids)	1		
nd (need to be 1 for sqr/rect grids)	1		
r	560	number of grounding rods	

Variable	ft	m	Description
d	0.038333318	0.01168399533	grid conductor diameter
D	10	3.048	spacing between parallel conductors
Lc	2800	853.44	Total length of conductor in the horizontal grid in meters
Lp	480	146.304	peripheray length of grid in meters (circumference)
A	14000	4267.2	Area of the grid m^2
Lx	140	42.672	max size of the grid in the horizontal direction (m)
Ly	100	30.48	max size of the grid in the horizontal direction (m)
Dm	172.0465053	52.43977483	max distance between any two points on the grid in meters
LR	11200	3413.76	total length of grounding rods
Lr	20	6.096	length of each grounding rod

$$n = n_a \times n_b \times n_c \times n_d$$

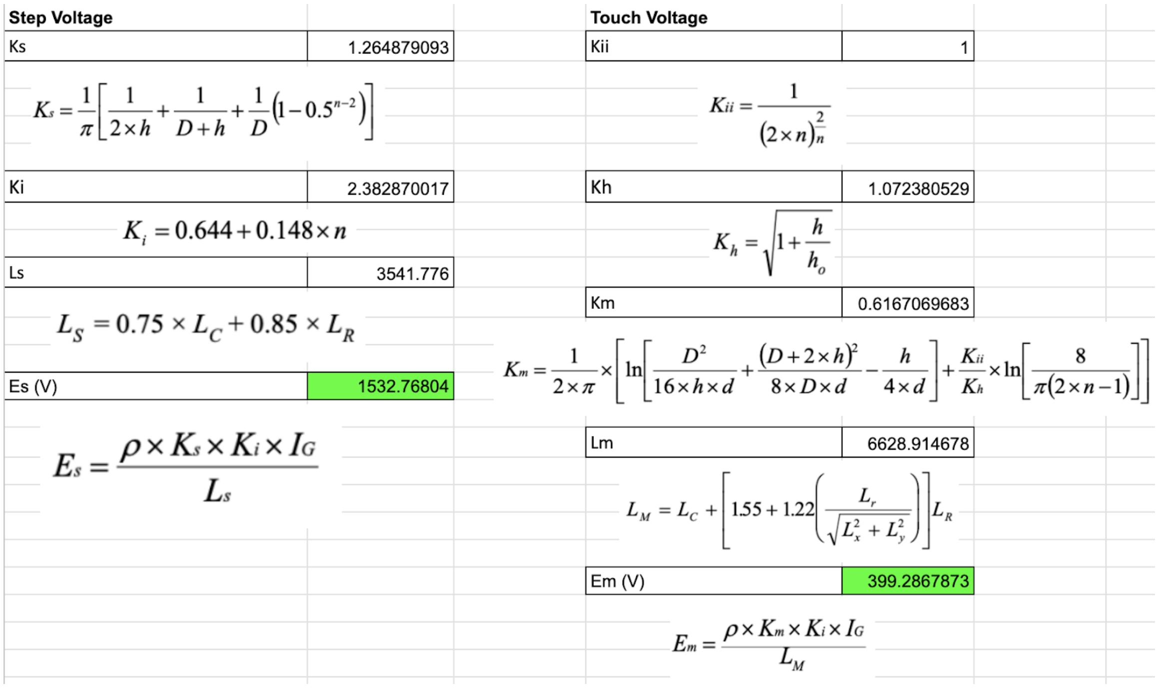
$$n_a = \frac{2 \times L_C}{L_p}$$

$$n_b = \sqrt{\frac{L_p}{4 \times \sqrt{A}}}$$

$$n_c = \left[\frac{L_x \times L_y}{A}\right]^{\frac{0.7 \times A}{L_x \times L_y}}$$

$$n_d = \frac{D_m}{\sqrt{L_x^2 + L_y^2}}$$

Figure 15: Calculations for Constants Relating to the Dimensions of the Grid. Used in Below Calculations



Step Voltage

Ks	1.264879093

$$K_s = \frac{1}{\pi}\left[\frac{1}{2 \times h} + \frac{1}{D+h} + \frac{1}{D}\left(1 - 0.5^{n-2}\right)\right]$$

Ki	2.382870017

$$K_i = 0.644 + 0.148 \times n$$

Ls	3541.776

$$L_S = 0.75 \times L_C + 0.85 \times L_R$$

Es (V)	1532.76804

$$E_s = \frac{\rho \times K_s \times K_i \times I_G}{L_s}$$

Touch Voltage

Kii	1

$$K_{ii} = \frac{1}{(2 \times n)^{\frac{2}{n}}}$$

Kh	1.072380529

$$K_h = \sqrt{1 + \frac{h}{h_o}}$$

Km	0.6167069683

$$K_m = \frac{1}{2 \times \pi} \times \left[\ln\left[\frac{D^2}{16 \times h \times d} + \frac{(D + 2 \times h)^2}{8 \times D \times d} - \frac{h}{4 \times d}\right] + \frac{K_{ii}}{K_h} \times \ln\left[\frac{8}{\pi(2 \times n - 1)}\right]\right]$$

Lm	6628.914678

$$L_M = L_C + \left[1.55 + 1.22\left(\frac{L_r}{\sqrt{L_x^2 + L_y^2}}\right)\right] L_R$$

Em (V)	399.2867873

$$E_m = \frac{\rho \times K_m \times K_i \times I_G}{L_M}$$

Figure 16: Calculations for Step and Touch Voltage

The dimensions of the grid could extend up to 3 feet on any side of the fence. Based on the size of the fence, 99 feet by 135.66 feet, it was decided that the best way to lay out the grounding grid would be a grid size of 100 feet by 140 feet. This ensures easier construction and allows for appropriate touch and step voltages.

In order to keep the step and touch voltages under the threshold set earlier but not so significantly below that it would be using excess copper, the grounding grid was determined to be best as a 14 x 10 with the rods every 10 feet in the x-axis and every 5 feet in the y-axis.

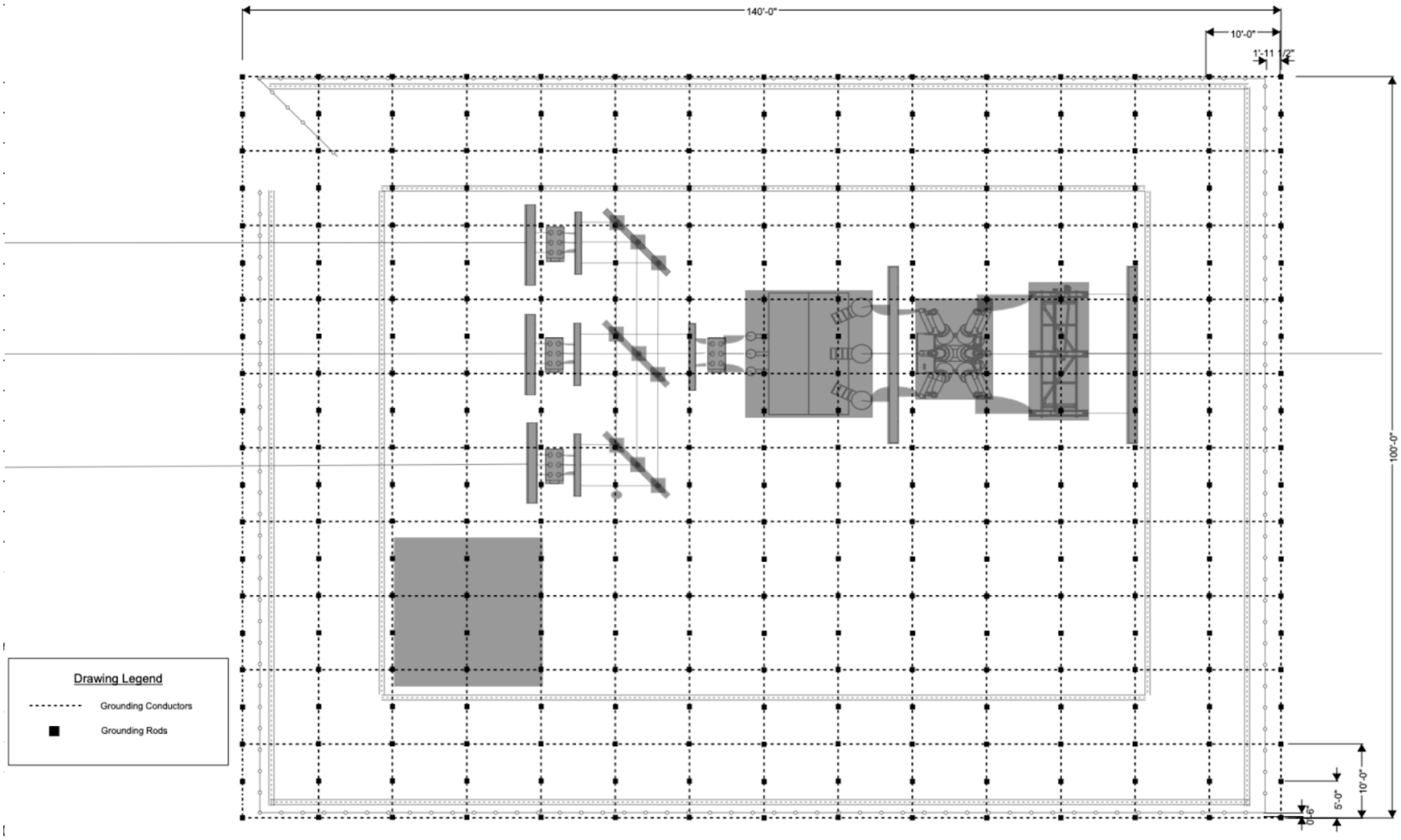
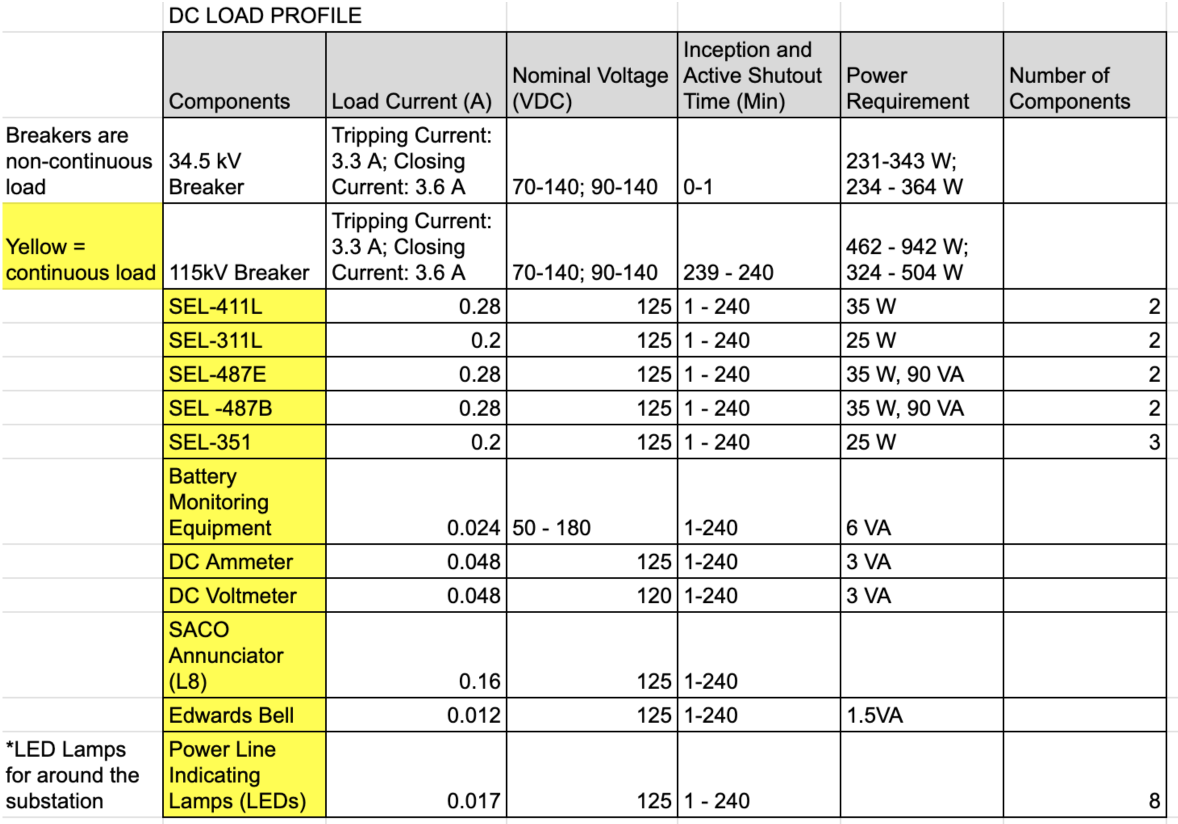


Figure 17: Grounding Grid

3.3.2 Additional Calculations

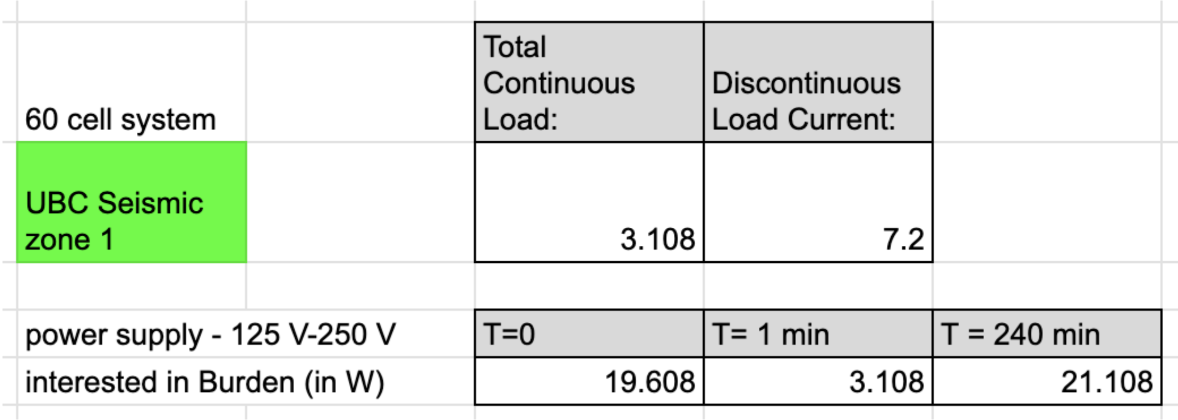
3.3.2.1 DC Battery Calculations

The DC battery calculations were necessary to determine the size and quantity of the batteries that would be servicing our substation should any auxiliary power be needed. To properly size our batteries we used a program called EnerSys, but first we needed to calculate the loads at T = 0 min, T = 1 min, and T = 240 min after the breaker trip. To properly do this we used an example given to us by Black and Veatch and used the IEEE 485 standards to verify our work.



	DC LOAD PROFILE					
	Components	Load Current (A)	Nominal Voltage (VDC)	Inception and Active Shutout Time (Min)	Power Requirement	Number of Components
Breakers are non-continuous load	34.5 kV Breaker	Tripping Current: 3.3 A; Closing Current: 3.6 A	70-140; 90-140	0-1	231-343 W; 234 - 364 W	
Yellow = continuous load	115kV Breaker	Tripping Current: 3.3 A; Closing Current: 3.6 A	70-140; 90-140	239 - 240	462 - 942 W; 324 - 504 W	
	SEL-411L	0.28	125	1 - 240	35 W	2
	SEL-311L	0.2	125	1 - 240	25 W	2
	SEL-487E	0.28	125	1 - 240	35 W, 90 VA	2
	SEL -487B	0.28	125	1 - 240	35 W, 90 VA	2
	SEL-351	0.2	125	1 - 240	25 W	3
	Battery Monitoring Equipment	0.024	50 - 180	1-240	6 VA	
	DC Ammeter	0.048	125	1-240	3 VA	
	DC Voltmeter	0.048	120	1-240	3 VA	
	SACO Annunciator (L8)	0.16	125	1-240		
	Edwards Bell	0.012	125	1-240	1.5VA	
*LED Lamps for around the substation	Power Line Indicating Lamps (LEDs)	0.017	125	1 - 240		8

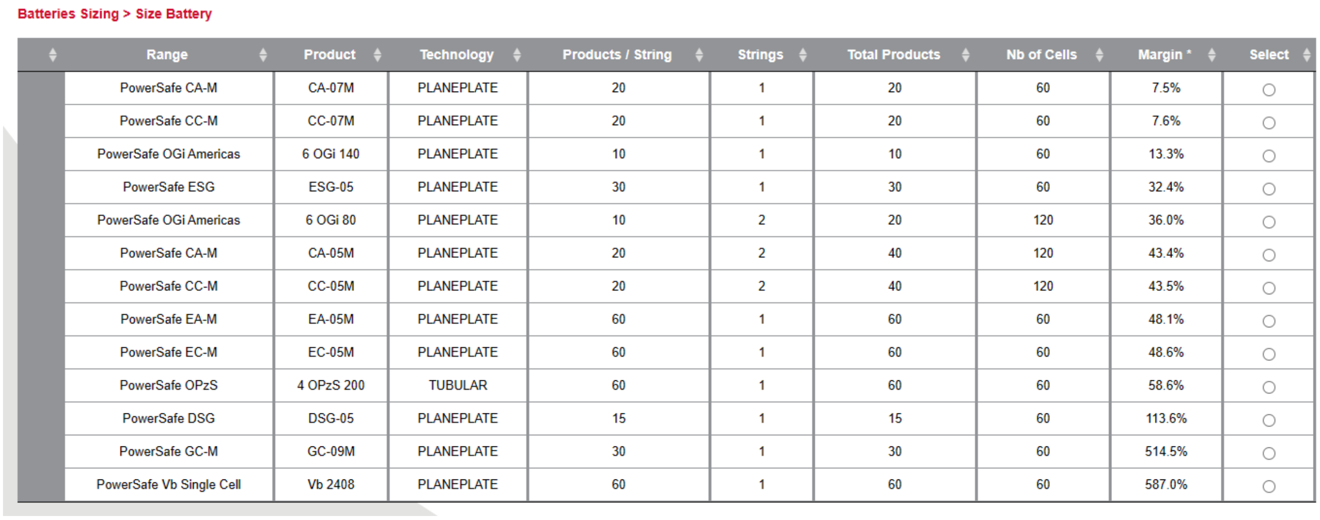
Figure 18: DC Load Profile



60 cell system		Total Continuous Load:	Discontinuous Load Current:	
UBC Seismic zone 1		3.108	7.2	
power supply - 125 V-250 V		T=0	T= 1 min	T = 240 min
interested in Burden (in W)		19.608	3.108	21.108

Figure 19: DC Load Profile - Total Loads and Timing

At T = 0 min, our burden (seen in the figure above) consisted of our 4 low side breakers, 1 high side breaker, and our continuous load (highlighted yellow). At T = 1 min when the breakers trip, our burden consists solely of the total continuous load. The total continuous load is the sum of the currents of each piece of equipment per unit. At T = 240 min, the load consists of the 4 low side breakers (closing current), the 1 high side breaker (closing current), and the continuous load once again. Furthermore, as seen above, the total discontinuous load is the sum of the closing currents for the breakers. We did not end up using this in our calculations but it was an interesting detail to know.



Batteries Sizing > Size Battery

	Range	Product	Technology	Products / String	Strings	Total Products	Nb of Cells	Margin *	Select
	PowerSafe CA-M	CA-07M	PLANEPLATE	20	1	20	60	7.5%	○
	PowerSafe CC-M	CC-07M	PLANEPLATE	20	1	20	60	7.6%	○
	PowerSafe OGi Americas	6 OGi 140	PLANEPLATE	10	1	10	60	13.3%	○
	PowerSafe ESG	ESG-05	PLANEPLATE	30	1	30	60	32.4%	○
	PowerSafe OGi Americas	6 OGi 80	PLANEPLATE	10	2	20	120	36.0%	○
	PowerSafe CA-M	CA-05M	PLANEPLATE	20	2	40	120	43.4%	○
	PowerSafe CC-M	CC-05M	PLANEPLATE	20	2	40	120	43.5%	○
	PowerSafe EA-M	EA-05M	PLANEPLATE	60	1	60	60	48.1%	○
	PowerSafe EC-M	EC-05M	PLANEPLATE	60	1	60	60	48.6%	○
	PowerSafe OPzS	4 OPzS 200	TUBULAR	60	1	60	60	58.6%	○
	PowerSafe DSG	DSG-05	PLANEPLATE	15	1	15	60	113.6%	○
	PowerSafe GC-M	GC-09M	PLANEPLATE	30	1	30	60	514.5%	○
	PowerSafe Vb Single Cell	Vb 2408	PLANEPLATE	60	1	60	60	587.0%	○

Figure 20: EnerSYS Battery Sizing Output Options

Once we input the different loads at each time T into the system, we were given a list of batteries that we could use for our substation. The image above shows the different options that EnerSYS's battery sizing system recommended based on the calculations shown previously. The smallest margin is the option that best matches our needs, and therefore we will use the PowerSafe CA-M , model CA-07M with a margin of 7.5%. Once that was completed, we input the seismic rating of Roswell NM as well as other details pertaining to our desired racking layout to get the racking report, racking diagram, and racking system configuration. All of this additional data regarding the battery sizing and racking is in the Appendix below.

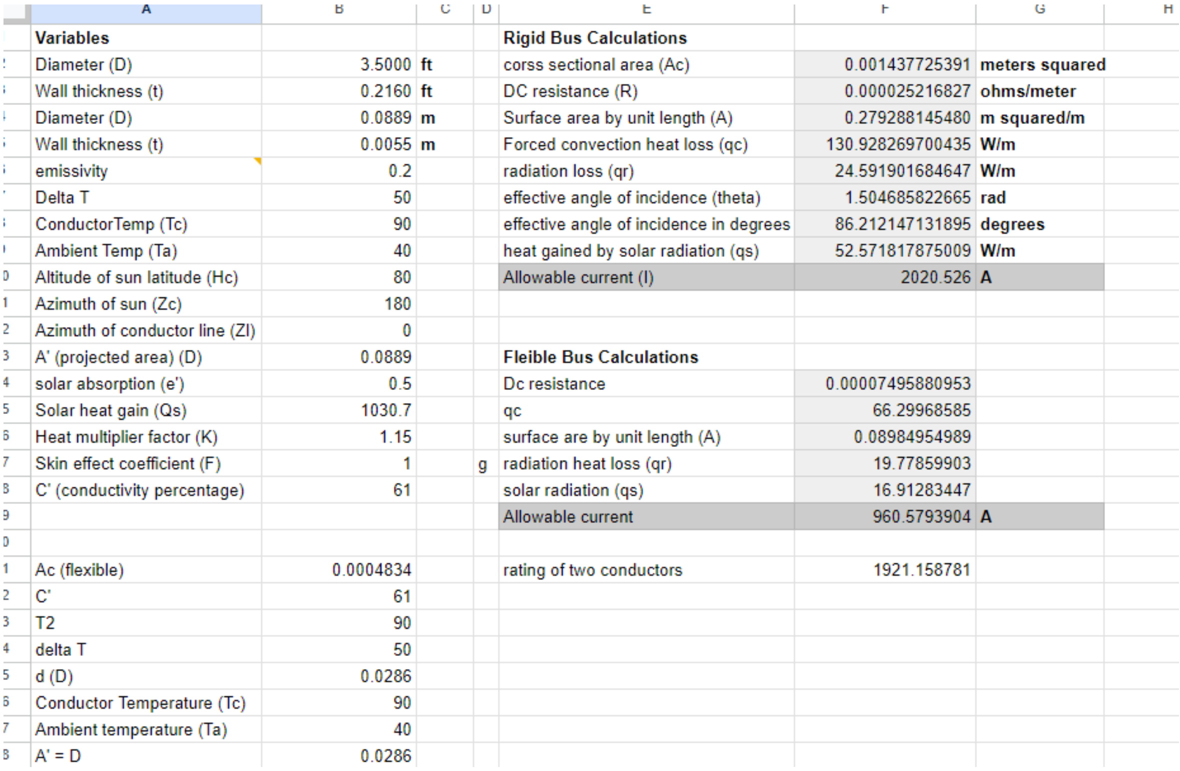
3.3.2.2 Lightning Protection

Lightning protection is considered one of the major protections for the substation.Our first step in designing the lightning protection was finding the highest equipment in the substation, and knowing that the lightning mast will be typically 20~30 ft taller than the highest equipment in the substation. Following IEEE Std 998-2012 we calculated the amount of protection each mast is able to provide at various heights using the empirical method of protection. Once mutual protection calculations were complete, we were able to position the masts accordingly to provide overlapping protection for every live component inside the substation.

3.3.2.3 Bus Calculations

Buses within substations control paths for current to travel between pieces of equipment and also ensure the equipment maintains at the same potential. The calculations were all completed using the IEEE Guide for Bus Design in Air Insulated substations. This document goes through the necessary steps to successfully calculate the ampacity, forces, and max allowable span for both rigid and flexible buses. Based on the client's requirements, the rigid bus was to be 3 inch nominal size with a 3.5 inch outside diameter and the flexible bus a Bluejay 1113 AWG ACSR.

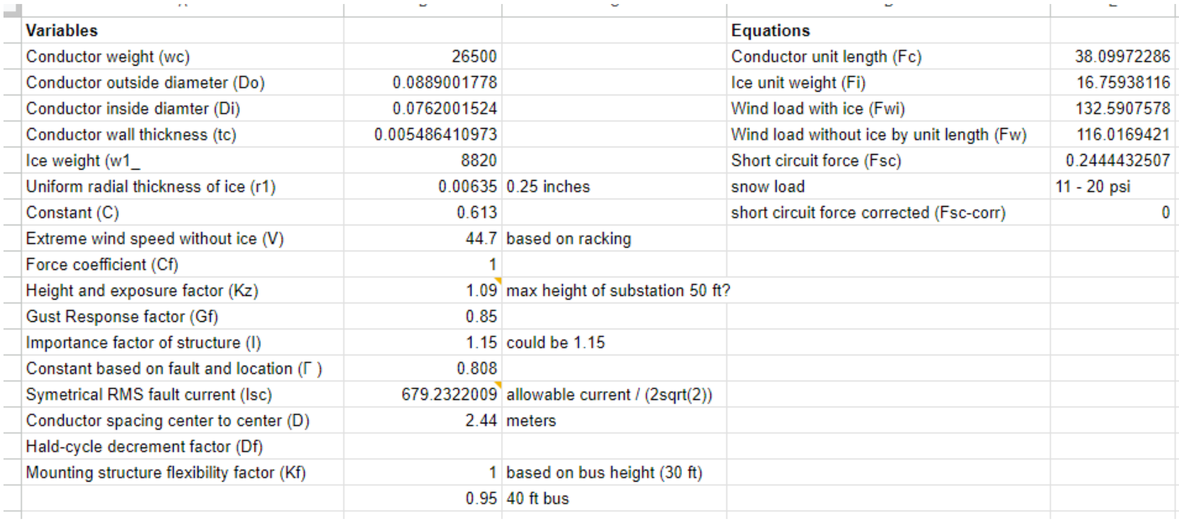
The ampacity is the amount of current a conductor can carry without exceeding a specified temperature. Some specific values that changed throughout the calculation to ensure that the buses can withstand the amount of current that goes through the substation were the emissivity and the altitude of the sun in degrees. We initially had the altitude of the sun at 70 degrees based on an estimated latitude value of the location of the substation. Later, a more detailed graph of solar azimuth vs. time of day at the location of our substation, that was used in the substation design, was examined to determine the value of the altitude of the sun to be 80 degrees. We also changed the emissivity from 0.4 to 0.2 because we assumed that our buses are made out of new aluminum rather than weathered aluminum. The rigid bus maximum allowable current was found to be 2020.526 A and the flexible bus 960.579 A, which withstands the amount of current that was previously calculated that goes through our substation design. Figure 21 shows the ampacity calculations.



A	B	C	D	E	F	G	H
Variables				**Rigid Bus Calculations**			
Diameter (D)	3.5000	**ft**		corss sectional area (Ac)	0.001437725391	**meters squared**	
Wall thickness (t)	0.2160	**ft**		DC resistance (R)	0.000025216827	**ohms/meter**	
Diameter (D)	0.0889	**m**		Surface area by unit length (A)	0.279288145480	**m squared/m**	
Wall thickness (t)	0.0055	**m**		Forced convection heat loss (qc)	130.928269700435	**W/m**	
emissivity	0.2			radiation loss (qr)	24.591901684647	**W/m**	
Delta T	50			effective angle of incidence (theta)	1.504685822665	**rad**	
ConductorTemp (Tc)	90			effective angle of incidence in degrees	86.212147131895	**degrees**	
Ambient Temp (Ta)	40			heat gained by solar radiation (qs)	52.571817875009	**W/m**	
Altitude of sun latitude (Hc)	80			Allowable current (I)	2020.526	**A**	
Azimuth of sun (Zc)	180						
Azimuth of conductor line (Zl)	0						
A' (projected area) (D)	0.0889			**Fleible Bus Calculations**			
solar absorption (e')	0.5			Dc resistance	0.00007495880953		
Solar heat gain (Qs)	1030.7			qc	66.29968585		
Heat multiplier factor (K)	1.15			surface are by unit length (A)	0.08984954989		
Skin effect coefficient (F)	1		g	radiation heat loss (qr)	19.77859903		
C' (conductivity percentage)	61			solar radiation (qs)	16.91283447		
				Allowable current	960.5793904	**A**	
Ac (flexible)	0.0004834			rating of two conductors	1921.158781		
C'	61						
T2	90						
delta T	50						
d (D)	0.0286						
Conductor Temperature (Tc)	90						
Ambient temperature (Ta)	40						
A' = D	0.0286						

Figure 21: Ampacity Calculations

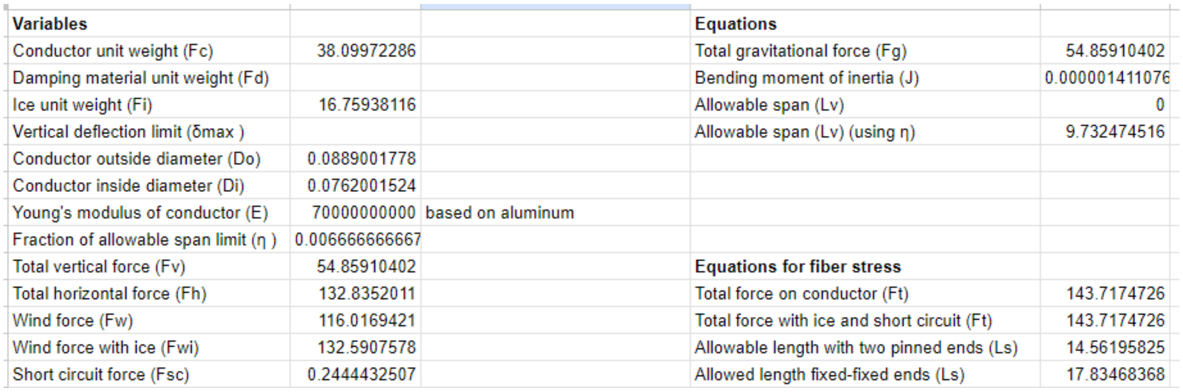
We also calculated the total forces that will be felt by the buses due to various weather and circuit characteristics. An interesting aspect of our substation location was that there could be an ice force on the buses. This is because, based on Figure 8 in the IEEE bus calculation guide, Roswell, NM is right on the cusp of enduring 0 inches to 0.25 inches of ice yearly. We chose to use the extreme in this case to ensure that the worst case scenario is accounted for when determining how much potential load will be on the buses. This caused an increase in the total load on the buses, with a wind load with ice to be 16.76 lb/in and the short circuit force 0.244 lb/in. Figure 22 shows the force calculations.



Variables			Equations	
Conductor weight (wc)	26500		Conductor unit length (Fc)	38.09972286
Conductor outside diameter (Do)	0.0889001778		Ice unit weight (Fi)	16.75938116
Conductor inside diamter (Di)	0.0762001524		Wind load with ice (Fwi)	132.5907578
Conductor wall thickness (tc)	0.005486410973		Wind load without ice by unit length (Fw)	116.0169421
Ice weight (w1_	8820		Short circuit force (Fsc)	0.2444432507
Uniform radial thickness of ice (r1)	0.00635	0.25 inches	snow load	11 - 20 psi
Constant (C)	0.613		short circuit force corrected (Fsc-corr)	0
Extreme wind speed without ice (V)	44.7	based on racking		
Force coefficient (Cf)	1			
Height and exposure factor (Kz)	1.09	max height of substation 50 ft?		
Gust Response factor (Gf)	0.85			
Importance factor of structure (I)	1.15	could be 1.15		
Constant based on fault and location (Γ)	0.808			
Symetrical RMS fault current (Isc)	679.2322009	allowable current / (2sqrt(2))		
Conductor spacing center to center (D)	2.44	meters		
Hald-cycle decrement factor (Df)				
Mounting structure flexibility factor (Kf)	1	based on bus height (30 ft)		
	0.95	40 ft bus		

Figure 22: Bus Force Calculations

The final bus calculation was the maximum allowable span. This is an integral aspect of the design process because it limits the maximum distance that two pieces of equipment can be apart in the substation. These calculations were also complete following the IEEE guide for bus design and are based on both the maximum allowable current and total forces calculated in previous steps. The maximum allowable span was calculated to be 9.73 m. The fiber stress for the span was also calculated using a similar process, with the allowable length with two pinned ends 14.56 m. and allowed length with fixed fixed ends 17.83 m. Figure 23 shows the maximum allowable span calculations.

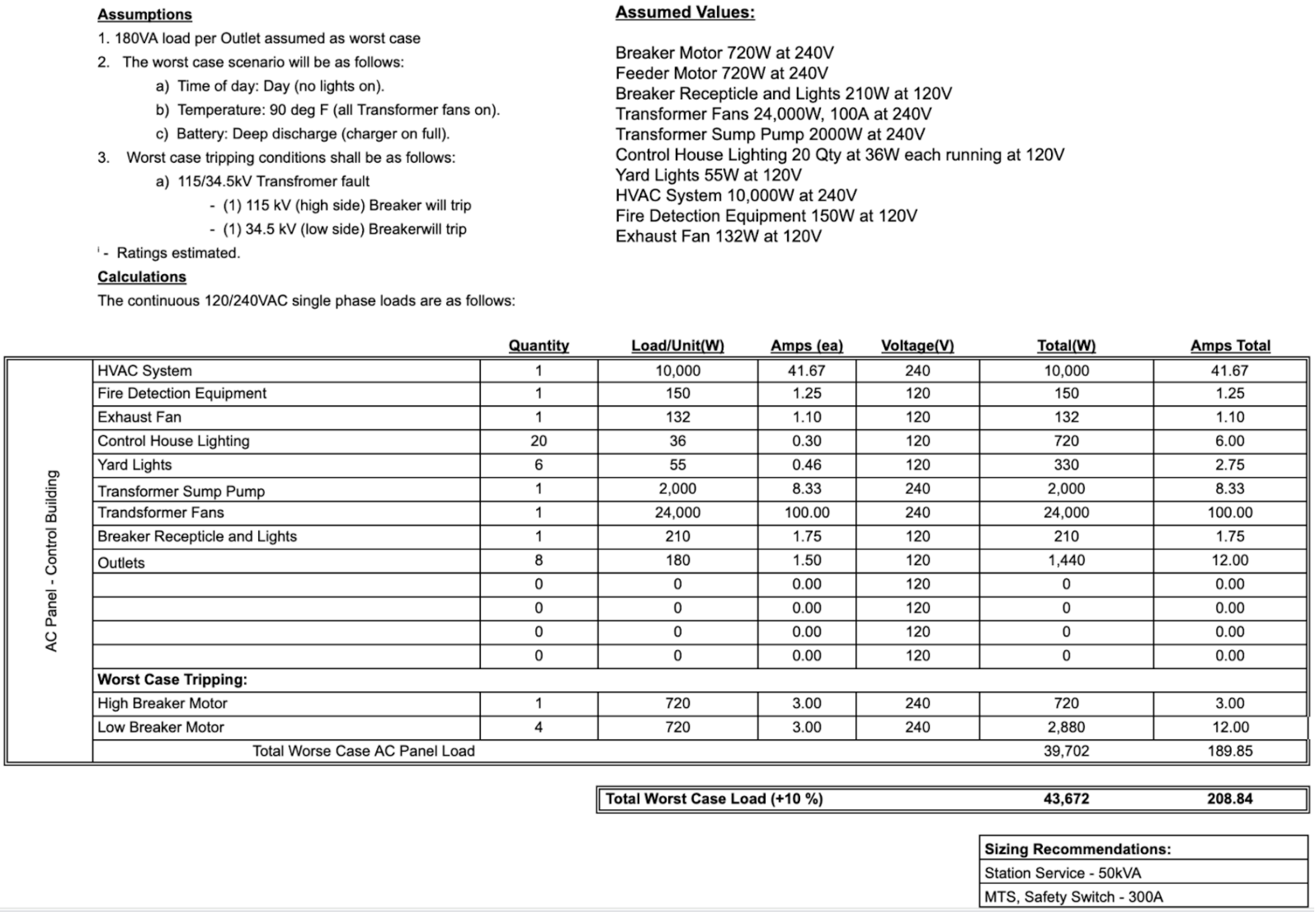


Variables			Equations	
Conductor unit weight (Fc)	38.09972286		Total gravitational force (Fg)	54.85910402
Damping material unit weight (Fd)			Bending moment of inertia (J)	0.000001411076
Ice unit weight (Fi)	16.75938116		Allowable span (Lv)	0
Vertical deflection limit (δmax)			Allowable span (Lv) (using η)	9.732474516
Conductor outside diameter (Do)	0.0889001778			
Conductor inside diameter (Di)	0.0762001524			
Young's modulus of conductor (E)	70000000000	based on aluminum		
Fraction of allowable span limit (η)	0.006666666667			
Total vertical force (Fv)	54.85910402		**Equations for fiber stress**	
Total horizontal force (Fh)	132.8352011		Total force on conductor (Ft)	143.7174726
Wind force (Fw)	116.0169421		Total force with ice and short circuit (Ft)	143.7174726
Wind force with ice (Fwi)	132.5907578		Allowable length with two pinned ends (Ls)	14.56195825
Short circuit force (Fsc)	0.2444432507		Allowed length fixed-fixed ends (Ls)	17.83468368

Figure 23: AC Load Calculations

3.3.2.4 AC Load Calculations

The AC Load calculations shown below are to calculate the AC draw from auxiliary equipment at the substation. This includes equipment such as lighting, HVAC, and fans for the primary equipment. Based on our calculations it was determined that the best size recommendation for the station service is at least 50 kVA, as it must be approximately 10% above the calculated draw and at a rating that is sold. For the MTS, Safety Switch the calculated value was just above 200A, so to comply with the 10% margin it must be at least 228A. However, we were advised that the ratings for this equipment are typically sold in 100A increments. Therefore, the recommended rating is 300 A.



Assumptions

1. 180VA load per Outlet assumed as worst case
2. The worst case scenario will be as follows:
    a) Time of day: Day (no lights on).
    b) Temperature: 90 deg F (all Transformer fans on).
    c) Battery: Deep discharge (charger on full).
3. Worst case tripping conditions shall be as follows:
    a) 115/34.5kV Transfromer fault
        - (1) 115 kV (high side) Breaker will trip
        - (1) 34.5 kV (low side) Breakerwill trip

[i] - Ratings estimated.

Calculations

The continuous 120/240VAC single phase loads are as follows:

Assumed Values:

Breaker Motor 720W at 240V
Feeder Motor 720W at 240V
Breaker Recepticle and Lights 210W at 120V
Transformer Fans 24,000W, 100A at 240V
Transformer Sump Pump 2000W at 240V
Control House Lighting 20 Qty at 36W each running at 120V
Yard Lights 55W at 120V
HVAC System 10,000W at 240V
Fire Detection Equipment 150W at 120V
Exhaust Fan 132W at 120V

		Quantity	Load/Unit(W)	Amps (ea)	Voltage(V)	Total(W)	Amps Total
AC Panel - Control Building	HVAC System	1	10,000	41.67	240	10,000	41.67
	Fire Detection Equipment	1	150	1.25	120	150	1.25
	Exhaust Fan	1	132	1.10	120	132	1.10
	Control House Lighting	20	36	0.30	120	720	6.00
	Yard Lights	6	55	0.46	120	330	2.75
	Transformer Sump Pump	1	2,000	8.33	240	2,000	8.33
	Trandsformer Fans	1	24,000	100.00	240	24,000	100.00
	Breaker Recepticle and Lights	1	210	1.75	120	210	1.75
	Outlets	8	180	1.50	120	1,440	12.00
		0	0	0.00	120	0	0.00
		0	0	0.00	120	0	0.00
		0	0	0.00	120	0	0.00
		0	0	0.00	120	0	0.00
	Worst Case Tripping:						
	High Breaker Motor	1	720	3.00	240	720	3.00
	Low Breaker Motor	4	720	3.00	240	2,880	12.00
	Total Worse Case AC Panel Load					39,702	189.85

Total Worst Case Load (+10 %)	**43,672**	**208.84**

Sizing Recommendations:
Station Service - 50kVA
MTS, Safety Switch - 300A

Figure 24: AC Load Calculations

3.3.2.5 Relaying Protection

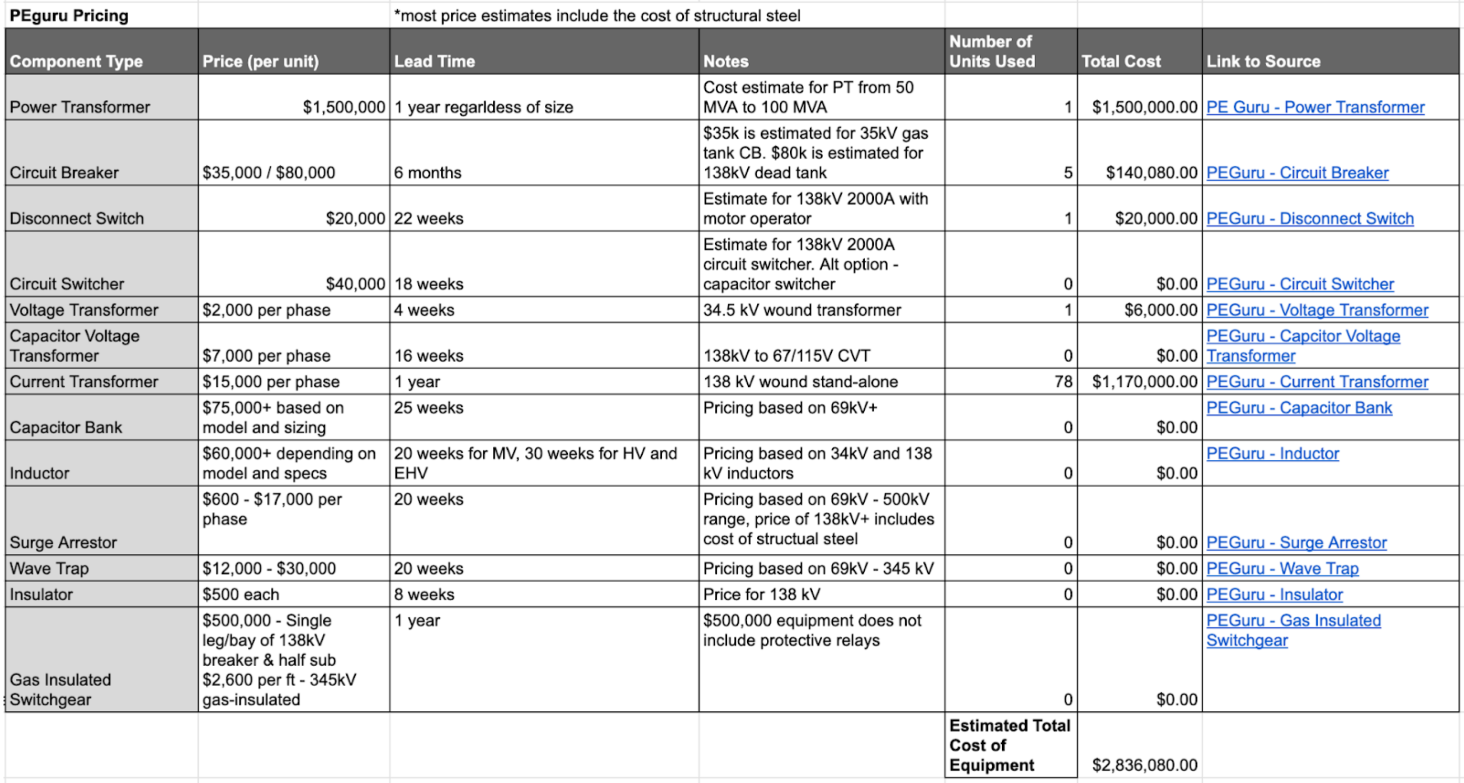
In order to protect many of the components inside of our substation, we utilized SEL's catalog of well documented relays in order to monitor the current and voltage levels at every point. Please see appendix a4 for our one line diagram. We used two SEL-487B-1s' across VCB1-3 to VCB4, one SEL-351s just after VCB1-3 that connected to VCB1-3 respectively, an SEL-411L and an SEL-311L across VCB4, two SEL-487Es across the transformer to transmission side of GSB1, and another pair of SEL-411L and SEL-311L across GSB1 heading towards transmission.

- SEL-487B-1 for under/over voltage, instantaneous overcurrent, and differential protection
- SEL-351s for automatic reclosing and synchronism check
- SEL-411L for under/over voltage, instantaneous overcurrent, differential protection, fault detection, fault detection, reclosing control, breaker failure protection,

- SEL-311L for under/over voltage, instantaneous overcurrent, differential protection
- SEL-487E under/over voltage, directional instantaneous overcurrent, differential protection, breaker failure, thermal, restricted earth fault & winding protection,

3.3.2.6 Cost Estimate

Getting an accurate assessment of price for the cost of equipment is difficult to do with this type of project as the companies producing the equipment have no incentive to provide accurate assessment of pricing for our project. It was recommended that we explore the website "PEGuru" to get estimates on price and lead times for the equipment in order to have an extremely rough estimate. The figure below provides the notes taken from that site on all substation related equipment that could have been applicable to our project. Based on our final design, our estimated price for primary substation equipment is approximately $2,800,000. This does not include things such as cabling and bus connections, the take-off structure, the control house, and other equipment.



PEguru Pricing		*most price estimates include the cost of structural steel				
Component Type	**Price (per unit)**	**Lead Time**	**Notes**	**Number of Units Used**	**Total Cost**	**Link to Source**
Power Transformer	$1,500,000	1 year regarldess of size	Cost estimate for PT from 50 MVA to 100 MVA	1	$1,500,000.00	PE Guru - Power Transformer
Circuit Breaker	$35,000 / $80,000	6 months	$35k is estimated for 35kV gas tank CB. $80k is estimated for 138kV dead tank	5	$140,080.00	PEGuru - Circuit Breaker
Disconnect Switch	$20,000	22 weeks	Estimate for 138kV 2000A with motor operator	1	$20,000.00	PEGuru - Disconnect Switch
Circuit Switcher	$40,000	18 weeks	Estimate for 138kV 2000A circuit switcher. Alt option - capacitor switcher	0	$0.00	PEGuru - Circuit Switcher
Voltage Transformer	$2,000 per phase	4 weeks	34.5 kV wound transformer	1	$6,000.00	PEGuru - Voltage Transformer
Capacitor Voltage Transformer	$7,000 per phase	16 weeks	138kV to 67/115V CVT	0	$0.00	PEGuru - Capcitor Voltage Transformer
Current Transformer	$15,000 per phase	1 year	138 kV wound stand-alone	78	$1,170,000.00	PEGuru - Current Transformer
Capacitor Bank	$75,000+ based on model and sizing	25 weeks	Pricing based on 69kV+	0	$0.00	PEGuru - Capacitor Bank
Inductor	$60,000+ depending on model and specs	20 weeks for MV, 30 weeks for HV and EHV	Pricing based on 34kV and 138 kV inductors	0	$0.00	PEGuru - Inductor
Surge Arrestor	$600 - $17,000 per phase	20 weeks	Pricing based on 69kV - 500kV range, price of 138kV+ includes cost of structual steel	0	$0.00	PEGuru - Surge Arrestor
Wave Trap	$12,000 - $30,000	20 weeks	Pricing based on 69kV - 345 kV	0	$0.00	PEGuru - Wave Trap
Insulator	$500 each	8 weeks	Price for 138 kV	0	$0.00	PEGuru - Insulator
Gas Insulated Switchgear	$500,000 - Single leg/bay of 138kV breaker & half sub $2,600 per ft - 345kV gas-insulated	1 year	$500,000 equipment does not include protective relays	0	$0.00	PEGuru - Gas Insulated Switchgear
				Estimated Total Cost of Equipment	$2,836,080.00	

Figure 25: Cost Estimate for Major Substation Equipment

3.4 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: This software was very beneficial in the creation of most of the diagrams and plans for the substation design. A challenge of this application was that only one person could work on the drawing at a time, making it time consuming and difficult for collaboration. However, there are many toolboxes that can be downloaded into the application to give the specific substation components, making it much easier to combine the pieces to create a full substation design. BlueBeam was used for the key plan, conduit plan, grounding plan, as well as the three lines. This is very applicable in the real world as Black & Veatch uses it daily in their own substation design projects.

ETAP: This software was very helpful in demonstrating how our design would react under specific circumstances. We only had access to this software on the computers in the senior design lab and could only have one person working on the project at a time. The tool helped us visualize how the substation and solar farm connected when completing the general layout for the simulation. The tool also gave us the ability to complete load flow and short circuit analysis studies. The load flow study allowed us to see the performance of the plant and the short circuit study allowed us to see the magnitude of the currents that flow during an electrical fault. Being able to conceptualize our project was the main advantage of this software. The main downsides of this software was the limited access to it with us only getting access to it about halfway through the semester, minimal amount of people being able to work on it at once, and having no experience in combination with little time to complete our desired studies.

3.5 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.

Our first substation configuration seen in figure 27, pursued a sectionalized bus layout due to its flexible operation, high reliability, and it being easier to isolate sections for maintenance and repair. It was for the same reasons that we had our feeders feed into two separated iron clad switchgears that are interconnected. However as time went on this layout and its extra emphasis on reliability was causing other parts of the project to become more complicated and time consuming, and we eventually decided that it was better to simplify this one-line so we may have more time to invest in additional aspects of the substation. Plus there were concerns on whether the additional reliability we gained from these extra components warranted the price of them.

Our second one line configuration is a single bus configuration (seen in appendix A4), which is essentially our fist configuration divided in half. During this transition period we salvaged as much of our work relating to bus calculations and relaying as possible. In our sectionalized configuration there were areas of buswork that would have had 3 zones of protection overlapping, when typically you'd want to only have 2 overlapping zones. So we investigated a device called the SEL-TMU which essentially would take readings from the CT, digitize it, and send it to multiple other relays so those relays wouldn't need to be physically connected to said CT, however we ran into problems with some secondary systems not having the correct type of port for the SEL-TMU. Luckily this problem wasn't one we needed to dwell on for too long as our new one line layout didn’t have these areas of triple overlap, and thus simplified the relaying portion greatly. Our old idea of having two separate iron-clad switch switchgears were replaced with 4 outdoor distribution circuit breakers from Siemens, all of which are able to be racked out which allows us to forgo having additional air disconnect switches on the lowside of the substation.

The key plan was a difficult aspect of the project because BlueBeam was a new tool to most of us and there were no clear standards that explained equipment placement. Equipment placing is typically based on client standards rather than an IEEE standard. Therefore, the equipment, based on the one line design, was placed randomly into the field. Upon further discussion with the client, we were given a table of typical distance values for each equipment piece. With this, however, it was decided to place the equipment to as close as constant value apart to simplify later calculations. For example, center line to centerline of the transformer, to the circuit breaker, to the switchgears are all whole values. This was done with the intent of standardizing the distance between the pieces of the grounding grid. If the fence was a whole number, then the grounding grid, which had to be made based on the fencing length and width, could also be standardized. The total fencing, however, had to change because an access road needed to be added around the outside of the substation but within the fence. We needed to ensure that a car could easily drive around the whole station, meaning there had to be a minimum of 15 feet on each side of the equipment. To accommodate this, four extra inches had to be added to the height and the length of the total station fence.

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. Additionally, all ETAP reports can be found in appendix A3.

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.

5.1 ETAP

To implement our project we used a software called ETAP to simulate our solar plant and substation. We then completed load flow and short circuit studies to ensure our design was acceptable. After obtaining access to the software, we began by building our solar farm and substation design. A nice feature on ETAP is that we can incorporate our actual solar panels (make and model) into our layout. Setting an array to the number of series and parallel combinations we verified our voltage drop calculations were correct. We confirmed the voltage going into one inverter was 1165 V in our ETAP design. We also found the current at one combiner box to be 235 (A) which corresponds to the same current value used in the voltage drop calculations. These were two numbers that we found that let us know our design and ETAP simulation were correct. After we had all 13 inverters and transformers incorporated into the solar design on ETAP, we began building our substation. As mentioned above, there are three feeders that connect our solar farm to our substation where each feeder has roughly ⅓ of the generated power. We have array's A-D fed into bus 1, array's E-H into bus 2, and array's I-M into bus 3. These buses are then fed into a large bus that connects the solar farm to the substation. Our substation design in ETAP is similar to the one-diagram provided in Appendix A3. We incorporated the current transformers, circuit breakers, relays, utility transformer, and set the load on the substation to 60 megawatts. The only difference between our ETAP and one-line design are the two added buses we placed on the low and high side of the utility transformer. We incorporated these two buses into our design to fault each bus during our short circuit study. The load of 60 megawatts was set to match the generated power in the solar plant. The following summarizes our load flow and short circuit studies.

Once we built the solar farm and substation in ETAP we were able to complete load flow and short circuit studies. A load flow study is able to determine the steady state performance of a system and see the changes on all of the equipment. It is able to determine any major problems and then determine how the network conditions change under different limits. The load flow analysis that we completed generated values that we could feel confident were correct values. We were able to confirm that the generation matched the demand which was our main goal of completing this study. A short circuit study is done to make sure that a system is properly protected. In our short circuit study we shorted the bus on the low side and the high side of the transformer and the low side main bus. The study tells us the short-circuit current during a line-ground fault on the low-side main bus of our substation is 7.3 (kA). This means our circuit breakers need to be rated to at least this value to verify that our system is completely protected. If the short circuit protection is too high on our protection equipment, during a fault condition the protection equipment will not trip, therefore there is nothing protecting the equipment resulting in conductors overheating and equipment being damaged. If the protection is set lower than the short circuit current, the protection may trip too often and damage equipment.

6 Closing Material

6.1 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 . 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.

6.2 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.

6.3 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 APPENDICES

Appendix A1 - Operations Manual

An operations manual does not apply to our project as our final product is only a design and not something that can be operated. For the step by step we took to create our solar array and substation designs, see the above sections. Particularly sections 3 Design and 5 Implementation.

Appendix A2 - Initial Versions of Design

For the figure below, as discussed in section 3.2.2.4 Voltage Drop, the combiner boxes were moved to be placed in the middle of the strings rather than at the end of the rows in order to keep the voltage drop within threshold.

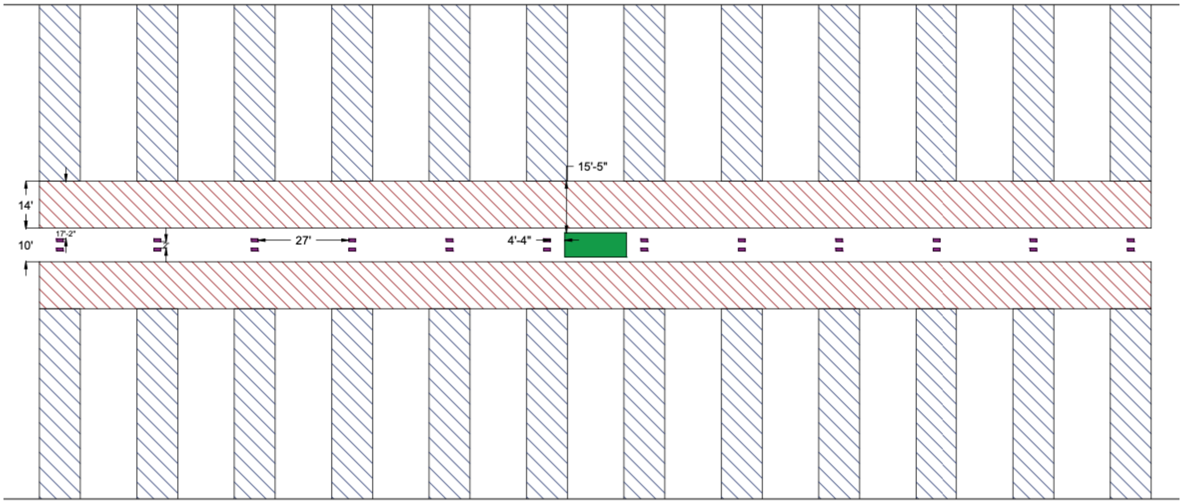


Figure 26: Original Placement of Combiner Boxes

The original design of our substation one-line was originally designed to have two power transformers to act as a redundancy in the event of maintenance or faults. After discussing this design with Black and Veatch for a period of time, it was determined to be too costly and have too many redundancies and we were advised to switch to a one transformer design.

The following one line is similar to our final one-line, but needed updates to the protection system within. The overall design is the same as our final, just with updates to locations of relays, current transformers, and circuit breakers.

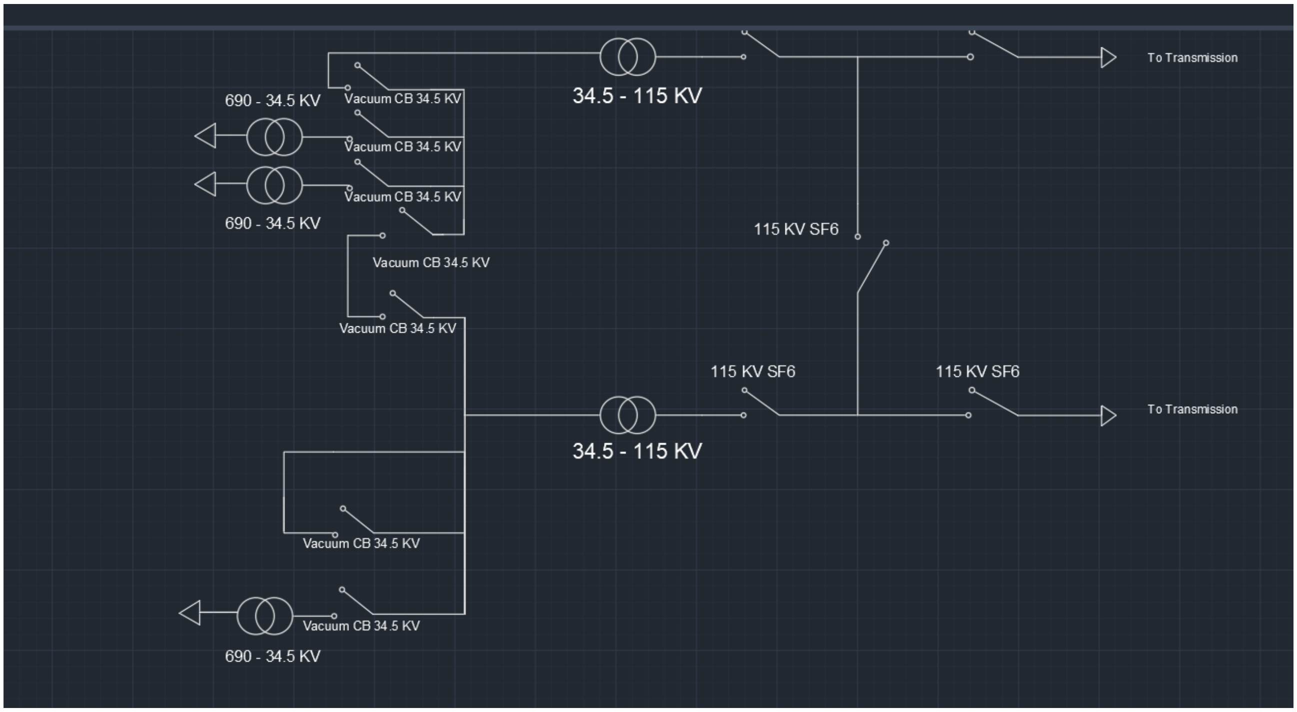


Figure 27: Initial One Line Diagram Before Change in Requirement

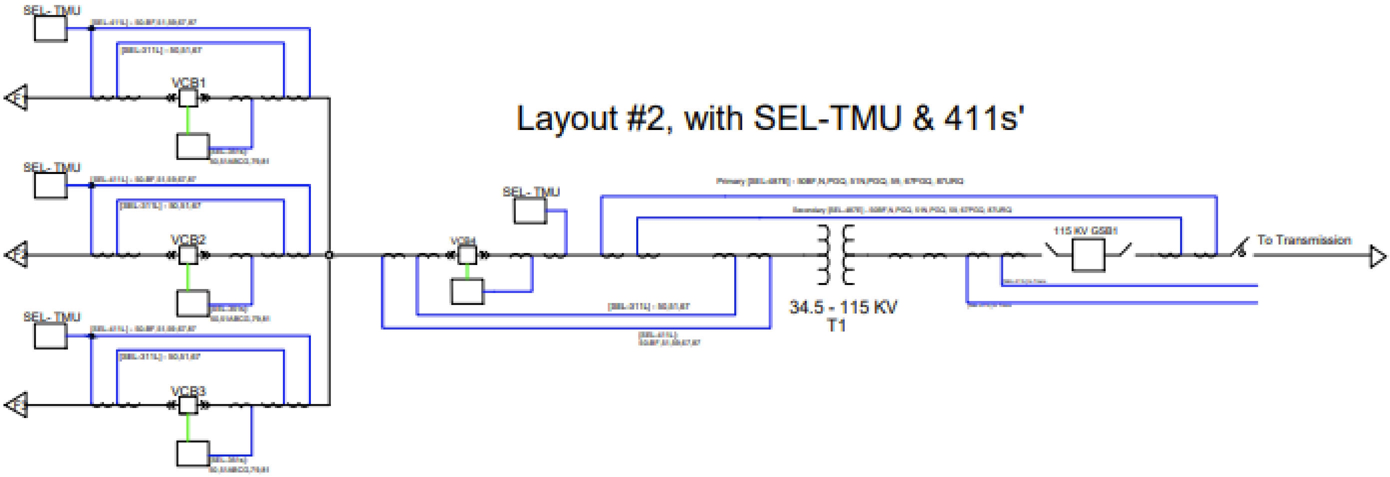
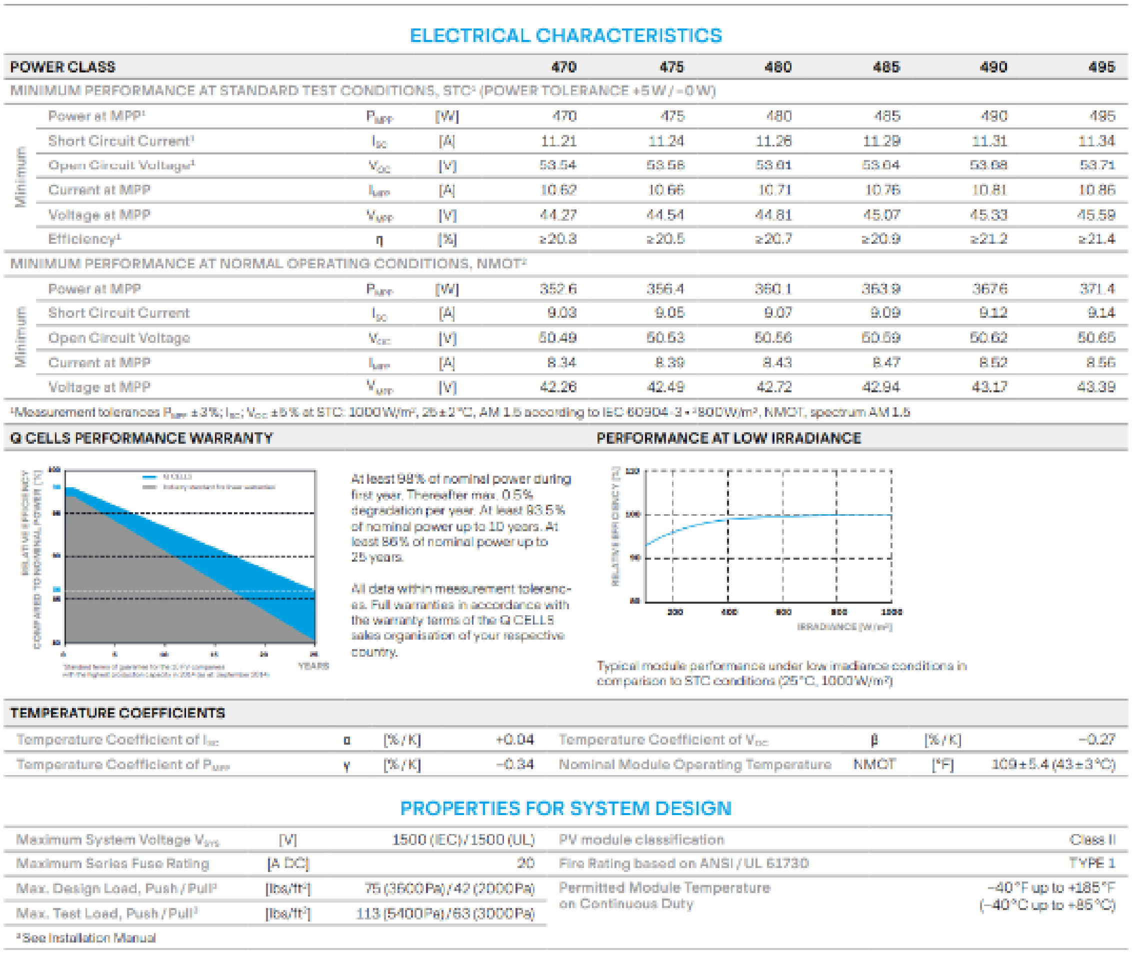


Figure 28: Initial One Line Diagram after Change in Requirements

Appendix A3 - Other Considerations



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

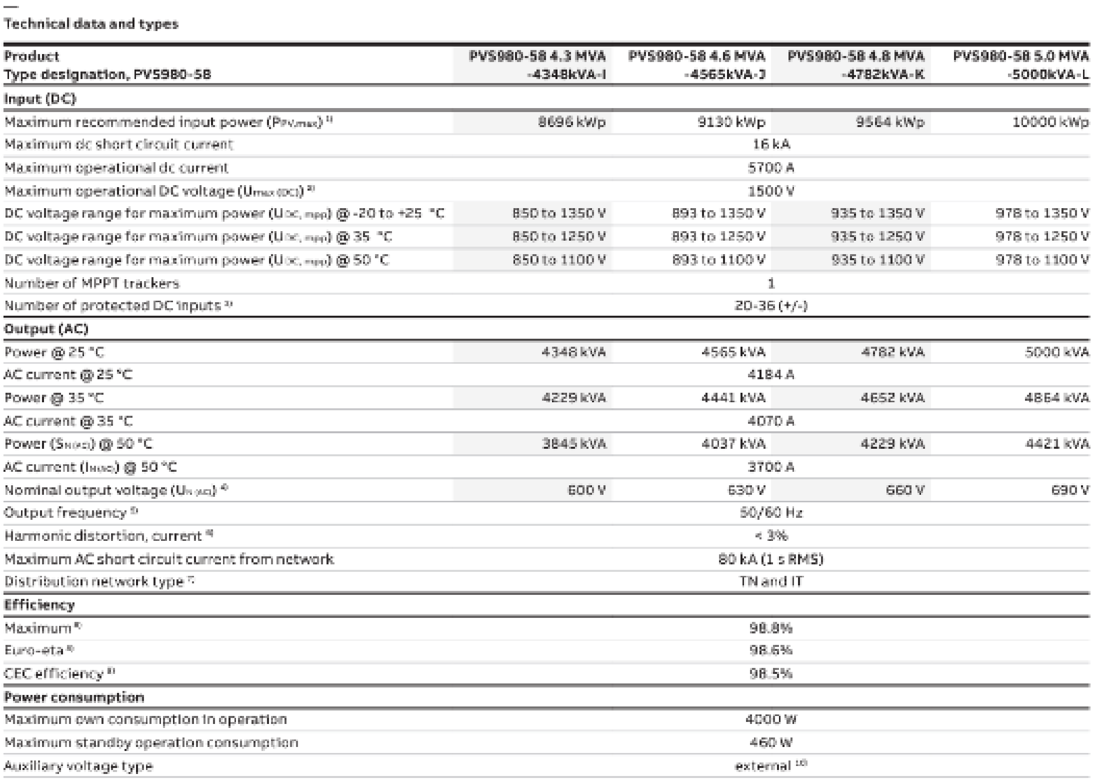
Temperature Coefficient of I_{SC}	α	[% / K]	+0.04	Temperature Coefficient of V_{OC}	β	[% / K]	−0.27
Temperature Coefficient of P_{MPP}	γ	[% / K]	−0.34	Nominal Module Operating Temperature	NMOT	[°F]	109±5.4 (43±3 °C)

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

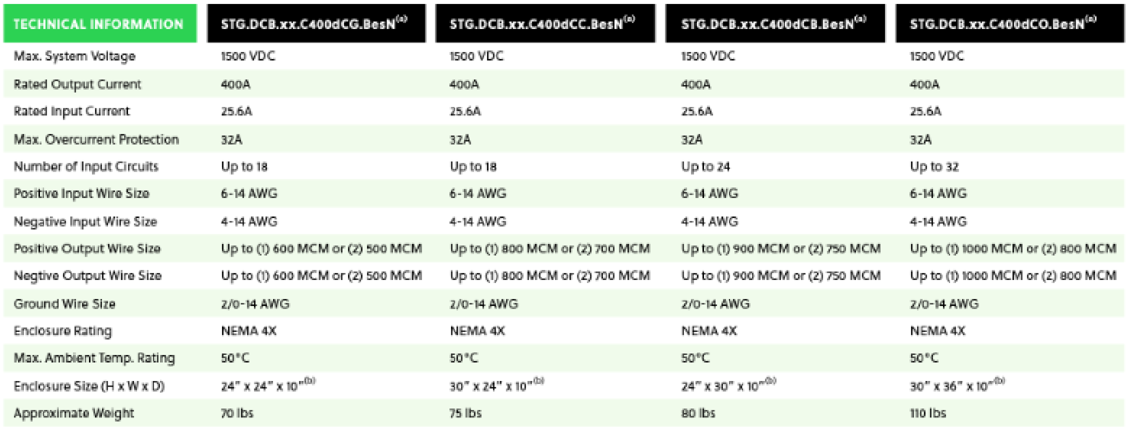
Figure 29: Solar Panel Datasheet



Technical data and types

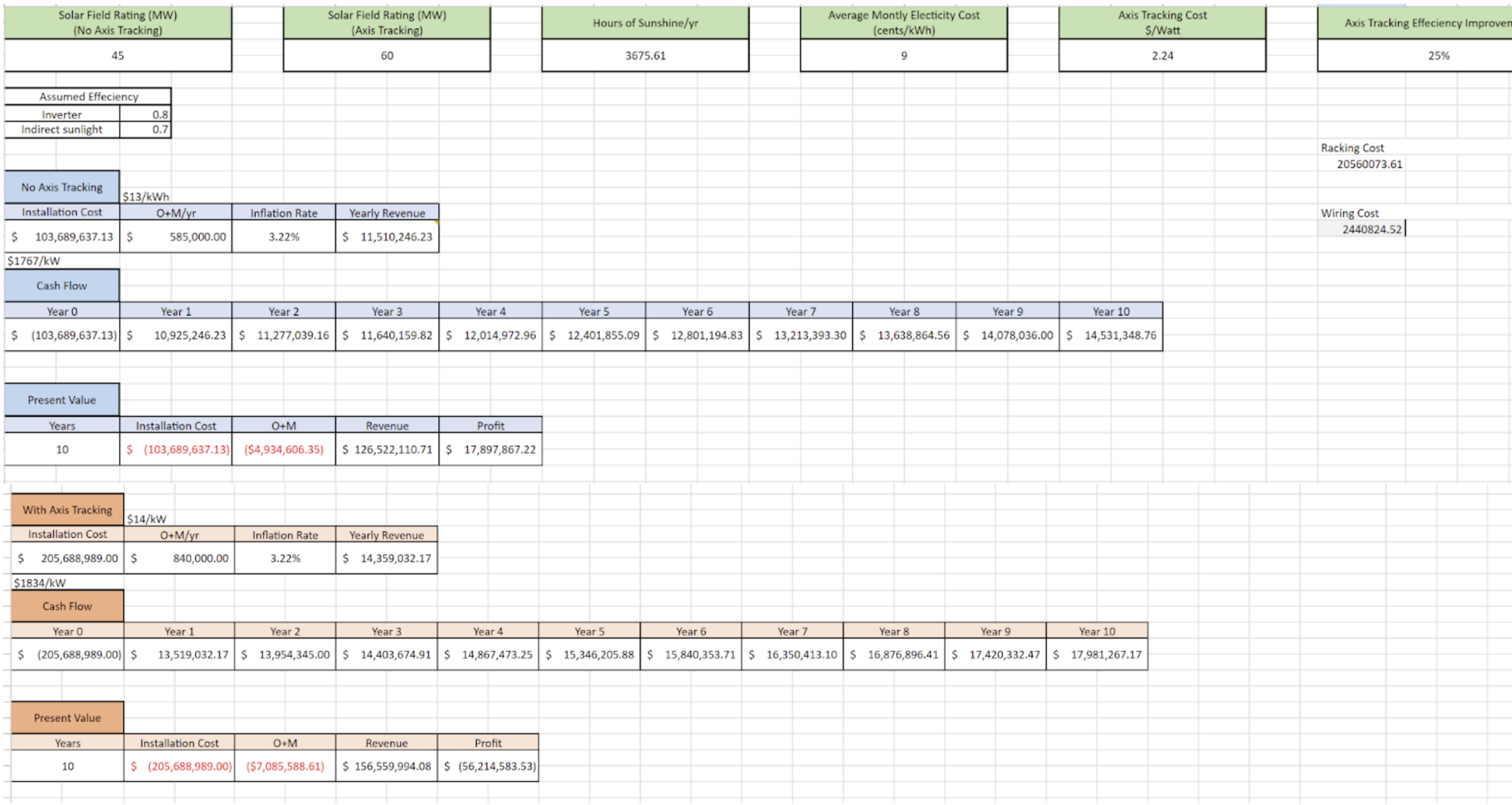
Product Type designation, PVS980-58	PVS980-58 4.3 MVA -4348kVA-I	PVS980-58 4.6 MVA -4565kVA-J	PVS980-58 4.8 MVA -4782kVA-K	PVS980-58 5.0 MVA -5000kVA-L
Input (DC)				
Maximum recommended input power ($P_{PV,max}$) 1)	8696 kWp	9130 kWp	9564 kWp	10000 kWp
Maximum dc short circuit current	16 kA			
Maximum 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)			

Figure 30: Inverter Datasheet



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

Figure 31: Combiner Box Datasheet



Solar Field Rating (MW) (No Axis Tracking)	Solar Field Rating (MW) (Axis Tracking)	Hours of Sunshine/yr	Average Montly Electicity Cost (cents/kWh)	Axis Tracking Cost $/Watt	Axis Tracking Effeciency Improvem
45	60	3675.61	9	2.24	25%

Assumed Effeciency	
Inverter	0.8
Indirect sunlight	0.7

Racking Cost
20560073.61

Wiring Cost
2440824.52

No Axis Tracking

$13/kWh

Installation Cost	O+M/yr	Inflation Rate	Yearly Revenue
$ 103,689,637.13	$ 585,000.00	3.22%	$ 11,510,246.23

$1767/kW

Cash Flow

Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
$ (103,689,637.13)	$ 10,925,246.23	$ 11,277,039.16	$ 11,640,159.82	$ 12,014,972.96	$ 12,401,855.09	$ 12,801,194.83	$ 13,213,393.30	$ 13,638,864.56	$ 14,078,036.00	$ 14,531,348.76

Present Value

Years	Installation Cost	O+M	Revenue	Profit
10	$ (103,689,637.13)	($4,934,606.35)	$ 126,522,110.71	$ 17,897,867.22

With Axis Tracking

$14/kW

Installation Cost	O+M/yr	Inflation Rate	Yearly Revenue
$ 205,688,989.00	$ 840,000.00	3.22%	$ 14,359,032.17

$1834/kW

Cash Flow

Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
$ (205,688,989.00)	$ 13,519,032.17	$ 13,954,345.00	$ 14,403,674.91	$ 14,867,473.25	$ 15,346,205.88	$ 15,840,353.71	$ 16,350,413.10	$ 16,876,896.41	$ 17,420,332.47	$ 17,981,267.17

Present Value

Years	Installation Cost	O+M	Revenue	Profit
10	$ (205,688,989.00)	($7,085,588.61)	$ 156,559,994.08	$ (56,214,583.53)

Figure 32: Solar Cost Analysis

PROJECT DESCRIPTION:

THIS GROUND-MOUNTED SOLAR PHOTOVOLTAIC (PV) SYSTEM, 80 MW (DC)/60 MW (AC), IS TO BE INSTALLED AT THE SPECIFIED LOCATION IN ROSWELL, NEW MEXICO.

SHEET INDEX

S NO.	SHEET NAME
PV-1	COVER PAGE
PV-2	KEY PLAN
PV-3	SOLAR PLANT
PV-4	DETAILED ARRAY
PV-5	COMPONENT LAYOUT
PV-6	RACKING DETAIL
E-1	ELECTRICAL LAYOUT #1: ARRAY (A)
E-2	ELECTRICAL LAYOUT #2: ARRAY (A)
E-3	ELECTRICAL LAYOUT #3: ARRAY (M)
E-4	ELECTRICAL CALCULATIONS

PHOTOVOLTAIC SYSTEM SUMMARY:

SYSTEM SIZE: DC STC: 80 MW
INVERTER AC OUTPUT: 60 MW
SOLAR MODULES: HANWHA 480W (166667 TOTAL)
MODEL #: Q.PEAK DUO XL G10.2
INVERTER: ABB 5.0 MVA (13 TOTAL)
MODEL #: PVS980-58 5.0 MVA-5000KVA-L
COMBINER BOX: SHOALS 1500V STANDARD COMBINER (292 TOTAL)
MODEL #: STG.DCB.18.C400DCG.BESN
MOUNTING SYSTEM: SNAPNRACK GROUND MOUNTED SYSTEM
MODEL #: 200 SERIES

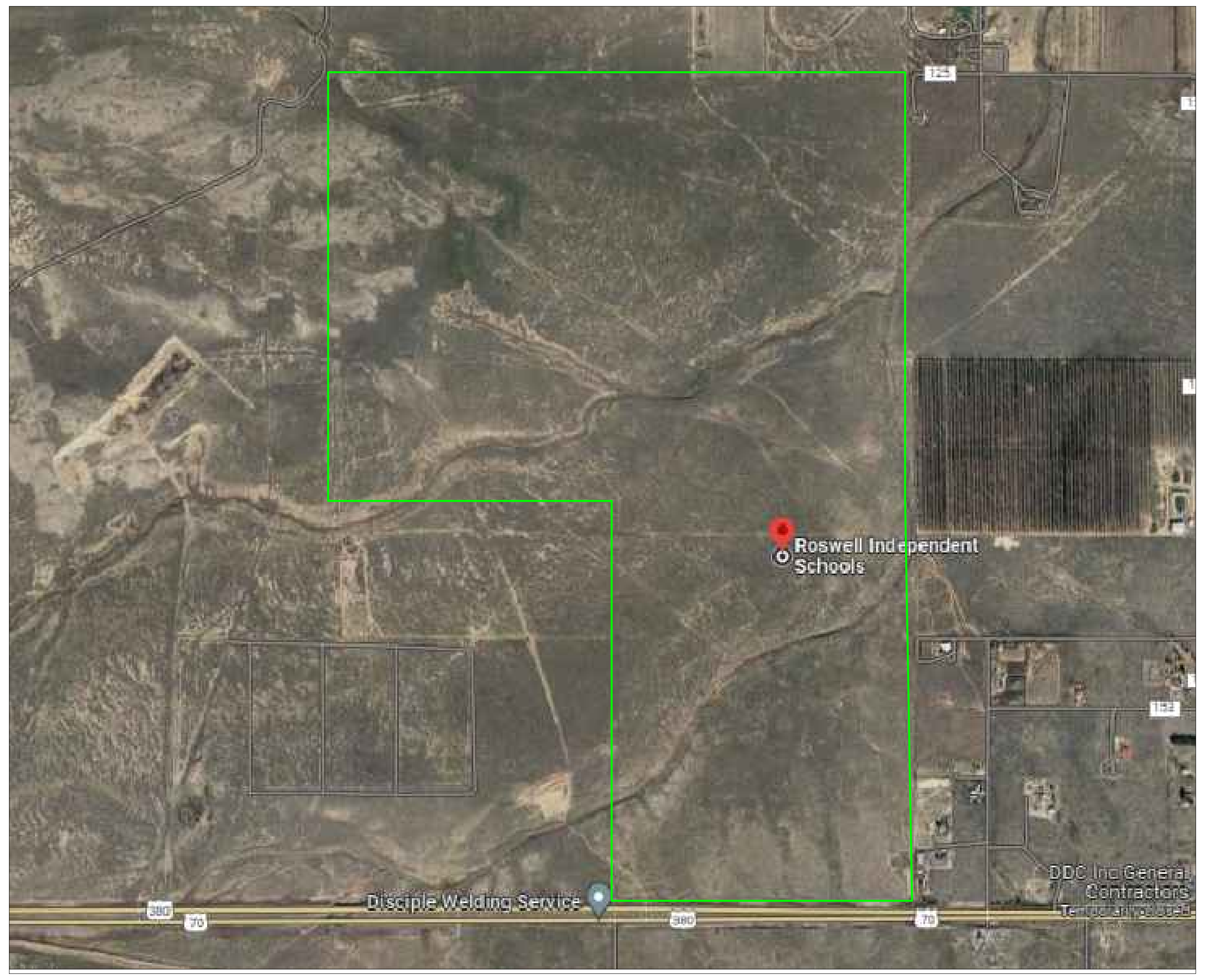
SOLAR PLANT NOTES:

1. SOLAR PLANT SHALL BE ACCESSIBLE ONLY TO AUTHORIZED PERSONNEL.
2. ALL ELECTRICAL CIRCUITS AND EQUIPMENT SHALL BE MAINTAINED AND OPERATED BY QUALIFIED PERSONNEL.
3. THE PV SYSTEM SHALL SAFELY AND EFFECTIVELY CONNECT WITH THE UTILITY SIDE THROUGH SWITCHGEAR, SUBSTATION, OR SWITCH YARD.
4. THE ELECTRICAL LOADS WITHIN THE PV ELECTRIC SUPPLY STATION SHALL ONLY BE USED TO POWER AUXILIARY EQUIPMENT FOR THE GENERATION OF THE PV POWER.
5. ALL EQUIPMENT SHALL BENEW AND LISTED BY RECOGNIZED ELECTRICAL TESTING LABORATORY.
6. ALL METALLIC EQUIPMENT SHALL BE GROUNDED.
7. THE ENGINEERED DESIGN REQUIRED BY NEC 691.6 SHALL DOCUMENT DISCONNECTION PROCEDURES AND MEANS OF ISOLATING EQUIPMENT.
8. DIRECT CURRENT OPERATING VOLTAGE CALCULATIONS SHALL BE INCLUDED IN THE DOCUMENTATION REQUIRED IN NEC 691.6.
9. ALL PHOTOVOLTAIC MODULES SHALL BE TESTED, LISTED, AND IDENTIFIED BY UL 1703.
10. ALL WORK SHALL BE IN ACCORD WITH THE 2020 NEC WITH EMPHASIS ON ARTICLE 691.

GOVERNING CODES:

2020 NFPA 70 (NATIONAL ELECTRICAL CODE)
2021 INTERNATIONAL FIRE CODE
2021 INTERNATIONAL BUILDING CODE
2021 INTERNATIONAL ELECTRICAL CODE
2021 INTERNATIONAL GREEN CODE
2021 MECHANICAL CODE
UL 1731
UL 1703
UL 61730
ALL OTHER ORDINANCES ADOPTED BY THE LOCAL GOVERNING AGENCIES

VICINITY MAP 1



AERIAL MAP 2

IOWA STATE UNIVERSITY
COLLEGE OF ENGINEERING

4100 MARSTON HALL,
533 MORRILL RD,
AMES, IOWA 50011

REVISIONS

DESCRIPTION	DATE	INIT.
DRAWING PLANS	10/19/2022	ZZ

SIGNATURE & SEAL:

PROJECT NAME & LOCATION:

BLACK & VEATCH

ROSWELL, NEW MEXICO
(CHAVES COUNTY)
PROPERTY ID: 10652755

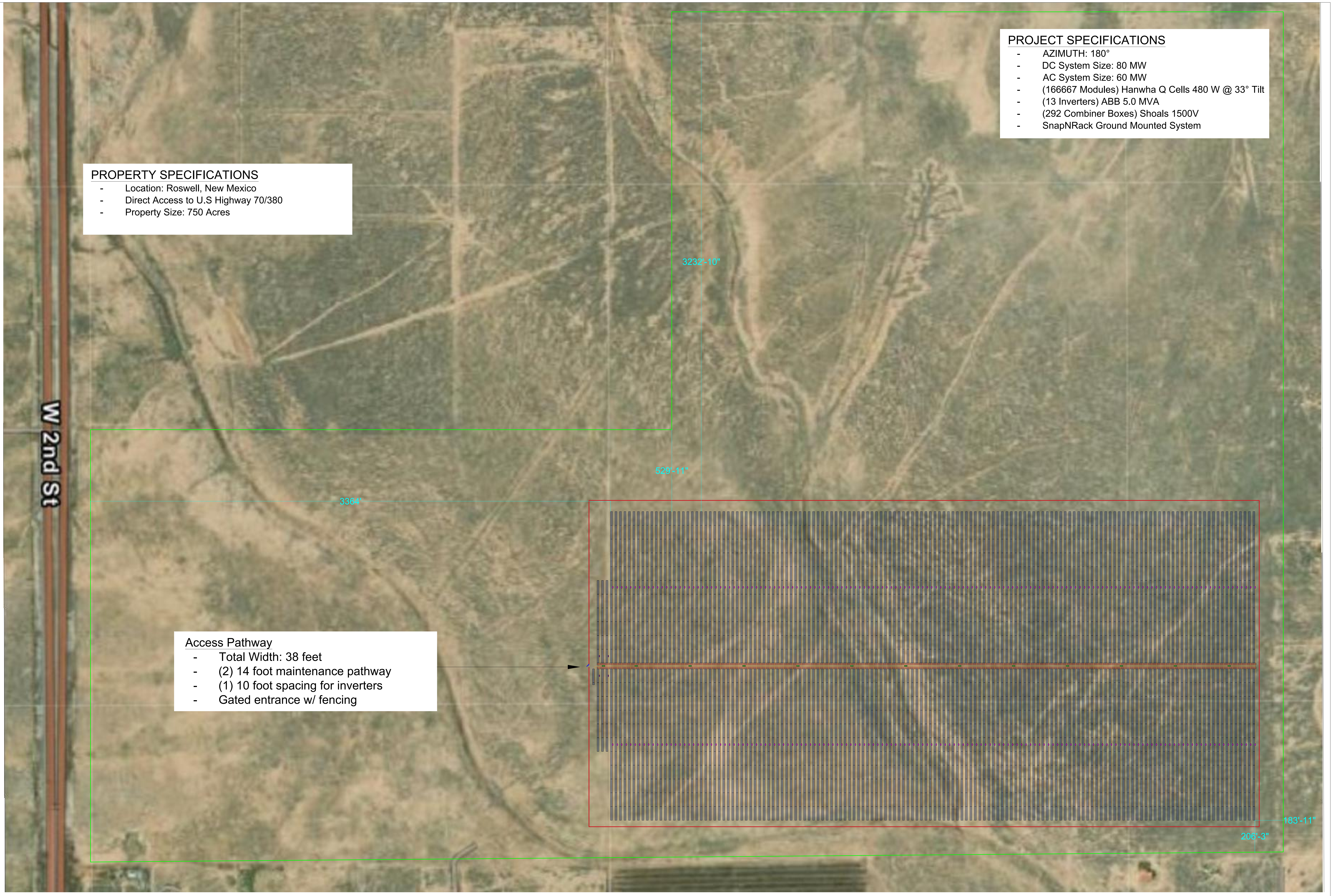
PROJECT TITLE:
60 MW SOLAR POWER PLANT

SHEET NAME:
COVER PAGE

SHEET SIZE:
36" x 24"

SHEET NUMBER:
PV-1

—	PROPERTY LINE
—	FENCE
—	GATE
—	CAB SYSTEM
🟩	SKID
🟪	COMBINER BOX
▨	SOLAR MODULE
▨	ACCESS PATHWAY



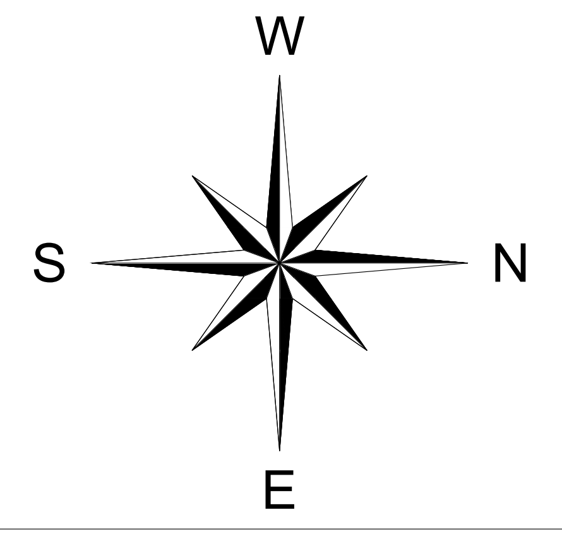
PROPERTY SPECIFICATIONS
- Location: Roswell, New Mexico
- Direct Access to U.S Highway 70/380
- Property Size: 750 Acres

PROJECT SPECIFICATIONS
- AZIMUTH: 180°
- DC System Size: 80 MW
- AC System Size: 60 MW
- (166667 Modules) Hanwha Q Cells 480 W @ 33° Tilt
- (13 Inverters) ABB 5.0 MVA
- (292 Combiner Boxes) Shoals 1500V
- SnapNRack Ground Mounted System

Access Pathway
- Total Width: 38 feet
- (2) 14 foot maintenance pathway
- (1) 10 foot spacing for inverters
- Gated entrance w/ fencing

1
PV-2

SOLAR PLANT KEY PLAN
NOT TO SCALE



IOWA STATE UNIVERSITY
COLLEGE OF ENGINEERING

4100 MARSTON HALL,
533 MORRILL RD,
AMES, IOWA 50011

REVISIONS

DESCRIPTION	DATE	INIT.
DRAWING PLANS	10/19/2022	ZZ

SIGNATURE & SEAL:

PROJECT NAME & LOCATION:

BLACK & VEATCH

ROSWELL, NEW MEXICO
(CHAVES COUNTY)
PROPERTY ID: 10652755

PROJECT TITLE:

60 MW SOLAR
POWER PLANT

SHEET NAME:

KEY PLAN

SHEET SIZE:

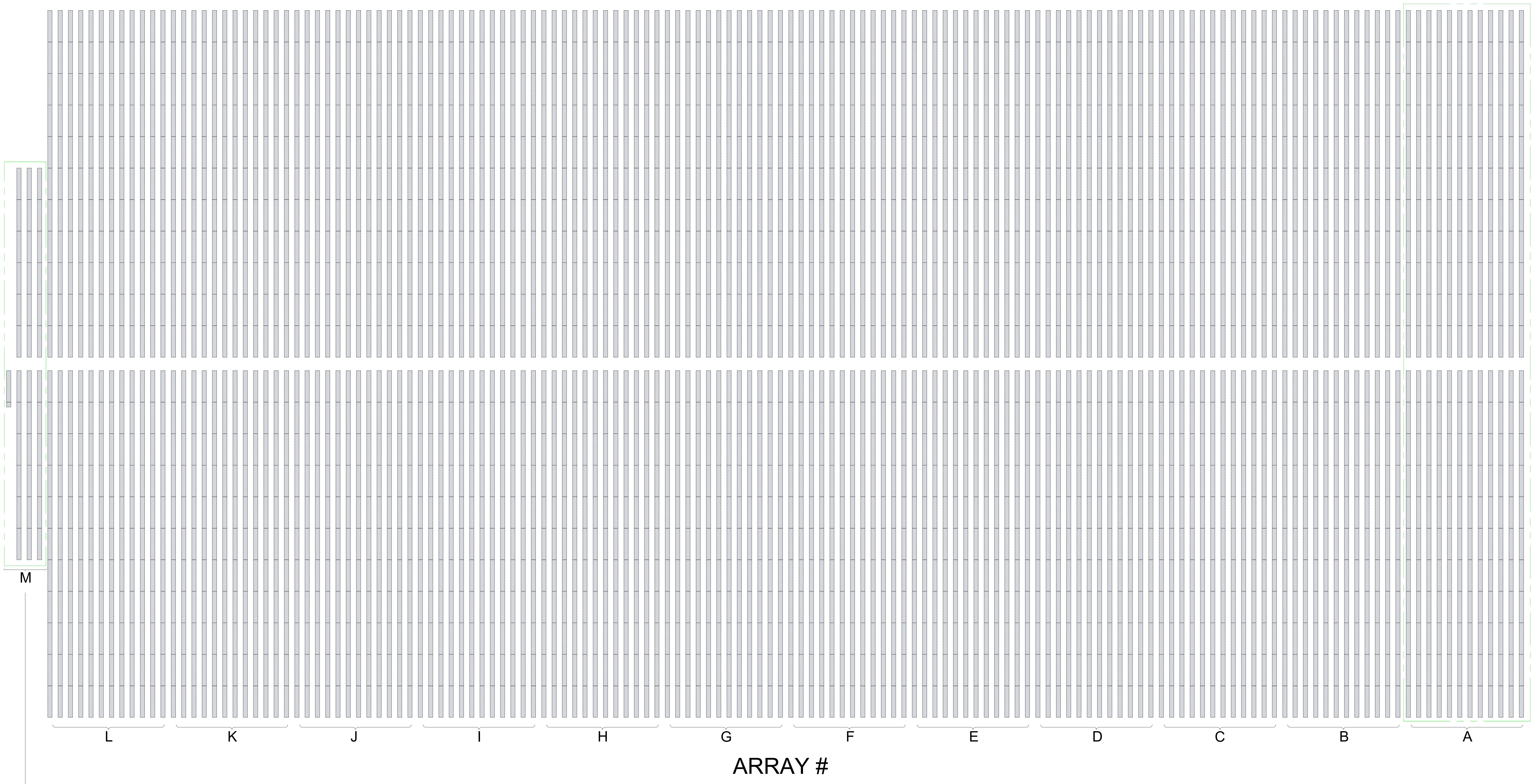
36" x 24"

SHEET NUMBER:

PV-2

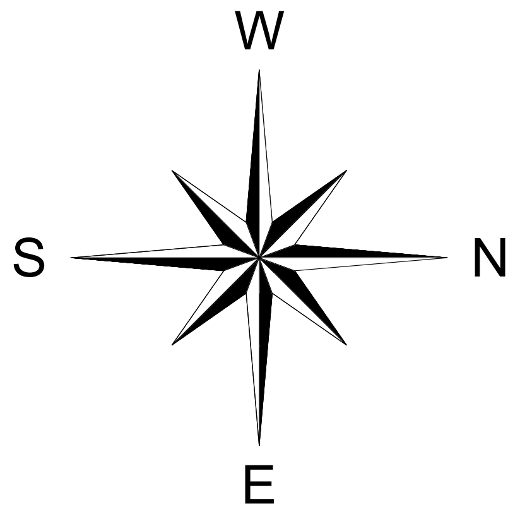
ARRAY (A - L) DIMENSIONS (TYP)

1
PV-3



2
PV-3

ARRAY (M) DIMENSIONS



1
PV-2

SOLAR PLANT ARRAY DESIGN
NOT TO SCALE

IOWA STATE UNIVERSITY
COLLEGE OF ENGINEERING

4100 MARSTON HALL,
533 MORRILL RD,
AMES, IOWA 50011

REVISIONS

DESCRIPTION	DATE	INIT.
DRAWING PLANS	10/19/2022	ZZ

SIGNATURE & SEAL:

PROJECT NAME & LOCATION:

BLACK & VEATCH
ROSWELL, NEW MEXICO
(CHAVES COUNTY)
PROPERTY ID: 10652755

PROJECT TITLE:

60 MW SOLAR
POWER PLANT

SHEET NAME:

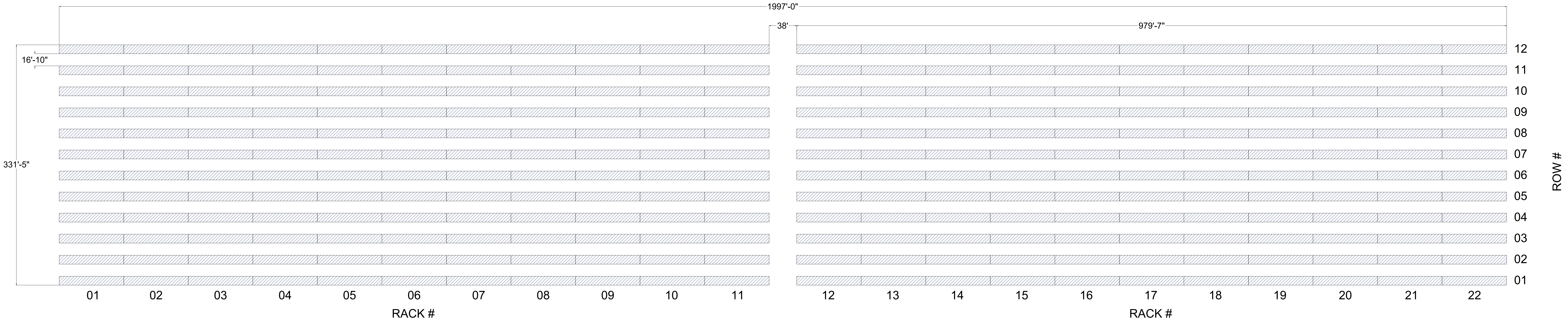
SOLAR PLANT

SHEET SIZE:

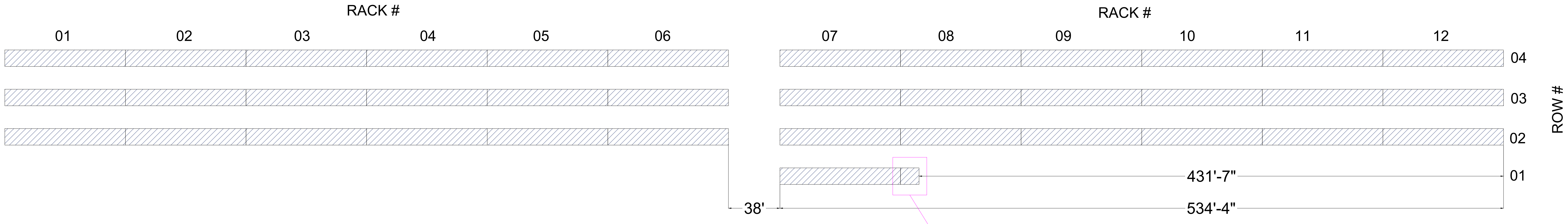
36" x 24"

SHEET NUMBER:

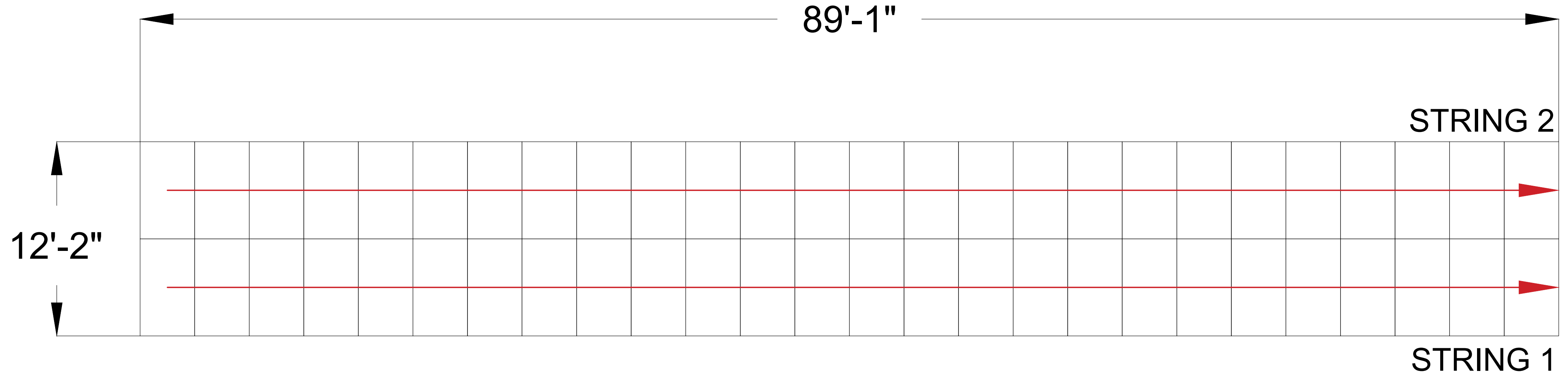
PV-2



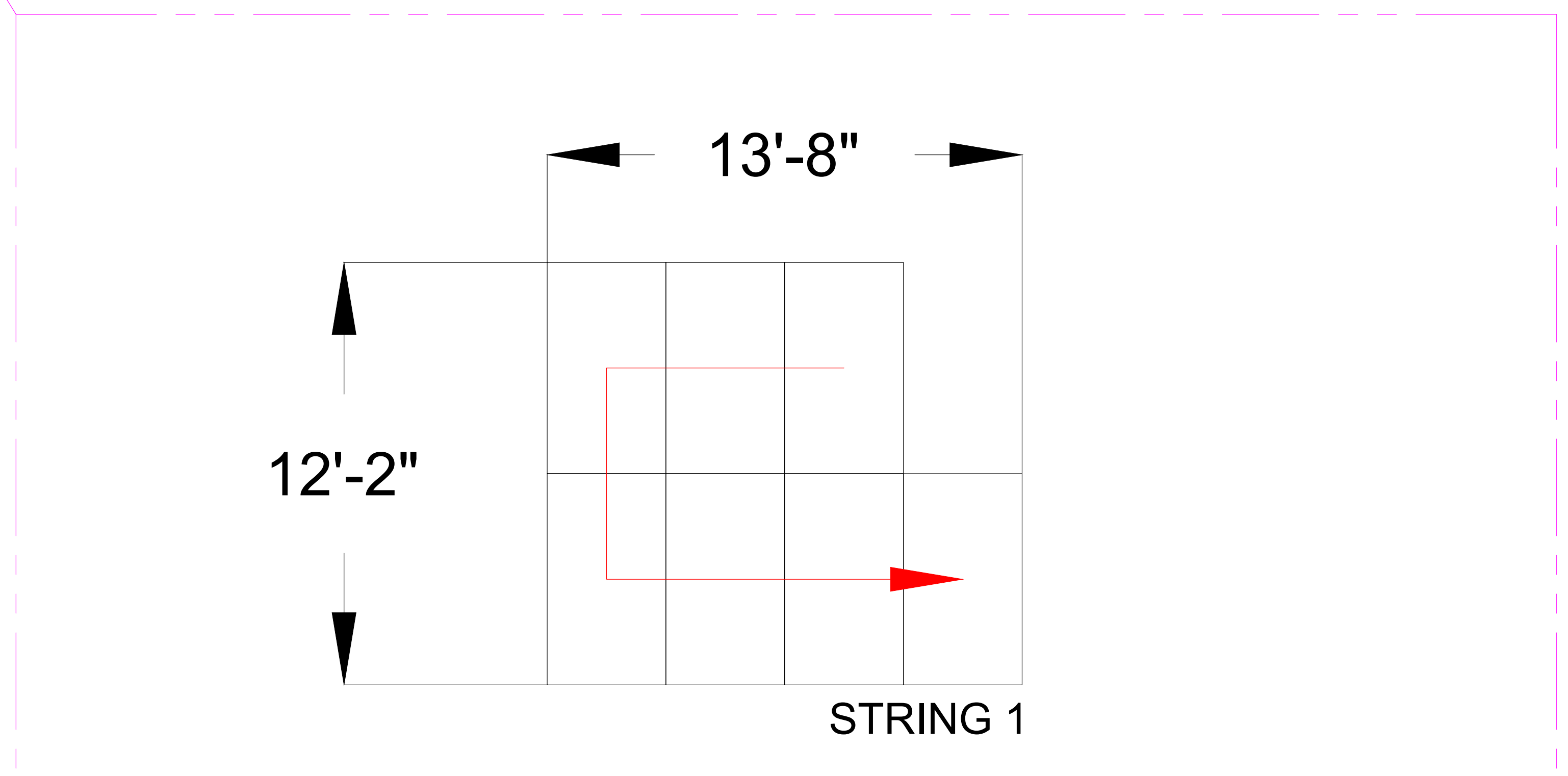
1 PV-3 ARRAY (A) DIMENSIONS (TYPICAL)
NOT TO SCALE



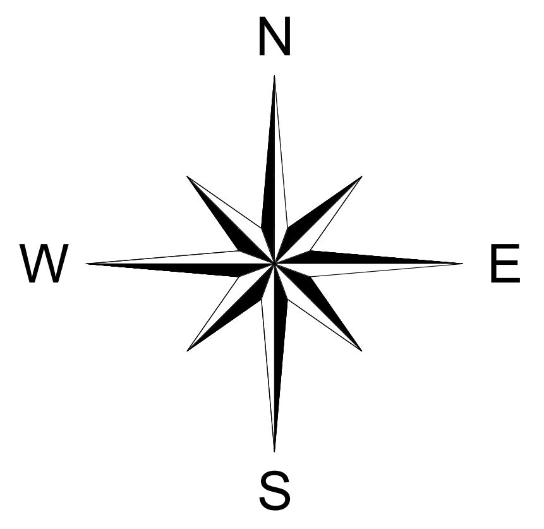
2 PV-3 ARRAY (M) DIMENSIONS
NOT TO SCALE



3 PV-3 RACK/STRINGING DETAIL (TYPICAL)
NOT TO SCALE



4 PV-3 RACK/STRINGING DETAIL
NOT TO SCALE



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ROSWELL, NEW MEXICO
(CHAVES COUNTY)
PROPERTY ID: 10652755

PROJECT TITLE:

60 MW SOLAR
POWER PLANT

SHEET NAME:

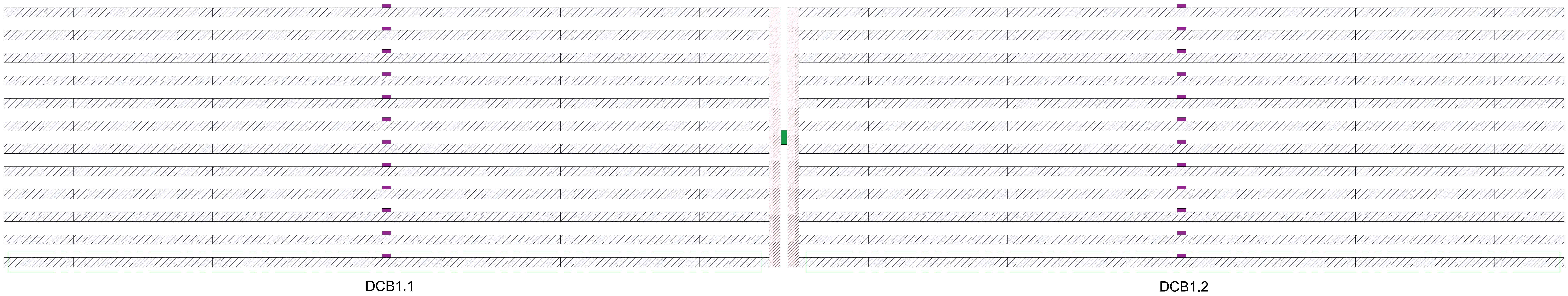
DETAILED ARRAY

SHEET SIZE:

36" x 24"

SHEET NUMBER:

PV-3

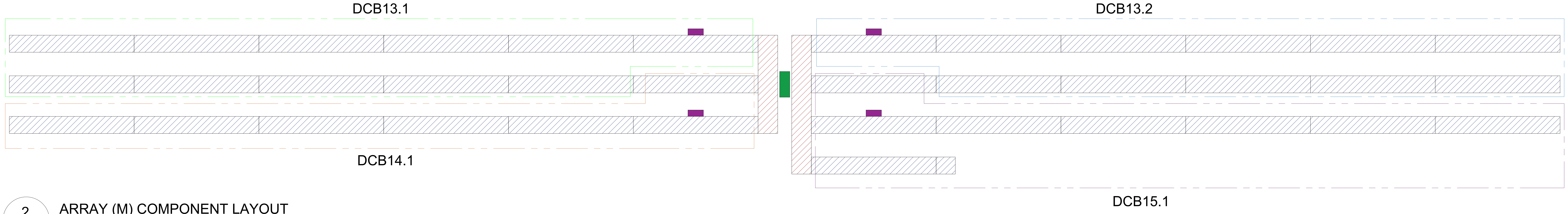


1
PV-4

ARRAY (A) COMPONENT LAYOUT (TYPICAL)
NOT TO SCALE

NOTE 1: ELECTRICAL DETAIL FOR ARRAY (A) IS SHOWN IN E-1 & E-2. EACH COMBINER BOX IS LABELED DCBX.X

NOTE 2: ELECTRICAL DETAIL FOR ARRAY (M) IS SHOWN IN E-3. EACH COMBINER BOX IS LABELED DCBX.X

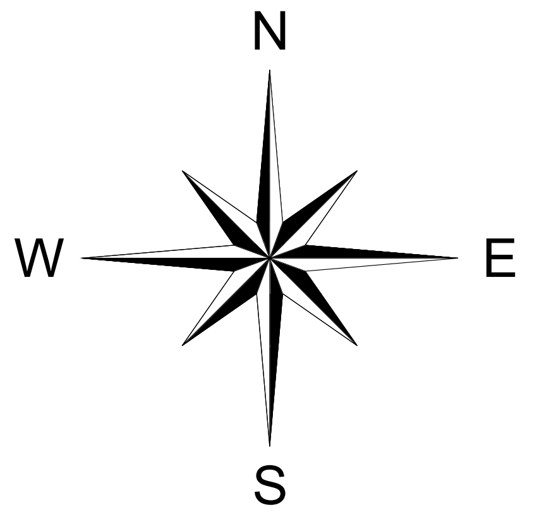


2
PV-4

ARRAY (M) COMPONENT LAYOUT
NOT TO SCALE

NOTE 3: CAB SYSTEM IS NOT SHOWN. REFER TO PAGE PV-2 FOR DETAILS.

▨ SOLAR MODULE
▨ ACCESS PATHWAY
🟩 SKID
🟪 COMBINER BOX



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REVISIONS

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DRAWING PLANS	10/19/2022	ZZ

SIGNATURE & SEAL:

PROJECT NAME & LOCATION:

BLACK & VEATCH
ROSWELL, NEW MEXICO
(CHAVES COUNTY)
PROPERTY ID: 10652755

PROJECT TITLE:

60 MW SOLAR
POWER PLANT

SHEET NAME:

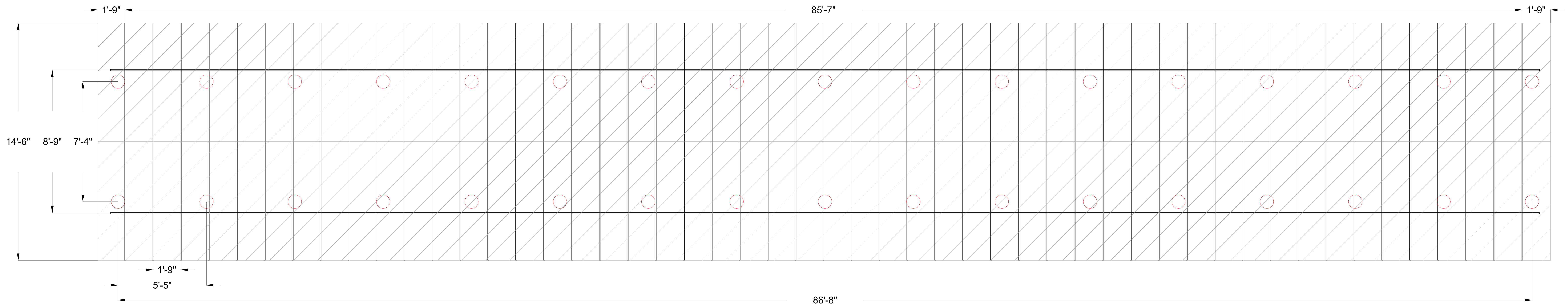
COMPONENT LAYOUT

SHEET SIZE:

36" x 24"

SHEET NUMBER:

PV-4

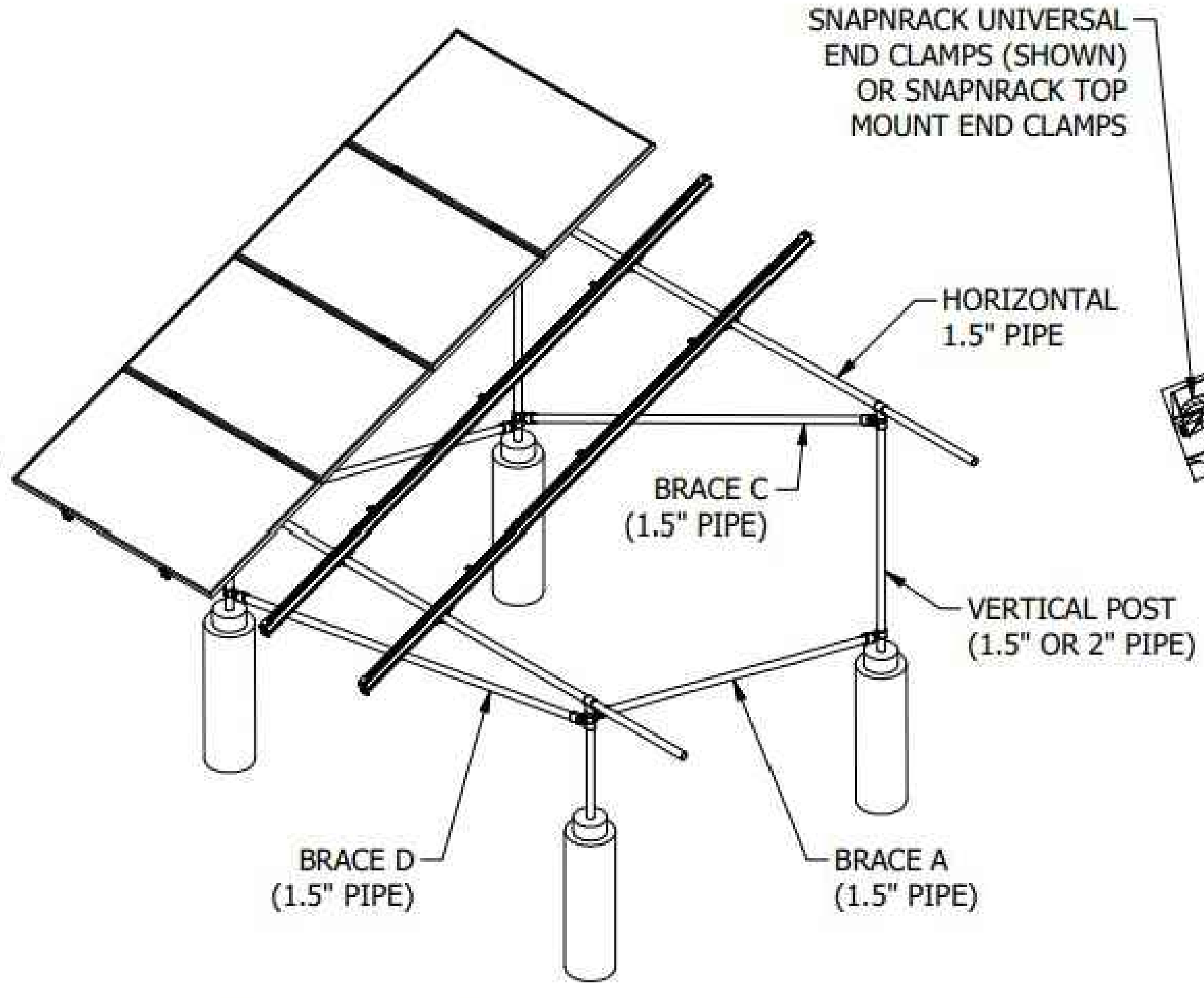


1 PV-5 RACK DETAIL: ATTACHMENT POINTS & COLUMNS

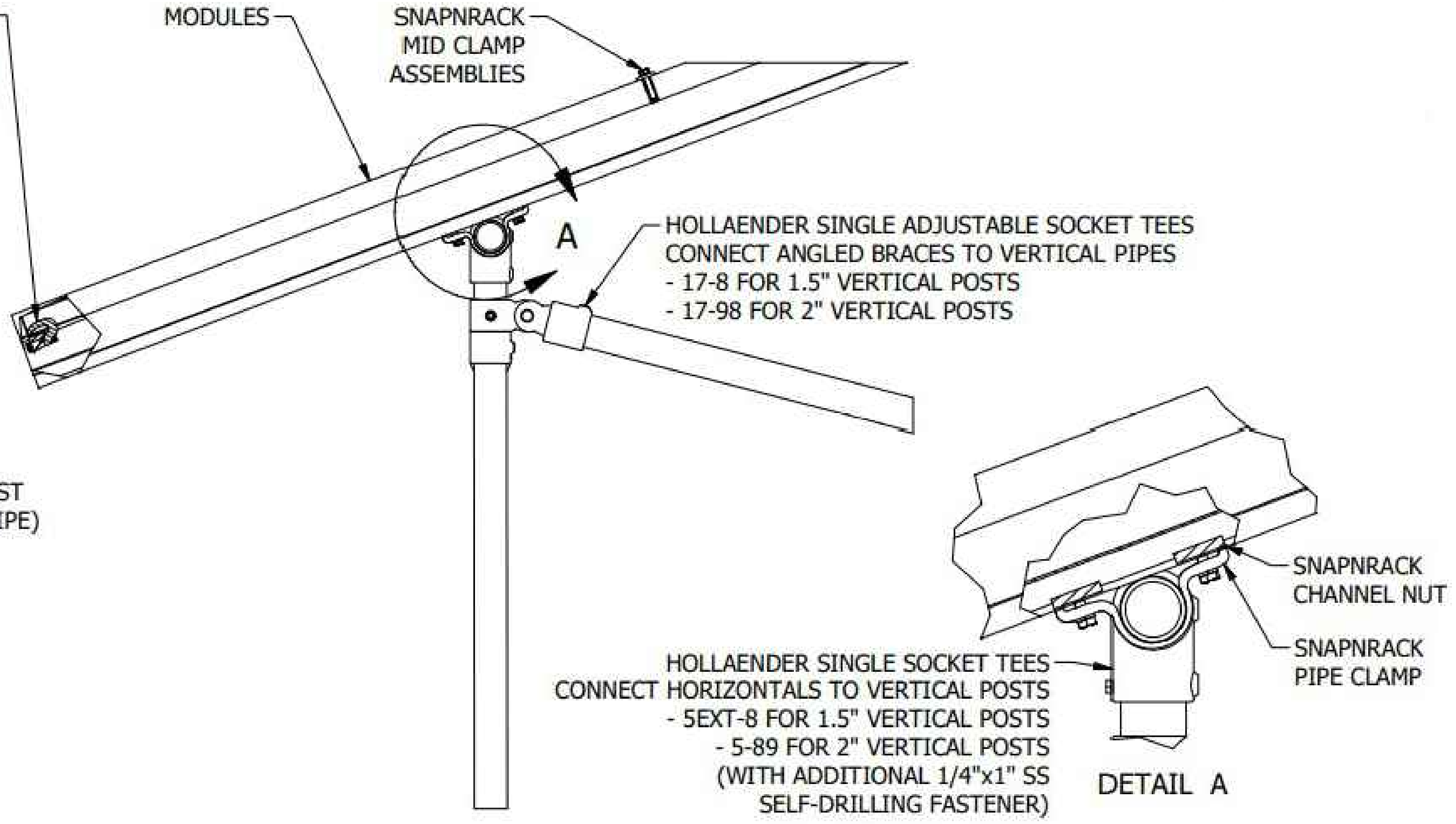
NOT TO SCALE

MAX RAIL LENGTH (RL) IS 214":
MAX RAIL SPAN (RS) = 144"
MAX RAIL OVERHANG (RO) = 35"

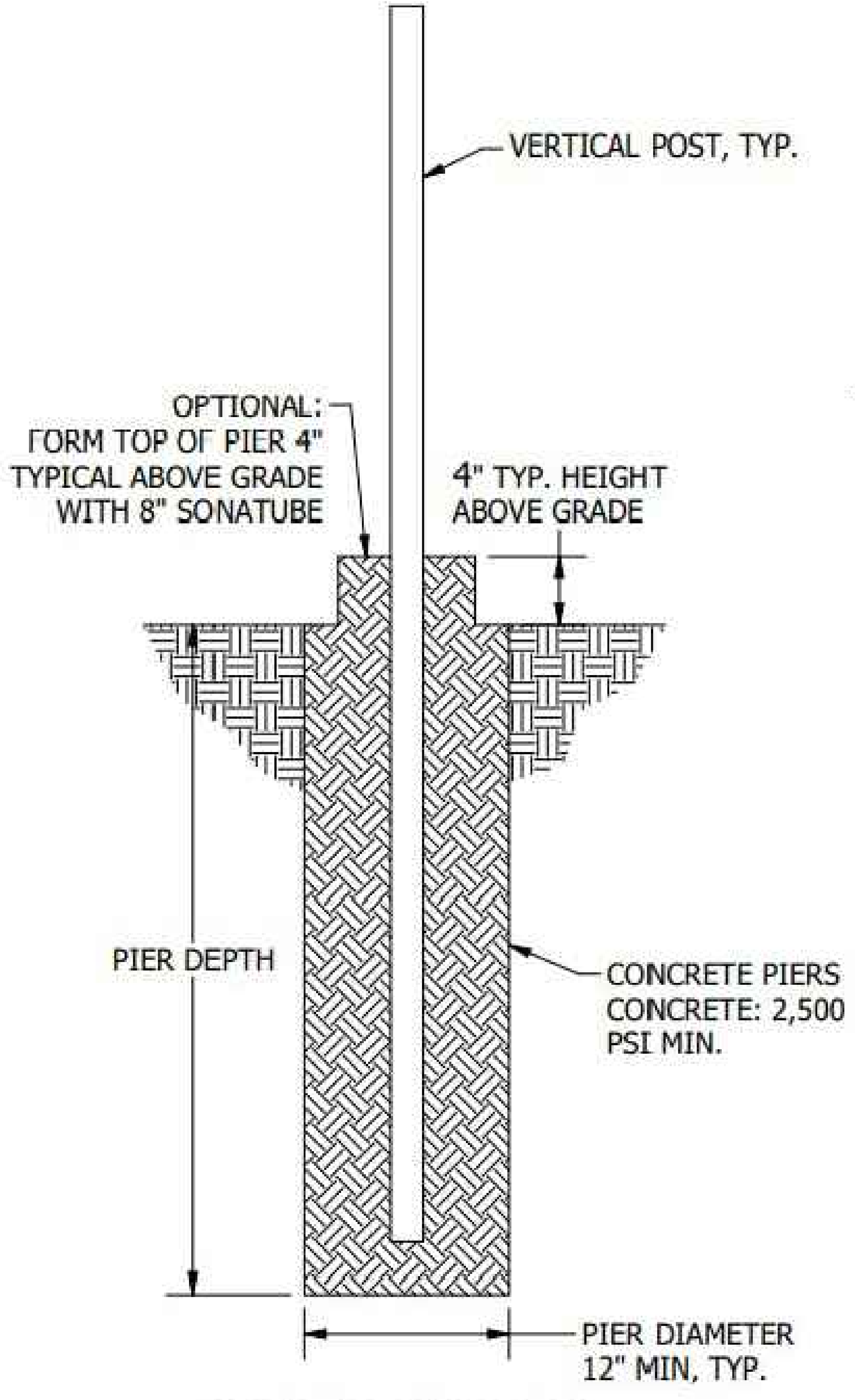
MAXIMUM MODULE WEIGHT IS
65 LBS



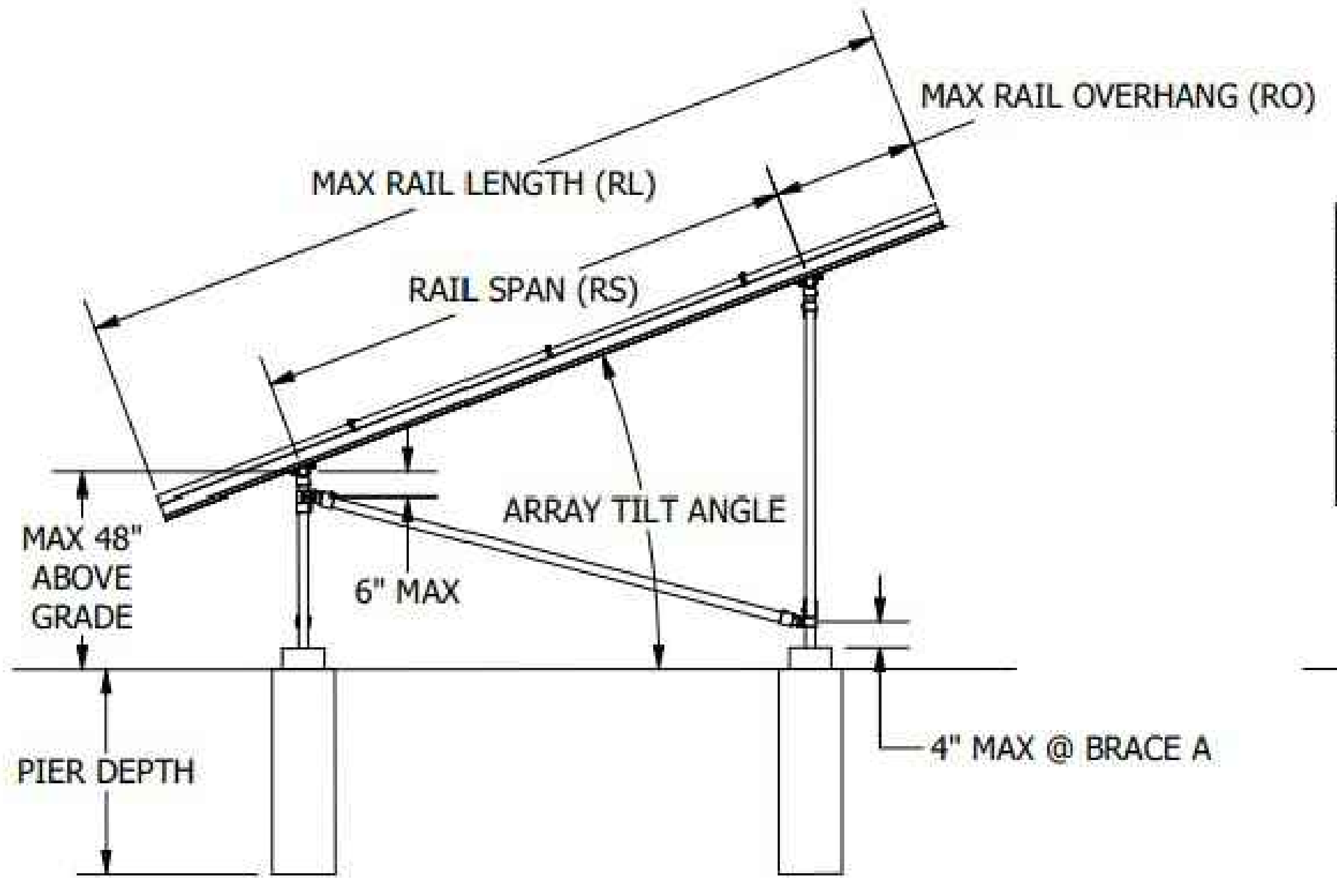
ISO VIEW OF RACKING ASSEMBLY



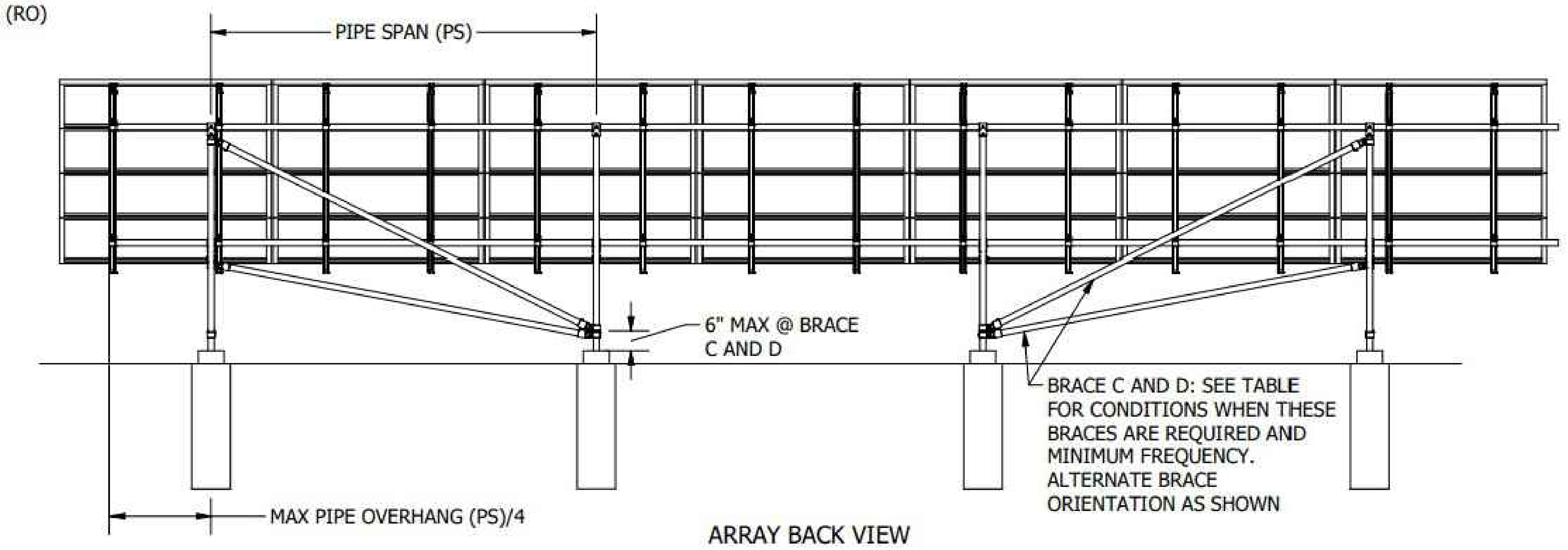
DETAILED VIEW OF PIPE TO RAIL AND BRACING INTERFACE



STANDARD PIER DETAIL



ARRAY SIDE VIEW



ARRAY BACK VIEW

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ROSWELL, NEW MEXICO
(CHAVES COUNTY)
PROPERTY ID: 10652755

PROJECT TITLE:

60 MW SOLAR
POWER PLANT

SHEET NAME:

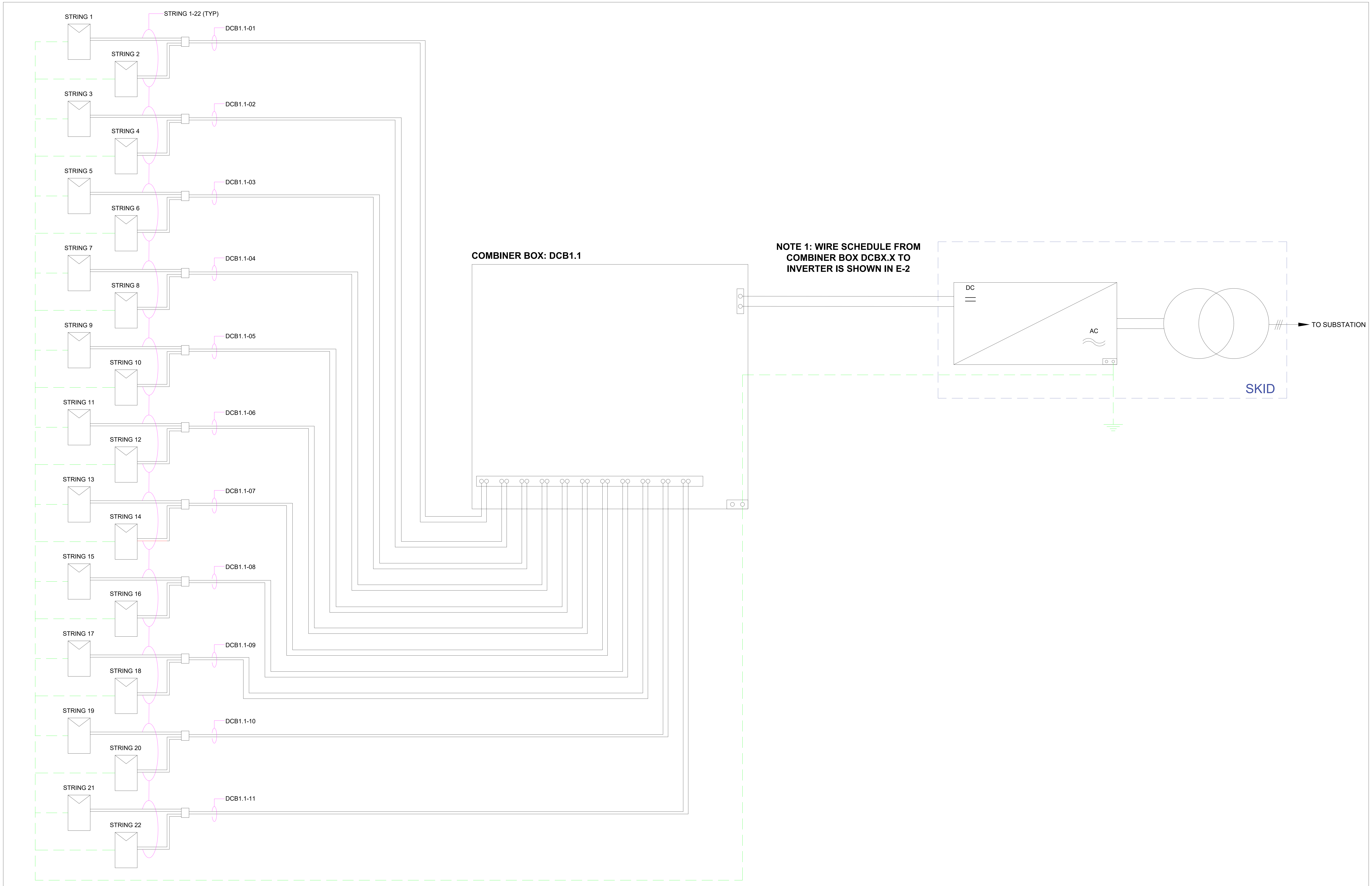
RACK DETAIL

SHEET SIZE:

36" x 24"

SHEET NUMBER:

PV-5



NOTE 1: WIRE SCHEDULE FROM COMBINER BOX DCBX.X TO INVERTER IS SHOWN IN E-2

1
E-1

ELECTRICAL LINE DIAGRAM: ARRAY (A) ROW 01.1 (TYPICAL)

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DRAWING PLANS	10/19/2022	ZZ

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PROJECT NAME & LOCATION:

BLACK & VEATCH

ROSWELL, NEW MEXICO
(CHAVES COUNTY)
PROPERTY ID: 10652755

PROJECT TITLE:

60 MW SOLAR
POWER PLANT

SHEET NAME:

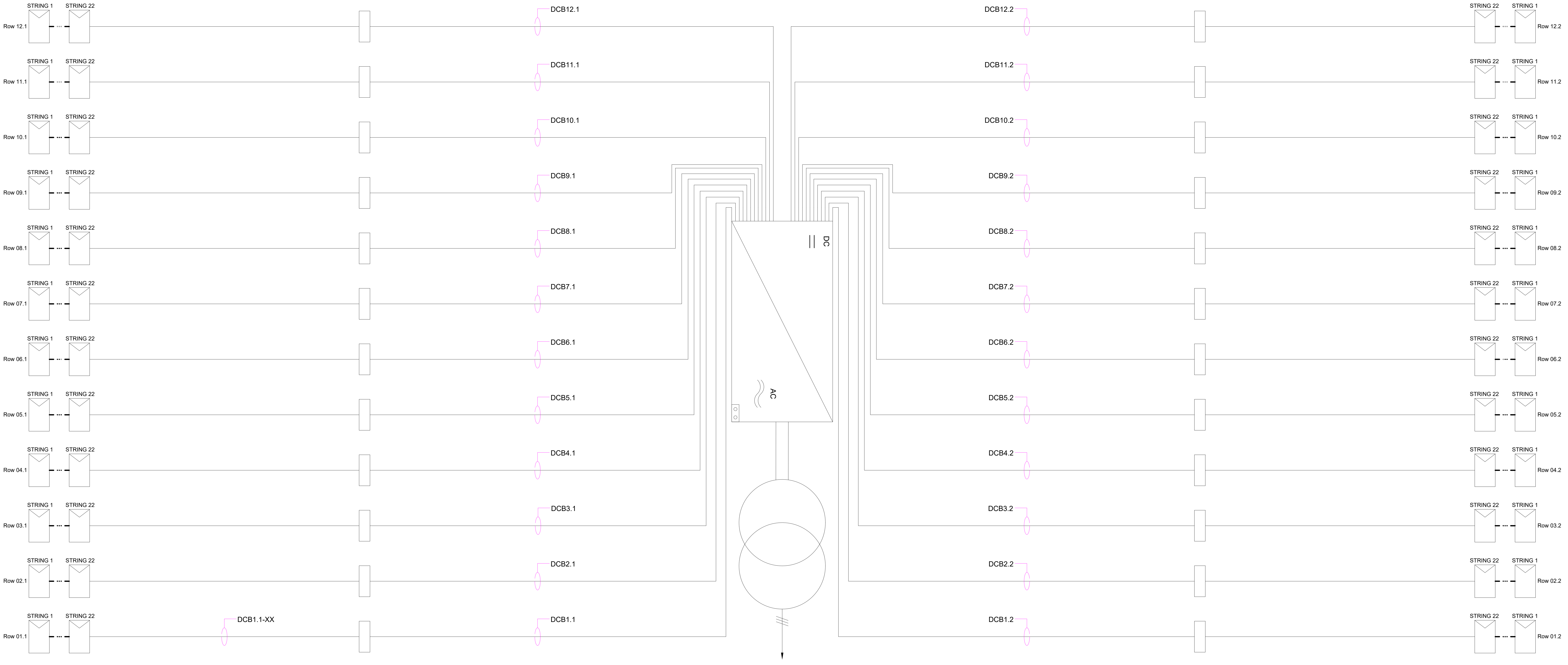
ELECTRICAL LAYOUT #1:
ARRAY (A)

SHEET SIZE:

36" x 24"

SHEET NUMBER:

E-1



NOTE 1: WIRE SCHEDULE FROM STRING TO DCB1.1-XX IS SHOWN IN E-1

1
E-2

ELECTRICAL LINE DIAGRAM: ARRAY (A) (TYPICAL)

NOT TO SCALE

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PROJECT NAME & LOCATION:

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ROSWELL, NEW MEXICO
(CHAVES COUNTY)
PROPERTY ID: 10652755

PROJECT TITLE:

60 MW SOLAR
POWER PLANT

SHEET NAME:

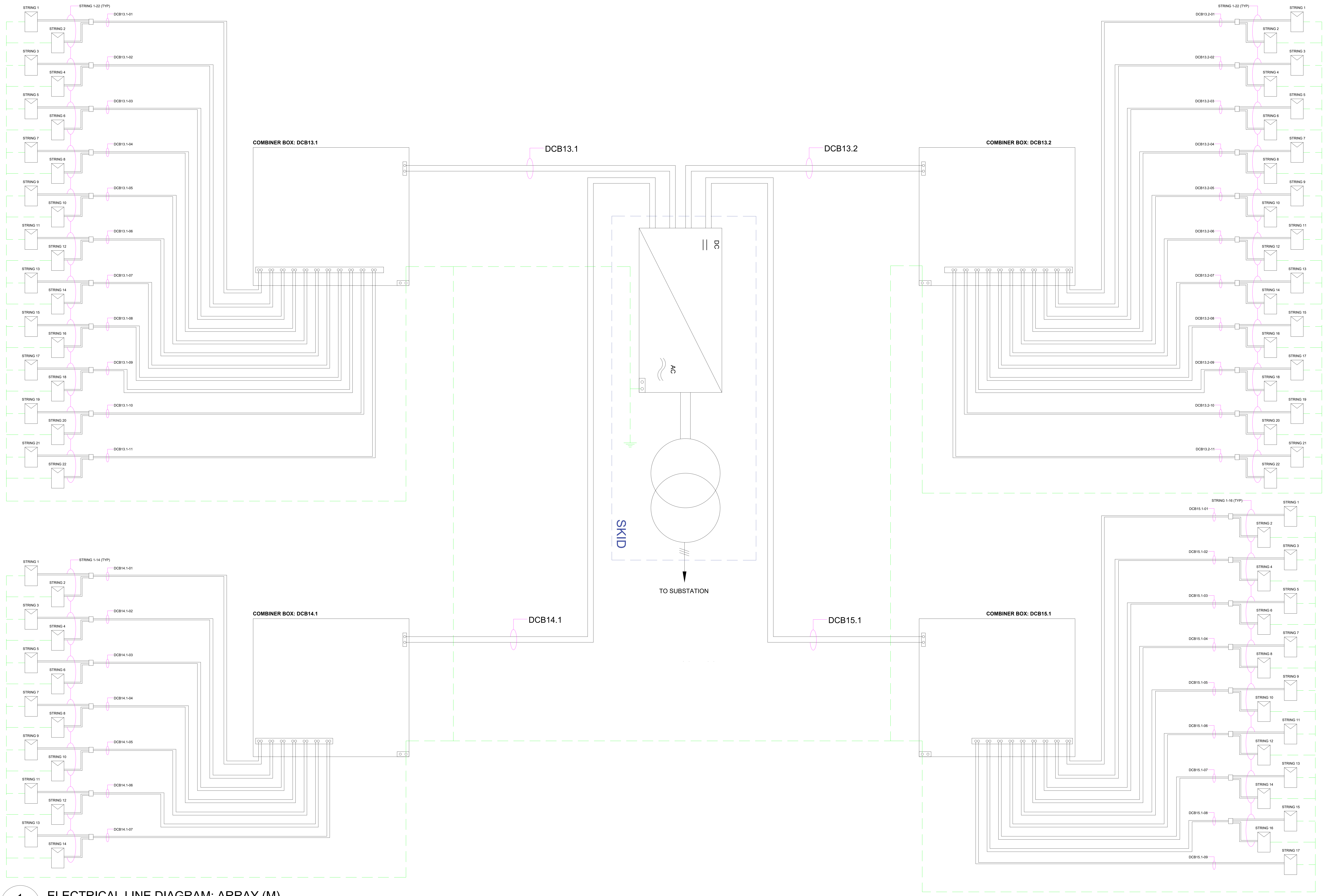
ELECTRICAL LAYOUT #2:
ARRAY (A)

SHEET SIZE:

36" x 24"

SHEET NUMBER:

E-2



1
E-3

ELECTRICAL LINE DIAGRAM: ARRAY (M)
NOT TO SCALE

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REVISIONS

DESCRIPTION	DATE	INIT.
DRAWING PLANS	10/19/2022	ZZ

SIGNATURE & SEAL:

PROJECT NAME & LOCATION:

BLACK & VEATCH

ROSWELL, NEW MEXICO
(CHAVES COUNTY)
PROPERTY ID: 10652755

PROJECT TITLE:

60 MW SOLAR
POWER PLANT

SHEET NAME:

ELECTRICAL LAYOUT #3:
ARRAY (M)

SHEET SIZE:

36" x 24"

SHEET NUMBER:

E-3

STRING SIZING CALC.

Min Temp.	-1.1100	°C
Voc	53.6100	V
Ref Temp.	25	°C
Temp. Coeff. of Voc	-0.0027	/°C
Temp. Delta	-26.1100	°C
Temp. Correction	1.0705	°C
Voc Corrected	57.3900	V
String Volt.	1500	V
String Size	26	

Voc Corrected = 53.61 + (53.61 * -26.11 * -0.0027)
String Size = 1500 / (Voc Corrected)

CB SIZING CALC.

mod/string Isc	11.260	A
NEC Multiplier	1.250	
nom Isc	14.075	A
NEC Multiplier	1.250	
Max Isc	17.594	A
Allowed Current	400.000	A
Strings per CB	22	
Racks per CB	11	

Stings per CB = (Allowed Current) / (Max Isc)

AMBIENT TEMPERATURE

Mean Low	-1.110	°C
Mean	16.380	°C
Mean High	34.300	°C

PV MODULE SPECIFICATIONS

Model Number	HANWHA QCELL Q.PEAK DUO XL G10.2 480W MODULES	
Weight	58.40	lbs
Dimensions	87.2 × 41.1 × 1.38	Inches
Power @ STC	480	Watts
Rated Voltage (Vmpp)	42.72	Volts
Rated Current (Impp)	8.43	Amps
Open-Circuit Voltage (Voc)	53.61	Volts
Short-Circuit Current (Isc)	11.26	Amps
Voc Temp. Coeff.	-0.0027	%/°C

INVERTER SPECIFICATIONS

Model Number	ABB 5.0 MVA PVS980-58 5.0 MVA-5000KVA-L	
Weight	6000	kg
Dimensions	5600 x 2200 x 1600	mm
Nominal AC Power	5000	kW
Nominal Output Voltage	690	Volts
Nominal Output Current	4184	Amps
Max DC Input Voltage	1500	Volts
Efficieny	98.8	%
Maximum Input Power	10000	kW
Maximum Output Power	5000	kW
Number DC Inputs	20-36	

COMBINER BOX SPECIFICATIONS

Model Number	SHOALS 1500V STG.DCB.18.C400DCG.BESN	
Weight	75	lbs
Dimensions	30 x 24 x 10	Inches
Maximum System Voltage	1500	Volts
Rated Output Current	400	Amps
Rated Input Current	25.60	Amps
Maximum OCPD	32	Amps
Maximum DC Inputs	18	

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

FEEDER VOLTAGE DROP CALCULATIONS: ARRAY A - L (TYP)

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	PERCENT	VOLT	VOLT	PERCENT
DCB1.1	11	235.400	641	600	0.035	0.044	10.653	0.91%	48.338	1165	4.15%
DCB1.2	11	235.400	641	600	0.035	0.044	10.653	0.91%	48.338	1165	4.15%
DCB2.1	11	235.400	612	600	0.035	0.042	10.171	0.87%	48.177	1165	4.14%
DCB2.2	11	235.400	612	600	0.035	0.042	10.171	0.87%	48.177	1165	4.14%
DCB3.1	11	235.400	583	600	0.035	0.040	9.689	0.83%	48.016	1165	4.12%
DCB3.2	11	235.400	583	600	0.035	0.040	9.689	0.83%	48.016	1165	4.12%
DCB4.1	11	235.400	553	600	0.035	0.038	9.190	0.79%	47.850	1165	4.11%
DCB4.2	11	235.400	553	600	0.035	0.038	9.190	0.79%	47.850	1165	4.11%
DCB5.1	11	235.400	524	600	0.035	0.036	8.708	0.75%	47.689	1165	4.09%
DCB5.2	11	235.400	524	600	0.035	0.036	8.708	0.75%	47.689	1165	4.09%
DCB6.1	11	235.400	494	600	0.035	0.034	8.210	0.70%	47.523	1165	4.08%
DCB6.2	11	235.400	494	600	0.035	0.034	8.210	0.70%	47.523	1165	4.08%
DCB7.1	11	235.400	494	600	0.035	0.034	8.210	0.70%	47.523	1165	4.08%
DCB7.2	11	235.400	494	600	0.035	0.034	8.210	0.70%	47.523	1165	4.08%
DCB8.1	11	235.400	524	600	0.035	0.036	8.708	0.75%	47.689	1165	4.09%
DCB8.2	11	235.400	524	600	0.035	0.036	8.708	0.75%	47.689	1165	4.09%
DCB9.1	11	235.400	553	600	0.035	0.038	9.190	0.79%	47.850	1165	4.11%
DCB9.2	11	235.400	553	600	0.035	0.038	9.190	0.79%	47.850	1165	4.11%
DCB10.1	11	235.400	583	600	0.035	0.040	9.689	0.83%	48.016	1165	4.12%
DCB10.2	11	235.400	583	600	0.035	0.040	9.689	0.83%	48.016	1165	4.12%
DCB11.1	11	235.400	612	600	0.035	0.042	10.171	0.87%	48.177	1165	4.14%
DCB11.2	11	235.400	612	600	0.035	0.042	10.171	0.87%	48.177	1165	4.14%
DCB12.1	11	235.400	641	600	0.035	0.044	10.653	0.91%	48.338	1165	4.15%
DCB12.2	11	235.400	641	600	0.035	0.044	10.653	0.91%	48.338	1165	4.15%

JUMPER VOLTAGE DROP CALCULATIONS: ARRAY M

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

FEEDER VOLTAGE DROP CALCULATIONS: ARRAY M

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	PERCENT	VOLT	VOLT	PERCENT
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%

1
E-4
ELECTRICAL CALCULATIONS
NOT TO SCALE

IOWA STATE UNIVERSITY
COLLEGE OF ENGINEERING

4100 MARSTON HALL,
533 MORRILL RD,
AMES, IOWA 50011

REVISIONS

DESCRIPTION	DATE	INIT.
DRAWING PLANS	10/19/2022	ZZ

SIGNATURE & SEAL:

PROJECT NAME & LOCATION:

BLACK & VEATCH
ROSWELL, NEW MEXICO
(CHAVES COUNTY)
PROPERTY ID: 10652755

PROJECT TITLE:

60 MW SOLAR
POWER PLANT

SHEET NAME:

CALCULATIONS

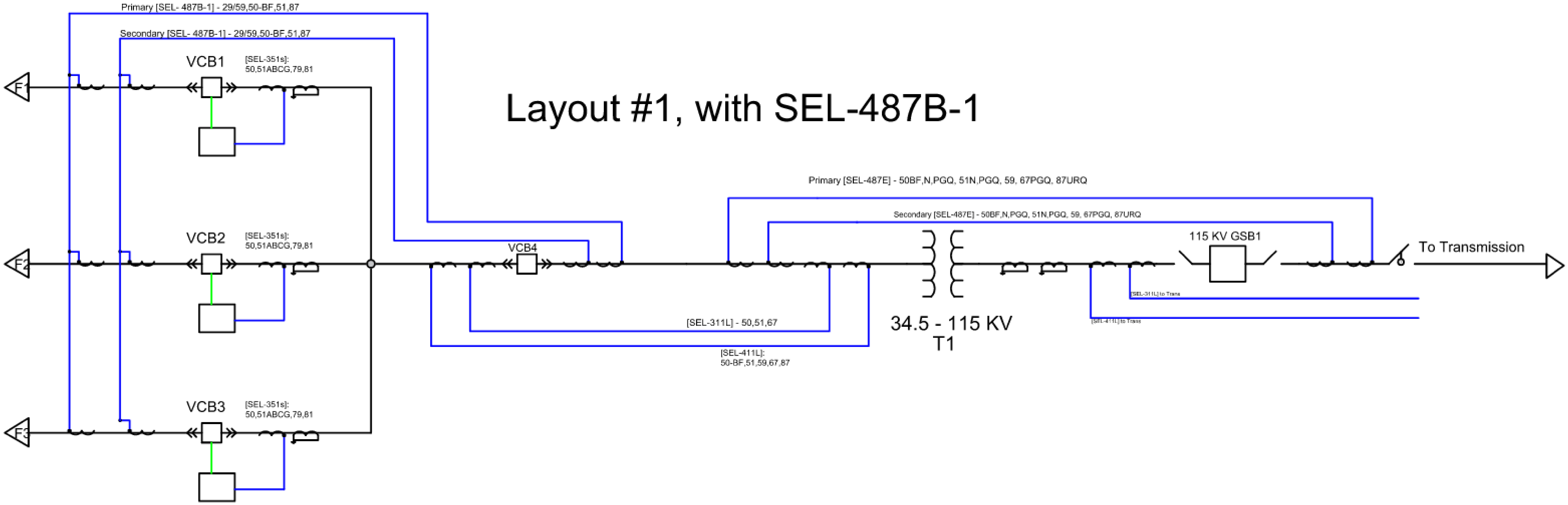
SHEET SIZE:

36" x 24"

SHEET NUMBER:

E-4

Layout #1, with SEL-487B-1



3	PROJ DESIGN	PROJ MANAGER	OTHERS
DATE			
		RFW/WO	
MADE BY	DATE	ACT	RELAY
CH'K BY	DATE	EP&PM	APVD FOR ISSUE

2	PROJ DESIGN	PROJ MANAGER	OTHERS
DATE			
		RFW/WO	
MADE BY	DATE	ACT	RELAY
CH'K BY	DATE	EP&PM	APVD FOR ISSUE

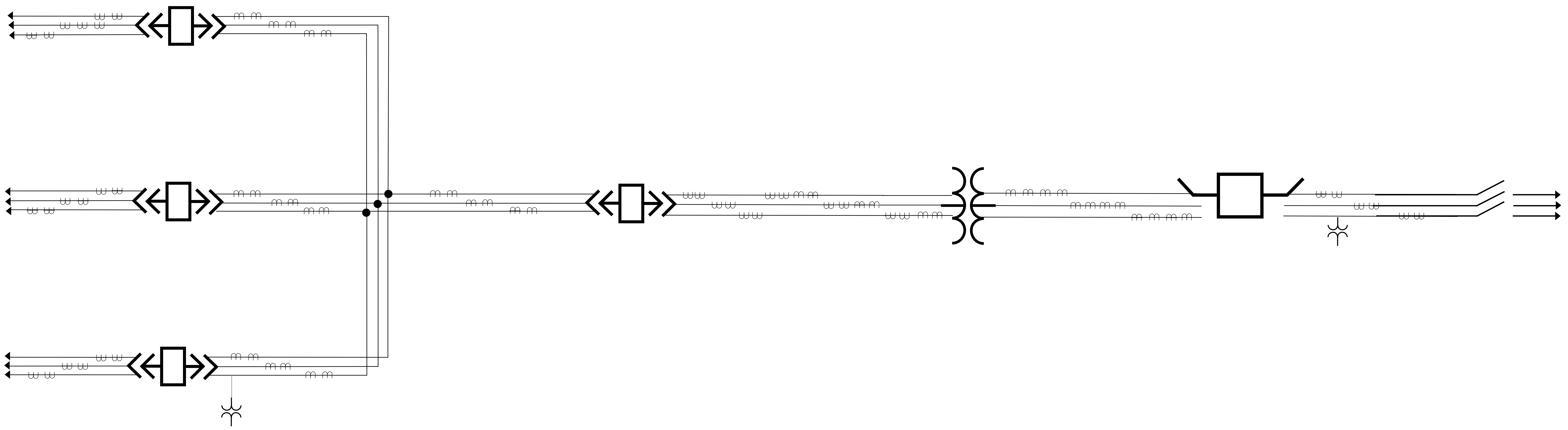
1	PROJ DESIGN	PROJ MANAGER	OTHERS
DATE			
		RFW/WO	
MADE BY	DATE	ACT	RELAY
CH'K BY	DATE	EP&PM	APVD FOR ISSUE

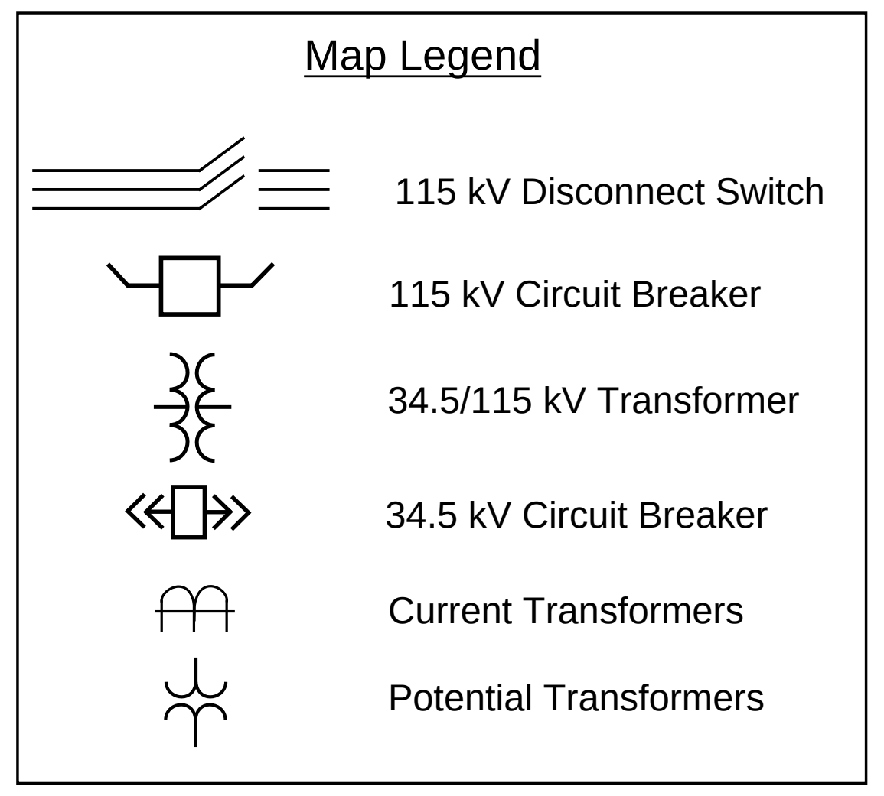
APPROVALS

OTHER		DATE	ENGINEERING	DATE
PROJECT MANAGER			MADE BY J.Miller	DATE 4/4/23
RELAY			LAYOUT BY	DATE
EP&PM			CHECKED BY	DATE
ACT			PROJECT DESIGN/ELECT	DATE
OTHERS			PROJECT DESIGN/ACT	DATE
			APPROVED FOR ISSUE	DATE

TITLE
One Line Drawing

LOCATION NAME
SERVICE CENTER
SCALE NONE
DRAWING NUMBER
REQUEST FOR WORK/WO
PROJECT DOCUMENT LIST





PANEL # BUS ##

3	PROJ DESIGN	PROJ MANAGER	OTHERS
DATE			

RFW/WO

MADE BY	DATE	ACT	RELAY
CH'K BY	DATE	EP&PM	APVD FOR ISSUE

2	PROJ DESIGN	PROJ MANAGER	OTHERS
	Madison Lakomek		
DATE	4/19/23		

-Deleted all CT connections that show relaying
-Added potential transformer to the key

RFW/WO

MADE BY	DATE	ACT	RELAY
ML	4/19		
CH'K BY	DATE	EP&PM	APVD FOR ISSUE

1	PROJ DESIGN	PROJ MANAGER	OTHERS
	Madison Lakomek		
DATE	4/18/23		

- Added additional buses to display all three phases of the system within the substation
-Connected the CTs to the corresponding CTs
-Added a key

RFW/WO

MADE BY	DATE	ACT	RELAY
ML	4/18		
CH'K BY	DATE	EP&PM	APVD FOR ISSUE

APPROVALS

OTHER		DATE
PROJECT MANAGER		
RELAY		
EP&PM		
ACT		
OTHERS		

ENGINEERING	
MADE BY	DATE
Madison Lakomek	4/18/23
LAYOUT BY	DATE
CHECKED BY	DATE
PROJECT DESIGN/ELECT	DATE
PROJECT DESIGN/ACT	DATE
APPROVED FOR ISSUE	DATE

TITLE

THREE LINE DIAGRAM

LOCATION NAME Roswell Solar Field Substation

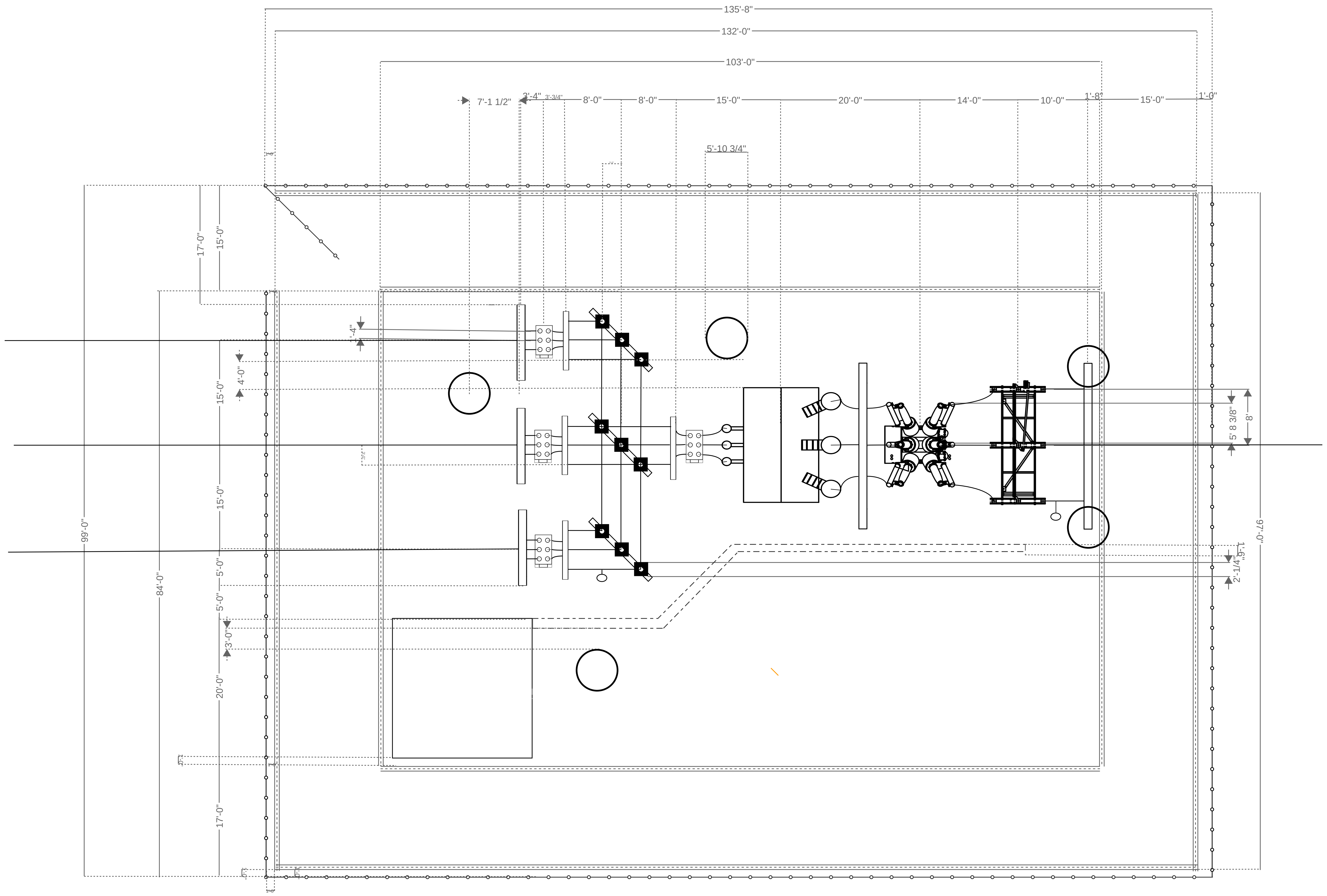
SERVICE CENTER

SCALE NONE

DRAWING NUMBER

REQUEST FOR WORK/WO

PROJECT DOCUMENT LIST



Map Legend

- 115 kV Disconnect Switch
- 115 kV Circuit Breaker
- 34.5/115 kV Transformer
- 34.5 kV Circuit Breaker
- Takeoff Structure
- 34.5 & 115 kV Bus Support
- 34.5 kV 3-Phase Bus Support
- Control Building
- Potential Transformer
- Access Road
- Lightning Mast
- Trench

PANEL # BUS ##

Rev.	PROJ DESIGN	PROJ MANAGER	OTHERS	DATE	Description	MADE BY	DATE
3	Madison Lakomek & Jacob Miller			4/25/23	- Added lightning masts - Updated map key to include lightning masts -Added distances for lightning masts	ML	4/25
2	Madison Lakomek			4/03/23	- Added trenching - Included distances for width of trenching - Updated map key to include access road and PT	ML	4/03
1	Madison Lakomek			3/29/23	- Added access road - Included measurements for distances between every component - Added a potential transformer on low side bus - Enlarged fence to ensure access road could fit within	ML	3/29

RFW/WO
ACT
RELAY
CH'K BY
DATE
EP&PM
APVD FOR ISSUE

APPROVALS

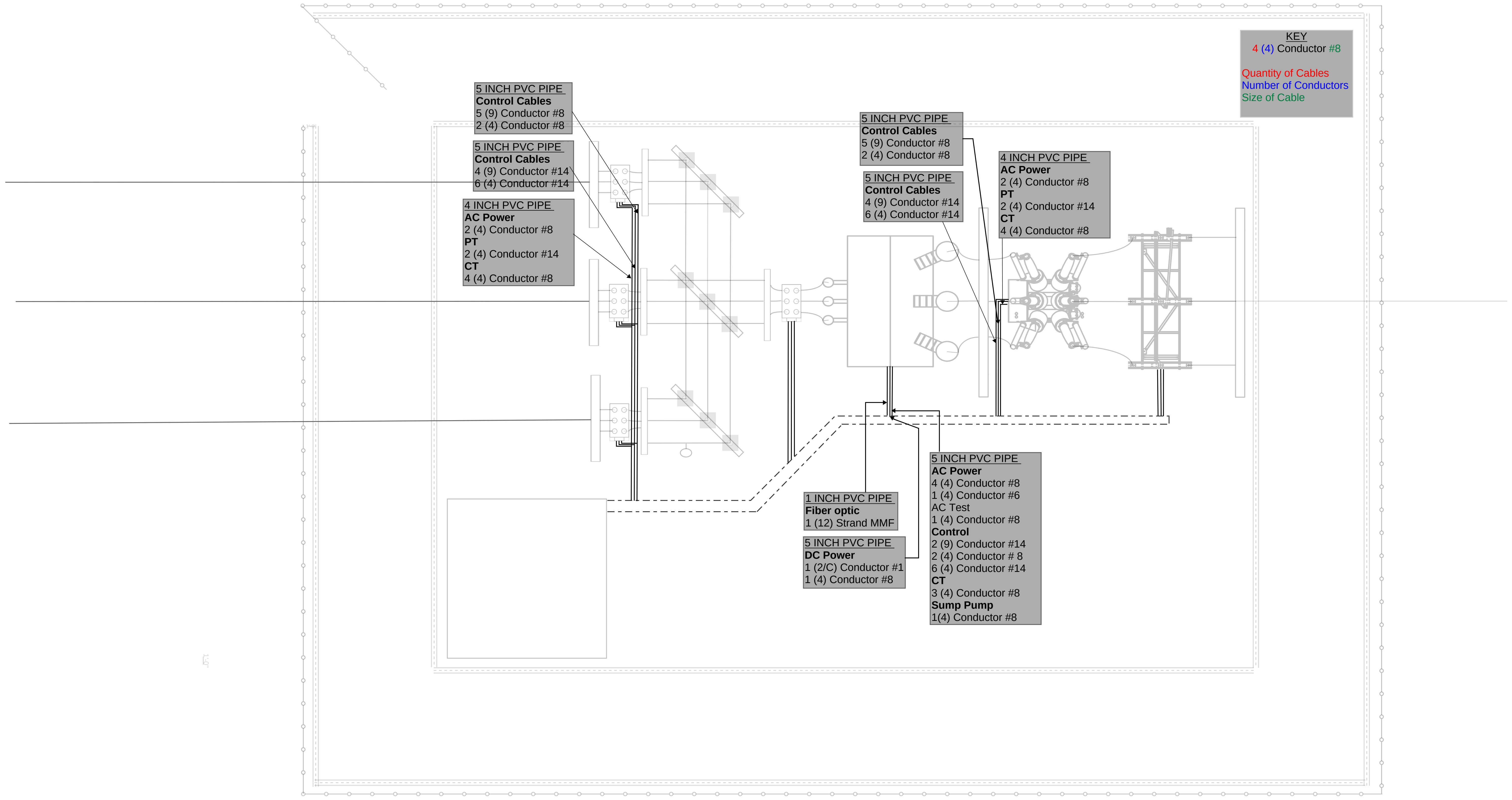
OTHER		DATE
PROJECT MANAGER		
RELAY		
EP&PM		
ACT		
OTHERS		

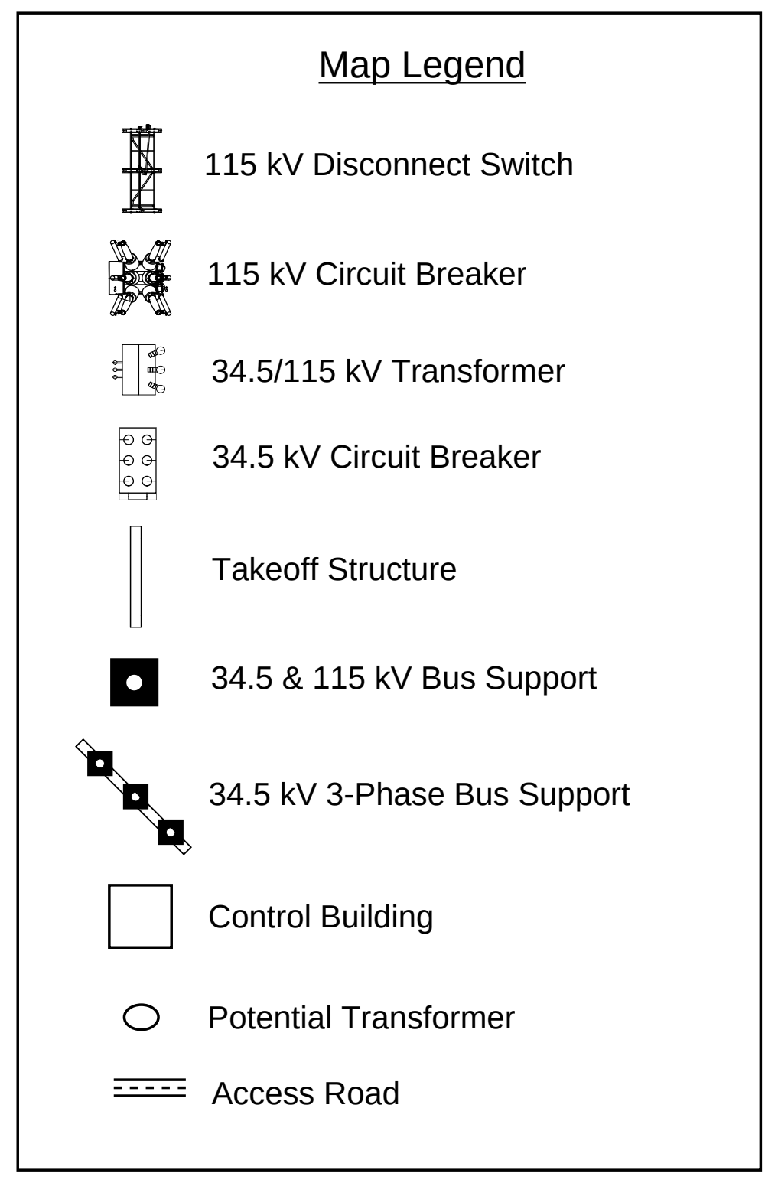
ENGINEERING	
MADE BY	DATE
Madison Lakomek	3/29/23
LAYOUT BY	DATE
CHECKED BY	DATE
PROJECT DESIGN/ELECT	DATE
PROJECT DESIGN/ACT	DATE
APPROVED FOR ISSUE	DATE

TITLE

KEY PLAN DIAGRAM

LOCATION NAME Roswell Solar Field Substation
SERVICE CENTER
SCALE NONE
DRAWING NUMBER
REQUEST FOR WORK/WO
PROJECT DOCUMENT LIST





PANEL # BUS ##

3	PROJ DESIGN	PROJ MANAGER	OTHERS
	Madison Lakomek & Brooke Nelson		
DATE	4/18/23		

- Added labels to specify which conduit wire was meant for which function of the components
-Added a key to explain conduit labeling

RFW/WO

MADE BY	DATE	ACT	RELAY
ML & BN	4/18		
CH'K BY	DATE	EP&PM	APVD FOR ISSUE

2	PROJ DESIGN	PROJ MANAGER	OTHERS
	Madison Lakomek		
DATE	4/06/23		

- Changed trenching to be at 45 degree angles instead of 90 degrees
-Changed location of PVC that connects 34.5 kV circuit breakers so they did not go under the equipment

RFW/WO

MADE BY	DATE	ACT	RELAY
ML	4/06		
CH'K BY	DATE	EP&PM	APVD FOR ISSUE

1	PROJ DESIGN	PROJ MANAGER	OTHERS
	Madison Lakomek		
DATE	4/03/23		

- Added trenching
- Included the PVC pipes connected to each piece of equipment

RFW/WO

MADE BY	DATE	ACT	RELAY
ML	4/03		
CH'K BY	DATE	EP&PM	APVD FOR ISSUE

APPROVALS

OTHER		DATE	ENGINEERING	DATE
PROJECT MANAGER			MADE BY	DATE
			Madison Lakomek	4/03/23
RELAY			LAYOUT BY	DATE
EP&PM			CHECKED BY	DATE
ACT			PROJECT DESIGN/ELECT	DATE
OTHERS			PROJECT DESIGN/ACT	DATE
			APPROVED FOR ISSUE	DATE

TITLE

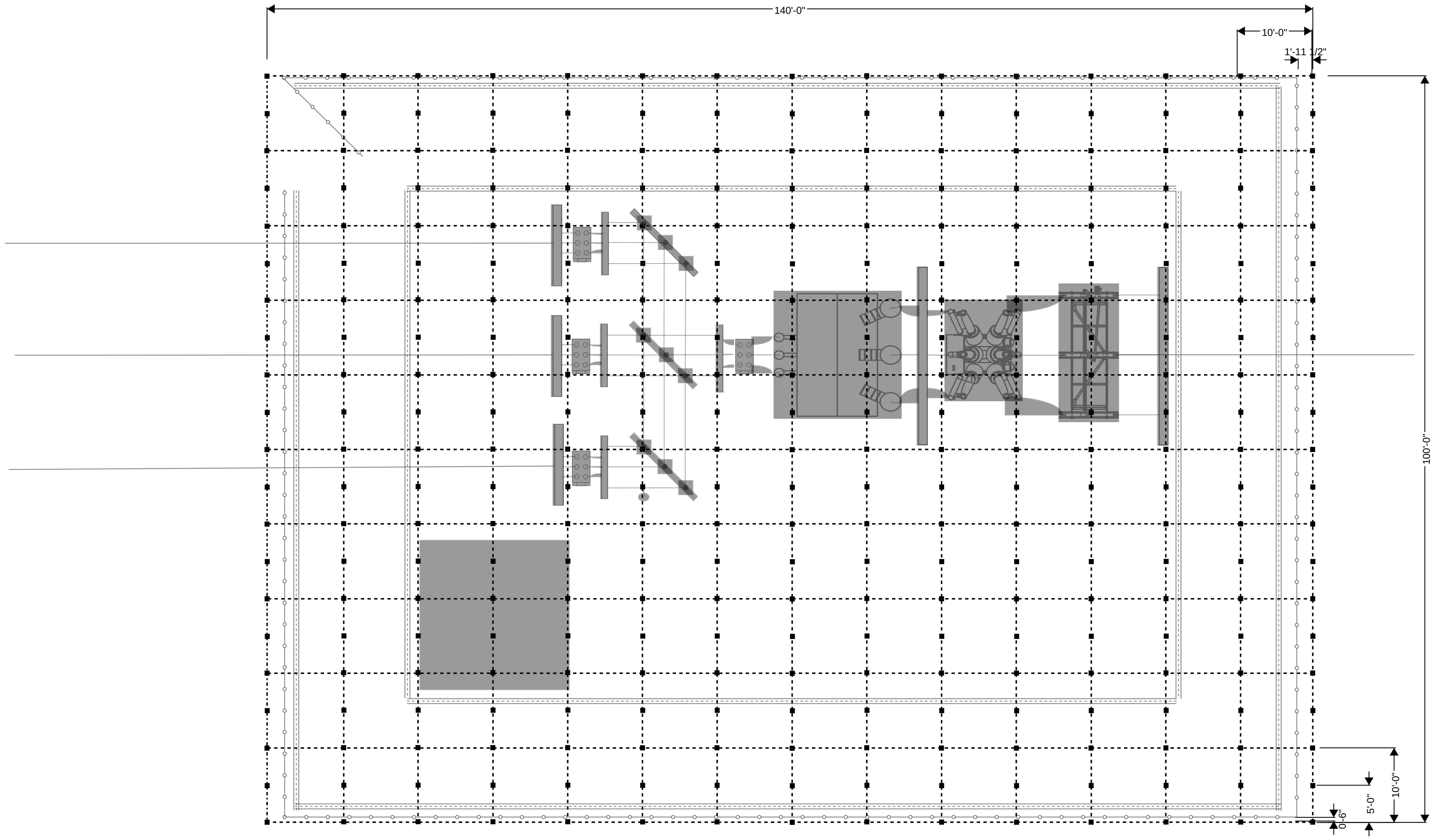
CONDUIT PLAN DIAGRAM

LOCATION NAME Roswell Solar Field Substation
SERVICE CENTER
SCALE NONE
DRAWING NUMBER
REQUEST FOR WORK/WO
PROJECT DOCUMENT LIST

Drawing Legend

- - - - - - Grounding Conductors

■ Grounding Rods



3	PROJ DESIGN	PROJ MANAGER	OTHERS
DATE			

RFW/WO

MADE BY	DATE	ACT	RELAY
CH'K BY	DATE	EP&PM	APVD FOR ISSUE

2	PROJ DESIGN	PROJ MANAGER	OTHERS
DATE			

RFW/WO

MADE BY	DATE	ACT	RELAY
CH'K BY	DATE	EP&PM	APVD FOR ISSUE

1	PROJ DESIGN	PROJ MANAGER	OTHERS
DATE			

RFW/WO

MADE BY	DATE	ACT	RELAY
CH'K BY	DATE	EP&PM	APVD FOR ISSUE

APPROVALS

	OTHER	DATE
PROJECT MANAGER		
RELAY		
EP&PM		
ACT		
OTHERS		

ENGINEERING	
MADE BY	DATE
M.Lawrence	4/4/23
LAYOUT BY	DATE
CHECKED BY	DATE
PROJECT DESIGN/ELECT	DATE
PROJECT DESIGN/ACT	DATE
APPROVED FOR ISSUE	DATE

TITLE

Grounding Grid Drawing

LOCATION NAME

SERVICE CENTER

SCALE NONE

DRAWING NUMBER

REQUEST FOR WORK/WO

PROJECT DOCUMENT LIST

Sizing Report Using IEEE-485 Method

Customer Name: Iowa State University
Location: Roswell, NM
Project: Senior Design
Email: lawrenmm@iastate.edu

Prepared by: Madissen Lawrence
Phone: 7152939879
Date: 3/3/23

Lowest Expected Electrolyte Temp. 77.0 °F (25.0 °C)   **Minimum Cell Voltage** 1.75

(1)	(2)	(3)	(4)	(5)	(6)	(7)	
PERIOD	LOAD (AMPERES)	CHANGE IN LOAD (AMPERES)	DURATION OF PERIOD (HH:MM:SS)	TIME TO END OF SECTION (HH:MM:SS)	CAPACITY AT T MIN RATE K FACTOR (Kt)	REQUIRED SECTION SIZE (3) * (6) = RATED AMP HOURS	
						POS VALUE	NEG VALUE
SECTION 1 - FIRST PERIOD ONLY - IF A2 IS GREATER THAN A1. GO TO SECTION 2							
1	19.61	19.61	00:00:00	00:00:00	0.625	12.255	0.000
					Sub Total	12.255	0.000
					Section 1 Total	12.255	
SECTION 2 - FIRST 2 PERIOD ONLY - IF A3 IS GREATER THAN A2. GO TO SECTION 3							
1	19.61	19.61	00:00:00	00:01:00	0.733	14.364	0.000
2	3.11	-16.50	00:01:00	00:01:00	0.733	0.000	-12.087
					Sub Total	14.364	-12.087
					Section 2 Total	2.277	
SECTION 3 - FIRST 3 PERIOD ONLY - IF A4 IS GREATER THAN A3. GO TO SECTION 4							
1	19.61	19.61	00:00:00	04:01:00	4.822	94.544	0.000
2	3.11	-16.50	00:01:00	04:01:00	4.822	0.000	-79.558
3	21.10	17.99	04:00:00	04:00:00	4.807	86.482	0.000
					Sub Total	181.026	-79.558
					Section 3 Total	101.468	

MAXIMUM SECTION(8) 101.47 + RANDOM SECTION SIZE(9) 0.00 = UNCORRECTED SIZE - (US)(10) 101.47

(US)(11) 101.47 x TEMP CORR(12) 1.000 x DESIGN MARGIN(13) 1.10 x AGING FACTOR(14) 1.25 = (15) 139.52

WHEN THE CELL SIZE IS GREATER THAN A STANDARD CELL SIZE, THE NEXT LARGER CELL IS REQUIRED.

REQUIRED CELL SIZE(16) = 150 AH (PRODUCT RATING PER STRING IS 150 AH)

THEREFORE 1 STRING OF (20) CA-07M IS RECOMMENDED
Margin : 7.5%
Total AH Removed for System: 84   **Number of Cells for System: 60**

Summary Margin Report

Customer: Iowa State University

Location:

Project:

Date Prepared: 3/3/23

Prepared By: Madissen Lawrence

Phone: 7152939879

E-Mail: lawrenmm@iastate.edu

Sizing Parameters

Application: Utility

Lowest Temp (°F): 77.00

Min. Voltage (Vpc): 1.75

Design Margin: 1.10

Aging Factor: 1.25

Line	Cell Model	Margin
1	CA-07M	7.5%
2	CC-07M	7.6%
3	6 OGi 140	13.3%
4	ESG-05	32.4%
5	6 OGi 80 (2 Strings)	36.0%
6	CA-05M (2 Strings)	43.4%
7	CC-05M (2 Strings)	43.5%
8	EA-05M	48.1%
9	EC-05M	48.6%
10	4 OPzS 200	58.6%
11	DSG-05	113.6%
12	GC-09M	514.5%
13	Vb 2408	587.0%

Battery Load Details

Number of Cells: 60

Total Time (Minutes): 241.00

Amp Hour Removed: 84.45

Period	Time (Mins.)	Load
1	0.00	19.61 A
2	1.00	3.11 A
3	240.00	21.10 A

Flooded System Configuration Report

Customer:	**Iowa State University**	Prepared By:	**Madissen Lawrence**
Location:	**N/A**	Phone Number:	**7152939879**
Date Prepared:	**03/21/2023**	Email:	**lawrenmm@iastate.edu**

Cells:	**60 of CA-07M**	AZMS Code:	**UD12**
Application:	**Utility Switchgear (60)**	Seismic Zone:	**UBC Zone 2L, at or Below Grade**
Strings:	**1**	Rack Style:	**2 Tier**
Jar/Cover:	**SAN Jar/PVC Cover (NFR)**	Rack Layout:	**Standalone**
Plate Orientation:	**Perpendicular**	Support Rails:	**2 Painted rails per tier or step**

Quantity	Part Number	Description	Weight (ea.)
Battery			
20	602040-CW	3CA-07M Charged & Wet (12.20L x 9.00W)	114 lb
Accessories - Smart Part Number: S06011091620T1SS			
1	88330	Thermometer, 30-130 F/0-55 C	
1	81332	Hydrometer, 1100-1300 S.G.	
1	27717	Hydrometer Holder Kit	
60	81099	Flame Arrestor, Black	
40	827279TP	Connector, 4.96x1.00x0.06, 3.96, Sn	
18	827281TP	Connector, 5.82x1.00x0.06, 4.66, Sn	
120	88589TP	Washer, Post Back-Up, 1.00 Sq.x0.13, Sn	
60	803963	Hardware Pkg, 1/4-20x1.50, (2) per Pkg.	
1	90991-042	Cable Assy, #2, (2)1-Hole, 5/16 Stud Lug, Sn, 42 inches	
1	US-FL-IOM	Instruction Manual, Flooded	
1	802372	Cell Number Labels, Small, 1-60	
1	82853	No-Ox Post Grease, 8oz, 227g	
Rack(s)			
1	UC2L2T132AP	Rack, UBC Zone 2L, 2 Tier, 132" long	412 lb
Spill Containment			
1	WUL-25-136	EnerSys UL System, 25" wide x 136" long	191 lb
Optional Accessories (Additional charges may apply)			
7	827437	Connector Cover, Grey, 72" Long, w/Holes, PVC	3 lb
11	827510	Connector Cover, Clear, 48" Long, w/Holes, PVC	2.25 lb
11	827435	Connector Cover, Clear, 48" Long, No Holes, PVC	2.25 lb
4	808770TP	Terminal Plate Pkg, 4 Runs, 601614TP, Sn	9 lb
4	825472	Terminal Plate Cover, 7.75" x 3.00" x 3.75"	1 lb

Rack Style	Standard Termination	Rack Style	Standard Termination
1 Tier	End-to-End (opposite end)	2 Step	Top-to-Bottom (same end)
2 Tier	Top-to-Bottom (same end)	3 Step	Top-to-Bottom (opposite end)
3 Tier	Top-to-Bottom (opposite end)	2 Step / 2 Tier	Top (same end)
2 Tier / 2 Row	Top (same end)	* **Please call if not standard termination** *	

Cables not supplied for "Across Aisle", "L", or "U" Shape configurations

ALL DATA SUBJECT TO CHANGE WITHOUT NOTICE.

Flooded Rack Configuration Report

Customer:	**Iowa State University**	Prepared By:	**Madissen Lawrence**
Location:	**N/A**	Phone Number:	**7152939879**
Date Prepared:	**03/21/2023**	Email:	**lawrenmm@iastate.edu**

Cells:	**60 of CA-07M**	AZMS Code:	**UD12**
No. Of Jars:	**20**	Seismic Zone:	**UBC Zone 2L, at or Below Grade**
Strings:	**1**	Rack Style:	**2 Tier**
Cells per String:	**60**	Rack Layout:	**Standalone**
System Voltage:	**120**	Support Rails:	**2 Painted rails per tier or step**
Plate Orientation:	**Perpendicular**		

Rack Information:

Qty	Part Number	Capacity	Length	Depth	Weight	Frames
1	**UC2L2T132AP**	**20 Jars**	**132.00 in**	**20.56 in**	**412 lb**	**3**

Spill Containment Information:

Qty	Part Number	Weight
1	**WUL-25-136**	**191 lb**

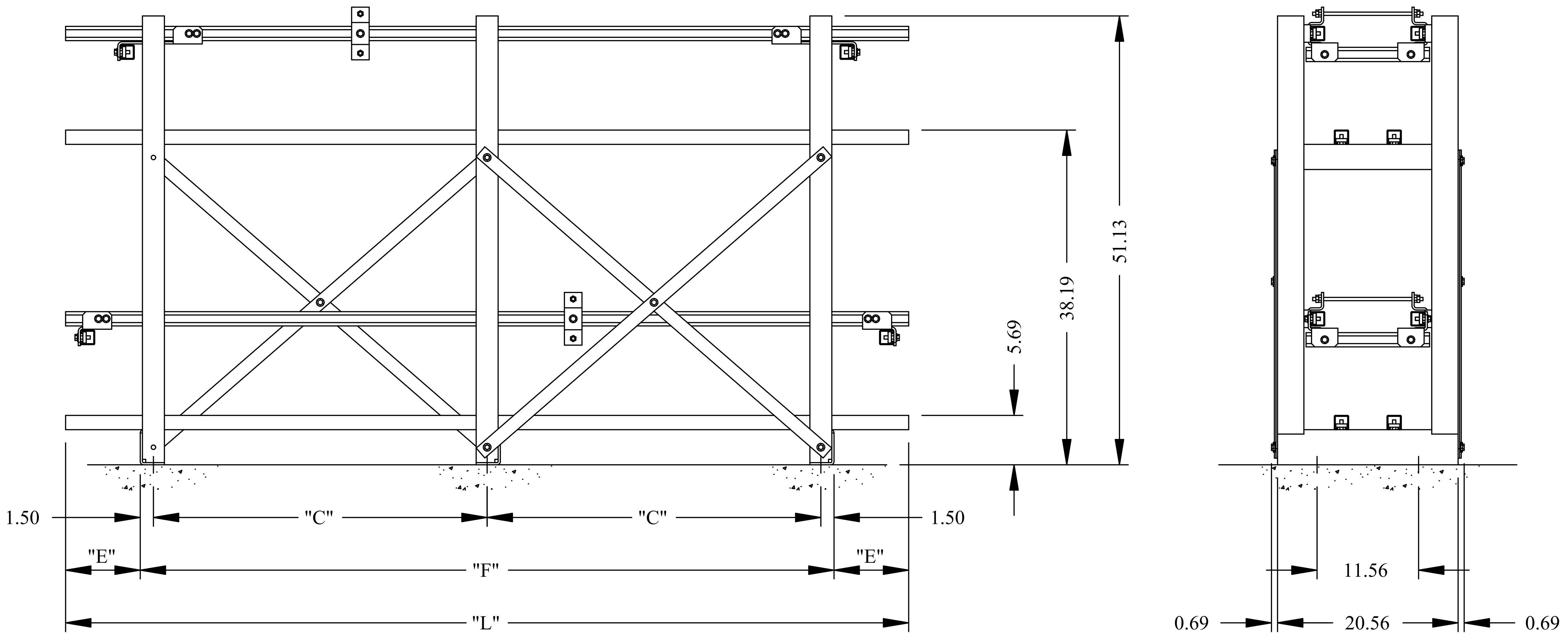
System Weights:

Weight of Racks:	**412 lb**
Weight of Accessories:	**57 lb**
Weight of Spill Containment:	**191 lb**
Weight of Batteries:	**2,280 lb**
Total System Weight:	**2,940 lb**

Floor Loading:

Contact Weight:	**21 lb/in ^{2}**
Projected / Shadow Weight:	**156 lb/ft ^{2}**

ALL DATA SUBJECT TO CHANGE WITHOUT NOTICE.



CATALOG NO.	AZMS NO.	"L" (in.)	"F" (in.)	"E" (in.)	"C" (in.)	WT. (lbs.)	# FRAMES
UC2L2T036AP	UD12-036	36.00	29.00	3.50	26.00	172	2
UC2L2T048AP	UD12-048	48.00	29.00	9.50	26.00	188	
UC2L2T060AP	UD12-060	60.00	43.00	8.50	40.00	204	
UC2L2T072AP	UD12-072	72.00	57.00	7.50	54.00	220	
UC2L2T084AP	UD12-084	84.00	57.00	13.50	54.00	292	
UC2L2T096AP	UD12-096	96.00	83.00	6.50	40.00	308	3
UC2L2T108AP	UD12-108	108.00	83.00	12.50	40.00	324	
UC2L2T120AP	UD12-120	120.00	111.00	4.50	54.00	340	
UC2L2T132AP	UD12-132	132.00	111.00	10.50	54.00	412	
UC2L2T144AP	UD12-144	144.00	111.00	16.50	54.00	435	
UC2L2T156AP	UD12-156	156.00	147.00	4.50	48.00	451	4
UC2L2T168AP	UD12-168	168.00	147.00	10.50	48.00	524	
UC2L2T180AP	UD12-180	180.00	165.00	7.50	54.00	540	
UC2L2T194AP	UD12-192	192.00	165.00	13.50	54.00	556	
UC2L2T204AP	UD12-204	204.00	195.00	4.50	48.00	572	5
UC2L2T216AP	UD12-216	216.00	195.00	10.50	48.00	644	
UC2L2T232AP	UD12-228	228.00	219.00	4.50	54.00	660	
UC2L2T240AP	UD12-240	240.00	219.00	10.50	54.00	676	

RAIL OPTIONS, IDENTIFIED BY CATALOG NO. SUFFIX:
AP - 2 PAINTED RAILS PER TIER (STANDARD)
A3RP - 3 PAINTED RAILS PER TIER

TITLE: RACK, UBC ZONE 2L, 2 TIER

EnerSys
Power/Full Solutions™

RESERVE POWER
READING, PA. 19605

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BATTERY: CA, CC, CX
CODE: UD12
REF.: N/A

RACK FAMILY: UC2L2TxxxAP
REV. A

DO NOT SCALE DRAWING
DATE: 06/11/2009

ETAP - Load Flow Analysis

Project:
Location:
Contract:
Engineer:
Filename: sd_etap_sim_v2

ETAP
22.0.1E

Study Case: LF

Page: 1
Date: 04-13-2023
SN: IASTATEPL
Revision: Base
Config.: Normal

LOAD FLOW REPORT

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
Bus 1	34.500	99.927	-0.1	0.000	0.000	0.000	0.000	Bus 4	59.118	4.216	992.6	99.7	
								Node 1	-59.118	-4.216	992.6	99.7	
Bus 2	34.500	99.914	-0.1	0.000	0.000	0.000	0.000	Bus 4	0.000	0.000	0.0	0.0	
								Node 2	0.000	0.000	0.0	0.0	
Bus 3	34.500	99.914	-0.1	0.000	0.000	0.000	0.000	Bus 4	0.000	0.000	0.0	0.0	
								Node 3	0.000	0.000	0.0	0.0	
Bus 4	34.500	99.914	-0.1	0.000	0.000	0.000	0.000	Bus 1	-59.110	-4.213	992.6	99.7	
								Bus 2	0.000	0.000	0.0	0.0	
								Bus 3	0.000	0.000	0.0	0.0	
								XFORMER LV	59.110	4.213	992.6	99.7	
*Node 1	34.500	100.000	0.0	59.157	4.274	0.000	0.000	Bus 1	59.157	4.274	992.6	99.7	
Node 2	34.500	99.914	-0.1	0.000	0.000	0.000	0.000	Bus 2	0.000	0.000	0.0	0.0	
Node 3	34.500	99.914	-0.1	0.000	0.000	0.000	0.000	Bus 3	0.000	0.000	0.0	0.0	
Node 4	115.000	99.496	-3.3	0.000	0.000	0.000	0.000	Node 5	59.006	0.888	297.8	100.0	
								XFORMER HV	-59.006	-0.888	297.8	100.0	
Node 5	115.000	98.852	-4.1	0.000	0.000	58.631	0.000	Node 4	-58.631	0.000	297.8	100.0	
XFORMER HV	115.000	99.496	-3.3	0.000	0.000	0.000	0.000	Node 4	59.006	0.888	297.8	100.0	
								XFORMER LV	-59.006	-0.888	297.8	100.0	
XFORMER LV	34.500	99.902	-0.1	0.000	0.000	0.000	0.000	Bus 4	-59.103	-4.209	992.6	99.7	
								XFORMER HV	59.103	4.209	992.6	99.7	

* Indicates a voltage regulated bus (voltage controlled or swing type machine connected to it)

\# Indicates a bus with a load mismatch of more than 0.1 MVA

Project:
Location:
Contract:
Engineer:
Filename: sd_etap_sim_v2

ETAP
22.0.1E

Study Case: SC

Page: 1
Date: 04-13-2023
SN: IASTATEPL
Revision: Base
Config.: Normal

Short-Circuit Summary Report

1/2 Cycle - 3-Phase, LG, LL, & LLG Fault Currents

Prefault Voltage = 100 % of the Bus Nominal Voltage

Bus		**3-Phase Fault**			**Line-to-Ground Fault**			**Line-to-Line Fault**			***Line-to-Line-to-Ground**		
ID	kV	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.
Bus 4	34.500	0.306	-5.697	5.706	0.716	-7.305	7.340	5.048	0.415	5.065	-5.444	4.453	7.033
XFORMER HV	115.000	0.063	-1.293	1.294	0.114	-1.757	1.760	1.140	0.079	1.142	1.081	1.360	1.737
XFORMER LV	34.500	0.310	-5.695	5.703	0.726	-7.293	7.329	5.045	0.418	5.063	-5.455	4.434	7.030

All fault currents are symmetrical (1/2 Cycle network) values in rms kA.
* LLG fault current is the larger of the two faulted line currents.

Project:		**ETAP**	Page: 2
Location:		22.0.1E	Date: 04-13-2023
Contract:			SN: IASTATEPL
Engineer:		Study Case: SC	Revision: Base
Filename:	sd_etap_sim_v2		Config.: Normal

Sequence Impedance Summary Report

Bus		**Positive Seq. Imp. (ohm)**			**Negative Seq. Imp. (ohm)**			**Zero Seq. Imp. (ohm)**			**Fault Zf (ohm)**		
ID	kV	Resistance	Reactance	Impedance	Resistance	Reactance	Impedance	Resistance	Reactance	Impedance	Resistance	Reactance	Impedance
Bus 4	34.500	0.18752	3.48595	3.49099	0.37063	3.30284	3.32357	0.23599	1.31397	1.33499	0.00000	0.00000	0.00000
XFORMER HV	115.000	2.47678	51.23170	51.29153	4.51139	49.19708	49.40350	0.36613	12.48491	12.49028	0.00000	0.00000	0.00000
XFORMER LV	34.500	0.18996	3.48721	3.49238	0.37307	3.30410	3.32509	0.24507	1.32137	1.34390	0.00000	0.00000	0.00000