115/34.5 kV Solar Power Plant & Substation Design Project

DESIGN DOCUMENT

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Client: Black & Veatch
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Executive Summary

Development Standards & Practices Used

We used our knowledge in power systems and programs such as ETAP, Bluebeam, and AutoCAD to design a 115/34.5 kV substation and solar field. We used IEEE, NEC, and some OSHA standards to ensure we construct a safe environment for everyone involved.

Summary of Requirements

List all requirements as bullet points in brief.

* Equipment sizing calculations (breakers, transformers, etc) – Excel files
* Solar layout drawings – Bluebeam/CAD/PDF editor
* Solar panel string sizing design – Excel files
* Electrical layout drawings (substation equipment) – Bluebeam/CAD/PDF editor
* Grounding analysis and ground-grid developed with IEEE-80 – Excel files
* Bus calculations for substation – Excel files
* Possibility of additional calculations (DC battery bank, lightning protection, etc.) – Excel files
* Creation of solar/substation design-optimizing tool – TBD
*Simulation of designed substation – SIMULATION SOFTWARE – STUDENT LICENSE [ETAP/SKM/ASPEN]
* Coordination Study / AC Arc Flash Study / Protection Element Analysis – SIMULATION SOFTWARE – STUDENT LICENSE [ETAP/SKM/ASPEN]
* Load Flow Scenario Wizard / Configuration Manager – SIMULATION SOFTWARE – STUDENT LICENSE [ETAP/SKM/ASPEN]

Applicable Courses from Iowa State University Curriculum

List all Iowa State University courses whose contents were applicable to your project.

EE322 Semiconductor Devices
EE303 Intro to Power Systems
EE455 Distribution Systems
EE456 Power Systems 1
EE457 Power Systems 2

New Skills/Knowledge acquired that was not taught in courses

List all new skills/knowledge that your team acquired that was not part of your Iowa State curriculum to complete this project.

AutoCAD – Computer-Aided-Design
ETAP – Electrical Transient Analysis Program
Solar and Substation Design

Table of Contents

List of figures/tables/symbols/definitions (This should be the similar to the project plan)

Definition

Term	Definition
ILR	Inverter load ratio, the ratio DC input capacity and the inverter AC output capacity, a higher DC input is required to overrun the inverter because the majority of operation the inverter is underrun.
Irradiance Correction Factor	A multiplier for the current output of a solar panel to compensate for current spikes due to high solar radiation.
Collector	The substation input from the solar array.
Xfmr or Xformer	Transformer abbreviation.
Feeder	Collector arrangement to 34.5 kV bus.
Array	A complete unit of solar panels and all associated components including inverters.
PV	Acronym for photovoltaic.
PV module/panel	Single solar module or panel unit. Module and panel are interchangeable terms.
STC	Standard temperature conditions, 1000 watts per meter squared irradiation & -25° C.
Inverter Skid	Base plate for inverter and step-up transformer in an array.
Jumper	Copper conductors connecting solar modules in series string.
String	A series combination of solar panel modules.
Rack	A solar string in parallel.
Combiner Box	Weatherproof enclosure for coupling DC conductors with serviceable disconnects, NEC690.16(B).
Azimuth	Angle between the north vector and the perpendicular projection of the star down onto the horizon.

1 Team

1.1 Team members

1.1.1 Baylor Clark

1.1.2 Eduardo Jimenez-Tzompaxtle

1.1.3 Eli Schaffer

1.1.4 Liam Gossman

1.1.5 Chicheng Tang

1.1.6 Siti Mohd Radzi

1.2 Required Skill Sets for Your Project

Technical Wise

CAD - Solar layout drawings
IEEE-80 - Grounding analysis and ground-grid calculations
Excel - Equipment sizing calculations, additional calculations (DC battery bank, lightning protection, etc), solar panel string sizing design. Grounding analysis and ground-grid calculations
ETAP/SKM/ASPEN- Solar Substation Simulation, Load flow scenario, Protection Element Analysis,
ETAP (Electric Transient Analysis Program) - Simulation software
Bluebeam - Electrical Layout drawings

1.3 Skill Sets covered by the Team

Everyone- Grounding and ground-grid circuit calculations/analysis

Baylor Clark: I have experience with project management and team communication through internships the past two summers. I also have experience working on projects with other group members from previous classes.

Elymus Schaffer: I bring my extrovert personality to help me invoke thought-provoking questions and discussions for our team. I have also worked for companies throughout semesters while keeping my grades up and communicating effectively with my employer. I know about creating a Bill of Materials and being able to help schedule who does what and when.

Eduardo Jimenez-Tzompaxtle: I have experience working with a group and communicating with people. I have taken some classes in transmission and power.

Chicheng Tang: I have experience collaborating with team members to complete the work. And I have taken a class about distribution and transmission systems.

Liam Gossman: I have experience with substation design and general operations through my internships at MidAmerican Energy. I also have experience with distribution systems design and effective communication skills necessary for collaboration between different design departments.

Siti Mohd Radzi: I have numerous experiences working in a team from various work environments, from working for technical projects, student organizations, volunteering programs, and fundraising; I believe I would be able to contribute to creating a healthy work environment within the team, by ensuring the expectation and performance of the team is consistent and good.

1.4 Project Management Style Adopted by the team

Majority vote in group decisions to keep everyone in the loop and ensure that nobody has more power than anyone else. People voice their opinions and concerns freely to avoid unfair or decision bias.

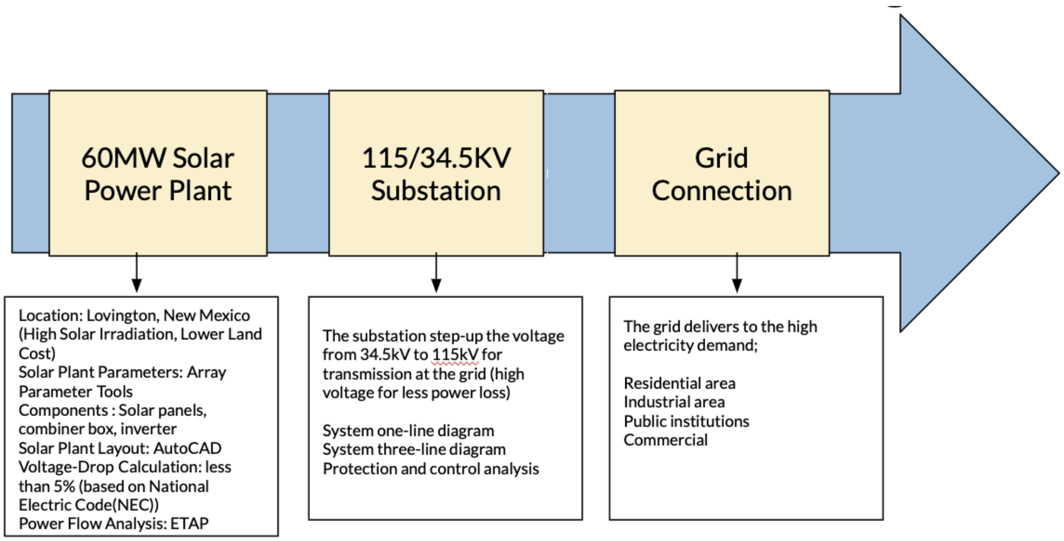
1.5 Initial Project Management Roles

- Baylor: Team Organizer
- Bell: Recorder and Testing
- Liam: Client Correspondent
- Chicheng: Research and Testing Leader
- Eduardo: Submission, Research and Testing Leader
- Eli: Team Lead

2 Introduction

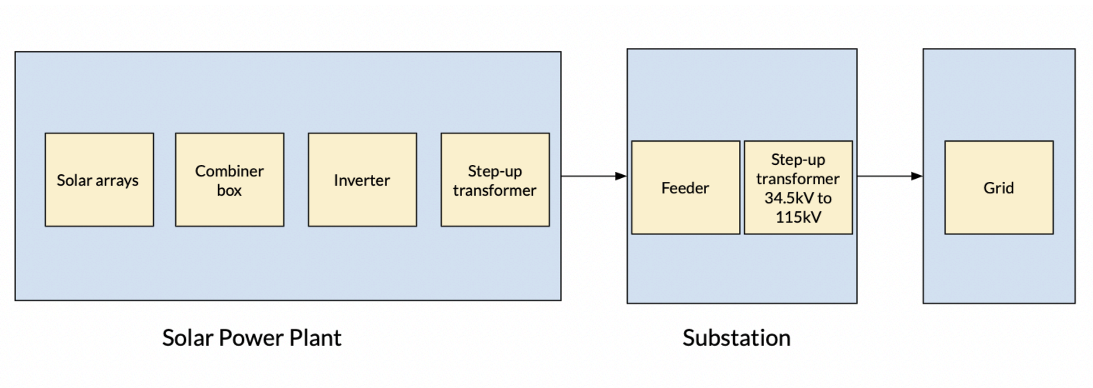
2.1 Problem Statement

Our project comprises a 60 MW solar power plant and a 115/34.5 kV substation design. For the Fall 2023 semester, we are focusing on designing the solar power plant, starting with the solar power plant. In this design part, considerations are taken into account: location, power rating of the components, solar layout design, voltage-drop analysis, and cost analysis. During the Spring 2024 semester, we continued designing the substation to increase the power from 34.5 kV to 115 kV before transmitting it to the grid. We focused on designing one-line and three-line diagrams for power flow, protection, and fault analysis in this design area. The power will then be transmitted to the grid and distributed to accommodate the high electricity demand from local demand, residential, industrial factories, commercials, and public needs.



[Figure 2.1.1: Solar Power Plant and Substation Design Process]

The solar power plant design consists of 4 components, which are the solar layout, combiner box, inverters, and step-up transformer. Meanwhile, the substation design consists of the feeder and the step-up transformer.



[Figure 2.1.2: Components of the design]

2.2 Requirements and constraints

In this project, we must design the solar power and substation plants using AutoCAD, ETAP, and Bluebeam. We also have requirements to calculate voltage drops, grounding currents, and design specifications. We are not required to have a replica of our designed substation and solar farm, but we must have all of the documentation that goes along with the design work. Here are a few deliverables we need to provide as well:

Functional

- Must be able to operate in environmental conditions
- Power rating at the solar farm of 60 MW
- Adhere to IEEE, NEC, ANSI standards
- Maintain reliability throughout the lifespan of the project
- Minimize voltage drop across solar plant
- Safely ground the entirety of the substation
- Establish overcurrent protection system
- Calculate overall DC and AC loads

This solar farm will operate outside in typically hot, sunny weather but also must be able to withstand temperatures below freezing. It must be resistant to common weather conditions of the area, such as thunderstorms or snow. The substation will operate in the same environment as the solar farm as it will only be 50 feet from the solar field.

Environmental

- Parcel of land must be flat and continuous (i.e. no hills, creeks, ravines)
- High amount of average sunshine per year
- High irradiance on the land
- Substation should be able to safely provide power to nearby communities
- Efficient use of land

Economic

- Our solar plant must be able to produce enough power per year to recover initial investment and operational costs over 10 years.

2.3 Engineering standards

Solar Power Plant Design Standards:

IEEE 1562:2007 - Guide for Array and Battery Sizing in Stand-Alone Photovoltaic (PV) Systems

IEEE 2778-2020 - Grounding System Design for Ground-Mount Photovoltaic (PV) Solar Power Plant

NEC690.8(B) - Overcurrent ratings shall not be less than 125% of the max current calculated

NEC690.8(A) - The maximum current shall be the sum of the short-circuit current ratings of the PV modules connected in parallel multiplied by correction multiplier, 125 percent.

NEC690.9 - PV system dc circuit and inverter output conductors and equipment must be protected against overcurrent.

NEC 240.6 - 240.6(A) Fuses and Fixed-Trip Circuit Breakers: The standard ampere ratings for fuses and inverse time circuit breakers shall be considered 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110, 125, 150, 175, 200, 225, 250, 300, 350, 400, 450, 500, 600, 700, 800, 1000, 1200, 1600, 2000, 2500, 3000, 4000, 5000, and 6000 amperes.

NEC 210.19 - Voltage drop would be 2% from DC, and 1% from AC side.

NEC Table 8 Conductor Properties & NEC AWG Chart - Provides information on conductor properties, including ampacity, insulation types, and other specifications. NEC AWG Chart provides information on the ampacity of conductors based on their size (gauge) and the type of insulation which is crucial for ensuring that the conductors used in electrical installations can safely carry the expected current without overheating.

Lovington & Lea County Ordinance - The fence, wall or barrier required by [this subsection] shall not be less than eight (8) feet in height with no openings, holes or gaps larger than four (4) inches measured in any direction. Gates and doors opening directly into the area enclosed by a fence, wall or barrier, as required by this section, shall be equipped with a lock to keep the doors or gates securely closed and locked at all times. Tower sites located within industrial yard areas with existing secure fencing of the entire yard may construct secure fencing six (6) feet in height.

Substation Standards:

IEEE 80-2013 - IEEE Guide for Safety in AC substation grounding

IEEE 998-2012 - IEEE Guide for Direct Lightning Stroke Shielding of Substations

IEEE 485-2020 - IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications

IEEE 605-2008 - IEEE Guide for Bus Design in Air Insulated Substations.

IEEE 1184-2006 - IEEE Guide for Batteries for Uninterruptible Power Supply Systems

NEC 2020- (National Electrical Code)

2.4 Intended users and uses

Two groups could potentially benefit from the results of our project. The first interest group is our sponsor company, Black & Veatch. After completion of the project, they can take our design and compare it to other senior design groups and traditional designs done at the company. The other group that could benefit from our project if it were to be implemented in the real world would be the public using the energy produced by our solar power plant. This would help out the local community and power grid by adding another 60 MW of power to be consumed.

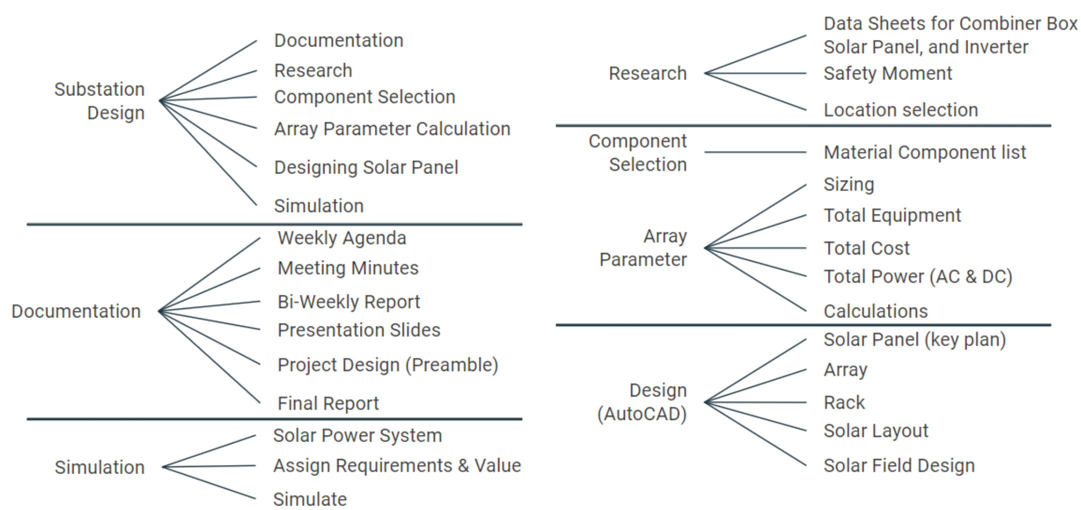
Black & Veatch is a group interested in designing and implementing solar power plants and substations. Renewable energy advocacy groups would also be interested in designing and creating a solar power plant. Black & Veatch could take the design of our project and implement our design if the situation makes sense and applies to a specific location.

3 Project Plan

3.1 Task Decomposition

3.1.1 Fall 2023

In this design project, there are two main tasks: designing a 60 MW solar farm in Fall 2023 and designing the 115/34.5 kV substation in Spring 2024. A few sub-tasks are worked on, such as research, component selection, simulation, designing, calculation, and documentation. The first sub-task is initial research. In the Fall of 2023, we worked on researching the strategic location for solar energy production by taking several factors into account, for example, solar irradiation, land cost, ROI, local policies, and many more. We also researched suitable components of the solar farm: Solar panels, combiner box, inverter skids, connectors, and fencing materials, by comparing different best components from the datasheet consisting of the information of the specification, power ratings, efficiency, and cost. Then, we continued designing the solar array by using array parameter tools using the specification values of the solar panels while considering standards to produce a DC power of 78.79 MW to finalize AC power of 60 MW, as per project requirement. Next, we draw the design in AutoCAD, from solar layout, solar mount, string connection diagram, and DC and AC one-line diagram. Next, we simulated the effectiveness of the design by calculating the voltage drop.



[Figure 3.1: Fall 2023 Solar Farm Task Decomposition]

3.1.2 Spring 2024

Building upon the previous semester's project, this plan focused solely on the research and design of a corresponding 115/34.5kV substation. Leveraging lessons learned, identifying key steps and progress was significantly smoother. The identification of key steps and progress for our project plan was much easier using the lessons learned from the previous semester. The first subtask again was initial research. Research for this portion of the project consisted of a couple of different areas. One area was researching the most effective layout and design of the substation itself. There are a number of different substation configurations and the group needed to determine the most effective solution. Another area of research was component specifications and requirements. Understanding the requirements for each substation component helps to guide in the component selection portion of the design. Some of these components include transformers, CTs, and PTs. Component selection carried through a majority of the semester due to changes in designs and specifications. Component selection was an iterative process throughout the semester due to evolving designs and specifications. The final major phase of the project plan involved calculations and power simulations. Black & Veatch provided spreadsheets for AC load, DC battery sizing, and other calculations. Additionally, ETAP power flow simulation software was used to verify the design compatibility between the solar farm and substation.

3.2 Project Management/Tracking Procedures

The group has adopted the waterfall management style for the organization and progression of the project. However, the group uses an agile methodology for communication and leadership between group members. The waterfall method emphasizes completing certain tasks before moving the project forward. Agile stresses the importance of leadership and freedom for group members.

A typical waterfall management style has five phases: requirements, design, implementation, verification, and maintenance. The style is a linear progression from one phase to the next. In particular, the next phase should not begin until the previous phase is completed. The typical waterfall style suggests not returning to previous phases once completed, but the group had some crossover between phases to revise and ensure everything was completed properly.

Our Gantt chart for tracking tasks and the design process loosely follows this waterfall design style. The Gantt chart the group has created details the different phases of design and what is involved in each phase. Furthermore, a timeline outlines when different phases should be completed, and deadlines are coming up in the future. Additionally, the group used GitHub to help keep track of design phases and assign tasks to each team member. The agile methodology involves frequent check-ins with group members and early detection of obstacles. This method of group collaboration allows for the most fluent progression through the phases of our senior design project.

3.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

3.3.1 Fall 2023

- Research Equipment
    - Collect 3 datasheets for PV panels, combiner boxes, and solar inverters
    - Research necessary components and present our understanding of them
- Select Components
    - Finalize component selection
    - Find appropriate location for construction
- Array Parameters
    - Use array calculation tool to select solar farm sizing (number of panels, combiner boxes, inverters, etc)
    - Component numbers and arrangement should result in an AC output of 60 MW and a DC to AC ratio of approximately 1.3
    - Component costs were calculated to provide overall array cost
    - Voltage drop calculations were done to provide realistic power loss statistics
- Design Solar Array (AutoCAD)
    - Solar array was designed in AutoCAD based on array calculation tools
    - A professional title block was created for array drawings
- Solar Farm Simulation
    - The solar farm was set up within a simulation software (ETAP)
    - The power flow of the solar farm was simulated
    - Array parameters were checked and adjusted to ensure all necessary deliverables are met

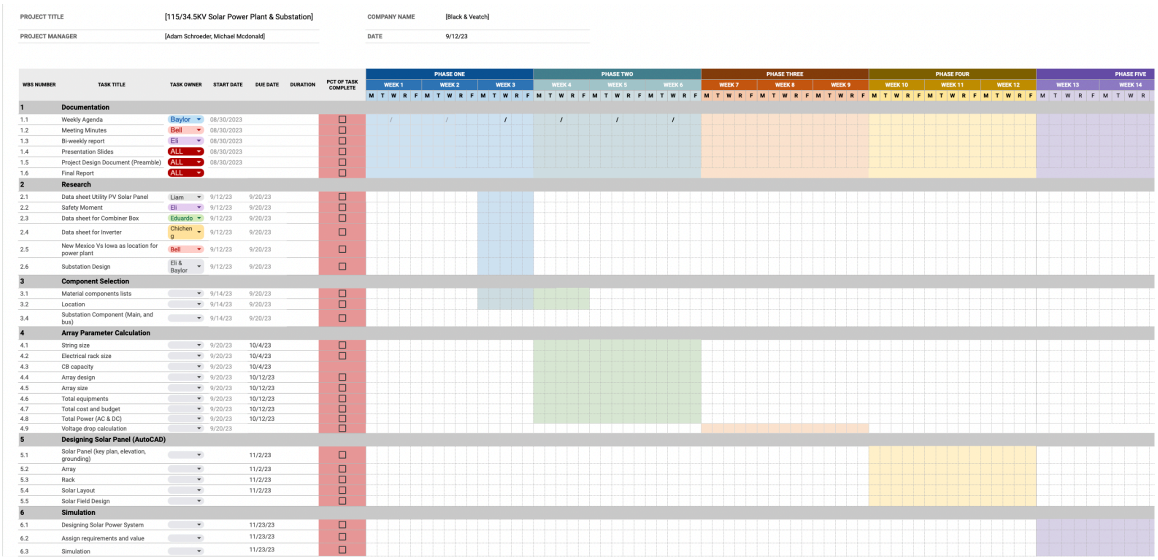
3.3.2 Spring 2024

- Research Equipment
    - Collect data sheets for transformers, and circuit breakers. conductors wire, relays, potential, and current transformers
    - Research necessary components and present our understanding of them
- Select Components
    - Finalize component selection
    - Find an appropriate location for control house, grounding, and substation construction
- Calculations
    - Estimate the AC load at the control house, considering the worst case load to estimate DC battery size needed
    - Calculate the DC Load profile for DC Battery sizing using EnerSys Battery Sizing program
    - Calculate grounding calculations to design grounding for the solar farm, considering few significant parameters: conductor sizing, Etouch, Estep

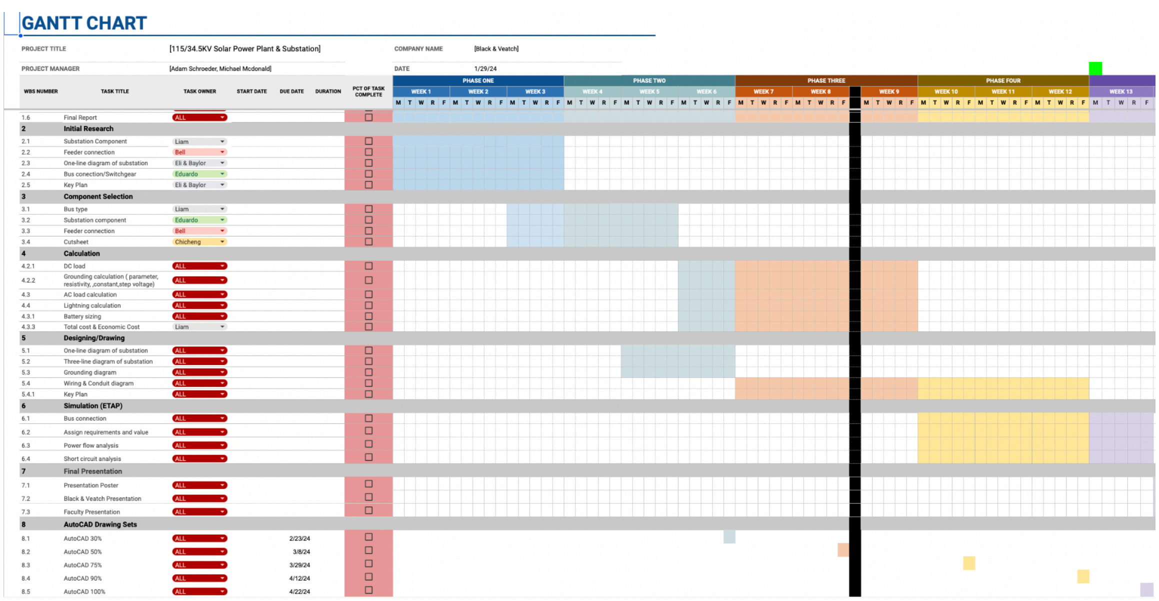
    - Implement bus calculations to calculate bus force, ampacity calculation, and maximum allowable span load.
    - Estimate overall cost for substation
- Design Substation (AutoCAD)
    - Create AC one-line and three line-diagram of the substation showing the interconnection of the components
    - Demonstrate the overall design of the substation through Key Plan drawing
    - Wiring drawing, Relays and protection drawing
    - Grounding drawing
    - A professional title block was created for all drawings
- Substation Simulation
    - The substation is set up within a simulation software (ETAP)
    - The power flow and short circuit test of the solar farm & substation were simulated
    - Array parameters were checked and adjusted to ensure all necessary deliverables are met

3.4 Project Timeline/Schedule

A realistic, well-planned schedule is an essential component of every well-planned project. Most scheduling errors occur due to improperly identifying the necessary activities (tasks and/or subtasks) or incorrectly estimating the effort required to complete the activity. A detailed schedule is needed for the plan: Start with a Gantt chart showing the tasks (that you developed in 2.2) and associated subtasks versus the proposed project calendar. The Gantt chart shall be referenced and summarized in the text. We annotated the Gantt chart with dates for when each project deliverable was delivered. Project schedule/Gantt chart can be adapted to an Agile or Waterfall development model. A sprint schedule with specific technical milestones/requirements/targets worked for our group for an agile schedule. Also, see Figures 8.4.2 - 8.4.5 for more information about our project timeline.

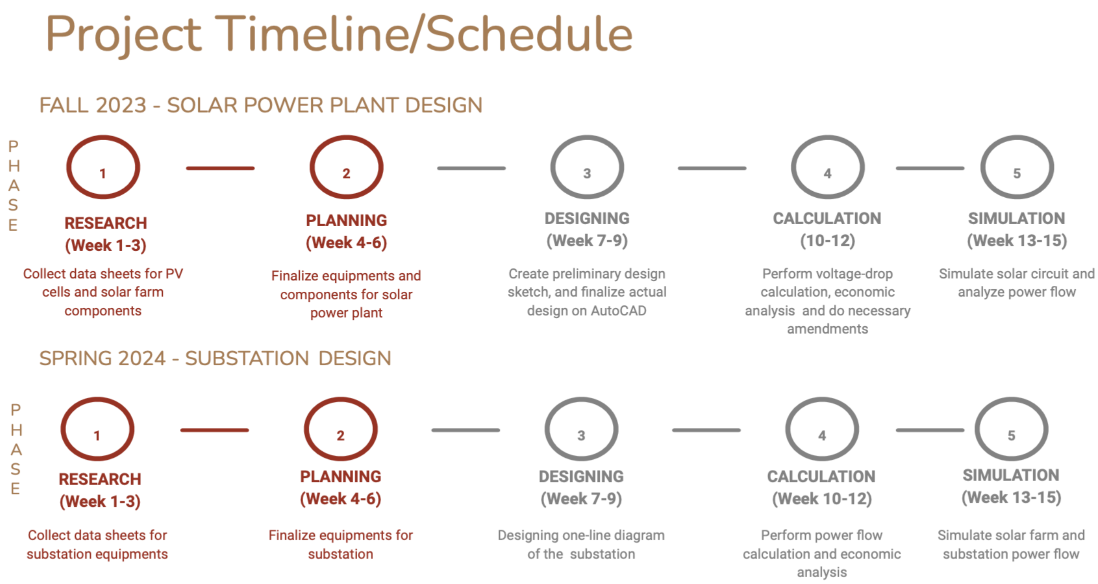


[Figure 3.4.1: Gantt Chart for Solar Power Plant Design for Fall 2023]



[Figure 3.4.2: Gantt Chart for Substation Design for Spring 2024]

The Figure below shows the summary of the Gantt chart above, displaying the design phases and each time frame allocated throughout the semester.



[Figure 3.4.3: Project Timeline]

3.5 Risks and Risk Management/Mitigation

3.5.1 Solar Farm

There are a lot of different risks that we have in our project. Some include technical, land and site, construction, financial, and policy risks. All of these risks can add up and cause a lot of potential mistakes that can happen in our project or the future. For our technical risks, we have technology selection and system design. This risk would be when we design something and don't fully understand the ratings or what amperage the wire can carry. If this were to happen, we would overload the wire and cause a fire or explosion. Another possible risk would be construction risks. This risk is out of project scope, but one that we need to consider in our design work. An example would be if a maintenance team worked in the arrays and then clipped a solar panel with a piece of equipment. We can mitigate this risk by giving more space in between the arrays. We found a larger piece of land than we need, so it shouldn't be an issue if we give extra space in the arrays.

We also have some hypothetical risks because we won't be constructing this array. We have identified some land, site, and financial and policy risks. Some land risks include acquisition risks, meaning someone else could buy the land out from under us, or we could lose in a bidding war with other companies. We also have a financial risk where we would have the risk of not being able to buy the property. We could also have trouble repaying a loan that we get when we purchase the land.

3.5.2 Substation

In the substation design process, several risks can impede progress. One significant challenge arises from the difficulty in sourcing relevant and compatible parts for designs, necessitating extensive research and calculation time to ensure optimal component selection. Another risk lies in scheduling constraints, requiring consistent meetings with clients and faculty even when inconvenient, leading to increased internal and external communications to maintain seamless connectivity with all stakeholders. Additionally, challenges with access and organization in software tools like ETAP and AutoCAD can hinder workflow efficiency. To mitigate these risks, detailed filing conventions have been established to prevent confusion, and proactive measures are taken to address issues before they escalate and cause disruptions.

Managing the challenges in substation design encompasses several key strategies. Firstly, to address the difficulty in sourcing compatible parts, we maintain an updated database and cultivate strong supplier relationships, while also implementing rigorous compatibility checks during the design phase. Secondly, scheduling constraints are managed by prioritizing tasks, utilizing agile methodologies, and leveraging collaborative scheduling tools to ensure alignment with client and faculty demands. Thirdly, to mitigate issues with ETAP and AutoCAD, we enforce detailed filing conventions, provide regular training, assign dedicated personnel for technical support, and utilize version control systems to maintain organization and efficiency in our design workflow. These measures collectively enable us to navigate the complexities of substation design while maintaining seamless communication with the clients.

3.6 Personnel Effort Requirements

3.6.1 Solar Farm (Fall 2023)

Task	People	Expected Person-Hours
Solar Power System Simulation	Chicheng & Baylor	10
Requirements and Values	Baylor	5
Simulation	ALL	20
Data Sheets for Equipment	ALL	10
Safety Moment	ALL	3
Location Selection	Bell	6
Material Component List	Liam	7
Sizing	Chicheng	4
Total Equipment	Eduardo	6
Total Cost	Eli	10
Total Power (AC & DC)	Liam	6
Calculations	Bell/Chicheng	7
Solar Panel Plan	Eduardo	5

Array	Baylor	8
Rack	Eli/Baylor	3
Solar Layout	Liam/Chicheng	5
Solar Field Design	Bell/Eduardo	15

[Table 3.6.1: Fall 2023 Personnel Requirements]

3.6.2 Substation (Spring 2024)

Task	People	Expected Person-Hours
Substation System Simulation	Eli	10
Requirements and Values	Baylor	5
ETAP Simulation	Baylor/Chicheng	20
Data Sheets for Equipment	ALL	10
Safety Moment	ALL	3
Bus calculation	Bell	6
Material Component Selection	Liam	6
Conductor sizing/research	Baylor/Chicheng	4
Total Equipment	Eduardo	6
Total Cost	Eli	10
AC and DC load calculation	Bell/Liam	6
Grounding Calculations	Bell	10
Substation Keyplan	Eduardo	10
Ring bus configuration	Baylor	8
Grounding	Eli/Baylor	10
Control House	Liam/Chicheng	5
One-line & Three-line diagram	Eli/Eduardo	15

[Table 3.6.2: Spring 2024 Personnel Requirements]

3.7 Other Resource Requirements

In the preparation of solar farm and substation designs, software tools play a pivotal role in ensuring accuracy, efficiency, and adherence to safety standards. AutoCAD is utilized for various schematic drawings including one-line diagrams, three-line diagrams, key plans, bus configurations, as well as wiring and conduit layouts. These drawings are essential for visualizing the electrical infrastructure and facilitating communication among design teams. Excel is instrumental in performing critical calculations such as AC and DC loads, bus force analysis, and grounding calculations, providing a structured approach to managing complex data. Additionally, ETAP is employed for comprehensive simulation tasks, particularly in solar farm and substation designs, enabling engineers to simulate power flow and conduct short circuit tests, thereby ensuring the reliability and stability of the electrical network under different operating conditions. These software tools collectively contribute to the seamless execution of design processes and the optimization of solar farm and substation performance.

4 Design

4.1 Design Content

Our project requires us to design several key features of the solar farm and substation. We must choose each array's solar panels, combiner boxes, and inverters for the solar farm. We must set up each array so that the solar farm's desired power output is met while not overloading or underloading each piece of equipment. For the substation, we must choose a bus layout to construct and the specific connections and equipment used. We must also analyze the substation for fault protection and design the protection methods to maintain safe operations.

4.2 Design Complexity

Our project contains multiple connected subsystems that each utilize distinct engineering principles. For the solar farm, each piece of equipment needs to be selected to meet the parameters of the overall farm but also selected to be compatible with each other. This means that voltage, current, and temperature ratings need to fit with the ratings of the other equipment while also being sufficient to fit the needs of the farm and the location it is built. These factors are related to the principles of efficiency and iteration, as many different component combinations must be iterated to find the most efficient setup.

Another design aspect of our project is the physical layout of the farm. The farm must be set up in a layout that fits the physical plot of land chosen for the farm, having all necessary access points and enough space for maintenance. This process is related to the principle of simplicity, as the arrangement of the arrays should not be needlessly complicated to avoid unnecessary expenses or inefficient land use.

The design of the substation is another component of our project that requires complex design. The layout of the substation and the protective equipment must be carefully analyzed to ensure faults are avoided, and reliable operation is maintained. This piece of the project is related to the principles of reliability and quality, as the substation must be designed to create the minimal expected number of outages and require the least amount of maintenance.

4.3 Modern Engineering Tools

Here are a few tools we expect to use during our project. There is some description of tasks to go along with it:

AutoCAD: Sheet/view editing software, Layout, Solar/substation design-optimizing tool

Bluebeam Revu: Sheet viewing software, markups from Industry professionals

ETAP: Coordination Study, AC Arc Flash Study, and Protection Element Analysis, Simulation of Designed Substation

Microsoft Excel: Equipment sizing calculations, voltage drop calculations, String sizing calculations, Grounding analysis, Bus calculations, DC Battery Bank calculations,

4.4 Design Context

4.4.1 Impact of the project

The target user of the 60MW solar farm & 115/34.5kV Substation design project primarily encompasses a diverse range of beneficiaries residing in New Mexico, with a special focus on the community of Lovington. This includes residential consumers, who will enjoy access to clean and sustainable energy for their homes, promoting energy efficiency and reducing utility costs. Additionally, commercial and industrial consumers stand to benefit from reliable and cost-effective electricity, fostering economic growth and competitiveness in the region. Moreover, government facilities will leverage the solar power generated to fulfill their energy needs sustainably, aligning with environmental initiatives and demonstrating a commitment to renewable energy adoption. Overall, the project caters to a broad spectrum of users, facilitating a transition towards a greener and more resilient energy infrastructure for the benefit of the entire community in terms of public health, global impact, environmental impact, and economical impact.

1. Public Health:

   Regarding public health and welfare, solar energy directly and indirectly affects the broader community. The direct impact is most evident in the physical placement of commercial solar facilities. Conventional solar plants necessitate extensive tracts of open land, a characteristic that may sometimes pose disruptions or inconveniences for nearby residents. Indirectly, commercial solar energy reduces the need for fossil fuels in electricity production. As a result, this reduction in air pollution plays a pivotal role in mitigating the prevalence of respiratory illnesses, particularly in communities near coal and natural gas facilities. With improved air quality from decreased pollution levels, a subsequent reduction in healthcare costs associated with respiratory diseases and other health conditions linked to air pollution becomes a tangible benefit.

2. Global Impact:

As the world shifts towards using renewable energy to counter climate change and other environmental impacts, governments and the general public have become much more receptive to the building and use of renewable alternatives. Solar and wind energy are on the leading edge of renewable energy worldwide. Commercial solar energy reduces greenhouse gasses being released into the atmosphere. Little to no emissions are produced through solar energy. The surge in solar energy production also fosters international cooperation. The exchange of ideas and knowledge among nations regarding renewable energy contributes to mutual understanding and strengthens diplomatic ties for the future.

3. Environmental Impact:

Commercial solar energy usage has some notable direct environmental drawbacks, primarily regarding the initial resource requirements for manufacturing solar panels and related equipment. However, it's crucial to emphasize the substantial, positive indirect benefits it offers in clean energy production. While producing solar panels necessitates utilizing natural resources, solar power plants, once constructed, do not entail ongoing resource consumption.

One direct environmental concern is the potential disruption of local biodiversity in the areas where solar fields are situated. Researchers are beginning to test the possibility of growing plants or crops under and around solar fields. Furthermore, certain interest groups are also bringing animals to graze on the grass that grows in and around solar fields. While solar power plants require large amounts of land, movements are being made to better use the land while the solar field is there.

4. Economical Impact:

The transition to solar energy significantly increases the demand for jobs in various sectors. The construction phase of solar power plants and installations calls for a skilled workforce, including engineers, electricians, and laborers. Additionally, the operation and maintenance of these facilities require technicians, maintenance workers, and monitoring staff. The adoption of renewable energy sources, like solar power, leads to a decrease in energy costs for both individuals and businesses. Solar panels and power plants generate electricity from a free and abundant energy source – the sun. Governments often incentivize the adoption of solar energy by providing tax exemptions, rebates, and other financial incentives. These measures make it more financially attractive for businesses to invest in solar power. The growth of the solar energy industry contributes significantly to economic stimulation. Investments in solar infrastructure, manufacturing, and research and development lead to a surge in economic activity. This growth impacts the solar sector and ripples through the entire supply chain, from raw material production to the transportation and installation of solar components.

Considering the design's overarching context is important to ensure your design continually mitigates any negative impacts on the categories discussed above. Furthermore, it motivates the group to consider each design option and ensure nothing negatively impacts a certain interest group. The group worked to remind ourselves of the importance of context through our design process.

4.4.2 Development Standards & Practices

In the dynamic realm of energy infrastructure, developing and adhering to industry standards plays a pivotal role in ensuring the safety, reliability, and efficiency of power generation and distribution systems. This project is a testament to the commitment to excellence, incorporating best practices from renowned organizations such as the National Electrical Code (NEC) and the Institute of Electrical and Electronics Engineers (IEEE).The design shall meticulously incorporate NEC provisions related to electrical installations, grounding, overcurrent protection, and equipment integrity. Compliance with NEC standards enhances safety and facilitates seamless integration with the broader electrical infrastructure. The IEEE, a globally recognized authority in advancing technology, provides a comprehensive framework for designing and operating electrical and electronic systems. For this project, IEEE standards, particularly those about substation design, equipment specifications, and power system reliability, serve as guiding principles. Adhering to IEEE standards ensures the project's alignment with global best practices, fostering interoperability, resilience, and optimal performance.

Practice Code	Standards Description
NEC690.8(B)	Overcurrent ratings shall not be less than 125% of the max current calculated
NEC690.8(A)	The maximum current shall be the sum of the short-circuit current ratings of the PV modules connected in parallel multiplied by correction multiplier, 125 percent.
NEC690.9	PV system DC circuit and inverter output conductors and equipment must be protected against overcurrent.
NEC240.6	240.6(A) Fuses and Fixed-Trip Circuit Breakers. The standard ampere ratings for fuses and inverse time circuit breakers shall be considered 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110, 125, 150, 175, 200, 225, 250, 300, 350, 400, 450, 500, 600, 700, 800, 1000, 1200, 1600, 2000, 2500, 3000, 4000, 5000, and 6000 amperes.
NEC 210.19	Voltage drop would be 2% from the DC side and 1% from the AC side
NEC Table 8 Conductor Properties & NEC AWG Chart	Provides information on conductor properties, including ampacity, insulation types, and other specifications. NEC AWG Chart provides information on the ampacity of conductors based on their size (gauge) and the type of insulation, which is crucial for ensuring that the conductors used in electrical installations can safely carry the expected current without overheating.
Lovington & Lea County Ordinance	The fence, wall, or barrier required by [this subsection] shall not be less than eight (8) feet in height with no openings, holes, or gaps larger than four (4) inches measured in any direction. As required by this section, gates and doors opening directly into the area enclosed by a fence, wall, or barrier shall be equipped with a lock to keep the doors or gates securely closed and locked at all times. Tower sites located within industrial yard

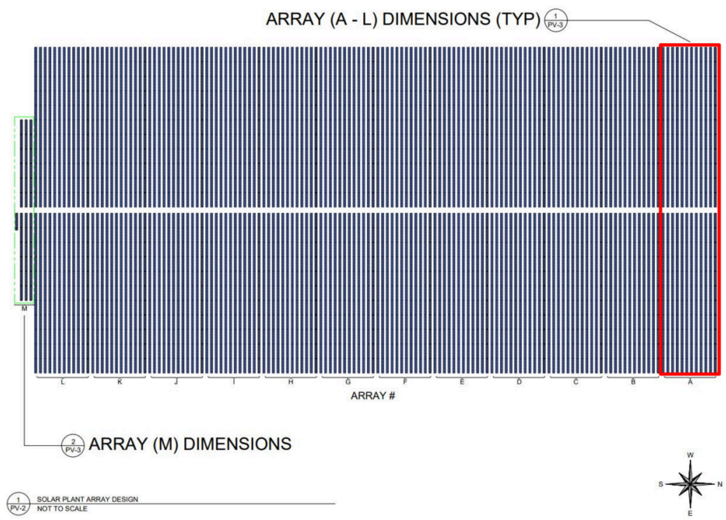
	areas with existing secure fencing of the entire yard may construct secure fencing six (6) feet tall.
IEEE 80-2013	IEEE Guide for Safety in AC substation grounding,
IEEE 998-2012	IEEE Guide for Direct Lightning Stroke Shielding of Substations
IEEE 485 -2020	**IEEE** Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications
IEEE 605- 2008	**IEEE** Guide for Bus Design in Air Insulated Substations.
IEEE 1184-2006	**IEEE** Guide for Batteries for Uninterruptible Power Supply Systems

[Figure 4.4.2.1: Design Standards & Practice]

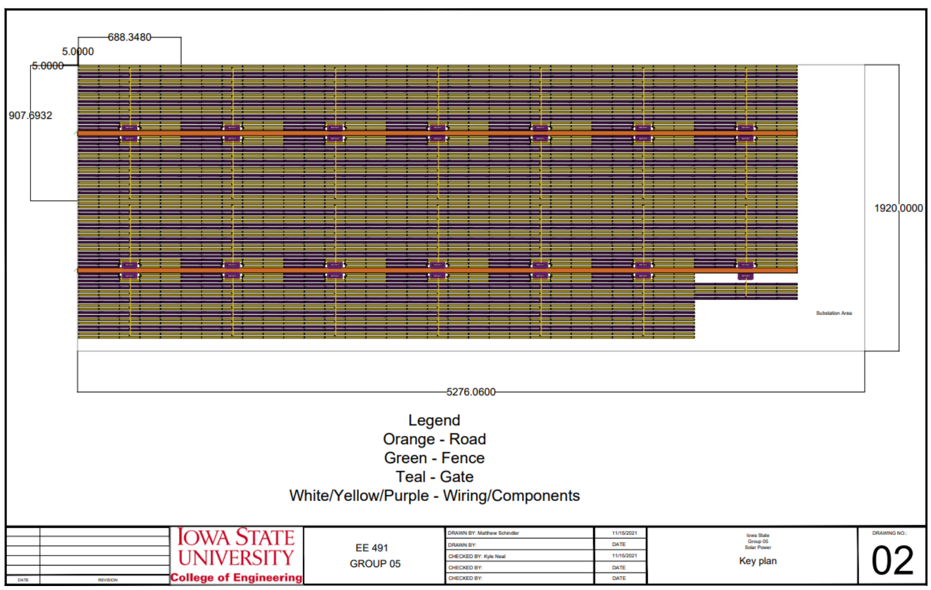
4.5 Prior Work/Solutions

Black & Veatch has sponsored this specific senior design project for several years. Furthermore, Black & Veatch has gone through the design process with their engineers. The group has several previous solutions to use only if needed. The group has made a point to use these previous solutions only when needed. Our selection of equipment and location of design makes it difficult to rely on any other previous projects. Beyond the scope of Iowa State University and Black & Veatch, commercial solar power plants are a continually growing renewable resource alternative. These projects outside the scope of our requirements are hard to use as a reference because any given product can differ greatly depending on several variables.

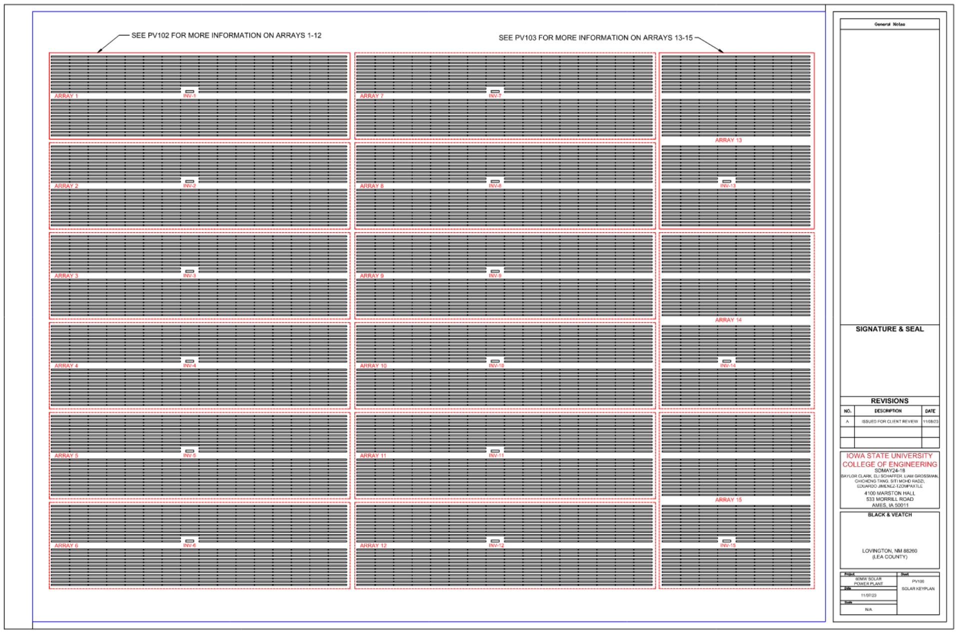
Some previous work done for this company and senior design projects can be viewed with these links, and we can compare some of their design choices with ours. Here are the links for the sdmay20-14 project, the sdmay21-37 project, the sdmay22-05 project, and the sdmay23-27 project. We can see that the project done in 2023, shown in Figure 4.5.1, has 13 different arrays with two different array sizes. We also have 2 different array sizes due to size restrictions in our plot of land. Figure 4.5.2 shows the work done by the 2022 senior design team. They used 22 inverters for their design, while we only used 15 inverters with them all balanced, which can be seen in Figure 4.5.3.



[Figure 4.5.1: sdmay23-27 Overall Array Layout]



[Figure 4.5.2: sdmay22-05 Overall Array Layout]



[Figure 4.5.3: sdmay24-18 Overall Array Layout]

We can see some topics as well as some pros and cons for those topics in figure 4.5.3. Some background we needed for this project was the knowledge of solar panels and their work. We also needed to understand how voltages and currents combine so we could rate the right equipment for the right purposes.

Topic	Pros	Cons
Solar Panel	550 W 41.1 V which gives us a nice string voltage of 1500 V	Limits 1 strings/rack
Combiner Box	1500 V rated and a price per combiner box	Only 16 inputs
Skid Inverter	4 MW so we only need 15 inverters for the project	Dual Output

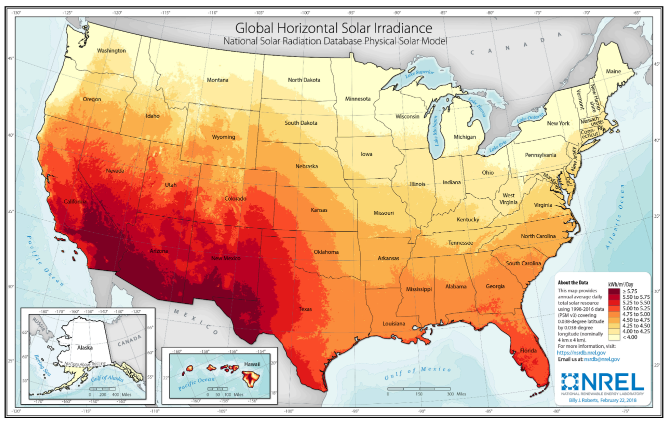
[Table 4.5.4: Pros and Cons For Our Design Choices]

There are many other solar farms and substation combos, but we can't use those designs because they belong to a company, and we don't have access to them. Our project differs from most solar farms because we use one rack to one combiner box. We also used a 4 MW skid inverter, which is uncommon in farms because of the size we need to achieve. There are many different options for designing a solar farm, so each design is unique.

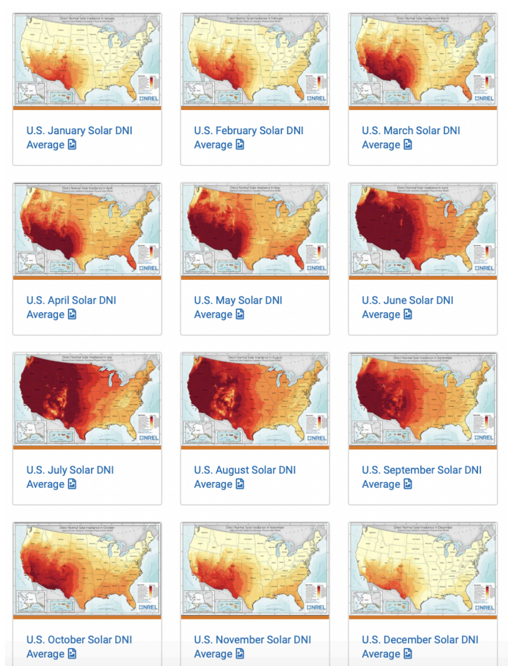
4.6 Design Decisions

4.6.1 Location

Our project will conceptually be in Lovington, New Mexico since it is a perfect candidate for producing power with a high level of sunlight and low amount of clouds throughout the year. New Mexico generally has a superior solar resource with higher solar irradiance and more sunny days throughout the year. This results in higher energy production and potentially better ROI.Solar resources of 5.00 - above 5.75 kWh/m2 per day are among the highest in Arizona, California, and Texas.



[Figure 4.6.1.1: Solar irradiance across U.S]



[Figure 4.6.1.2: Solar irradiance throughout the year]

Realistic average daily solar insolation by month ($kWh/m^2/day$)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2.835	3.592	4.645	5.587	5.932	6.321	5.954	5.503	4.460	3.792	2.885	2.410

[Figure 4.6.1.3: Solar insolation of Lovington, New Mexico

There are several solar energy projects around Lovington, New Mexico, which shows that the area/location is a strategic location, whereas the solar radiation, access to water supply, labor and maintenance resources, and grid connection are reliable. Land costs can vary significantly in New Mexico, but land may be more affordable in many areas than in regions with high agricultural demand. Land in southern New Mexico, particularly in rural areas, is often more affordable than other regions with high population density. Lower land costs can significantly reduce the overall project expenses, making it economically attractive for solar developers. One of the cheapest in the US, approximately $1931 per acre. 60 MW solar farm would need approximately 230 acres (estimate 1 kWh per sq ft) + 20 acres (for substation) = 250 acres. Estimated Cost = $2000 X 250 acres = $500,000.

This is our chosen location for the solar farm and substation in Lovington, New Mexico. It is a ranch with flat land with a size of 406 acres costing $609,000. It is also on the border of New Mexico and Texas, which makes the laws and other regulations more difficult to follow.

[Figure 4.6.1.4: Site location]

4.6.2 Solar Farm

The group experienced a number of different design decision iterations. Component selection had to be reassessed due to change in technical specifications and pricing availability. Furthermore, limitations on space and required functionality lead out decision making. The combiner box has a capacity of 1,500 V, 16 inputs, 1 output, and will cost about $1812. The skid is an inverter transformer combination. The skid has a capacity of 1500 volts and can output 4600 kVA in AC. The solar panel changed from the original selection, but we decided to pick a panel with a capacity of 550 watts and an efficiency of 21.48%. The open circuit voltage for the panel is 50.2 volts with a short circuit current of 13.89 amps each. The cables connecting from the combiner box to the inverter are #10 AWG sizing. Following the NEC wire sizing table a 600 MCM wire is needed from the inverter to the substation.

In order to account for the loss through the inversion process, the solar farm was designed with an input of 78 MW in DC to 60 MW AC since there will be a loss of power when converting from DC to AC. The connection of each component was arranged in the order of a solar panel, combiner box, inverter, transformer, and to the grid/substation. The solar farm consists of 15 array modules stacked in 2 columns with 6 rows for one set and 1 column with 3 rows for a different set due to constraints on the land the group has selected.

4.6.3 Substation

The design process for the substation mirrored that of the solar farm in its emphasis on component selection. However, the substation decisions involved greater complexity due to factors like bus configuration, component layout, and detailed specifications. After careful consideration, the team opted for a ring bus layout to optimize reliability and safety within the solar farm context. This choice proved relatively straightforward, as the ring bus demonstrably suited the system's needs and aligned with past project designs.

Component selection and specifications comprised another significant aspect of the decision-making process. Substations necessitate a diverse range of components, including current transformers (CTs), circuit breakers, switchgear, and transformers. To ensure accurate design choices, the team consulted with Black & Veatch, a leading engineering firm. Throughout the process, some components required adjustments to meet the project budget and design constraints.

Finally, the semester culminated with decisions regarding protection and relays – a domain where the team's knowledge was limited. Black & Veatch's expertise proved invaluable in navigating this critical design aspect. Overall, the design decision-making process served as an essential training ground for future engineering careers. Large-scale projects like this one highlight the importance of balancing informed decision-making with timelines to keep projects on schedule.

4.6.4 Cost

The cost of a solar farm and solar substation can be estimated by compiling a comprehensive bill of materials (BOM) that includes all the necessary components for implementation in the real industry. By summing up the total prices of all components listed in the BOM, we can determine the overall cost of the solar farm and substation project. This detailed breakdown ensures transparency and accuracy in cost estimation, enabling project planners to budget effectively and make informed decisions throughout the implementation process. Attached below are the Bills of Materials for solar farm, substation, and miscellaneous.

4.6.4 .1 Bill of Materials (BOM)

Solar Component							
Component Type	SKU/Model Number	Quantity	Price	Datasheet Link	Total Price	Pricing Link	
PV Panels	ZXM7-SHDB144-550/M	143250	$270.00	Link	$38,677,500.00	Link	
Combiner Boxes	BHSZ-16-1-1500V	360	$1,921.00	Link	$691,560.00	Link	
Inverters	PVS980-MWS-4000kVA-K-34.5-Dry	15	$200,000.00	Link	$3,000,000.00	Page 31	
2" Conduit	2 in. x 10 ft. Sch. 40 PVC Conduit	6960	$25.90		$180,264.00	Link	
3" Conduit	3 in. x 10 ft. PVC Schedule 40 Conduit	2450	$60.78		$148,911.00	Link	
600 MCM		21128.92	$15.65		$330,667.60	Link	
10 AWG		1395	$0.38		$530.10	Link	
					$0.00		
					$0.00		
					$0.00		
					$0.00		
					$0.00		
					$0.00		
					$0.00		
				Total Solar Farm Cost	$43,029,432.70		

[Figure 4.6.4.1: Solar Farm Bill of Materials]

Substation Component							
Component Type	SKU/Model Number	Quantity	Price	Datasheet/Website Link	Total Price	Pricing Link	
SEL-411L	0411L1X6X1C7CDXH5C424XX	1	$11,170.00	Link	$11,170.00	Link	
SEL-311L	0311L03C0325XXXX	1	$6,920.00	Link	$6,920.00	Link	
SEL-487E	0487E3X611XXC5X5H675XXX	1	$8,860.00	Link	$8,860.00	Link	
GE Multilin T35	T35J03AKHF8MH6DM8RP6EU67WXX	1	$4,500.00	Link	$4,500.00	Link	
SEL-587E	0587Z02325312XX	1	$2,740.00	Link	$2,740.00	Link	
ABB REU615	2rca025340a0001b	2	$750.00	Link	$1,500.00	Link	
SEL-352	035211425H2X4XX	2	$4,690.00	Link	$9,380.00	Link	
CB1	OHB 36.25.25	3	$35,000.00	Link	$105,000.00	Circuit Breaker (35 kV)	
CB2	SPS2-123-40-2	1	$95,500.00	Link	$95,500.00	Circuit Breaker (115kV)	
DS1	EV-H	8	$7,000.00	Link	$56,000.00	Discon. Switch (34.5 kV)	
DS2	65742-A	2	$20,000.00	Link	$40,000.00	Discon. Switch (138 kV)	
LA1	PEXLIM Q36-XN36 (H)	6	$500.00	Link	$3,000.00	Surge Arrestor (34.5kV)	
LA2	AZES013G115144	3	$2,000.00	Link	$6,000.00	Surge Arrestor (138kV)	
T1 (Power XFMR)	SF-9000000/15	1	$2,000,000.00	Link	$2,720,000.00	Page 7	
T2 (Station Power)	MT-PML-R50-1P-GMA-50KVA-SZ-LT-DF-Z6-BB-CS-2BZ-M1	1	$18,641.04	Link	$18,641.04	Link	
CT2	OSKF123	6	$15,000.00	Link	$90,000.00	Current XFMR (138kV)	
PT1	G840520TA	3	$2,000.00	Link	$6,000.00	Volt XFMR (34.5kV)	
PT2	Unavailable	1	$7,000.00	Link	$7,000.00	Cap Volt XFMR (138kV)	
Battery MTS	GF224NR	1	$842.73	Link	$842.73	Link	
Battery Backup	3CA-5M	20	$1,152.75	Link	$23,055.00	Link	
				Total Substation Cost	$3,216,108.77		

[Figure 4.6.4.2: Substation Bill of Materials]

Misc Component							
Component Type	SKU/Model Number	Quantity	Price	Datasheet/Website Link	Total Price	Pricing Link	
Bus Bars					$0.00		
Fence (50' Segment)		340	$633.00		$215,220.00	Link	
					$0.00		
					$0.00		
					$0.00		
					$0.00		
					$0.00		
					$0.00		
					$0.00		
					$0.00		
					$0.00		
					$0.00		
					$0.00		
					$0.00		
				Total Misc Cost	$215,220.00		

[Figure 4.6.4.3: Misc. Bill of Materials]

The BOM lists various components such as solar panels, inverters, mounting structures, cables, transformers, switchgear, and miscellaneous items required for the installation. Each component is specified with its type, model number, quantity needed, unit price, total price, and a link to the datasheet and pricing for reference. The total cost for a solar farm is $43,029,432.7, the substation is $3,216,108.77, and the miscellaneous is $215,220.00, all summed to a total of $46,460,761.47.

4.6.4 .2 Cost Analysis

In the cost analysis for designing a 60MW solar farm, we began by considering key factors such as the solar field's rating and the average hours of sunshine per year, which stood at 6.6 hours per day, totaling 2400 hours annually. We evaluated both fixed and one-axis tracking systems, factoring in their respective efficiencies.

Economic Cost Analysis

Solar Field Rating (MW) (Fixed Axis)	Hours of sunshine/year	Average Monthly Electricity Cost (cents/kwh)
60MW	6.6/day = 2400/year	14.71

Assumed Efficiency	
Inverter	0.8
Indirect sunlight	0.7

Solar Field Rating (MW) (Axis Tracking)	PPA	Axis Tracking Efficiency
74.85MW	$49/MWh	0.2475
		Annual 7,762,532.66

Hours of sunshin	ws.com/blog/peak-sun-hours-explained
Average monthly	gy.com/resources/electricity-bills-by-state/
ninverter	
nindirectsun	
PPA	North American Solar and Wind PPA Prices Increased 6.6 ...LevelTen Energyhttps://www.leveltenenergy.com › post
O&M	
Payback period	MQFnoECC4QAQ&url=https%3A%2F%2Fwww.energysage.com%2Fsolar-panels%2Fnm%2F&usg=AOvVaw36O5dbAHZvRAaloVuX0hfL&opi
CF	l.com%2Fmarketintelligence%2Fen%2Fnews-insights%2Fresearch%2Fusual-sun-states-shine-bright-at-top-of-us-solar-capacity-factor-leader
Price	0.16/kwh
Tracking Cost	cker-cost%2F%23%3A~%3Atext%3DHigh%252Dperformance%2520single%252Daxis%2520GPS%2C%253A%2520%25240.08%2520%25

Fixed Tilt (No axis tracking) — 5.8 kw

Installation cost ($)	O+M/year	Infaltion rate (%)	Annual Revenue	Space Cost (Acre/MW)
63,912,000	348,000	3.7	15,277,467	4-5

Cash flow

Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
63,912,000	14,929,467	14,941,884	14,953,857	14,965,404	14,976,538	14,987,275	14,997,629	15,007,614	15,017,242	15,035,481

Present Value

Year	Installation cost	O+M	Revenue	Profit
10	63,912,000	2419868.02	149,812,392	147,392,524

1-axis tracking) — 6.96 kw

Installation cost ($/MW)	O+M/year	Infaltion rate (%)	Annual Revenue	Space Cost (Acre/MW)
71,712,000	417,600	3.7	22,622,400	4-7

Cash flow

Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
71,712,000	22,204,800	22,189,349	22,173,326	22,156,710	22,139,480	22,121,612	22,103,082	22,083,868	22,063,942	22,043,279

Present Value

Year	Installation cost	O+M	Revenue	Profit
10	71,712,000	2903841.623	221,279,447	218,375,606

[Figure 4.6.4.4: Solar Farm Cost Analysis]

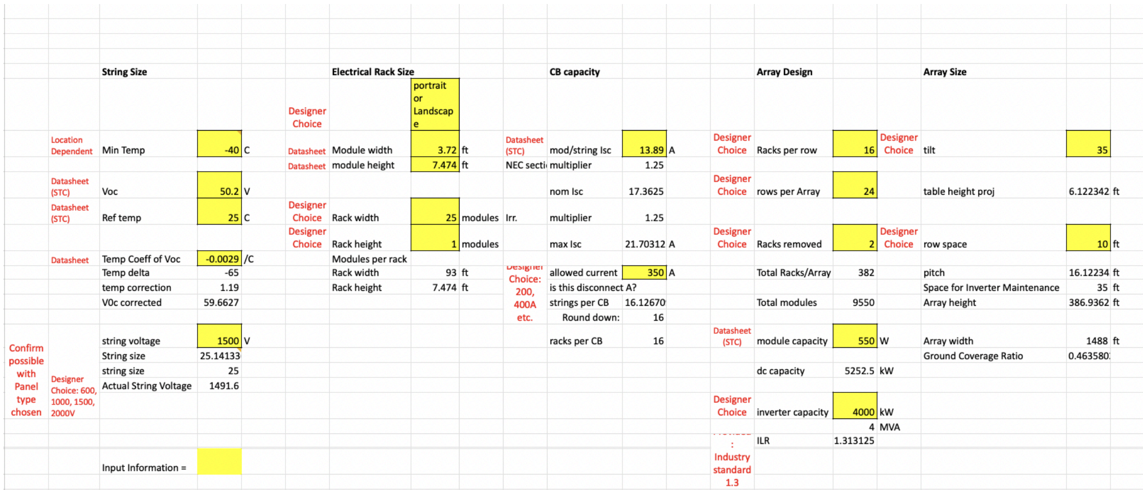
Our analysis aimed at calculating the cash flow over a 10-year payback period and determining the present value of the investment. By comparing the financial outcomes of the fixed and one-axis tracking systems, we gained insights into their long-term economic viability and efficiency.

4.7 Proposed Design

4.7.1 Design 0 (Initial Design)

4.7.1.1 Solar Farm

Initially, we researched strategic locations such as solar sites to compare locations in Iowa and New Mexico. We have decided to locate the solar power plant and substation at Lovington, New Mexico, due to high irradiation throughout the year and lower land cost, which would be cost-effective and profitable. Next, we went through the process of surveying the suitable components, solar panels, combiner boxes, and inverters by taking note of the power rating, efficiency, and compatibility with the condition and weather of the proposed location. Then, we continued estimating the DC power output using the information from the components data sheet and analyzed them to fit our design criteria. DC power output was around 79 MW to produce a net AC power output of approximately 60 MW, using the Array Parameter Tools provided by Black and Veatch. Our current design component is shown below.



	String Size		
Location Dependent	Min Temp	-40	C
Datasheet (STC)	Voc	50.2	V
Datasheet (STC)	Ref temp	25	C
Datasheet	Temp Coeff of Voc	-0.0029	/C
	Temp delta	-65	
	temp correction	1.19	
	V0c corrected	59.6627	
Confirm possible with Panel type chosen; Designer Choice: 600, 1000, 1500, 2000V	string voltage	1500	V
	String size	25.14133	
	string size	25	
	Actual String Voltage	1491.6	
	Input Information =		

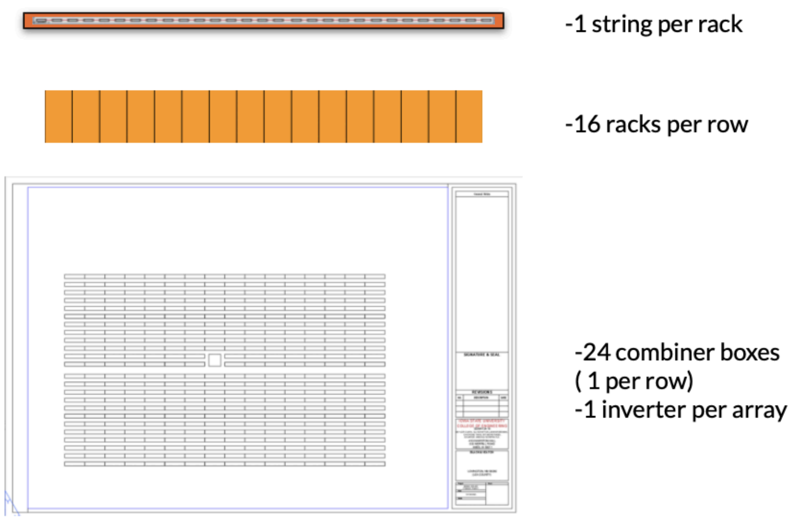
	Electrical Rack Size		
Designer Choice		portrait or Landscape	
Datasheet	Module width	3.72	ft
Datasheet	module height	7.474	ft
Designer Choice	Rack width	25	modules
Designer Choice	Rack height	1	modules
	Modules per rack		
	Rack width	93	ft
	Rack height	7.474	ft

	CB capacity		
Datasheet (STC)	mod/string Isc	13.89	A
NEC secti	multiplier	1.25	
	nom Isc	17.3625	
Irr.	multiplier	1.25	
	max Isc	21.70312	A
Designer Choice: 200, 400A etc.	allowed current	350	A
	is this disconnect A?		
	strings per CB	16.12670	
	Round down:	16	
	racks per CB	16	

	Array Design		
Designer Choice	Racks per row	16	
Designer Choice	rows per Array	24	
Designer Choice	Racks removed	2	
	Total Racks/Array	382	
	Total modules	9550	
Datasheet (STC)	module capacity	550	W
	dc capacity	5252.5	kW
Designer Choice	inverter capacity	4000	kW
		4	MVA
: Industry standard 1.3	ILR	1.313125	

	Array Size		
Designer Choice	tilt	35	
	table height proj	6.122342	ft
Designer Choice	row space	10	ft
	pitch	16.12234	ft
	Space for Inverter Maintenance	35	ft
	Array height	386.9362	ft
	Array width	1488	ft
	Ground Coverage Ratio	0.463580	

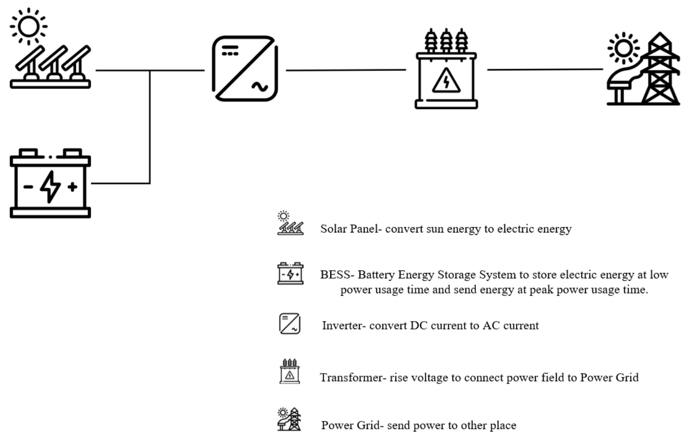
[Figure 4.7.1.1.1: Array Parameter Tool]



[Figure 4.7.1.1.2: Solar Rack Layout Design]

We have determined the location, the components, and the basic structure of the solar farm. Currently, we are using AutoCAD to design the structure of the solar power plant, for example, how to place all the solar panels, how to place the combiner box, how to connect the combiner box to the inverter, and finally to the substation.

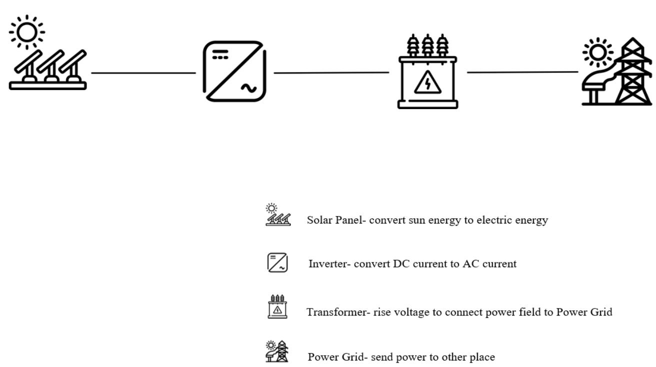
4.7.1.2 Substation



[Figure 4.7.1.2.1: Solar Rack Layout Design]

Solar power plants use solar panels to absorb sunlight. These panels are made of semiconductor materials (such as silicon) and can convert sunlight into direct current (DC) electricity. Since the power grid uses alternating current (AC), solar power plants need inverters to convert the DC power to AC power. Finally, the voltage is regulated to the desired level for the grid by using a transformer. Once the voltage is regulated properly, it can be fed into the grid. In the initial design, we used BESS (Battery Energy Storage System), which stores power from solar energy and releases it when it is unavailable, e.g., at night.

4.7.2 Design 1 (Design Iteration)



[Figure 4.7.2.1: Solar Rack Layout Design]

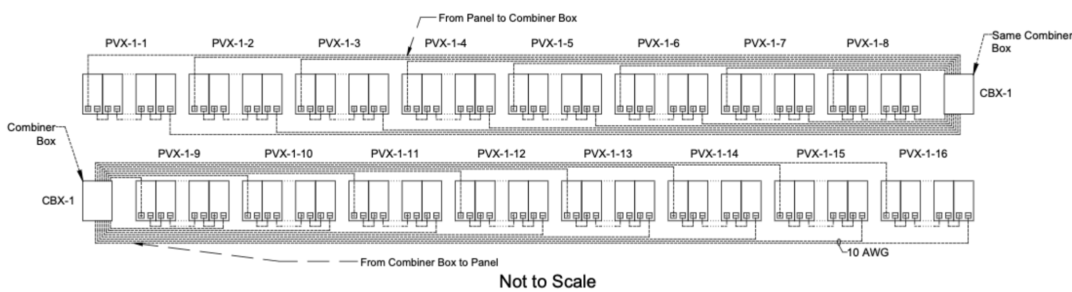
In the current design, we have eliminated the BESS system because our power plant is directly connected to the grid, so other regulation mechanisms may not require a large energy storage system. Secondly, the cost of a large energy storage system may be relatively high. According to the "*U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks: Q1 2021*," if we use a two-hour system, we need 120 MWh of batteries for our Solar farm, which would cost $857 per kWh, or about $100 million in total for batteries. Third, the production and disposal of batteries at this stage may cause environmental problems. For these reasons, we have decided to abandon the use of BESS.

4.7.3 Final Design

4.7.3.1 Solar Farm

In designing a solar farm, meticulous planning and precise execution are paramount. Beginning with detailed calculations, we craft a comprehensive blueprint utilizing AutoCAD software. Our design encompasses crucial elements such as the solar string diagram, mapping out the arrangement of panels for optimal efficiency. We meticulously outline the solar rack mounting profile, ensuring sturdy and efficient installation. The DC one-line diagram provides a clear visualization of the electrical connections, facilitating seamless energy flow. Meanwhile, the electrical site plan delineates the placement of inverters, transformers, and other key components. Additionally, the feeder site plan guides the routing of power distribution lines for maximum effectiveness. Lastly, meticulous attention is given to cabling, ensuring robust connectivity throughout the system. Through meticulous planning and precise drafting, our design endeavors to harness solar energy effectively and sustainably.

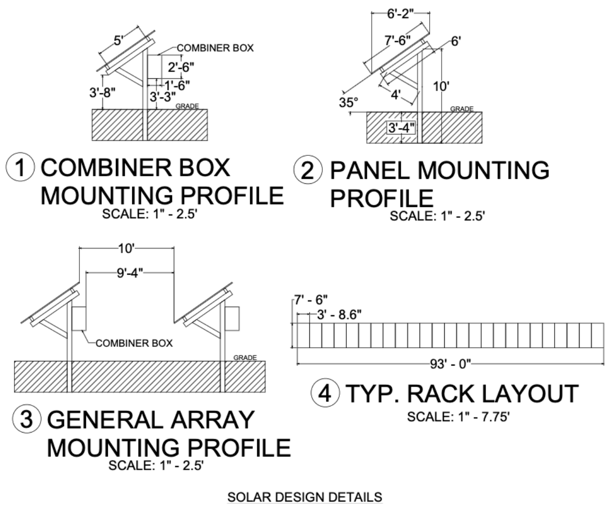
4.7.3.1.1 Solar String Diagram



[Figure 4.7.3.1.1: Solar String Diagram]

Our solar string diagram was meticulously designed, comprising 16 racks, each adorned with 25 modules of solar panels. These panels were seamlessly connected in series, optimizing energy production. Every string converged at a combiner box, efficiently consolidating the power generated. To ensure robust connectivity, we utilized 10 AWG wire connections throughout the system, guaranteeing reliable performance and minimal energy loss.

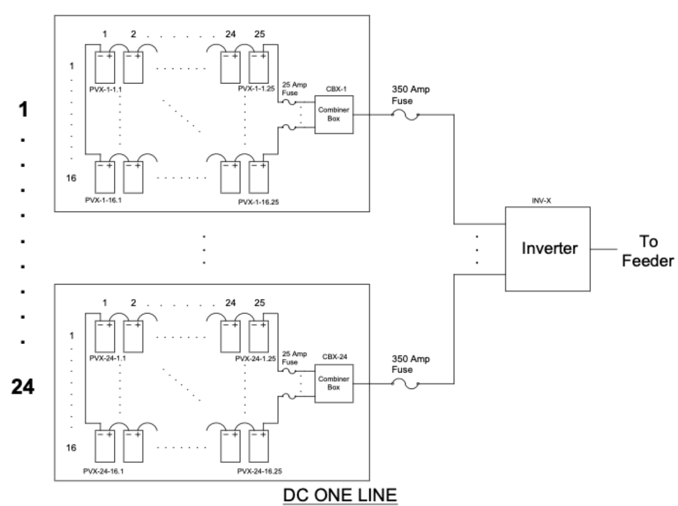
4.7.3.1.2 Solar Rack Mounting Profile



[Figure 4.7.3.1.2: Solar Rack Mounting Details]

Our solar rack mounting profiles were meticulously designed using AUTOCAD, ensuring precise sizing and scale for optimal installation. First, the combiner box mounting profile was crafted to securely hold the combiner box in place, ensuring efficient electrical connections. Second, the panel mounting profile was engineered to accommodate the solar panels securely, providing stability and durability against various environmental conditions. Third, the general array mounting profile was designed to offer flexibility and ease of installation for the entire solar array. Fourth, the rack layout was meticulously planned, incorporating the mounting profiles seamlessly to maximize space utilization and ensure a robust support structure for the solar panels.

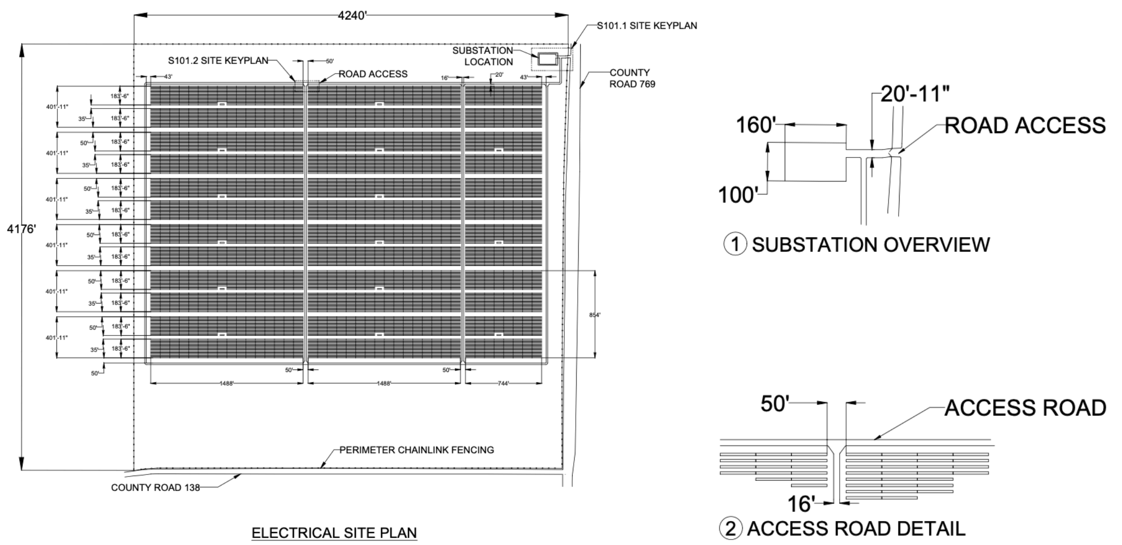
4.7.3.1.3 Solar DC One-Line



[Figure 4.7.3.1.3: Solar DC One-Line]

The solar farm's DC one-line diagram, meticulously designed, featured 24 rows of 16 racks, each hosting 25 modules, ensuring optimal sunlight harnessing, each connected to 16-input combiner boxes interconnecting to the inverter, facilitating the conversion to AC power seamlessly, the system boasted efficiency and reliability. Incorporating a robust protection system, including 350 Amps fuses, meticulously calculated to align with the array's maximum current allowance of 347 Amps, ensured safety and operational integrity. More details of the components are attached in the Appendix. Additionally, two racks were strategically removed to accommodate the placement of the inverter, optimizing functionality and space utilization.

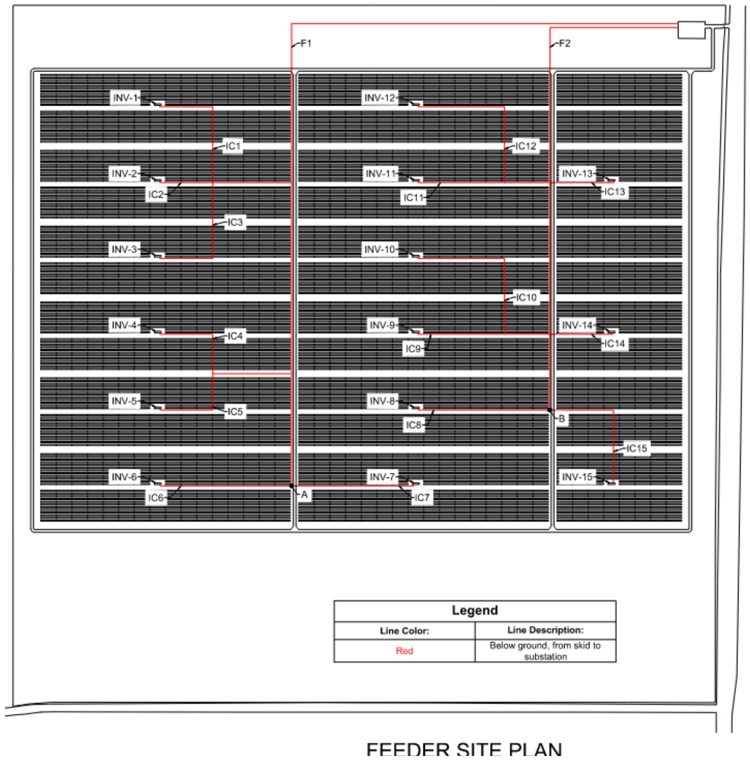
4.7.3.1.4 Solar Array Electrical Site Plan



[Figure 4.7.3.1.4: Solar Array Electrical Site Plan]

The solar array electrical site comprised a total of 15 arrays, with 12 arranged horizontally and 3 vertically due to land constraints on a 406-acre plot measuring 4240 by 4176 feet. For the overall array layout, the size is 3820 feet by 2655-6 feet. For each horizontal array, it is 401-11.25 feet in length by 1488 feet in width. The layout, depicted in a detailed drawing, showcased two road accesses positioned between three columns of arrays, each spaced 50 feet apart, allowing for 16 feet of road width. Adjacent to the site, a substation measuring 160 by 100 feet was erected, with an access road spanning 20 by 11 feet. Details for horizontal and vertical array layout is on Appendix.

4.7.3.1.5 Solar Array Feeder Site Plan and Cabling



CABLE NAME	CABLE LENGTH	START	END	SIZE	CONDUIT
F1	4778' - 4"	A	SUB	600 MCM	3"
F2	3043' - 3"	B	SUB	600 MCM	3"
IC1	1242' - 6"	INV-1	F1	600 MCM	3"
IC2	791' - 8"	INV-2	F1	600 MCM	3"
IC3	1243' - 6"	INV-3	F1	600 MCM	3"
IC4	1027'	INV-4	F1	600 MCM	3"
IC5	1008'	INV-5	F1	600 MCM	3"
IC6	791' - 8"	INV-6	A	600 MCM	3"
IC7	734'	INV-7	A	600 MCM	3"
IC8	794' - 5"	INV-8	B	600 MCM	3"
IC9	794' - 5"	INV-9	F2	600 MCM	3"
IC10	1246' - 5"	INV-10	F2	600 MCM	3"
IC11	794' - 5"	INV-11	F2	600 MCM	3"
IC12	1246' - 5"	INV-12	F2	600 MCM	3"
IC13	388' - 10"	INV-13	F2	600 MCM	3"
IC14	388' - 10"	INV-14	F2	600 MCM	3"
IC15	814' - 9"	INV-15	B	600 MCM	3"

[Figure 4.7.3.1.5: Solar Array Feeder Site Plan]

The solar array feeder site plan featured a meticulous arrangement of cabling details to optimize energy distribution. Inverters 1 to 7 were assigned to Feeder 1, while Inverters 8 to 15 were allocated to Feeder 2. Each inverter and feeder are labeled accordingly, denoted as INV-X and F-X, respectively. Beneath the ground, feeder lines extended from the skids of each inverter to the substation, ensuring seamless connectivity. The cabling system was designed with precision: Inverters 1, 2, and 3 were paralleled with Inverter Cables 1, 2, and 3, marked as IC-1, IC-2, and IC-3. Similarly, Inverters 4, 5, and 6 shared Inverter Cables 4, 5, and 6, labeled as IC-4, IC-5, and IC-6. Inverters 6 and 7 were linked via Inverter Cables 6 and 7, identified as IC-6 and IC-7. Inverters 8 and 15 were paired with Inverter Cables 8 and 15, designated as IC-8 and IC-15. The remaining inverters were connected in parallel arrangements with their respective cables, meticulously labeled throughout the site. We utilized 600 MCM cables and 3 feet conduits to ensure efficient energy transmission. The length of each inverter and feeder cable was clearly depicted, delineating the precise path from sending to receiving endpoints.

4.7.3.2 Design Calculation

Calculations for AC load, DC load, battery sizing, bus calculations, and grounding calculations are imperative in the design of solar power plants and substations. AC load calculations are essential to determine the amount of power needed to supply electrical appliances and systems efficiently. DC load calculations help in sizing the equipment and components necessary for converting solar energy into usable electricity. Battery sizing ensures that sufficient energy storage is available to meet demand during periods of low solar irradiance or at night. Bus calculations are crucial for designing the electrical distribution system, ensuring proper voltage levels and efficient power transmission. Grounding calculations are vital for safety, ensuring that the electrical system is properly grounded to prevent electric shocks and equipment damage. These calculations collectively ensure the optimal performance, reliability, and safety of solar power plants and substations, facilitating sustainable energy generation and distribution.

4.7.3.2.1 AC Load Calculation

AC load calculation for a control house in substation design is crucial to ensure that the electrical system can handle the expected loads under various conditions, especially during worst-case scenarios like transformer faults. By determining the worst-case tripping conditions, such as when a 115/34.5 kV transformer fault occurs, engineers can assess the demands placed on the system. Assumptions like 180VA load per outlet and specific environmental conditions like high temperature and deep battery discharge help in estimating the maximum load requirements accurately.

AC Panel - Control Building		Quantity	Load/Unit(W)	Amps (ea)	Voltage(V)	Total(W)	Amps Total
	Breaker Recepticle and Lights	4	210	1.75	120	840	7.00
	Transformer Fans	1	12,000	50.00	240	12,000	50.00
	Transformer Sump Pump	1	2,000	8.33	240	2,000	8.33
	Control House Lighting	20	36	0.30	120	720	6.00
	Yard Lights	6	55	0.46	120	330	2.75
	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
	AC Battery Charger	1	4,800	20.00	240	4,800	20.00
	Power Outlet	10	180	1.50	120	1,800	15.00
	Feeder Motor	2	720	3.00	240	1,440	6.00
		0	0	0.00	120	0	0.00
		0	0	0.00	120	0	0.00
	Worst Case Tripping:						
	High Side Breaker Motor	1	720	3.00	240	720	3.00
	Low Side Breaker Motor	3	720	3.00	240	2,160	9.00
	Total Worse Case AC Panel Load					37,092	171.10
	Total Worst Case Load (+10 %)					**40,801**	**188.21**

Sizing Recommendations:
Station Service - 50 kVA
MTS, Safety Switch - 200 A

[Figure 4.7.3.2.1: AC Load Calculation]

Calculating the continuous 120/240VAC single-phase loads allows for sizing recommendations of a 50 kVA station service and a 200A MTS safety switch, based on the total power and total amps, which are 40.8kW and 188.21, respectively, incorporating a 10% buffer to the final value ensures that the system can accommodate unexpected spikes in demand. This meticulous approach ensures the reliability and safety of the substation's electrical infrastructure, preventing potential failures during critical operations.

4.7.3.2.2 DC load & Battery Sizing Calculation

DC load calculation for solar and substation design involves determining how much power the DC loads used. This includes figuring out the power needs of appliances, lights, and other devices connected to the DC system. We also considered how often and for how long these devices will be used. Once we know the total power needed, we can choose the right size of solar panels and batteries to ensure we generate and store enough energy to meet these needs. For substations, we also factor in the power requirements of control circuits, communication gear, and monitoring equipment. Getting these calculations right helps us design solar systems and substations that are efficient, reliable, and cost-effective, while making the most of renewable energy sources.

DC Load Profile

Components	Load Current (A)	Nominal Voltage (V) DC	Inception and Active Shutout Time (Min.)	Power Requirement (remember to account for # of relays required)	Number of Components	Total Load Current (A)
34.5kV Breaker:	Tripping Current: 3.3A Closing Current: 2.6A	70 – 140 90 - 140	0 -1	231 - 343W 234 - 364W	3	Tripping Current: 9.9 A Closing Current: 7.8 A
115kV Breaker:	Tripping Current: 6.6A Closing Current: 3.6A	70 – 140 90 - 140	239- 240	462 - 924W 324 – 504W	1	Tripping Current: 6.6A Closing Current: 3.6A
SEL-411L (Line)	0.28	125	1 - 240	35 W	1	0.28
SEL-311L (Line)	0.2	125	1 - 240	25 W	1	0.2
SEL-487E (XFMR)	0.28	125	1 - 240	35 W	1	0.28
GE Multilin T35 (XFMR)	0.7	125	1 - 240	87.5 W	1	0.7
SEL-587E (Bus/XFMR)	0.044	125	1 - 240	5.5 W	1	0.044
ABB REU615 (Bus/Feeder)	0.144	125	1 - 240	18 W	2	0.288
SEL-352 (Breaker/Bus)	0.2	125	1 - 240	25 W	2	0.4
Battery Monitoring Equipment	0.024	50 -180	1 - 240	3VA	1	0.024
DC Ammeter	0.048	125	1 - 240	6VA	1	0.048
DC Voltmeter	0.048	120	1 - 240	6VA	1	0.048
SACO Annunciator (L8)	0.12	125	1 - 240	15 W	3	0.36
Edwards Bell	0.012	125	1 - 240	1.5VA	1	0.012
Power Line Indicating Lamps (LEDs)	0.017	125	1 - 240	2.125 W	8	0.136

60 cell system	Continuous Load	Discontinuous Load Current
	2.82	9.9

Power Supply Burden (W)	T = 0	T = 1 min	T = 240 min
	19.32	2.82	14.22

[Figure 4.7.3.2.2: DC Load Calculation]

To calculate the DC load for both solar and substation design, we considered the load profile of various components along with their respective current, nominal voltage, and operational time. For instance, the 34.5kV and 115kV breakers have different tripping and closing currents, influencing their power requirements. Similarly, equipment like SEL-411L, SEL-311L, and others have specific load characteristics contributing to the overall load current. Additionally, power supply burdens, such as those for the 60-cell system, should be accounted for across different time intervals. By summing up the power requirements of individual components over their respective operational times, along with considering continuous and discontinuous loads, we accurately determined the total DC load, which is 2.82 A for continuous load, and 9.9 A for discontinuous load.

We utilized the BSP (Battery Sizing Programme) developed by Enersys to accurately determine the appropriate size of the battery needed for backup power. This software helps us calculate the optimal battery capacity based on various factors such as the power requirements of the load, the duration of backup needed, the efficiency of the battery system, and other relevant parameters. By inputting these data into the BSP, we obtained precise recommendations for the size and type of battery that best suited the specific requirements of our application. This ensures that the backup power solution is appropriately sized to provide a reliable and uninterrupted power supply during outages or when renewable energy sources are unavailable. See Appendix.

4.7.3.2.3 Bus Calculation

During our project we calculated the number of voltages and currents in each of our buses in our substation. We used ETAP to do this, and we can see the results in Figure 4.7.3.2.3.1. This figure shows the nominal kV, Voltage, MW loading and amperage.

Bus ID	Nominal kV	Voltage	MW Loading	Mvar Loading	Amp Loading	
Bus1_1	115	100	67.328	4.623	338.8	High side of xfm
Bus2_1	34.5	100.23	31.555	0.005	526.8	PV to Feeder 1
Bus2_2	34.5	100.16	36.06	0.0047	602.5	PV to Feeder 2
Bus2_3	34.5	99.95	35.987	0.147	602.5	Feeder 2 to Ring bus
Bus2_4	34.5	99.95	49.46	0.25	828.1	Feeder 1 to Ring bus
Bus2_5	34.5	99.95	67.454	0.323	1129	Low side of xfm

[Figure 4.7.3.2.3: Substation Bus Calculations]

We see that Bus2_1 which connects inverters 1-7 to the substation has 527 amps at 100.23 volts. Bus2_2 connects inverters 8-15 to the substation and through some of the substation components as well. We see that these buses are not equal, but that is ok because we had an odd number of inverters so it would never be balanced.

4.7.3.2.4 Grounding Calculation

Below we see grounding calculations for our substation. It shows the tolerable and maximum step and touch voltages. The tolerable voltages are in Figure 4.7.3.2.4.1 and the maximum are shown in Figure 4.7.3.2.4.2. Step voltage refers to the voltage difference between two possible steps a person can take in the substation. The voltage is caused by the currents in the ground from the grounding grid. Touch voltage refers to the amount of voltage that a person may experience from touching a piece of equipment while standing on the ground.

3	Calculation for Tolerable Step Voltage		
$E_{step50} = (1000 + 6C_s \cdot \rho_s)\frac{0.116}{\sqrt{t_s}}$	E(step50)	1263.175554	V
4	**Calculation for Tolerable Touch Voltage**		
$E_{touch50} = (1000 + 1.5C_s \times \rho_s)\frac{0.116}{\sqrt{t_s}}$	E(touch50)	377.3121784	V

[Figure 4.7.3.2.4.1: Substation Grounding Calculations]

5	Calculation for Maximum Step Voltage		

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

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

$$L_s = 0.75\cdot L_C + 0.85\cdot L_R$$

$$E_s = \frac{\rho\cdot K_s\cdot K_i\cdot I_G}{L_S}$$

Ks	1.26493	
Ki	1.937540498	
Ls	4044.0864	
Es	1091.553474	V

6	Calculation for Maximum Touch Voltage		

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

$$K_h = \sqrt{1+\frac{h}{h_o}} \qquad h_o = 1\text{m (grid reference depth)}$$

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

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

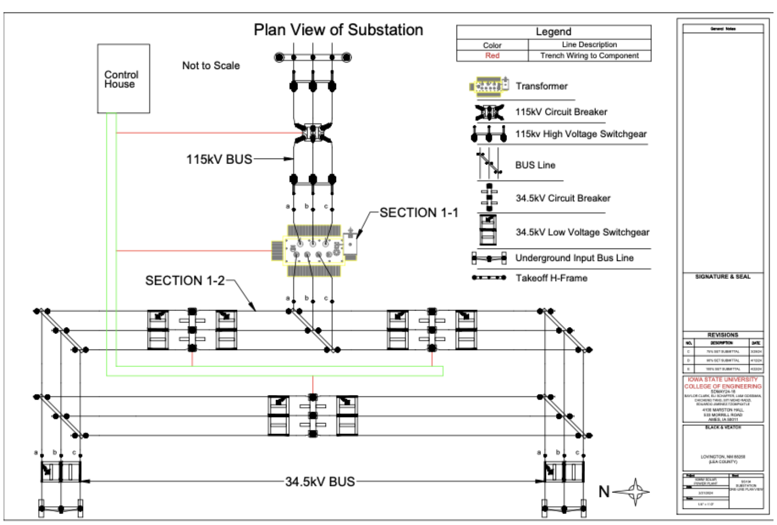
$$E_m = \frac{\rho\cdot K_m\cdot K_i\cdot I_G}{L_M}$$

Kii	1	
Kh	1.072380529	
Km	0.607411	
Lm	7527.13	
Em	281.6126665	V

[Figure 4.7.3.2.4.2: Substation Grounding Calculations]

4.7.3.3 Substation

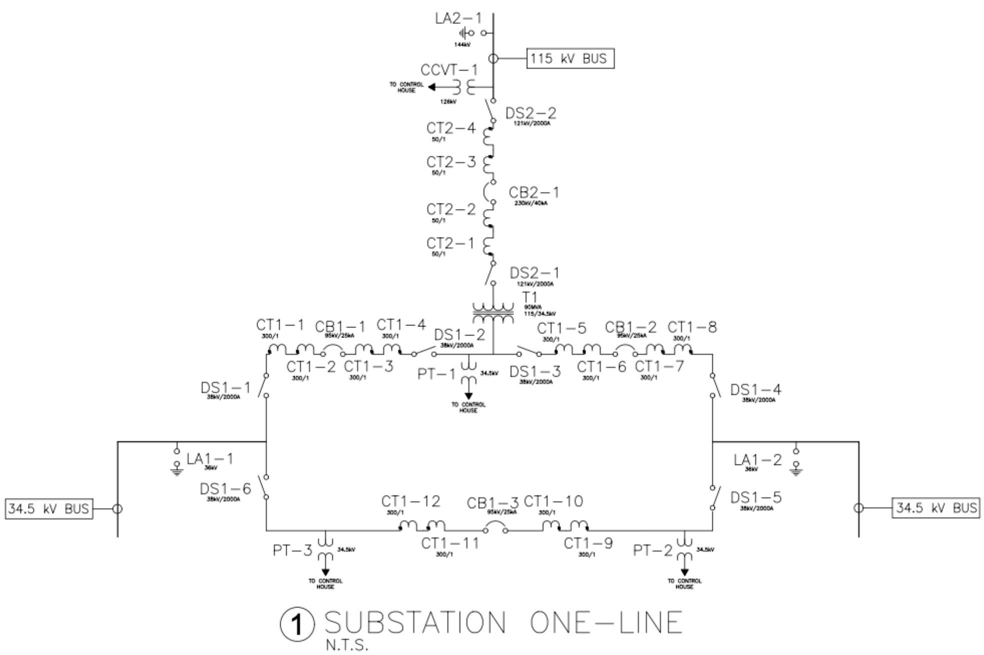
4.7.3.3.1 Substation Key Plan



[Figure 4.7.3.3.1: Substation Key Plan]

The design showcases a comprehensive layout depicted in a key plan view of the substation. Two feeders originating from the solar arrays are prominently featured, seamlessly connected to the 34.5kV bus. Each feeder is meticulously linked to the 34.5kV low voltage switchgear, accompanied by circuit breakers ensuring operational safety. Following this path, the transformers efficiently step up the voltage to 115kV, marking a pivotal stage in the power transmission process. The interconnected components proceed to the 115kV high-voltage switchgear, fortified by circuit breakers for enhanced control. Notably, these elements are strategically tethered to the control house, optimizing monitoring and management. The design's clarity is further accentuated by the delineation of conduits in red lines and trenches in green lines. Moreover, the key plan's division into two sections—1-1 for the high voltage side and 1-2 for the low voltage side—provides a structured understanding of the substation's functionality and layout.

4.7.3.3.2 Substation One-Line Diagram

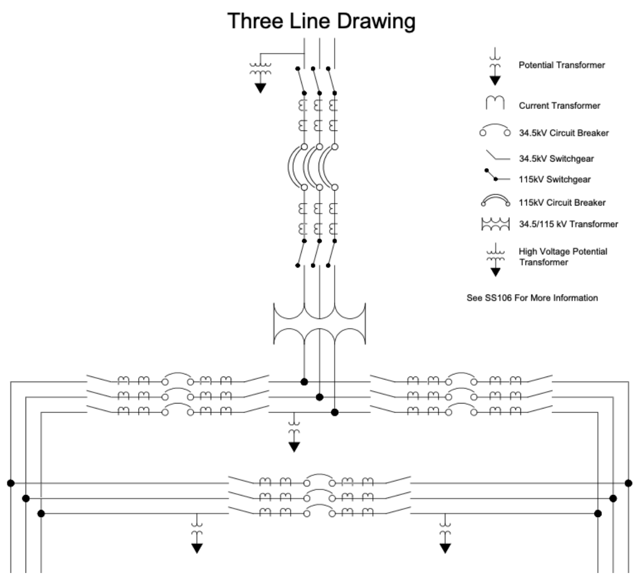


[Figure 4.7.3.3.2: Substation One-Line Diagram]

The design encompasses a detailed substation one-line diagram, portraying the electrical configuration of the substation. The decision to employ a ring bus topology is justified by its resilience and redundancy, ensuring continuity of power supply even in case of faults. The diagram showcases an array of essential components, including Current Transformers (CT), Circuit Breakers (CB), Disconnect Switches (DS), Potential Transformers (PT), Lightning Arresters (LA), and Coupling Capacitor Voltage Transformers (CCVT). Each component serves a crucial role in monitoring, protecting, and managing the flow of electricity within the substation. The diagram delineates the connections among these components, delineating two distinct voltage levels, from 34.5 kV buses to 115 kV bus, while also connected to a control house This is a schematic overview rather than a precise scale rendering. More details of the ratings of the components are in Appendix.

4.7.3.3.3 Substation Three-Line Diagram

The substation three-line diagram provides a comprehensive overview of the electrical connections within a substation, illustrating the interconnections between various components showing phase lines. Unlike the simplified one-line diagram, this offers a more detailed representation, crucial for understanding the intricate network of the substation. It delineates the connection from two feeders, the 34.5kV bus, to the 115kV bus, facilitated by a transformer for voltage stepping. We have also included the essential protection components such as Potential Transformers (PT), Current Transformers (CT), Circuit Breakers (CB), Switchgear, and High Voltage Potential Transformers (HVPT).

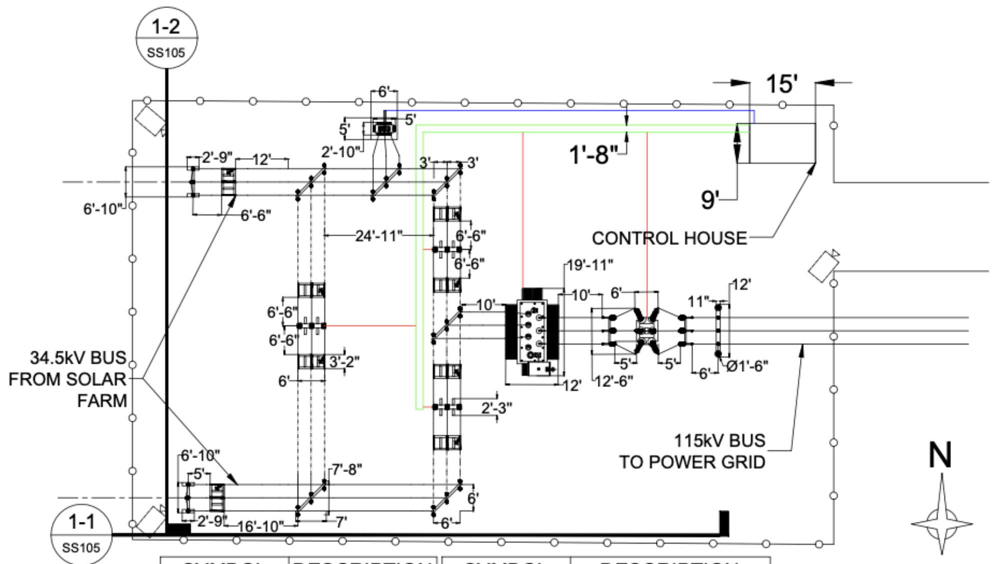


[Figure 4.7.3.3.3: Substation Three-Line Diagram]

This diagram serves as a vital tool for engineers and technicians, to grasp the configuration and functionality of the substation's electrical system comprehensively, aiding in design, maintenance, and troubleshooting endeavors.

4.7.3.3.4 Substation Conduit & Trench

The top view site plan provides information on the sizing of each component. The dash lines on the left side are the underground input feeding lines, and each side is connected to the ring bus. Each circuit breaker is separated enough for maintenance to be conducted when needed. A smaller transformer north of the substation will power the control house connected by the channel feeder in blue. The green and red lines represent the trench and conduit connecting the circuit breakers and control house. The left half of the substation represents the 34.5kV power lines and after the large transformer the power lines will be the 115kV which connect to the h-frame to deliver the power to the grid. The substation will be surrounded with a metal fence and protected with cameras on most corners, and an entrance to the left.

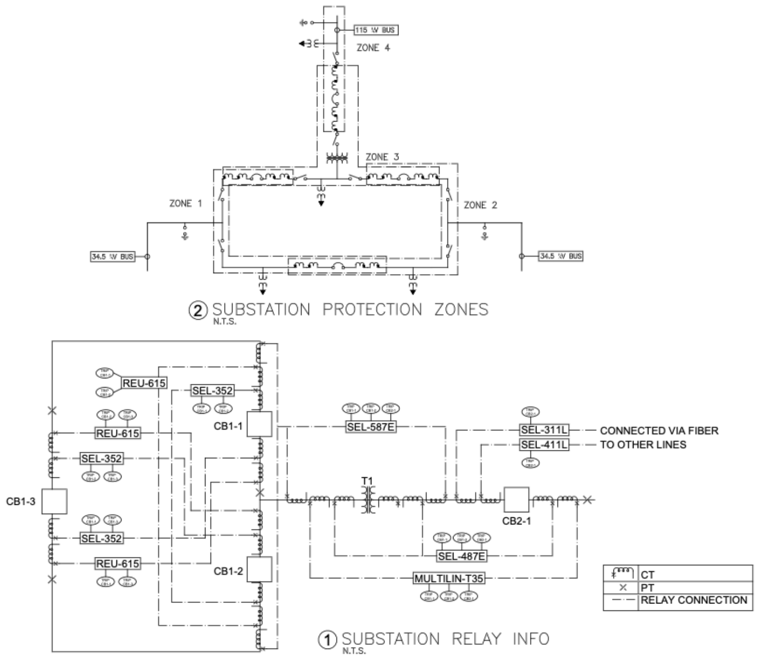


SYMBOL	DESCRIPTION	SYMBOL	DESCRIPTION
	CONDUIT		UNDERGROUND
	CH FEEDER		RIGID BUS
	TRENCH		STRAIN BUS

[Figure 4.7.3.3.4: Solar Array Electrical Site Plan]

4.7.3.3.5 Substation Protection & Relay Connection

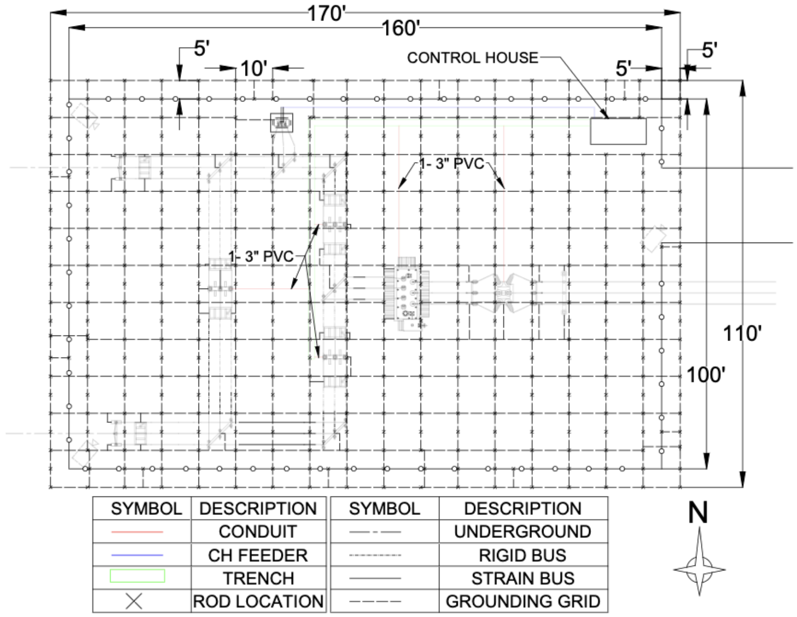
The first picture shows the 4 zones of the substation that will protect the components. The zones will disconnect the circuit breakers when too much power travels on the bus lines. The diagram on the bottom of this section demonstrates how each connection will work with one another. Current transformer and power transformers will determine if the substation operates in the correct power rating.



[Figure 4.7.3.3.5: Substation Protection & Relay Connection]

4.7.3.3.6 Substation Grounding

The figure below shows the grounding grid for our substation. The grounding rods are 20' long and run into the earth. There are 420 total rods to help with the grounding. The grid consists of 10'x10' squares that connect to all of our equipment and our fence. Using this as a parameter for our grounding calculations, we found that there was ample amount of spacing and rods to lower our step and touch voltages.



[Figure 4.7.3.3.6: Substation Grounding]

4.8 Technology Considerations

Solar panel technology is advancing, leading to a wide array of equipment with varying specifications. While higher-wattage solar panels offer increased energy production in a smaller space, they come at a higher cost and necessitate equipment capable of managing the greater load. Copper cables, though more efficient than aluminum, prove notably pricier when the gauge needed for transmitting utility-scale power is considered. Sun tracking technology enhances solar panel efficiency and power generation but entails heightened maintenance requirements and increased installation expenses. The typical trade-off in equipment selection revolves around the balance between power/efficiency and cost.

Following thorough research, economic assessment, and consultations with mentors, our conclusion was that implementing axis-tracking technology was unnecessary. The advantages of generating more power were outweighed by the additional installation and maintenance costs, especially given the already substantial power production from the sheer number of solar panels. Regarding the specific tilt angle for our panels, various sources indicated that an angle between 30 and 40 degrees is optimal for a region like New Mexico. Since we did not adjust the panel angle throughout the year, opting for the angle that yields the best year-round results makes more sense. Considering the lower sunlight output during winter, optimizing the tilt angle to maximize power during this season becomes paramount. Consequently, a carefully chosen angle of 35 degrees compensates for the reduced sunlight levels in the New Mexico winter. This meticulous design approach represents the sole means to minimize the impact of these trade-offs.

4.9 Design Analysis

The initial plan for battery storage on the solar array was abandoned due to the high cost of two-hour power generation. The general design concepts for the solar farm remained consistent. The project identified the potential for future expansion of solar power capacity. Black & Veatch emphasized the importance of designing the solar farm to accommodate this potential growth. However, the initial substation design was based solely on the current output and electrical specifications of the solar farm.

The design of the substation itself did not undergo major changes throughout the project. The focus shifted to selecting components with future expandability in mind. The approach involved choosing components that met the current requirements and parameters, followed by consultation with Black & Veatch to ensure their suitability for future increases in power. This likely involved selecting higher-capacity transformers, expandable switchgear, and a substation layout that facilitates the addition of new components. Through collaboration with Black & Veatch and prioritizing flexibility, the project ensured the substation could handle the current load while remaining adaptable to future growth of the solar farm.

5 Testing

5.1 Unit Testing

For unit testing, the group used software and calculation spreadsheets to confirm all the design calculations are correct. The voltage drop, current, power, and safety systems, like circuit breakers, were tested for each component. The group used ETAP software to confirm the calculations. Voltage and current was measured for the solar panels, combiner box, and cables, while the skid measured for voltage and power output.

For the voltage drop calculations, we needed to use the equation shown in Figure 5.1.1, where L is the length of the wire, R is the wire resistance per foot, and I is the current running through the wire. We used two different wires in our project; one was a #10 AWG wire, and the other was 600 MCM. The resistance of the #10 AWG is 0.9989 ohms/1000,' and the resistance of the 600 MCM is 0.0309 ohms/1000'.

$$VD = \frac{2 \times L \times R \times I}{1,000}$$

$$VD\% = \frac{VD}{\text{SOURCE VOLTAGE}} \times 100$$

[Figure 5.1.1: Voltage Drop Equation and Voltage Drop Percentage]

Figure 5.2.1 and 5.2.2 below shows us the voltage drop at the DC section of the power plant by calculating the voltage drop of the string to the combiner box and the wire connection from the combiner box to the inverter. The calculation is made by using the voltage drop formula, considering the specification value of the components, such as the wire length, the resistance per ft, and maximum short circuit current, referring to the datasheet and NEC Table 8 Conductor properties, to adhere with the NEC standards of voltage drop less than 2% DC, and less than 1% for AC part. The result shows that horizontal and vertical voltage drops met the standards with 0.51% & 0.63% voltage drops, respectively.

Voltage-Drop Calculation = <3%

Resources	NEC Table 8 Conductor Properties
	NEC AWG Chart

16 racks Combiner box (Horizontal Array)

DCB	Strings per rack	ISC for string	String length	String wire size	String conductor resistance	String resistance	Voltage drop of string(AWG #12)	Voltage drop of string
DCB#-##	per rack	Amp	feet	AWG	ohm/kft	ohm	Volts	%
DCB1-01	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-02	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-03	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-04	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-05	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-06	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-07	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-08	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-09	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-10	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-11	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-12	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-13	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-14	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-15	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-16	1	13.89	93	10	1.24	0.11532	3.204	0.214

AWG=600

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	16	222.24	161	600	0.0241	0.004	1.725	0.11	8.13	1500	0.54
DCB2	16	222.24	151	600	0.0241	0.004	1.618	0.11	8.02	1500	0.53
DCB3	16	222.24	141	600	0.0241	0.003	1.510	0.10	7.92	1500	0.53
DCB4	16	222.24	131	600	0.0241	0.003	1.403	0.09	7.81	1500	0.52
DCB5	16	222.24	121	600	0.0241	0.003	1.296	0.09	7.70	1500	0.51
DCB6	16	222.24	111	600	0.0241	0.003	1.189	0.08	7.60	1500	0.51
DCB7	16	222.24	101	600	0.0241	0.002	1.082	0.07	7.49	1500	0.50
DCB8	16	222.24	91	600	0.0241	0.002	0.975	0.06	7.38	1500	0.49
DCB9	16	222.24	81	600	0.0241	0.002	0.868	0.06	7.27	1500	0.48
DCB10	16	222.24	71	600	0.0241	0.002	0.761	0.05	7.17	1500	0.48
DCB11	16	222.24	61	600	0.0241	0.001	0.653	0.04	7.06	1500	0.47
DCB12	14	222.24	51	600	0.0241	0.001	0.546	0.04	6.95	1500	0.46
DCB13	14	222.24	41	600	0.0241	0.001	0.439	0.03	6.85	1500	0.46
DCB14	16	222.24	82	600	0.0241	0.002	0.878	0.06	7.29	1500	0.49
DCB15	16	222.24	92	600	0.0241	0.002	0.986	0.07	7.39	1500	0.49
DCB16	16	222.24	102	600	0.0241	0.002	1.093	0.07	7.50	1500	0.50
DCB17	16	222.24	112	600	0.0241	0.003	1.200	0.08	7.61	1500	0.51
DCB18	16	222.24	122	600	0.0241	0.003	1.307	0.09	7.71	1500	0.51
DCB19	16	222.24	132	600	0.0241	0.003	1.414	0.09	7.82	1500	0.52
DCB20	16	222.24	142	600	0.0241	0.003	1.521	0.10	7.93	1500	0.53
DCB21	16	222.24	152	600	0.0241	0.004	1.628	0.11	8.04	1500	0.54
DCB22	16	222.24	162	600	0.0241	0.004	1.735	0.12	8.14	1500	0.54
DCB23	16	222.24	172	600	0.0241	0.004	1.842	0.12	8.25	1500	0.55
DCB24	16	222.24	182	600	0.0241	0.004	1.950	0.13	8.36	1500	0.56
										Average of worst-case DCB Voltage drop (%)	0.51

[Figure 5.2.1: Horizontal Array DC Voltage Drop]

Voltage-Drop Calculation = <3%

Resources	NEC Table 8 Conductor Properties
	NEC AWG Chart

16 racks Combiner box (Vertical Array)

DCB	Strings per rack	ISC for string	String length	String wire size	String conductor resistance	String resistance	Voltage drop of string (AWG=12)	Voltage drop of string
DCB#-##	per rack	Amp	feet	AWG	ohm/kft	ohm	Volts	%
DCB1-01	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-02	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-03	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-04	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-05	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-06	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-07	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-08	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-09	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-10	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-11	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-12	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-13	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-14	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-15	1	13.89	93	10	1.24	0.11532	3.204	0.214
DCB1-16	1	13.89	93	10	1.24	0.11532	3.204	0.214

AWG= 600, diameter = 22-32mm

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	16	222.24	607	600	0.0214	0.013	5.774	0.38	12.181	1500	0.81
DCB2	16	222.24	585	600	0.0214	0.013	5.564	0.37	11.972	1500	0.80
DCB3	16	222.24	563	600	0.0214	0.012	5.355	0.36	11.762	1500	0.78
DCB4	16	222.24	541	600	0.0214	0.012	5.146	0.34	11.553	1500	0.77
DCB5	16	222.24	519	600	0.0214	0.011	4.937	0.33	11.344	1500	0.76
DCB6	16	222.24	497	600	0.0214	0.011	4.727	0.32	11.135	1500	0.74
DCB7	16	222.24	440	600	0.0214	0.009	4.185	0.28	10.592	1500	0.71
DCB8	16	222.24	418	600	0.0214	0.009	3.976	0.27	10.383	1500	0.69
DCB9	16	222.24	396	600	0.0214	0.008	3.767	0.25	10.174	1500	0.68
DCB10	16	222.24	374	600	0.0214	0.008	3.557	0.24	9.965	1500	0.66
DCB11	16	222.24	352	600	0.0214	0.008	3.348	0.22	9.755	1500	0.65
DCB12	14	222.24	330	600	0.0214	0.007	3.139	0.21	9.546	1500	0.64
DCB13	14	222.24	258	600	0.0214	0.006	2.454	0.16	8.861	1500	0.59
DCB14	16	222.24	236	600	0.0214	0.005	2.245	0.15	8.652	1500	0.58
DCB15	16	222.24	214	600	0.0214	0.005	2.036	0.14	8.443	1500	0.56
DCB16	16	222.24	192	600	0.0214	0.004	1.826	0.12	8.233	1500	0.55
DCB17	16	222.24	170	600	0.0214	0.004	1.617	0.11	8.024	1500	0.53
DCB18	16	222.24	148	600	0.0214	0.003	1.408	0.09	7.815	1500	0.52
DCB19	16	222.24	91	600	0.0214	0.002	0.866	0.06	7.273	1500	0.48
DCB20	16	222.24	113	600	0.0214	0.002	1.075	0.07	7.482	1500	0.50
DCB21	16	222.24	135	600	0.0214	0.003	1.284	0.09	7.691	1500	0.51
DCB22	16	222.24	157	600	0.0214	0.003	1.493	0.10	7.901	1500	0.53
DCB23	16	222.24	179	600	0.0214	0.004	1.703	0.11	8.110	1500	0.54
DCB24	16	222.24	201	600	0.0214	0.004	1.912	0.13	8.319	1500	0.55
										Average of worst-case DCB Voltage drop	0.63

[Figure 5.2.2: Vertical Array DC Voltage Drop]

5.2 Interface Testing

The design of our solar power plant and substation did not follow many of the same processes as software design and testing. The testing sections were harder to interpret in terms of our project. Our project was split up into two major phases of design. The solar power plant was designed in the fall semester, and the substation would be designed in the spring semester. Speaking in terms of our solar power plant design, there were a couple of “interfaces” that we tested during design. One interface could have been the wiring and design of the solar array itself. The second interface of the solar power system was the current inversion in the skid inverters and the feeders from the inverters to the substation.

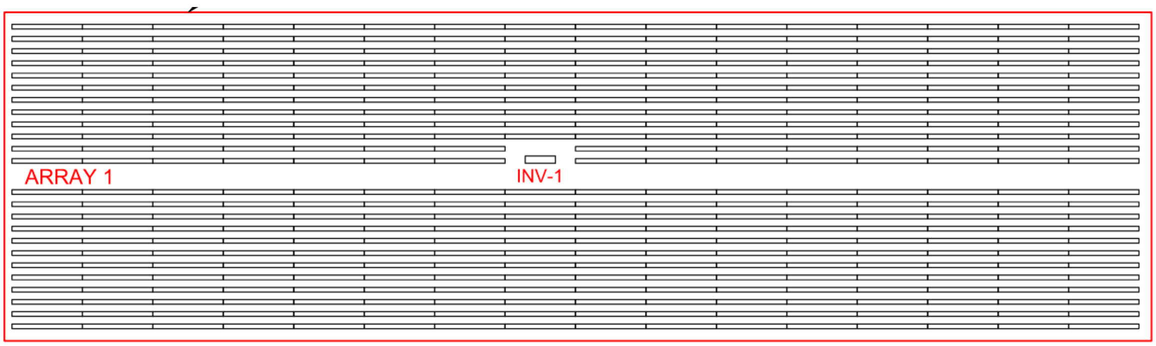
Calculations had to be made to determine voltage drop and power being delivered from the solar strings to the combiner box. Then, the current and power were delivered to the inverter. After the current was inverted to AC. The voltage drop had to be calculated from the feeder lengths between the substation and the inverters. There was very little the group could do to “test” the design of our solar power plant. However, the group did need to calculate voltage drop and voltage differences to ensure code compliance and maximum power usage of our system.

The tools we would use were calculating spreadsheets to find voltage drop and power flow. Furthermore, the group would use ETAP for power simulation to ensure our calculations were correct. Ensuring calculations and simulations were important to ensure safety and maximum use of power available.

5.3 Integration Testing

Some important paths in our project were the paths from the solar panels to the inverters and the grid interconnection. We also had monitoring and control systems and safety and protection systems. For the path from the solar panels to the inverters, we tested the efficiency of the panels, combiner boxes, and inverters, all under various conditions of input and other weather conditions. We also would have tested the panels' durability if we had been able to obtain a physical panel. We planned to test the grid interconnection's power quality to see how well the substation would have responded to a short circuit or possible lightning strikes. We also would have tested the entire system for anti-islanding protection, which protects system elements from blackouts. We also would have tested our monitoring and control systems with data accuracy and communication reliability. Then, we would have tested the safety and control systems with grounding calculations and added circuit breakers for voltage spike protection.

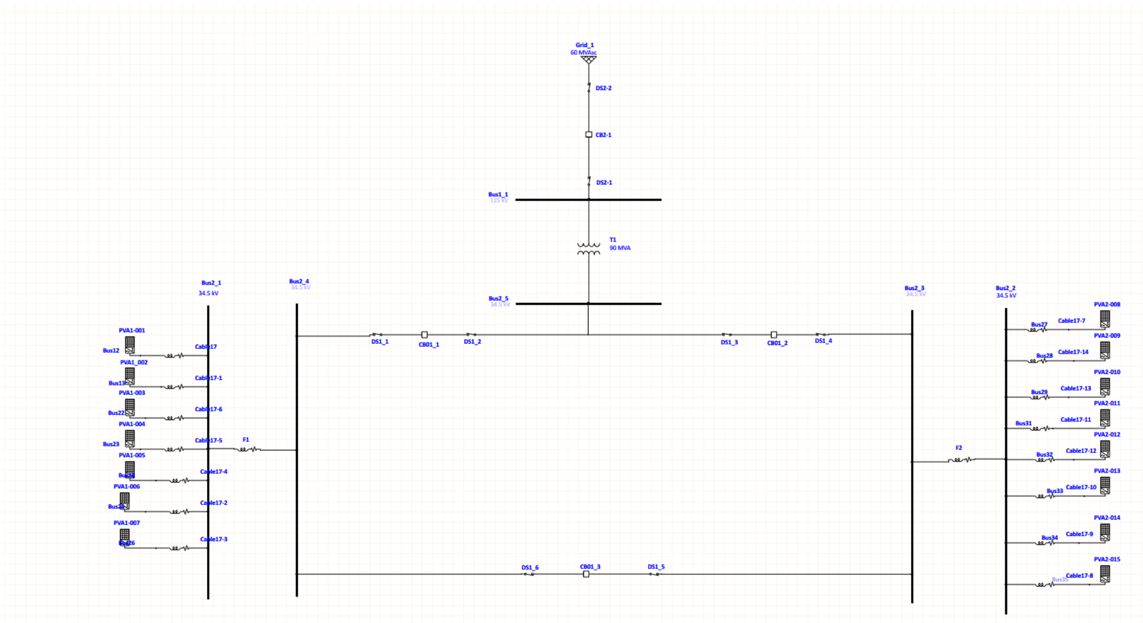
5.4 System Testing



[Figure 5.4.1: Single Array]

The group has decided to integrate all system parts into one large test for the system testing. We started with one array and then moved to combining them. We start the system testing by calculating the voltage drop for each row. Then we combine the rows with each inverter. Once we have the full voltage drop for one array, we can use those values to calculate the AC voltage drops from the inverters to the substation. After calculating those units, we can start with the integration testing for the inverter and panel efficiencies for various weather conditions.

Figure 5.4.2 below shows the modeling of all components of our solar power plant in ETAP. The modeling took into account the specification values of all the components, such as wire data, solar panel data, and the use of ETAP's built-in library to accurately fit the entire power plant designed by the group.



[Figure 5.4.2: ETAP Simulation Model]

Figure 5.4.3 and 5.4.4 below shows us the power flow result in each bus also for the whole system. As a result, each PV array is producing 4.5MW of power. The whole system is producing 67.3MW power, which is 12% more than 60 MW.

Bus ID	Nominal kV	Voltage	MW Loading	Mvar Loading	Amp Loading	
Bus1_1	115	100	67.328	4.623	338.8	High side of xfm
Bus2_1	34.5	100.23	31.555	0.005	526.8	PV to Feeder 1
Bus2_2	34.5	100.16	36.06	0.0047	602.5	PV to Feeder 2
Bus2_3	34.5	99.95	35.987	0.147	602.5	Feeder 2 to Ring bus
Bus2_4	34.5	99.95	49.46	0.25	828.1	Feeder 1 to Ring bus
Bus2_5	34.5	99.95	67.454	0.323	1129	Low side of xfm

[Figure 5.4.3: ETAP Power Flow Simulation result]

ID	Rating/Limit	Rated kV	MW	Mvar	Amp	% PF	% Generation
Grid_1	60 MVA	115	-67.328	4.623	338.8	-99.77	
PVA1-001	4 MW	34.5	4.508	0	75.26	100	112.4
PVA1_002	4 MW	34.5	4.507	0	75.24	100	112.4
PVA1-003	4 MW	34.5	4.512	0	75.32	100	112.5
PVA1-004	4 MW	34.5	4.508	0	75.26	100	112.4
PVA1-005	4 MW	34.5	4.508	0	75.26	100	112.4
PVA1-006	4 MW	34.5	4.508	0	75.26	100	112.4
PVA1-007	4 MW	34.5	4.508	0	75.26	100	112.4
PVA2-008	4 MW	34.5	4.508	0	75.31	100	112.5
PVA2-009	4 MW	34.5	4.508	0	75.31	100	112.5
PVA2-010	4 MW	34.5	4.508	0	75.31	100	112.5
PVA2-011	4 MW	34.5	4.508	0	75.31	100	112.5
PVA2-012	4 MW	34.5	4.508	0	75.31	100	112.5
PVA2-013	4 MW	34.5	4.508	0	75.32	100	112.5
PVA2-014	4 MW	34.5	4.508	0	75.32	100	112.5
PVA2-015	4 MW	34.5	4.508	0	75.31	100	112.5

[Figure 5.4.3: ETAP Power Flow Simulation result]

5.5 Regression Testing

To ensure that new features of our designs did not compromise previous ones, our team calculated new values to compare against the requirements of our project. Certain values of our project were set, such as the 60 MW output of the solar farm and the operating voltages of the substation. Our team used calculations from equipment specifications to ensure that the overall parameters of the project were met and that each component fit within the acceptable operating range of every other component in the design. Values such as component voltage and current had to combine to meet the overall requirements while also fitting within the requirements of each component. Any new components or layouts were tested via calculations to determine if they met both of these requirements.

5.6 Acceptance Testing

Our team creates weekly presentations to keep our industry clients up-to-date on our design choices. In doing so, we present our calculations demonstrating the effectiveness of our designs as well as explaining our reasons for making each design decision. Most of our projects' design choices are numerical tolerances and individual/overall output values. These design choices are simple to demonstrate, relying on numerical analysis of component values and overall outputs. Other design choices, such as component spacing and layout, are less reliant on numerical analysis and are based on ease of access and design simplicity. These design choices are shown to our industry clients for review, allowing them to confirm their acceptance of the design or offer changes that they think would improve it.

5.7 Results

The results of the group testing ensured that there would hopefully be minimal additional work or redesign if someone wanted to construct this solar array. The group could not test physical components due to the size of the project, ETAP simulation results show that each component meets design requirements and operates well. The power generated meets the 60 MW power requirement with some design redundancy for special cases. Another result from the system testing was that the percentage of your voltage drops fell within the range expected by the NEC for solar designs. Most of the testing throughout the project fell under the category of verification from codes or other standards from IEEE, NEC, or calculations. The group did the best they could to have accurate results in the case it were to be constructed. From the ETAP analysis the system produces 67.3 MW which is 4.5 MW per array. The results show a 12% higher output then calculated initially. The group did not have time to fully understand the reason for the difference in output. However, with more time we would look to go back and redo calculations to verify what the simulations were saying. The increase in output shouldn't have any effect on the specifications of each component within the substation.

6 Implementation

Our engagement with the project implementation was indirect. The two semesters were dedicated to distinct but interconnected design projects. There is no implementation process by Black & Veatch. They sponsor this project to provide students with experience in the design of power systems and the components are integral in designing a project like this. Even though this project was not implemented the group is taking valuable information from this project and will help greatly moving into our professional career.

7 Professionalism

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

7.1 Areas Of Responsibility

Area of Responsibility	Definition	NSPE Canon	IEEE Code of Ethics	Difference from NSPE Version
Work Competence	Perform work of high quality, integrity, timeliness, and professional competence.	Perform services only in areas of their competence; Avoid deceptive acts.	Ensure high standards of competence and strive for high-quality performance in their professional work.	The IEEE Code emphasizes both competence and high-quality performance, aligning with the NSPE Canon.
Financial Responsibility	Deliver products and services of realizable value and at reasonable costs.	Act for each employer or client as faithful agents or trustees	Be accurate and honest in all professional interactions, including financial aspects. Strive to deliver products and services at a reasonable cost while maintaining quality and value.	Similarities in terms of honesty and integrity in financial dealings, with IEEE emphasizing accuracy and honesty.
Communication Honesty	Report works truthfully, without deception, and is understandable to stakeholders.	Issue public statements only objectively and truthfully; Avoid deceptive acts.	Be honest and realistic in stating claims or estimates based on available data.	A similar emphasis on honesty, but IEEE specifically mentions being realistic in statements, aligning closely

				with the NSPE Canon.
Health, Safety, Well-Being	Minimize risks to the safety, health, and well-being of stakeholders	Hold paramount the safety, health, and welfare of the public.	Consider the safety, health, and welfare of the public and the impacts of work on society. Strive to minimize negative impacts.	Both codes prioritize safety and well-being, but the IEEE Code broadens the focus to consider societal impacts, aligning closely with the NSPE Canon.
Property Ownership	Respects clients' and others' property, ideas, and information.	Act for each employer or client as faithful agents or trustees	Respect the proprietary information and intellectual property of others and protecting it appropriately.	Both codes emphasize respect for property and information, with IEEE specifically addressing intellectual property.
Sustainability:	Protect the environment and natural resources locally and globally		Contribute to the progress and application of technology for the benefit of society. Consider environmental impact and promote sustainable practices.	The IEEE Code explicitly addresses sustainability and the environmental impact of technology, which is not explicitly mentioned in the NSPE Canon.
Social Responsibility	Produce products and services that benefit society and communities	Conduct themselves honorably, responsibly, ethically, and lawfully to enhance the honor, reputation, and usefulness of the profession.	Strive to enhance the quality of life for society and communities by applying technology. Act responsibly to foster public trust and confidence.	Both codes stress the importance of benefiting society, with the IEEE Code specifying the role of technology in enhancing quality of life and public trust.

[Table 7.1.1: Area of Responsibility]

7.2 Project Specific Professional Responsibility Areas

Work Competence:

- Applicability: This is highly relevant as the design and implementation of a solar power plant and substation require a high level of engineering competence.
- Team Performance: The team consists of EE students under the supervision of Faculty and Advisor, with the clients of a solar company, Black and Veatch. The team's performance in this area is expected to be high.

Financial Responsibility:

- Applicability: This is relevant, especially considering the cost analysis aspect of your project. Design decisions can impact costs, and delivering value within budget constraints is crucial.-
- Team Performance: Cost analysis is done, and the result is seen based on the Return of Investment (ROI) in 10 years. The project can be implemented in real life if the overall cost analysis shows a positive outcome. The performance is expected to be medium to high.

Communication Honesty:

- Applicability: Truthful and clear communication is crucial in engineering projects, especially when presenting designs and analysis results to the faculty and clients.
- Team Performance: The team ensures that communication is honest, clear, and realistic in presenting claims or estimates based on available data. The performance should be at a high level.

Health, Safety, Well-Being:

- Applicability: Safety considerations are vital, especially in a solar power plant's construction and operation phases. This includes the safety of workers during installation and the impact on the community's well-being.
- Team Performance: The team is actively considering and minimizing risks to safety, health, and well-being, the performance should be high.

Property Ownership:

- Applicability: Respect for intellectual property is crucial, especially in the design phase where proprietary information and innovative solutions may be involved.
- Team Performance: The project adheres to local policies and rules. The team appropriately respects and protects intellectual property, and the performance should be high.

Sustainability:

- Applicability: Sustainability is highly relevant since the project involves a solar power plant. The team needs to consider the environmental impact and promote sustainable practices.
- Team Performance: The team actively considers and incorporates sustainability practices in the design. The performance should be high.

Social Responsibility:

- Applicability: The project has a direct impact on society by providing electricity to local demand, residential, industrial factories, commercials, and public needs.
- Team Performance: The team is conscious of the societal impact, strives to enhance the quality of life through technology, and acts responsibly to foster public trust. The performance should be high.

In summary, the team's performance in each of the seven professional responsibility areas seems to depend on the team's awareness, commitment, and implementation of ethical considerations. Given the nature of the project, with a focus on sustainability and societal impact, the team has the potential to perform at a high level in these professional responsibility areas. However, ongoing vigilance and commitment to ethical considerations were essential as the project progressed.

7.3 Most Applicable Professional Responsibility Area

For the project of designing a 60 MW solar power plant and a 115/34.5 kV substation, the most applicable professional responsibility area is likely Sustainability.

Given that the project involves the development of a solar power plant, a sustainable and renewable energy source, the team's actions and decisions directly impact environmental sustainability. The team must consider the long-term environmental effects, minimize the carbon footprint, and promote sustainable practices in designing and implementing the solar power plant. This includes aspects such as the selection of materials, energy efficiency, and the overall ecological impact of the project.

Sustainability aligns closely with the goals of designing and implementing solar energy projects, making it a key professional responsibility area for the team. It reflects the broader societal and global context of environmental awareness and the need for responsible engineering practices to address climate change and promote a sustainable future.

8 Closing Material

8.1 Discussion

Our project goal was to design a 60 MW solar farm and a 115/34.5 kV substation along with it. Our group thinks that we met our project goal and other project deliverables along the way. We worked directly with our clients to meet their needs and expectations. Using different sections of code, general knowledge, and input from our industry professionals and academic advisors, we designed a well-laid-out project that gives us room to expand. We have completed drawings for construction and a few for conceptual purposes so that we understood what we were building and the people building it understood what was being built.

8.2 Conclusion

During the initial semester, we accomplished the selection and sizing of components for the solar farm, scrutinized voltage drop, and explored various layout options. We have designed the whole solar farm layout and a simple one-line diagram of the substation. Additionally, we conducted a cost analysis to assess the return on investment over 10 years, and the outlook appears promising. During the spring semester, we enhanced the economic analysis by incorporating substation equipment, construction, and operational costs. Despite the supplementary cost associated with the substation, the project still exhibits a positive return on investment after a decade. The substation's design encompassed one-line diagrams detailing bus configuration, grounding, and overall substation layout, including breakers, lighting, and a transformer. These design specifications were meticulously chosen based on calculations to ensure the solar farm's safe and efficient operation. We are confident that this solar farm represents a robust investment for those seeking to contribute more renewable energy to US power.

8.3 References

400 MCM XHHW Aluminum Cable 600V, NNC, https://nassaunationalcable.com/products/400-mcm-xhhw?gclid=CjwKCAjw9-6oBhBaEiwAHv1QvPhGD1bLfyeFvRUZHMv1qLskzqZHGp2rT_UdkagI7l1YAYmZsAk-7x0CsREQAvD_BwE.

"\/." *YouTube*, 16 June 2023, https://a1solarstore.com/var/attachments/product/17149/Q_CELLS_Data_sheet_Q.PEAK_DUO_XL-G10.3-BFG_475-490_2021-12_Rev04_NA.pdf. Accessed 3 December 2023.

"— ABB megawatt station PVS980-MWS – 3.6 to 4.6 MW." *Fimer*, https://www.fimer.com/sites/default/files/PVS980-MWS_megawatt_station_flyer_3AXD50000042986_RevC_EN_lowres.pdf. Accessed 3 December 2023.

IEEE SA -The Institute of Electrical and Electronics Engineers Standards Association

National Fire Protection Association - National Electrical Code 2023 Codebook

"Q CELLS 480W Solar Panel 156 cells Q.Peak Duo XL-G10.d/BFG." *A1 Solar Store*, https://a1solarstore.com/q-cells-480w-solar-panel-156-cells-q.peak-duo-xl-g10.d-bfg.html. Accessed 3 December 2023.

Schroeder, Dennis. "U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks: Q1 2021." *NREL*, https://www.nrel.gov/docs/fy22osti/80694.pdf. Accessed 3 December 2023.

"ZBENY AFCI Combiner Box BHSZ-8/1." *VoltaconSolar*, https://voltaconsolar.com/protection-monitoring/pv-combiner-boxes/zbeny-afci-combiner-box-bhsz-16-1-1500v.html. Accessed 3 December 2023.

"Substation Design | Power System Analysis" *PEguru,* https://peguru.com/substation-cost-estimator/. Accessed 24 April 2024.

8.4 Appendices

TABLE 8 Conductor Properties

Size (AWG or kcmil)	Area		Conductors							Direct-Current Resistance at 75°C (167°F)					
			Stranding			Overall				Copper					
				Diameter		Diameter		Area		Uncoated		Coated		Aluminum	
	mm^2	Circular mils	Quantity	mm	in.	mm	in.	mm^2	$in.^2$	ohm/km	ohm/kFT	ohm/km	ohm/kFT	ohm/km	ohm/kFT
18	0.823	1620	1	—	—	1.02	0.040	0.823	0.001	25.5	7.77	26.5	8.08	42.0	12.8
18	0.823	1620	7	0.39	0.015	1.16	0.046	1.06	0.002	26.1	7.95	27.7	8.45	42.8	13.1
16	1.31	2580	1	—	—	1.29	0.051	1.31	0.002	16.0	4.89	16.7	5.08	26.4	8.05
16	1.31	2580	7	0.49	0.019	1.46	0.058	1.68	0.003	16.4	4.99	17.3	5.29	26.9	8.21
14	2.08	4110	1	—	—	1.63	0.064	2.08	0.003	10.1	3.07	10.4	3.19	16.6	5.06
14	2.08	4110	7	0.62	0.024	1.85	0.073	2.68	0.004	10.3	3.14	10.7	3.26	16.9	5.17
12	3.31	6530	1	—	—	2.05	0.081	3.31	0.005	6.34	1.93	6.57	2.01	10.45	3.18
12	3.31	6530	7	0.78	0.030	2.32	0.092	4.25	0.006	6.50	1.98	6.73	2.05	10.69	3.25
10	5.261	10380	1	—	—	2.588	0.102	5.26	0.008	3.984	1.21	4.148	1.26	6.561	2.00
10	5.261	10380	7	0.98	0.038	2.95	0.116	6.76	0.011	4.070	1.24	4.226	1.29	6.679	2.04
8	8.367	16510	1	—	—	3.264	0.128	8.37	0.013	2.506	0.764	2.579	0.786	4.125	1.26
8	8.367	16510	7	1.23	0.049	3.71	0.146	10.76	0.017	2.551	0.778	2.653	0.809	4.204	1.28
6	13.30	26240	7	1.56	0.061	4.67	0.184	17.09	0.027	1.608	0.491	1.671	0.510	2.652	0.808
4	21.15	41740	7	1.96	0.077	5.89	0.232	27.19	0.042	1.010	0.308	1.053	0.321	1.666	0.508
3	26.67	52620	7	2.20	0.087	6.60	0.260	34.28	0.053	0.802	0.245	0.833	0.254	1.320	0.403
2	33.62	66360	7	2.47	0.097	7.42	0.292	43.23	0.067	0.634	0.194	0.661	0.201	1.045	0.319
1	42.41	83690	19	1.69	0.066	8.43	0.332	55.80	0.087	0.505	0.154	0.524	0.160	0.829	0.253
1/0	53.49	105600	19	1.89	0.074	9.45	0.372	70.41	0.109	0.399	0.122	0.415	0.127	0.660	0.201
2/0	67.43	133100	19	2.13	0.084	10.62	0.418	88.74	0.137	0.3170	0.0967	0.329	0.101	0.523	0.159
3/0	85.01	167800	19	2.39	0.094	11.94	0.470	111.9	0.173	0.2512	0.0766	0.2610	0.0797	0.413	0.126
4/0	107.2	211600	19	2.68	0.106	13.41	0.528	141.1	0.219	0.1996	0.0608	0.2050	0.0626	0.328	0.100
250	127	—	37	2.09	0.082	14.61	0.575	168	0.260	0.1687	0.0515	0.1753	0.0535	0.2778	0.0847
300	152	—	37	2.29	0.090	16.00	0.630	201	0.312	0.1409	0.0429	0.1463	0.0446	0.2318	0.0707
350	177	—	37	2.47	0.097	17.30	0.681	235	0.364	0.1205	0.0367	0.1252	0.0382	0.1984	0.0605
400	203	—	37	2.64	0.104	18.49	0.728	268	0.416	0.1053	0.0321	0.1084	0.0331	0.1737	0.0529
500	253	—	37	2.95	0.116	20.65	0.813	336	0.519	0.0845	0.0258	0.0869	0.0265	0.1391	0.0424
600	304	—	61	2.52	0.099	22.68	0.893	404	0.626	0.0704	0.0214	0.0732	0.0223	0.1159	0.0353
700	355	—	61	2.72	0.107	24.49	0.964	471	0.730	0.0603	0.0184	0.0622	0.0189	0.0994	0.0303
750	380	—	61	2.82	0.111	25.35	0.998	505	0.782	0.0563	0.0171	0.0579	0.0176	0.0927	0.0282
800	405	—	61	2.91	0.114	26.16	1.030	538	0.834	0.0528	0.0161	0.0544	0.0166	0.0868	0.0265
900	456	—	61	3.09	0.122	27.79	1.094	606	0.940	0.0470	0.0143	0.0481	0.0147	0.0770	0.0235
1000	507	—	61	3.25	0.128	29.26	1.152	673	1.042	0.0423	0.0129	0.0434	0.0132	0.0695	0.0212
1250	633	—	91	2.98	0.117	32.74	1.289	842	1.305	0.0338	0.0103	0.0347	0.0106	0.0554	0.0169
1500	760	—	91	3.26	0.128	35.86	1.412	1011	1.566	0.02814	0.00858	0.02814	0.00883	0.0464	0.0141
1750	887	—	127	2.98	0.117	38.76	1.526	1180	1.829	0.02410	0.00735	0.02410	0.00756	0.0397	0.0121
2000	1013	—	127	3.19	0.126	41.45	1.632	1349	2.092	0.02109	0.00643	0.02109	0.00662	0.0348	0.0106

Notes:

1. These resistance values are valid **only** for the parameters as given. Using conductors having coated strands, different stranding type, and, especially, other temperatures changes the resistance.
2. Equation for temperature change: $R_2 = R_1 [1 + \alpha (T_2 - 75)]$ where $\alpha_{cu} = 0.00323$, $\alpha_{AL} = 0.00330$ at 75°C.
3. Conductors with compact and compressed stranding have about 9 percent and 3 percent, respectively, smaller bare conductor diameters than those shown. See Table 5A for actual compact cable dimensions.
4. The IACS conductivities used: bare copper = 100%, aluminum = 61%.
5. Class B stranding is listed as well as solid for some sizes. Its overall diameter and area is that of its circumscribing circle.

Informational Note: The construction information is in accordance with NEMA WC/70-2009 or ANSI/UL 1581-2001. The resistance is calculated in accordance with National Bureau of Standards Handbook 100, dated 1966, and Handbook 109, dated 1972.

[Figure 8.4.1: NEC Table 8 Conductor Properties]

1	**Documentation**			
1.1	Weekly Agenda	Baylor	08/30/2023	
1.2	Meeting Minutes	Bell	08/30/2023	
1.3	Bi-weekly report	Eli	08/30/2023	
1.4	Presentation Slides	ALL	08/30/2023	
1.5	Project Design Document (Preamble)	ALL	08/30/2023	
1.6	Final Report	ALL		
2	**Research**			
2.1	Data sheet Utility PV Solar Panel	Liam	9/12/23	9/20/23
2.2	Safety Moment	Eli	9/12/23	9/20/23
2.3	Data sheet for Combiner Box	Eduardo	9/12/23	9/20/23
2.4	Data sheet for Inverter	Chicheng	9/12/23	9/20/23
2.5	New Mexico Vs Iowa as location for power plant	Bell	9/12/23	9/20/23
2.6	Substation Design	Eli & Baylor	9/12/23	9/20/23
3	**Component Selection**			
3.1	Material components lists		9/14/23	9/20/23
3.2	Location	Bell	9/14/23	9/20/23
3.4	Substation Component (Main, and bus)	Eduardo	9/14/23	9/20/23

[Figure 8.4.2: Fall 2023 Gantt Chart Part A]

4	**Array Parameter Calculation**			
4.1	String size	Baylor	9/20/23	10/4/23
4.2	Electrical rack size	Liam	9/20/23	10/4/23
4.3	CB capacity	Liam	9/20/23	10/4/23
4.4	Array design	Liam	9/20/23	10/12/23
4.5	Array size	Liam	9/20/23	10/12/23
4.6	Total equipments	Liam	9/20/23	10/12/23
4.7	Total cost and budget	Bell	9/20/23	10/12/23
4.8	Total Power (AC & DC)	Liam	9/20/23	10/12/23
4.9	Voltage drop calculation	Bell	9/20/23	
4.1	Economic analysis	Bell		
5	**Designing Solar Panel (AutoCAD)**			
5.1	Solar Panel (key plan, elevation, grounding)	Liam		11/2/23
5.2	Array	Eduardo		11/2/23
5.3	Rack	Eduardo		11/2/23
5.4	Solar Layout	ALL		11/2/23
5.5	Solar Field Design	Eli & Baylor		
6	**Simulation (ETAP)**			
6.1	Designing Solar Power System	ALL		11/23/23
6.2	Assign requirements and value	ALL		11/23/23
6.3	Simulation	ALL		11/23/23
7	**Final Presentation**			
7.1	Black & Veatch Presentation	ALL		11/29/23
7.2	Faculty Presentation	ALL		12/6/23

[Figure 8.4.3: Fall 2023 Gantt Chart Part B]

1	**Documentation**	
1.1	Weekly Agenda	Baylor
1.2	Meeting Minutes	ALL
1.3	Bi-weekly reports	Eli
1.4	Presentation Slides	ALL
1.6	Final Report	ALL
2	**Initial Research**	
2.1	Substation Component	ALL
2.2	Safety Moment	ALL
2.3	One-line diagram of substation	ALL
2.4	Substation Design	ALL
2.5	Presentation Slides	ALL
3	**Component Selection**	
3.1	Bus and line	Liam
3.2	Main Component	Eduardo
3.3	Component Spec	Bell
3.4	Substation Component (Main, and bus)	Chicheng
4	**Calculation**	
4.2.1	DC battery calculation	Eduardo
4.2.2	Grounding calculation	Chicheng
4.3	AC load calculation	Baylor
4.4	Lightning calculation	Eli
4.3.1	Total equipment	Bell
4.3.2	Total cost	Bell
4.3.3	Total Power (AC & DC)	Liam

[Figure 8.4.4: Spring 2024 Gantt Chart Part A]

5	**Designing**	
5.1	One-line diagram of substation	ALL
5.2	Bus plan	ALL
5.3	Grounding diagram	ALL
5.4	Conduit diagram	ALL
5.4.1	Whole Solar and Substation Layout	ALL
6	**Simulation (ETAP)**	
6.1	Designing Solar Power System	ALL
6.2	Assign requirements and value	ALL
6.3	Simulation	ALL
7	**Final Presentation**	
7.1	Black & Veatch Presentation	ALL
7.2	Faculty Presentation	ALL

[Figure 8.4.5: Spring 2024 Gantt Chart Part B]

	Pmax (W)	Vmp (V)	Imp (A)	Voc (V)	Isc (A)	Mod Eff (%)
PVX-Y-Z.W	550	41.90	13.13	50.20	13.89	21.29

Model No. ZXM7-SHDB144

	Vmax (V)	Input #	Imax in (A)	Imax out (A)
CBX-Y	1500	16	30	350

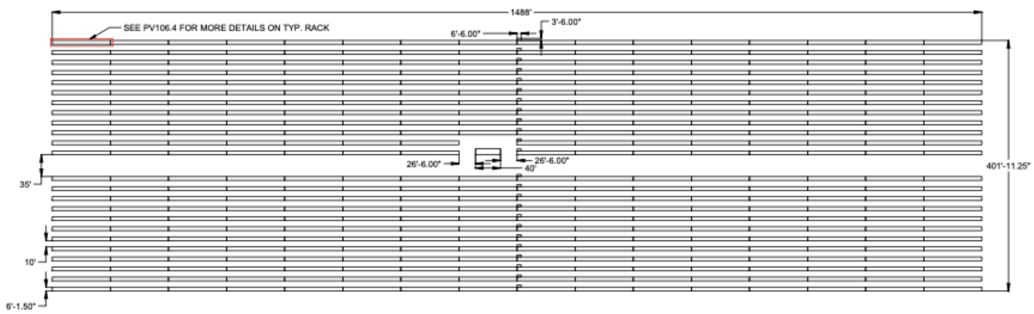
Model No. BHTZ-16/1

	INPUT (DC)			OUTPUT (AC)			
	PVmax (kWp)	DC Volt Range (V)	DC Inputs	Snom (kVA)	Smax (kVA)	Output Freq (Hz)	Inv Eff (%)
INV-X	2 x 3200	935-1500	24	4000	4400	60	98.8

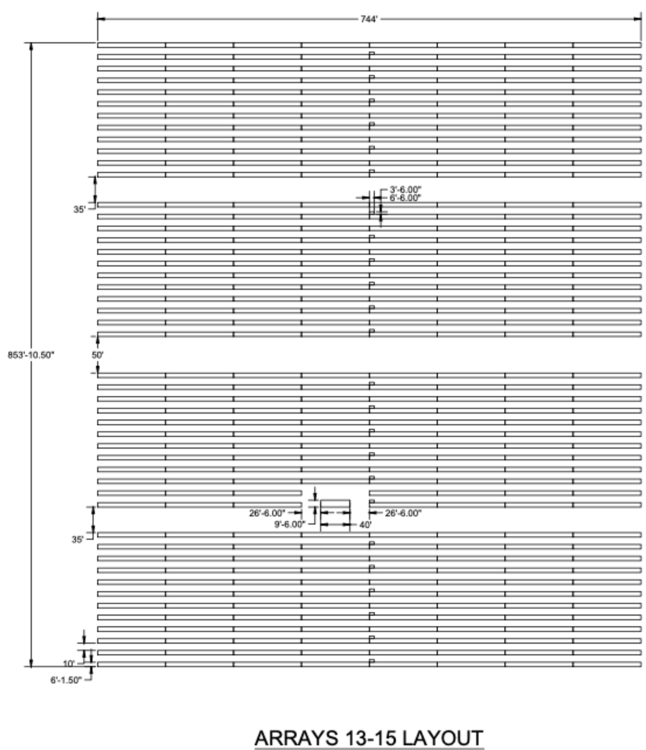
Model No. PVS980-MWS-4000kVA-K

X = INVERTER #
Y = CB #
Z = STRING #
W = MODULE #

[Figure 8.4.6: Solar Farm Parameters]



[Figure 8.4.7: Horizontal Array]



[Figure 8.4.8: Vertical Array Layout]

	Vmax (kV rms)	Isc (kA rms)	Curr Rating (A rms)	Model No.	
CB1-X	36	25	2500	OHB 36	SEE SS110 FOR MORE INFO
CB2-X	126	40	3150	LW25A-126	SEE SS111 FOR MORE INFO

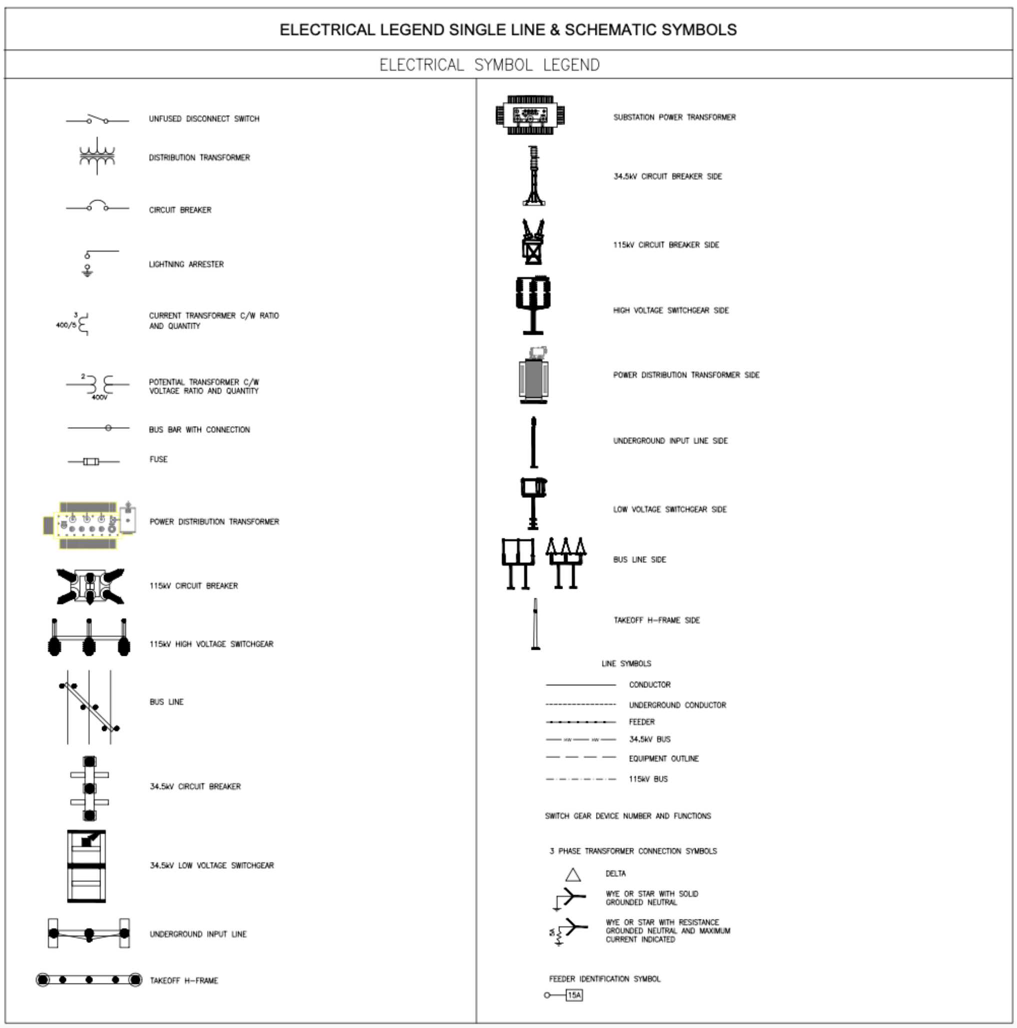
	Vmax (kV rms)	Isc (kA rms)	Curr Rating (A rms)	Model No.	
DS1-X	38	16	2000	VacClad W 38kV	SEE SS112 FOR MORE INFO
DS2-X	121	40	2000	657428-Z3	SEE SS113 FOR MORE INFO

	Vnom (kV)	Vmax (kV)	Isc (kA rms)	Vmcov (kV)	Model No.	
LA1-X	36	217	63	3.9 (1-impulse)	USAA036029A1845A11	SEE SS114 FOR MORE INFO
LA2-X	144	770	65	5.6 (1-impulse)	AZES013G115144	SEE SS115 FOR MORE INFO

	LOW SIDE		HIGH SIDE				
	Vnom (kV)	Inom (kA)	Vnom (kV)	Inom (A)	Rating (MVA)	Model No.	
T1	34.5	1.5	115	451.8	90	SF-900000/115	SEE SS116 FOR MORE INFO

	Vmax (kV rms)	Curr Ratio
CT1-X	34.5	300:1
CT2-X	123	50:1

[Figure 8.4.9: Substation Component Parameters]



[Figure 8.4.10: Substation Components]

EnerSys
Power/Full Solutions

Summary Margin Report

Customer:	Iowa State University under Black & Veatch
Location:	Lovington, New Mexico
Project:	115/34.5kV Solar Power Plant & Substation
Date Prepared:	4/26/24
Prepared By:	Siti Nabila Mohd Radzi
Phone:	515-7081944
E-Mail:	bellaahn@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	6 OGi 80	0.9%
2	CA-05M	6.3%
3	CA-03M (2 Strings)	6.3%
4	CC-05M	6.4%
5	CC-03M (2 Strings)	6.4%
6	6 OGi 60 (2 Strings)	34.5%
7	ESG-05	96.4%
8	DSG-05	216.8%
9	EA-05M	119.7%
10	EC-05M	120.5%
11	GC-09M	811.7%
12	4 OPzS 200	135.3%
13	Vb 2408	919.2%

Battery Load Details

Number of Cells: 60
Total Time (Minutes): 241.00
Amp Hour Removed: 56.93

Period	Time (Mins.)	Load
1	0.00	19.32 A
2	1.00	2.82 A
3	240.00	14.22 A

[Figure 8.4.11: Battery Sizing Calculation]

EnerSys
Power/Full Solutions

Sizing Report Using IEEE-485 Method

Customer Name:	Iowa State University under Black & Veatch	**Prepared by:**	Siti Nabila Mohd Radzi
Location:	Lovington, New Mexico	**Phone:**	515-7081944
Project:	115/34.5kV Solar Power Plant & Substation	**Date:**	4/26/24
Email:	bellaahn@iastate.edu		

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	19.32	19.32	00:00:00	00:00:00	0.625	12.075	0.000
					Sub Total	12.075	0.000
					Section 1 Total	12.075	
SECTION 2 - FIRST 2 PERIOD ONLY - IF A3 IS GREATER THAN A2. GO TO SECTION 3							
1	19.32	19.32	00:00:00	00:01:00	0.733	14.153	0.000
2	2.82	-16.50	00:01:00	00:01:00	0.733	0.000	-12.087
					Sub Total	14.153	-12.087
					Section 2 Total	2.066	
SECTION 3 - FIRST 3 PERIOD ONLY - IF A4 IS GREATER THAN A3. GO TO SECTION 4							
1	19.32	19.32	00:00:00	04:01:00	4.822	93.155	0.000
2	2.82	-16.50	00:01:00	04:01:00	4.822	0.000	-79.558
3	14.22	11.40	04:00:00	04:00:00	4.807	54.796	0.000
					Sub Total	147.951	-79.558
					Section 3 Total	68.393	

MAXIMUM SECTION(8) 68.39 + RANDOM SECTION SIZE(9) 0.00 = UNCORRECTED SIZE - (US)(10) 68.39

(US)(11) 68.39 x TEMP CORR(12) 1.000 x DESIGN MARGIN(13) 1.10 x AGING FACTOR(14) 1.25 = (15) 94.04

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

REQUIRED CELL SIZE(16) = 100 AH (PRODUCT RATING PER STRING IS 100 AH)

THEREFORE 1 STRING OF (20) CA-05M IS RECOMMENDED
Margin : 6.3%
Total AH Removed for System: 57 **Number of Cells for System: 60**

[Figure 8.4.12: Battery Sizing Calculation]

Flexible conductor:

Code Word	Size (AWG or kcmil)	Strand-ing (Al/Stl)	Diameter (ins.)				Weight Per 1000 ft. (lbs.)			Content (%)		Rated Strength (lbs.)	Resistance OHMS/1000 ft.		Allowable Ampacity+ (Amps)
			Individual Wires		Steel Core	Complete Cable	Al	Stl	Total	Al	Stl		DC @ 20°C	AC @ 75°C	
			Al	Stl											
Bluejay	1113	45/7	.1573	.1048	.3145	1.258	1048	205	1253	83.67	16.33	29800	.0155	.0194	1092

+Conductor temperature of 75°C, ambient temperature 25°C, emissivity 0.5, wind 2 ft./sec., in sun.

Rigid bus:

Physical & Electrical Properties of Aluminum

Standard Pipe-Size Conductors at Typical Conductivities

Nominal Size in	A: Outside Diameter of Tube in	B: Wall Thickness in	Area sq in	Weight lbs/ft	Inductive reactance 1 ft spacing 60 Hz microhm/ft	6063-T6 DC Resistance at 20°C microhms/ft	6063-T6 60 Hz Rac/RDC at 70°C	6063-T6 AC Resistance at 70°C 60 Hz microhms/ft	6063-T6 Current Ratings Amp at 60 Hz (1) (2) (3) (4) Outdoor	6061-T6 DC Resistance at 20°C microhms/ft	6061-T6 60 Hz Rac/RDC at 70°C	6061-T6 AC Resistance at 70°C 60 Hz microhms/ft	6061-T6 Current Ratings Amp at 60 Hz (1) (2) (3) (4) Outdoor
Schedule 40 Pipe													
1	1.315	0.133	0.494	0.581	68.24	31.120	1.00039	36.580	681	38.360	1.00032	43.820	622
1 1/4	1.660	0.140	0.669	0.786	62.68	22.990	1.00050	27.030	859	28.340	1.00039	32.370	705
1 1/2	1.900	0.145	0.800	0.940	59.45	19.220	1.00064	22.600	984	23.690	1.00046	27.070	900
2	2.375	0.154	1.075	1.264	54.15	14.300	1.00082	16.820	1234	17.630	1.00055	20.140	1128
2 1/2	2.875	0.203	1.704	2.004	49.85	9.019	1.00220	10.620	1663	11.170	1.00150	12.710	1520
3	3.500	0.216	2.228	2.621	45.19	6.897	1.00300	8.126	2040	8.500	1.00180	9.725	1865

[Figure 8.4.13: Bus Calculations]

Table B.4 — Aluminum tubular bus—schedule 40 ac ampacity (53.0% conductivity)

SPS[a] size	OD	Wall thickness	Emissivity = 0.20, with sun temperature rise above 40 °C ambient							Emissivity = 0.20, without sun temperature rise above 40 °C ambient						
(in)	(in)	(in)	30	40	50	60	70	90	110	30	40	50	60	70	90	110
1.0	1.315	0.133	591	688	770	840	903	1011	1102	638	728	804	871	931	1035	1123
1.5	1.900	0.145	837	978	1097	1199	1290	1447	1580	914	1043	1153	1250	1336	1486	1614
2.0	2.375	0.154	1035	1213	1362	1490	1605	1802	1969	1139	1300	1438	1558	1666	1854	2015
2.5	2.875	0.203	1377	1618	1818	1992	2147	2413	2640	1527	1743	1928	2090	2235	2488	2705
3.0	3.500	0.216	1666	1962	2208	2422	2612	2940	3220	1861	2126	2351	2550	2728	3038	3305
3.5	4.000	0.226	1897	2239	2523	2770	2989	3367	3690	2132	2435	2695	2923	3127	3484	3792
4.0	4.500	0.237	2134	2523	2847	3127	3376	3807	4175	2412	2755	3049	3307	3539	3945	4295
5.0	5.563	0.258	2636	3127	3536	3890	4204	4748	5213	3010	3439	3807	4131	4422	4933	5374
6.0	6.625	0.280	3153	3752	4250	4681	5063	5726	6294	3633	4152	4597	4990	5343	5963	6500
8.0	8.625	0.322	4142	4954	5629	6213	6731	7631	8404	4843	5538	6135	6662	7138	7975	8703
SPS size	OD	Wall thickness	Emissivity = 0.50, with sun temperature rise above 40 °C ambient							Emissivity = 0.50, without sun temperature rise above 40 °C ambient						
(in)	(in)	(in)	30	40	50	60	70	90	110	30	40	50	60	70	90	110
1.0	1.315	0.133	572	690	788	872	948	1078	1190	686	785	870	945	1013	1133	1238
1.5	1.900	0.145	805	981	1127	1252	1363	1556	1723	992	1136	1260	1370	1469	1645	1800
2.0	2.375	0.154	991	1217	1402	1561	1703	1949	2161	1244	1425	1581	1720	1845	2068	2264
2.5	2.875	0.203	1314	1623	1876	2094	2287	2623	2914	1677	1921	2132	2320	2490	2793	3060
3.0	3.500	0.216	1582	1969	2284	2555	2795	3214	3576	2056	2357	2617	2848	3059	3434	3766
3.5	4.000	0.226	1796	2248	2614	2929	3208	3694	4116	2366	2712	3012	3280	3523	3957	4342
4.0	4.500	0.237	2015	2534	2954	3315	3635	4192	4675	2686	3080	3421	3726	4004	4500	4940
5.0	5.563	0.258	2474	3142	3680	4141	4550	5262	5880	3375	3872	4304	4690	5041	5671	6232
6.0	6.625	0.280	2943	3771	4435	5003	5506	6382	7144	4098	4703	5230	5701	6131	6902	7591
8.0	8.625	0.322	3830	4982	5899	6681	7373	8581	9633	5515	6334	7048	7688	8274	9328	10 274

[a]SPS = standard pipe size.

[Figure 8.4.14: Bus Calculations]

8.4.1 Team Contract

Team Members:

1) Baylor Clark
2) Elymus Schaffer
3) Eduardo Jimenez-Tzompaxtle
4) Chicheng Tang
5) Liam Gozzman
6) Siti Mohd Radzi

8.4.1.1 Team Procedures

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

3 o'clock on Wednesdays in the library, room dependent.

8.4.1.1.2 Preferred method of communication updates, reminders, issues, and scheduling (e.g., e-mail, phone, app, face-to-face):

Discord for online meetings and regular updates (reminders, issues)

Email will be used as a communication channel between clients, TA, and project advisor.

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

Majority vote while considering situations and cases by creating issues on GitLab.

Gitlab for team progress tracking and task delegation

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

Meetings will be recorded through meeting minutes and shared in the Google Drive and GitLab by Siti Nabila (Bell)

8.4.1.2 Participation Expectations

8.4.1.2.1 Expected individual attendance, punctuality, and participation at all team meetings:

Record all meeting minutes with any meeting you have with anyone, you and the group or you and any advisor or client.

Team members are expected to attend all meetings (regular, TA meetings, Advisor meetings, and client meetings) and be punctual for meetings; in case of absence or late, notice should be given to the whole team.

8.4.1.2.2 Expected responsibility for fulfilling team assignments, timelines, and deadlines:

Tasks will be assigned in GitLab with a date attached to it to create a time frame and deadlines for the assignments.

Individual progress will be tracked weekly or daily, depending on the time frame for each assignment.

Teams are expected to keep up with everyone's progress on individual tasks.

Loose deadlines will be set up to ensure that hard deadlines can be met.

8.4.1.2.3 Expected level of communication with other team members:

Response within a day is expected.

8.4.1.2.4 Expected level of commitment to team decisions and tasks:

Varying upon weeks but ensuring that everyone is included in team decisions.

8.4.1.3 Leadership

8.4.1.3.1 Leadership roles for each team member (e.g., team organization, client interaction, individual component design, testing, etc.):

Baylor: Team Organizer

Bell: Recorder and Testing

Liam: Client Correspondent

Chicheng: Research and Testing

Eduardo: Submission

Eli: Team Lead

8.4.1.3.2 Strategies for supporting and guiding the work of all team members:

If someone asks for help, you help them with the preface of you're working on something else first then can help them.

8.4.1.3.3 Strategies for recognizing the contributions of all team members:

Voicing your opinions on team issues and then weekly recognition from the Issues Board.

8.4.1.4 Collaboration and Inclusion

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

Baylor Clark: I have experience with project management and team communication through internships over the past two summers. I also have experience working on projects with a couple of the other group members from previous classes.

Elymus Schaffer: I bring my extrovert personality to help me invoke thought-provoking questions and discussions for our team. I have also worked for companies throughout semesters while keeping my grades up and communicating effectively with my employer. I know about creating a Bill of Materials and being able to help schedule who does what and when.

Eduardo Jimenez-Tzompaxtle: I have experience working with a group and communicating with people. I have taken some classes in transmission and power

Chicheng Tang: I have experience collaborating with team members to complete the work. And I have taken a class about distribution and transmission systems.

Liam Gossman: I have experience with substation design and general operations through my internships at MidAmerican Energy. I also have experience with distribution systems design and effective communication skills necessary for collaboration between different design departments.

Siti Mohd Radzi: I have numerous experiences working in a team, from various work environments, from working for technical projects, student organizations, volunteering programmes, and fundraising; I believe I would be able to contribute to creating a healthy work environment within the team, by ensuring the expectation and performance of the team is consistent and good.

8.4.1.4.2 Strategies for encouraging and supporting contributions and ideas from all team members:

Asking everyone what they think on each topic and congratulating each other when a task gets completed.

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

Talk to the group during the weekly meetings, knowing that not everyone is perfect. Google survey about weekly personal performance.

8.4.1.5 Goal-Setting, Planning, and Execution

8.4.1.5.1 Team goals for this semester:

Making sure everyone is on the same page and making sure that we communicate well and know what we are doing.

8.4.1.5.2 Strategies for planning and assigning individuals and teamwork:

Ensuring everyone has a task for the week and ensuring they are mostly even.

8.4.1.5.3 Strategies for keeping on task:

Setting "loose" deadlines for tasks as well.

8.4.1.6 Consequences for Not Adhering to Team Contract

8.4.1.6.1 How will you handle infractions of any of the obligations of this team contract?

Bring the problems up in the group meetings and find a way to solve the problem.

Give the individual or team a time frame to settle the issue and track the progress until the issue is resolved.

8.4.1.6.2 What will your team do if the infractions continue?

Bring it up to the professor if continuous for an extended period.

a) I participated in formulating the standards, roles, and procedures as stated in this contract.
b) I understand that I am obligated to abide by these terms and conditions.
c) I understand that if I do not abide by these terms and conditions, I will suffer the consequences as stated in this contract.

1) ____Elymus Schaffer________________________________ DATE ___27/04/2024______

2) ____Baylor Clark___________________________________ DATE __27/04/2024________

3) ____Chicheng Tang_________________________________ DATE __27/04/2024________

4) ____Liam Gossman_________________________________ DATE __27/04/2024________

5) ____ Eduardo Jimenez-Tzampotxle___________________ DATE __27/04/2024________

6) ____Siti Mohd Radzi ________________________________ DATE __27/04/2024________