115/34.5KV Solar Plant & Substation Design Project

DESIGN DOCUMENT

Team Number: 41

Client: Black & Veatch

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Executive Summary

For our group's senior design project, we were tasked with creating a fictitious solar farm and substation that will connect to the grid to supply power to its users. Our design was built from the ground up, and we were not given any true requirements to follow; however, our clients, Black and Veatch, did give us some tips to get our design started, which included building it in the state of New Mexico. The solar farm will help the earth's atmosphere by providing New Mexican users with greener energy. The farm will produce 60 Mega Watts (MW)

of power and will be connected to a substation through a 115 Kilo Volts (kV)/34.5 kV transformer. The solar farm was designed during the fall semester, and our substation integration was designed during the spring semester.

Our design process started with selecting our three solar farm components: the solar panel modules, combiner boxes, and inverters. The solar panels convert the sun's energy into an electrical current (direct current (DC)), and the combiner boxes take this current from multiple panels and get it to a centralized point. The DC current at this point is then fed into an inverter, which converts the DC current into an alternating current (AC), which is the current type used for power on the grid. Using the data sheets from the equipment selected, and a spreadsheet provided by our clients, we were able to design our rack arrays, which told us how many panels we would need to reach our goal of 60 MWs.

Using this information, we were able to design the rack arrays to fit into our land plot that we are fake buying to build on. The first spreadsheet left us with a few rack layout designs, but we had to figure which layout was the most efficient by calculating the voltage lost while it traveled through the various cables. When we got our voltage drops within the allowed percentage lost (3-5 percent), we used AutoCAD to draft our panels and create wiring diagrams for future contractors to use when installing the equipment.

We followed a similar design process for the substation. We first selected our components which included transformers, circuit breakers, and switches. After this we researched and decided on a bus configuration by weighing the pros and cons of each configuration such as cost, land constraints, and levels of protection. Using this decision, we developed a one-line diagram detailing where each circuit breaker, transformer, and switch goes. Using this as a foundation we were able to develop other drawings like our key plan and three line.

Calculations such as grounding, AC, and DC calculations were done so we could use and adhere to various IEEE standards. The grounding calculations are very important for workers safety, and proper circuit and equipment operation. The AC calculations are used to size the station service voltage transformer (SSVT) and the DC calculations are used to size the backup battery packs. These played a crucial role in our design process.

Learning Summary

Development Standards & Practices Used

We're applying our knowledge of power systems and using tools like ETAP, Bluebeam, and AutoCAD to design a 115/34.5 kV substation and solar farm. By following standards like IEEE, NEC, and OSHA, we're committed to creating a safe and reliable environment for everyone involved.

Summary of Requirements

- Equipment sizing calculations (breakers, transformers, etc)
- Excel fil * Solar layout drawings – Bluebeam/CAD/PDF editor
- Solar panel string sizing design – Excel file
- Electrical layout drawings (substation equipment) – Bluebeam/CAD/PDF editor
- Grounding analysis and ground-grid developed with IEEE-80 – Excel file
- Bus calculations for substation – Excel file
- Possibility of additional calculations (DC battery bank, lightning protection, etc.) – Excel file
- 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

- EE3320 - Semiconductor Materials and Devices
- EE3030 - Energy Systems and Power Electronics
- EE4550 - Introduction to Energy Distribution Systems
- EE4560 - Power System Analysis I
- EE4570 - Power System Analysis II
- EE4580 - Economic Systems for Electric Power Planning

New Skills/Knowledge Acquired 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

List of Figures/Tables/Symbols/Definitions

1. Introduction

1.1 Problem Statement

Nowadays, with the world facing concerns over climate change and the increase of non-renewable energy resources, the need for sustainable energy solutions has become increasingly urgent. Traditional energy sources, such as coal and natural gas, contribute significantly to environmental degradation and greenhouse gas emissions. As global attention shifts toward renewable energy to mitigate these effects, large-scale solar power plants have emerged as an adequate solution. The 115/34.5 kV Solar Plant & Substation Senior Design Project will strive to build a system that produces this green energy. Our clients, Black & Veatch, aim to address the challenges associated with transitioning to cleaner energy and will help guide us through the process. Through our collaboration, the solar plant will generate clean, sustainable electricity that can be efficiently integrated into the local power grid.

This project not only contributes to minimizing carbon emissions or provide job opportunities in New Mexico, but also supports the global shift toward renewable energy. Using engineering concepts, we will implement an additional way to generate renewable energy and integrate it into the electrical systems by designing a 60MW solar farm and substation. We will be focusing on designing the solar plant for the first semester, then work on the substation for the second semester.

1.2 Intended Users

1.2.1. Utility Companies

- Description: Utility companies responsible for distributing electricity to residential, commercial, and industrial sectors.

- Need: As part of the energy transition, utility companies require reliable, sustainable power sources to meet demand, reduce emissions, and comply with renewable energy regulations.

- Benefit: The solar plant will provide a consistent, renewable power supply that utility companies can distribute to their customers. This supports their goals of reducing environmental impact while ensuring a stable energy supply. Additionally, utility companies can benefit from lower operational costs due to the long-term savings associated with solar energy.

1.2.2. Local Communities in Luna County

- Description: Residents and businesses in the Luna County region who will directly benefit from the availability of clean energy.

- Need: Access to affordable, reliable, and clean electricity is a growing concern for local communities, especially in regions where energy costs are high and non-renewable sources dominate.

- Benefit: The solar plant will provide local residents and businesses with a reliable source of clean electricity. This can lead to lower energy bills, reduced dependence on non-renewable resources, and a smaller environmental footprint for the community. The project also enhances local job opportunities during the construction and operation phases.

2. Requirements, Constraints, And Standards

2.1. Requirements & Constraints

- Equipment sizing calculations (solar panels, inverters, etc) – Excel files
- Solar layout drawings – Bluebeam/CAD/PDF editor
- Solar panel string sizing design – Excel file
- Electrical layout drawings (substation equipment) – Bluebeam/CAD/PDF editor
- Grounding analysis and ground-grid developed with IEEE-80 – Excel files
- Additional calculations (AC, DC, etc.) – Excel files
- Simulation of designed substation – SIMULATION SOFTWARE – STUDENT LICENSE [ETAP/SKM/ASPEN]
- Load Flow Analysis / Protection Element Analysis – SIMULATION SOFTWARE – STUDENT LICENSE [ETAP/SKM/ASPEN]
- Creation of solar/substation conceptual design-optimizing tool – Microsoft Access/TBD

2.2. Engineering Standards

1. **NEC2020- (National Electrical Code)**

   This is a comprehensive set of safety standards developed to ensure safe electrical design, installation, and inspection practices across a wide range of electrical systems, including substations. We believe it is relevant to our project because it covers wiring and protection, equipment for general use, grounding, and bonding, along with other electrical installations. The goal is to protect people and property from electrical hazards by defining standards that minimize the risk of fires, electrical shock, and failures in power systems.

2. **IEEE 1547.3-2023**

   This standard focuses on the **interconnection of distributed energy resources (DERs),** such as solar arrays with the electrical grid. We believe that this is relevant to our project because according to our model, we might potentially have 15 solar arrays in our design project and this standard will ensures that our solar plants can connect to the grid while maintaining stability. In addition, the standard addresses how to keep voltage levels within acceptable limits during power transfers to and from the grid, ensuring reliable and safe grid operations, especially with increasing renewable energy integration.

3. **IEEE 2778-2020**

   This standard guides the **grounding system design for utility-scale photovoltaic (PV) solar power plants**. Grounding is crucial for ensuring safety and operational integrity by minimizing the risks of electrical faults, overvoltage, and shock hazards. We believe that this standard is relevant because it is designed for solar power plants larger than 5 MW, (which is our case) helping utilities design safe and efficient grounding systems that comply with regulatory requirements and improve the overall resilience of the plant.

After discussing with the team, some of my team members have chosen other standards, such as **IEEE 519-2014**, which focuses on harmonics in electrical systems. This is critical in managing the power quality in our solar plant. Others have also referenced **IEC 62109**, which deals with the safety of power converters used in solar installations, ensuring that inverters and similar equipment meet global safety requirements. Finally, based on the above standards, we plan to make the following modifications to our project design:

- **Grounding system adjustments**: We will incorporate the guidelines from **IEEE 2778-2020** to ensure that our grounding system is strong enough for utility-scale operation, with a special focus on safety during fault conditions.
- **Grid interconnection features**: We will apply **IEEE 1547.3-2023** to properly ensure that our solar plant maintains voltage stability and power quality while exporting power to the grid.
- **NEC 2020 compliance**: We will make sure that all electrical installations within the substation conform to **NEC 2020** to prevent electrical hazards, optimizing the layout and wiring based on safety standards.

3. Project Plan

3.1. Project Management/Tracking Procedures

Our team adopted the waterfall project management style to structure and guide the progression of our senior design project. The waterfall method emphasizes a sequential, linear approach where each phase must be completed before advancing to the next. This ensures that every stage, from requirements to design, implementation, verification, and maintenance, is thoroughly addressed before moving forward.

The clear milestones and well-defined deliverables at each stage help us maintain focus and direction, while minimizing the need for frequent iterations once the initial designs are finalized. This approach offers more predictability, a well-ordered schedule of tasks, and comprehensive documentation, making it easier to detect potential issues early in the planning or design stages. As a result, the Waterfall method offers the control and structure that suits the complexity of our project.

While we are not strictly following an agile methodology, our advisor stressed the importance of leadership and adaptability, key agile principles. In response, we've implemented a rotating leadership structure, allowing team members to take on leadership roles at different stages of the project. This not only promotes a shared sense of responsibility but also gives each team member the opportunity to guide specific aspects of the project. This role rotation helps us remain flexible and dynamic, fostering collaboration and responsiveness to challenges. This approach ensures we maintain open communication and can quickly address any issues that arise. In practice, we recognize that it's common to revisit earlier phases to refine designs or resolve problems, and our team is prepared to allow for some overlap between phases if needed.

Our Gantt chart reflects this waterfall structure, helping us track tasks and design progression in a clear and organized manner. Additionally, the group will use SMS for quick communication and Cybox for file management and updates, ensuring seamless tracking of design phases and task assignments. Although we aren't using Agile in its pure form, we incorporate its principles by emphasizing regular check-ins and early detection of obstacles, allowing for a smooth progression through the phases of our senior design project.

3.2. Task Decomposition

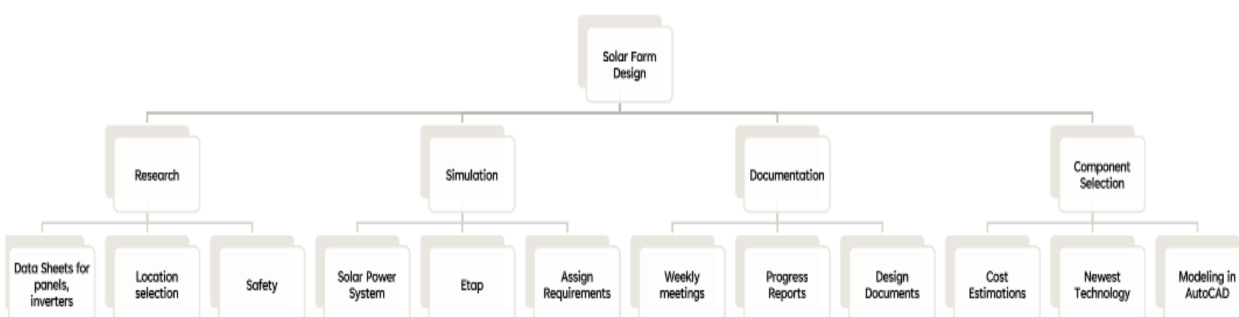
Our team has decomposed our project into many different tasks. These tasks can be applied throughout every step of our waterfall project management style. The decomposition of the tasks helps us understand what needs for the project. This includes: research, simulation, documentation, and component selection.

For the research component of our decomposition, we have broken it down into three parts: component data sheets, location, and safety. These are the main objectives that we started our project with. We are unable to progress through the waterfall if we do not do our research on these things, as everything we do will depend on them. There are other tasks that fall under the research category such as our weekly safety moments and new technologies. These are a short part of our weekly presentation that give us insight into the industry. As we continue through our project there will be other things to research such as how to use software and how to do certain calculations.

Moving to the simulation component this mostly applies to the later part of both our solar farm and substation design. We will be doing a separate simulation for each of these things using ETAP. We will be able to ensure our design meets the set requirements and operates as intended. This task is very important because if it does not function as intended then we must go back and redesign our project to get it up to standard.

Our project also involves large amounts of documentation for everything. We have weekly meetings, progress reports, and design documents to make. These tasks are separate from the waterfall progression of our project. These are to keep us up to date and on target for the tasks that make up the waterfall. For our weekly meetings we take notes and send them to all attendees to make sure we are on the same page for what we have to do. Relating to the main tasks of the project we have to document all research that we do in order to complete them. We also create drawings and have excel spreadsheets for calculations. This falls under things we are documenting as they are the key deliverables of the project.

The final part of the decomposition is component selection. This comes after a lot of our research and also applies to both the solar farm and substation. From our research on components, we need and their data sheets, we will select the components we think will work best for our design. We also consider factors such as cost, and how new the technology is. After we do this, we can begin our initial design with these components and make models on AutoCAD.



[Figure 3.2.1 Task Decomposition]

3.3. Project Proposed Milestones, Metrics, and Evaluation Criteria

Throughout our project, we will utilize clear milestones, metrics, and evaluation criteria to track our progress comprehensively across both semesters. While many milestones apply to both the solar array and substation portions of our project, some are specific to individual tasks but remain under unified categories. Utilizing numerical evaluations allows us to monitor our progress precisely through quantifiable metrics.

3.3.1 Fall Semester – Solar Plant

Milestones:

- Site selection and validation (Completed: Luna County, New Mexico)
- Component selection (solar panels, inverters, mounting structures)
- Initial site design and layout
- Voltage drops and power output calculations
- Efficiency optimization through design and orientation (south-facing, 30-degree tilt)
- Completion of initial simulation models

Metrics:

- Achieve 60 MW peak AC power output
- Voltage drops across the solar array 2.81%
- Operational efficiency target of 75% (actual output vs. theoretical continuous 60 MW generation)

Evaluation Criteria:

- Compliance with IEEE standards
- Validation of calculations using ETAP

3.3.2 Spring Semester – Substation Design

Milestones:

- Completion of detailed substation drawings (single-line diagrams, three-line layout)
- Detailed electrical calculations (fault current, grounding, protective relay settings)
- Component specification and selection (transformers, circuit breakers, protective equipment)
- Completion of power system simulations
- Cost analysis and component sourcing

Metrics:

- Efficiency in terms of minimal power losses within the substation

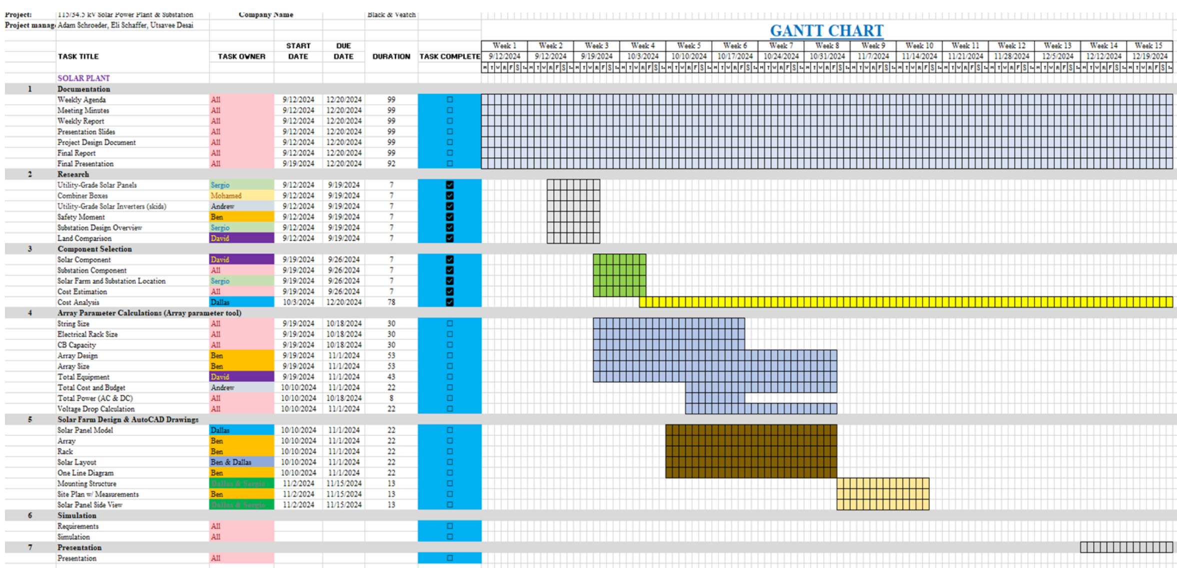
- Voltage regulation and stability metrics
- Fault tolerance and protective system reliability
- Compliance with grid interconnection standards

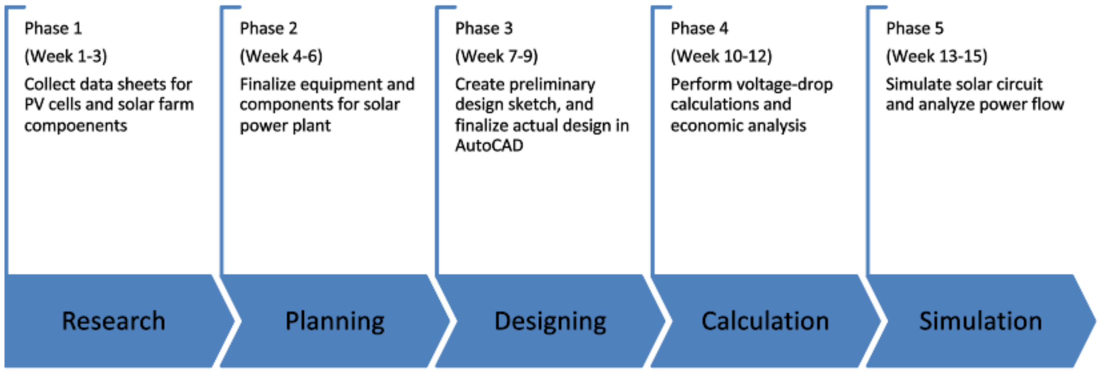
Evaluation Criteria:

- Adherence to IEEE and industry-specific standards for substation design
- Successful simulation results demonstrating reliable and efficient operation
- Validation of cost-effectiveness and component suitability
- Peer review by academic and industry advisors to confirm professional-level quality and compliance

3.4. Project Timeline/Schedule

The Gantt chart serves as a crucial tool for our project, serving as a visual representation of our schedule. It clearly lists the duration and sequence of each task, ensuring that our client will have an understanding of the project's progression within the defined timeframe. This chart will be regularly referenced and summarized within project documentation to emphasize key milestones and deliverables across both semesters. By doing so, it will ensure there is a clear alignment between individual tasks and the project's overarching objectives. Including this chart in presentations and reports will facilitate effective communication, help track project progress, and allow for timely adjustments. This will overall enhance the strategic execution of our project and set our team up for a successful completed project.





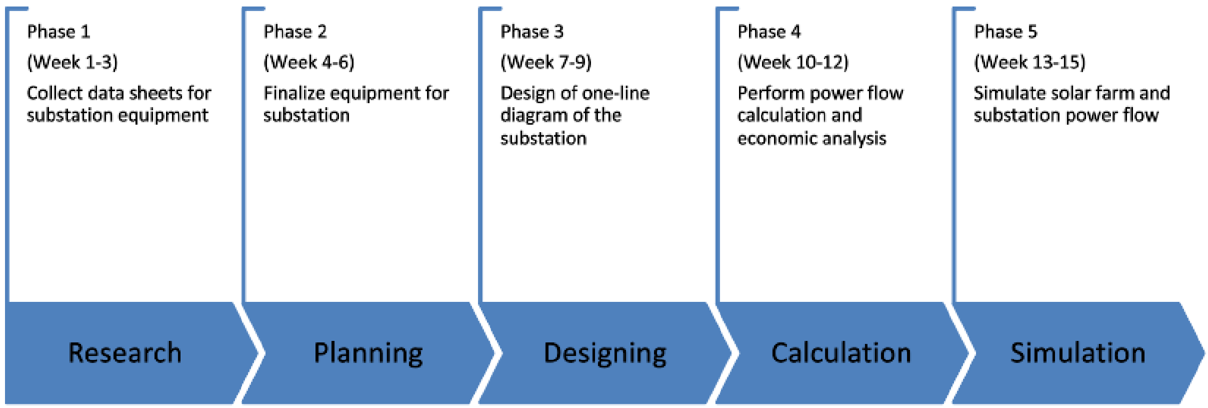
[Figure 3.4.1 Solar Farm Design]

Project: 115/34.5 kV Solar Power Plant & Substation — **Company Name** Black & Veatch
Project manager Adam Schroeder, Eli Schaffer, Utsavee Desai

Week 1 (1/27/2025) | Week 2 (2/3/2025) | Week 3 (2/10/2025) | Week 4 (2/17/2025) — M T W R F S Su

	TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION	TASK COMPLETE
	SUBSTATION					
1	**Documentation**					
	Weekly Agenda	All	1/27/2025	5/16/2025	109	☑
	Meeting Minutes	All	1/27/2025	5/16/2025	109	☑
	Weekly Report	All	1/27/2025	5/16/2025	109	☑
	Presentation Slides	All	1/27/2025	5/16/2025	109	☑
	Project Design Document	All	1/27/2025	5/16/2025	109	☑
	Final Report	All	1/27/2025	5/16/2025	109	☑
	Revamp Gantt Chart	All	2/10/2025	2/23/2025	13	☐
	10% Deliverable - Bus Config., Prelim Component Selection, One-Line	All	1/27/2025	2/16/2025	20	☑
	40% Deliverable - Physical & Relaying Plans, AC & DC Calc.	All	2/17/2025	3/23/2025	34	☐
	70% Deliverable - Three-Line, Grnd & Conduit Plans & Calc Revised	All	3/24/2025	4/20/2025	27	☐
	90% Deliverable - Equip. Section Views, Control House Plans, ETAP Sim	All	4/21/2025	5/4/2025	13	☐
	100% Deliverable - All Calculations, Sheets, Documents Sent to BV	All	5/5/2025	5/16/2025	11	☐
2	**Research**					
	Substation Components - Transformers	David & Ben	1/27/2025	2/9/2025	13	☑
	Substation Components - Disconnect Switches	David	1/27/2025	2/9/2025	13	☑
	Substation Components - Circuit Breakers	Mohamed & Ben	1/27/2025	2/9/2025	13	☑
	Substation Components - CCVTs	Sergio & Andrew	1/27/2025	2/9/2025	13	☑
	Bus Configuration	All	2/3/2025	2/16/2025	13	☑
	One-Line Plan	Ben	2/3/2025	2/16/2025	13	☑
3	**Component Selection**					
	Circuit Breakers	Mohamed & Ben	2/3/2025	2/16/2025	13	☑
	Transformer	David & Ben	2/3/2025	2/16/2025	13	☑
	Switches	David	2/3/2025	2/16/2025	13	☑
	Control Building - Cables, Relays, Panels, Backup Batteries	Andrew & Dallas	2/3/2025	2/23/2025	20	☑

Calculation & Design					
Electrical Layout Drawings (Substation Equipment)	Andrew	2/17/2025	3/2/2025	13	☑
Physical and Relaying Plans	Ben	2/17/2025	3/2/2025	13	☑
AC & DC Calculations Including Batteries - IEEE 485	Sergio & David	2/17/2025	3/2/2025	13	☑
Three-Line Plan	Mohamed	3/3/2025	3/16/2025	13	☐
Grounding Analysis With IEEE-80	Andrew & Dallas	3/3/2025	3/16/2025	13	☐
Load Flow Analysis - IEEE 3002.2	Mohamed	3/3/2025	3/16/2025	13	☐
AC Arc Flash Study - IEEE 1584	Sergio	3/3/2025	3/16/2025	13	☐
Protection Analysis - IEEE 998	Andrew	3/3/2025	3/16/2025	13	☐
Conduit Plans and Calculations	Dallas	3/3/2025	3/16/2025	13	☐
Incorporate AC & DC Calculations	Sergio & David	3/17/2025	3/30/2025	13	☐
Substation AutoCAD Drawings					
One Line	Ben	2/3/2025	2/16/2025	13	☐
Three Line	Mohamed	3/3/2025	3/16/2025	13	☐
Control House & Physical Drawings	Andrew	3/3/2025	3/16/2025	13	☐
Equipment Section Views	Dallas	3/17/2025	3/30/2025	13	☐
Revise Conduit Plans and Calculations	Dallas	3/17/2025	3/30/2025	13	☐
Simulation of Designed Substation					
ETAP Simulation	Mohamed	2/10/2025	5/4/2025	83	☐
All Calculations, Sheets, Documents Sent to BV	Mohamed	4/7/2025	5/4/2025	27	☐
Presentation					
Final Presentation	All	5/5/2025	5/16/2025	11	☐
Industry Presentation	All	5/5/2025	5/16/2025	11	☐



[Figure 3.4.2 Substation Design]

Shown in the figure above is a structured, semester-wise timeline for the design phases of our solar power plant and a substation project, spanning Fall 2024 and Spring 2025. Each semester is divided into five distinct phases: Research, Planning, Designing, Calculation, and Simulation. In Fall 2024, the focus is on designing the solar farm, starting with the research and collection of data sheets for photovoltaic cells and other components, moving through planning and selection of equipment, then leading to detailed AutoCAD design and simulation of circuit performance and power flow. Spring 2025 shifts focus to the substation, following a similar phase structure, beginning with the research of substation equipment, to planning and finalizing the equipment, creating detailed drawings, and performing necessary calculations and simulations to ensure efficient operation and profitability. Each phase is planned to ensure a seamless transition from research to practical design and operational testing, laying a strong foundation for a successful project.

3.5. Risks and Risk Management/Mitigation

One significant risk is inaccurate calculations for arrays and inverters, which could lead to performance issues. With a moderate-to-high chance, we'll address this by regularly validating calculations and, if necessary, using advanced software. Dedicated sprints will refine these calculations and verify performance. There's also a risk of non-compliance with local standards, which could cause delays. To manage this, we'll keep up with compliance checks, assign team members to research regulations, and use standard templates if needed.

Data entry errors in the array tool also pose a risk, affecting sizing and load calculations. To reduce this, we'll use automated data validation in the tool and rely on weekly reviews to catch errors early. This agile approach allows us to focus each sprint on high-priority risks, using weekly Black & Veatch reviews for oversight, to keep the project aligned with technical goals and regulations.

For the simplicity of our substation design, we chose to buy the same pieces of equipment from the same companies. This poses a risk because if one piece fails, there is an increased chance that one of the other pieces will fail with a similar issue. In actual practice, we would have bought our equipment from a variety of vendors to help limit these potential risks. Our biggest risk is having two transformers from the same company, as they are critical in the distribution of power. Even though one of them can take on the whole load if the other failed, we do not want both potentially failing as no power would be distributed.

3.6.1 Personnel Effort Requirements - Fall 2024

Task	People	Expected Person hours
Utility-Grade Solar panel Research	Sergio	7
Combiner Box Research	Mohamed	7
Utility-Grade Solar Inverters (skids) Research	Andrew	7
Substation Design Overview	Sergio	7
Land Comparison	David	7
Solar Component Selection	David	7
Substation Component Selection	All	7
Solar Farm and Substation Location	Sergio	7
Cost Estimation	All	7
Cost Analysis	Dallas	10
String Sizing	All	30
Electrical Rack Sizing	All	30

CB Capacity Selection	All	30
Array Design	Ben	25
Array Sizing	Ben	25
Total Equipment Estimation	David	25
Total Cost & Budget Estimation	Andrew	22
Voltage Drop Calculations	All	22
Solar Panel Drawings	Dallas	22
Solar Layout	All	22

[Figure 3.6.1 Personnel Effort Requirements - Fall 2024]

3.6.2 Substation Design Task Table - Spring 2025

Task	People	Expected Person-Hours
Substation Components - Transformers	David & Ben	8
Substation Components - Disconnect Switches	David	8
Substation Components - Circuit Breakers	Mohamed & Ben	8
Substation Components - CCVTs	Sergio & Andrew	8
Bus Configuration	All	15
One-Line Plan	Ben	15
Circuit Breakers	Mohamed & Ben	8
Transformer	David & Ben	8
Switches	David	8
Control Building - Cables, Relays, Panels, Backup Batteries	Andrew & Dallas	20
Electrical Layout Drawings (Substation Equipment)	Andrew	20

Physical and Relaying Plans	Ben	20
AC & DC Calculations Including Batteries - IEEE 485	Sergio & David	20
Three-Line Plan	Mohamed	15
Grounding Analysis With IEEE-80	Andrew & Dallas	20
Load Flow Analysis - IEEE 3002.2	Mohamed	15
AC Arc Flash Study - IEEE 1584	Sergio	10
Protection Analysis - IEEE 998	Andrew	10
Conduit Plans and Calculations	Dallas	20
Incorporate AC & DC Calculations	Sergio & David	20
One Line (AutoCAD)	Ben	20
Three Line (AutoCAD)	Mohamed	15
Control House & Physical Drawings	Andrew	15
Equipment Section Views	Ben	15
Revise Conduit Plans and Calculations	Dallas	20

[Figure 3.6.2 Substation Design Task Table - Spring 2025]

The table presented above details the distribution of tasks, assigns responsibilities to specific team members, and estimates the person-hours required for each task within our project framework. This approach ensures clarity in roles and expectations for each team member. This allows for effective management and coordination across various project segments. By allocating tasks and estimating the time each team member will spend on their assigned duties, we aim to optimize productivity and maintain a clear roadmap towards successful project completion. This organization will improve operational efficiency and also allows for transparent monitoring and adjustment of resources as needed throughout the project lifecycle.

3.7. Other Resource Requirements

To help us with our design and tasks, we have utilized AutoCAD, BlueBeam, and Excel. We are using AutoCAD to draft our drawings of the farm and substation. Bluebeam is being used as a way of feedback from our clients on our AutoCAD drawings, as it is easier to collaborate on. Our clients have been giving us certain Excel spreadsheets to aid us with our calculations throughout our design process and layout. ETAP will help us with our substation simulations to ensure our power flow is as expected.

4. Design

4.1. Design Context

Our project is to design a 60 MW solar farm and a 115/34.5 kV substation. For the solar farm, we had to choose the type of solar panels, how many to use, and how to connect them using combiner boxes and inverters. We needed to make sure the system could safely and efficiently produce the required amount of power without overloading any equipment. For the substation, we had to pick a layout for the buses and decide where to place major equipment like breakers, transformers, and relays. We also had to study how the substation would respond to faults and design protection systems to keep the equipment and people safe during abnormal conditions.

4.1.1 Broader Context

Our project is part of a larger effort to create a cleaner and more reliable power grid using renewable energy technology. Our team has been tasked with designing a 60 MW solar farm and a 115/34.5 kV substation, which will help supply renewable energy to the electric grid in Deming, New Mexico. We are designing for our client's needs and our design will be implemented for utility companies, who will operate and maintain the solar farm and substation. The project also positively impacts local communities, who will benefit from a more stable energy supply and cleaner air. By providing renewable energy, we are helping reduce the need for fossil fuels, which supports environmental goals and public health.

This project addresses important needs like reducing carbon emissions, creating access to renewable energy, improving grid reliability, and supporting economic growth through the creation of jobs. Our design also considered the long-term impact on land use, energy efficiency, and safety for workers and nearby residents. As the project developed, we made choices that reflected these goals. For example, we selected a location with high solar potential, low land costs, and nearby transmission lines, which helps make the project both environmentally and financially sustainable.

Area	Description	Examples
Public health, safety, and welfare	How the project affects the well-being of people and communities.	Our project helps reduce pollution by providing clean energy, and improves safety by following proper substation design and

		following adequate IEEE and NEC standards.
Global, cultural, and social	How the project respects and fits with the values and goals of different groups or communities.	Our project supports the global move toward clean energy. It does not require any cultural or lifestyle changes in the local community.
Environmental	How the project affects the natural environment, either positively or negatively.	The solar farm reduces the use of fossil fuels and supports clean energy goals. Our team has selected an ideal location with minimal environmental disruption and access to high voltage transmission lines.
Economic	How the project affects money and jobs, for both users and developers.	The project helps lower energy costs in the long term and supports job creation during construction and maintenance. It's also designed to be cost effective for the needs of our client.

[Figure 4.1.1 Broader Context]

4.1.2 Prior Work/Solutions

This senior design project has been sponsored by Black & Veatch for several years, and we were able to look at past teams' work as reference only when needed. Our team made an effort to build our design independently. Many of our design choices, like location, equipment, and layout, are different from past projects due to changes in our design process and feedback from our client.

We reviewed projects from past Iowa State teams such as sdmay21-37, sdmay22-05, sdmay23-27, and sdmay24-18. For example, the 2024 team has a 406 acres parcel of land listed at $609,000. Our parcel of land was much cheaper per acre being priced at $217,700 for 311 acres, flatter, undeveloped, and has better access to high voltage transmission lines in the area. Our plot of land has more than enough room for the solar panels and substation. It will also allow room for expansion if required.

Many commercial solar farms and substations exist, but their designs are usually not publicly available, so we could not rely on them directly. However, we used relevant IEEE standards and NEC standards to help guide our technical decisions and ensure safety and compliance.

We also looked into published research and technical resources to better understand solar farm layouts, equipment selection, and substation design:

References

[1] IEEE Standard 605-2008, *IEEE Guide for Bus Design in Air Insulated Substations*, IEEE, 2008.
[2] IEEE Standard 998-2012, *IEEE Guide for Direct Lightning Stroke Shielding of Substations*, IEEE, 2012.
[3] IEEE Standard 485-2020, *IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications*, IEEE, 2020.

Each solar and substation design is unique because of different site conditions, power targets, and utility requirements. Our design stands out by using one rack per combiner box and fewer, larger inverters, which keeps the layout simple and minimizes voltage drop.

4.1.3 Technical Complexity

Our project includes many connected systems that each require different areas of engineering knowledge. For the solar farm, we had to choose equipment like solar panels, combiner boxes, and inverters that all work together. We had to make sure the voltage, current, and power ratings were compatible, and that everything followed industry safety and performance standards. This required us to use engineering principles related to power systems, electrical design, and efficiency.

We also had to design the layout of the solar farm to fit the exact shape of the land in Deming, New Mexico. This included calculating voltage drop, arranging the arrays to reduce cable loss, and planning for easy access and maintenance. These tasks involved engineering challenges like minimizing energy losses and making the design simple and cost-effective. The substation was another complex part of our project. We had to create one-line and three-line diagrams, size the transformers, circuit breakers, and relays, and design grounding and protection systems that can handle faults and keep the system safe. These involved calculations using IEEE standards and electrical safety guidelines. We also used simulation software like ETAP to test the design and make sure it works under different operating conditions.

Our design meets and even exceeds industry standards in some areas. For example, we used 4 MW skid inverters, which are not common in most solar farms of this size, and allowed us to reduce complexity while maintaining strong performance. Overall, our project required us to apply a wide range of scientific and engineering principles across multiple systems, making it a technically challenging and realistic real-world design.

4.2 Design Exploration

4.2.1 Design Decisions

Since our design is from scratch, we had many decisions to make as a team. The main decisions of our design focus on the location, layout, and equipment used in our system. Our starting point was to determine our location.

We started by comparing two proposed locations, Iowa and New Mexico. Our research led us to placing our system in Deming, New Mexico. The solar irradiance levels in Deming range from 5.75 to over 6.50 kWh/m² daily, and with few cloudy days, it provides conditions ideal for solar energy production. This can provide higher energy production, leading to a better return on investment. Deming's climate also includes low hail risks, so we can prolong our reliability while keeping maintenance costs down. Additionally, land costs are low, at around $5,000 per acre, and financial incentives like the Federal Investment Tax Credit (30%) and New Mexico's state-level tax credit (up to 10%) make the location even more financially attractive. The Deming site is also close to existing high-voltage transmission lines, which minimizes the need for addition materials to connect to the grid. These choices help set our solar farm project up for both immediate efficiency and future growth. Together, they create a strong foundation for a successful and sustainable solar installation in Deming.

The next decision was to finalize the layout of our solar farm panels. Our clients were able to provide us with a tool that would tell us how many total panels we would need in one array. With this information, we were able to figure out how many arrays were needed to allow us to produce the 60 MW needed. This led us to need fifteen total arrays, and using voltage drop calculations, we selected the layout of the arrays that would have the lowest total voltage loss across the cables. This value also needed to be no larger than 5%, otherwise it would not be up to standard.

Our other priority was to select the equipment that would be used. We had to pick three components in the solar farm, the panels, combiner boxes, and inverters. For the substation, we had to pick our transformer(s), circuit breakers, switches, relays, and bus conductors. With a plethora of companies offering these pieces, each member picked different ones, and we localized all the data sheets. After discussing them together, we picked each component based on the data sheet, looking at the specifications and efficiency, particularly. We wanted pieces that were efficient, even if it meant it would cost more, to provide the best results to our end users. We had to make sure as well that the equipment could handle the voltage and current that we would be sending into it, so that we would limit maintenance issues.

4.2.2 Ideation

Our primary decision was to select Deming, New Mexico, as the location for our solar farm. We evaluated Iowa and New Mexico across several vital factors to make an informed choice. This structured approach allowed us to identify sub-options that would determine the project's feasibility and return on investment in each location. We applied structured analysis to identify options by evaluating both Iowa and New Mexico based on the following five critical criteria:

- Solar Radiation and Energy Production

We considered two main options for maximizing power output: selecting a location with high solar irradiance or exploring alternative solar technologies to boost efficiency. Ultimately, we chose New Mexico, which has daily solar irradiance levels between 5.75 and 6.50 kWh/m²—significantly higher than Iowa. This choice provides a substantial increase in energy production potential and a promising return on investment.

- Land Availability and Cost

We considered two options to secure land for the solar installation: purchasing affordable land or exploring leasing opportunities, particularly in high-cost areas. In New Mexico, the cost of land was $6,000 per acre, which provided a financially attractive option for large-scale development. Given its affordability and ample availability for expansion, New Mexico emerged as the most viable choice, supporting both current project needs and future growth potential.

- Proximity to High-Voltage Transmission Lines

We considered two options for grid access: selecting a site near existing transmission lines to reduce infrastructure costs or investing in additional infrastructure for locations farther from the grid. Deming's proximity to high-voltage transmission lines offered a straightforward and cost-effective solution for grid connectivity, making it the optimal choice for our project.

- Weather and Environmental Resilience

We evaluated two options to ensure reliable solar energy production: selecting a location with consistently favorable weather year-round or considering areas with mild climate risks and minimal severe weather. Deming, New Mexico, stood out with its low risk of hail and other adverse weather conditions, which promises reduced maintenance needs and greater reliability for energy production.

- State Financial Incentives

Regarding the project's financial viability, we considered two options: selecting a location with strong state incentives or relying solely on federal incentives where state support was limited, as in Iowa. New Mexico offered a 10% state tax credit in addition to the federal credit, making it a more attractive choice by significantly boosting the project's potential returns.

4.2.3 Decision-Making and Trade-Off

For selecting the main component for our project especially the combiner boxes, inverter and solar panels we compared different options to find the best fit based on performance, cost, durability, and scalability. Here's how we approached the decision-making process and arrived at our final choices.

Identifying Key Factors:

Efficiency: Higher efficiency means we need fewer components and less land, which can lower costs.
Cost: We looked at both the upfront cost and long-term savings from reliable components.

Weighing Trade-Offs:

PV Modules:

Monocrystalline: These are the most efficient, meaning we need fewer panels to reach our power target, saving on land costs. Although they cost a bit more upfront, they're reliable and have a longer lifespan, making them more cost-effective over time.
Polycrystalline: These are cheaper but less efficient, so we would need more panels and land, which would increase maintenance costs.
Thin-film: These are the least expensive per watt, but they're much less efficient, meaning we'd need even more land and they would degrade faster, leading to higher long-term costs.

Combiner Boxes:

NEMA4 This option offers high protection against weather, which is crucial for an outdoor, utility-scale setup. It's a bit more costly, but the durability justifies the expense by reducing the need for repairs.
NEMA 3R: A more affordable option, but with lower protection ratings, meaning it might not hold up as well in harsh outdoor conditions.

Inverters:

High-Capacity Inverter: This inverter is highly efficient and scalable, meaning it can handle large power loads and allows for potential future expansion.
Moderate-Capacity Inverter: This option is less costly but less efficient and not as flexible.

Final decision:
Monocrystalline PV Modules for their high efficiency and long-term cost savings.
NEMA 4 Combiner Boxes for their durability and protection, making them reliable in outdoor settings.

High-Capacity Inverters for their efficiency, scalability, and low harmonic distortion, which aligns with our utility-scale needs.

4.3 Final Design

4.3.1 Overview

Our project spans both semesters and consists of two major phases: designing a solar array (Fall) and designing a substation (Spring). Together, these systems form a 60 MW solar power generation and transmission facility aimed at delivering clean, renewable energy to the grid.

Fall Semester – Solar Array Design

We began our project by focusing on the solar array. This system is made up of several key components working together to convert solar energy into usable electrical power. At the base level are photovoltaic (PV) modules, which make up individual solar panels. These panels are connected in series and parallel configurations to form strings, and two strings are combined to form a rack. Each rack is designed to meet specific voltage and current ratings that align with a DC combiner box, which consolidates the outputs from multiple racks. These combiner boxes feed into central inverters, where DC power is converted to AC. To meet our 60 MW power target, we have designed multiple arrays, each with several combiner boxes. Our system incorporates 15 central inverters, whose outputs are aggregated and sent to the substation.

Key design decisions in the fall included:

- Site selection (Luna County, NM) for optimal irradiance
- Rack configuration and string sizing
- Tilt and orientation of panels (30 degrees, south-facing)
- Voltage drop calculations

Spring Semester – Substation Design

With the solar array design completed, we transitioned into the substation design during the spring semester. This part of the project involves stepping up the 34.5 kV output voltage from the solar plant to 115 kV, suitable for grid integration.

Key design decisions in the fall included:

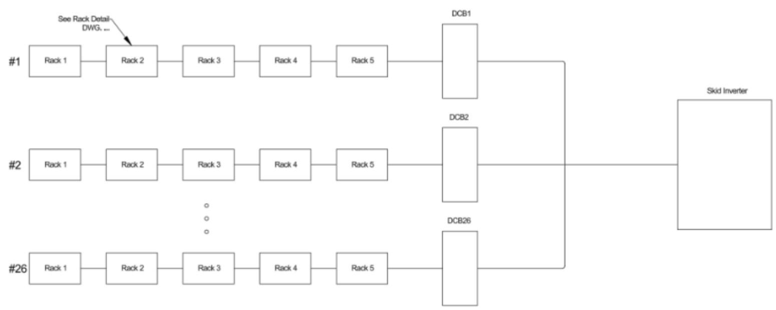
- Transformers selection for voltage stepping
- Circuit breakers, relays, and switches for protection and control

- Bus configurations to manage power flow

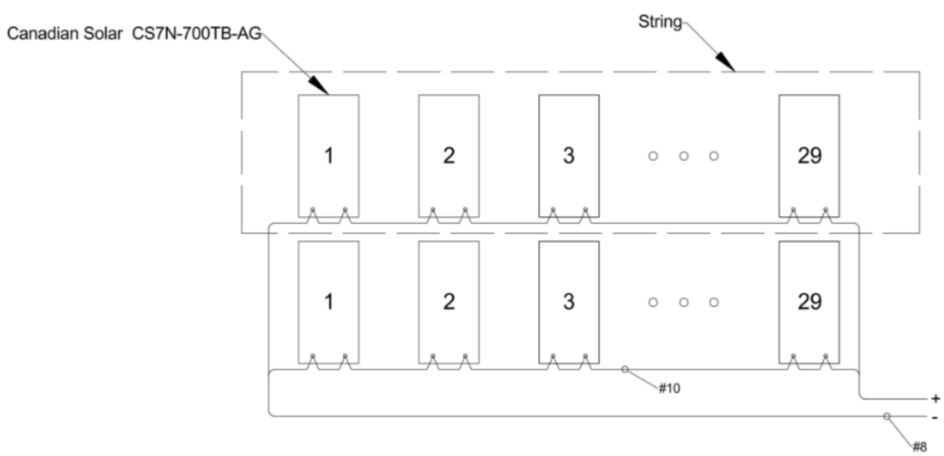
4.3.2 Detailed Design and Visuals

After selecting the site for our power system, we got to work on the design of both the solar farm and substation. Starting out with the solar farm, we looked into finding the three components we would be using: solar panels, combiner boxes, and inverters. Using the data sheets of the selected equipment, we took the key values we needed to design the layout. Black & Veatch provided us with an array parameter tool to aid with the calculations. We used the open circuit voltage and short circuit current of the panels to design our array. Our combiner box is rated for 1500V and 320A, so we matched our string to have 1500V, which took 29 modules to achieve. Using the short circuit current we found that we could connect 11 strings to each combiner box (max current divided by short circuit current). Then, using the ratings of the inverter we selected, we found the number of racks that were needed to complete an array. Incorporating the losses that occur inside the inverter, we needed the DC power the be 30% higher than the AC output desired to reach our stated goal. By adding more racks into the array, we were able to achieve the correct values. Since the inverter is rated for 4095 kW and our DC power per array is 5274 kW, we needed to have 15 inverters, and since each array uses one inverter, 15 arrays total for our solar farm.

After finding out we needed 15 arrays to achieve our estimated power, our next objective was to create the layout of each array. We came up with a few different layouts; however, the deciding factor to which layout would be the final one, we turned to another tool provided by our clients. This tool helped us calculate the total amount of voltage lost across the cable distance between the panels and combiner boxes, and then the boxes to the inverter. This loss needed to be no more than 5 percent, and using AutoCAD's dimension ability, we found which layout had the lowest voltage loss. This comes from the equation: $V*I*R*L/1000$. If the voltage drop is too high, we will increase the cable size which decreases the resistance through the cables.



[Figure 4.3.2 Detailed Design and Visuals]



[Figure 4.3.3 String Arrangement]

These two drawings show how the solar farm is laid out. The first image illustrates how the racks connect to the combiner box, and then how the combiners boxes feed into the inverter. The second drawing shows how the panels are individually connected to make a string, and how 29 panels make up one string. The size of the cables used are indicated with the #10 and #8.

Subsystems and Their Roles

Power Transformers (2 Units)

Type: 115kV/34.5kV, 90 MVA, 3-phase

Function: Step-up voltage from the solar plant to grid level

Specs: Rated current 451.84A (HV), 1506.13A (LV)

Circuit Breakers

Low Voltage Side: Mitsubishi EDD 38kV, vacuum interrupter

High Voltage Side: Mitsubishi 120-SFMT-40F, SF6 gas interrupter, 145kV rated voltage

Disconnect Switches

Voltage Range: 38kV to 362kV

Current Rating: 1200A to 5000A

Standards: ANSI; BIL Rating: 200-1050/1300 kV

CCVTs (Capacitor Coupled Voltage Transformers)

Capacitive VT Rating: 254–1270 kV

Coupling Capacitor Range: 115–1095 kV

Standards: IEC & IEEE

Transformer Relaying

Primary Relay: SEL 487E

Provides distance and multiwinding protection

Secondary Relay: SEL 587

Offers differential current protection

Line Relaying:

Primary Relay: SEL 311C

Includes distance protection, load shedding, breaker failure detection, and reclosing

Secondary Relay: SEL 311L

Simpler protection for backup (distance and overcurrent)

Grounding System

Function: Safe fault current dissipation

Analysis: Compliant with IEEE-80, touch and step potential evaluated

For the substation we selected a ring bus configuration. This configuration is very robust and flexible and allows for uninterrupted power flow in the event of a fault. Each solar array feeder has a circuit breaker on each side that trips when a fault occurs. The power from the other feeders can then flow around the ring instead of being cutoff. This configuration was chosen due to these pros even though the cost and land usage are higher.

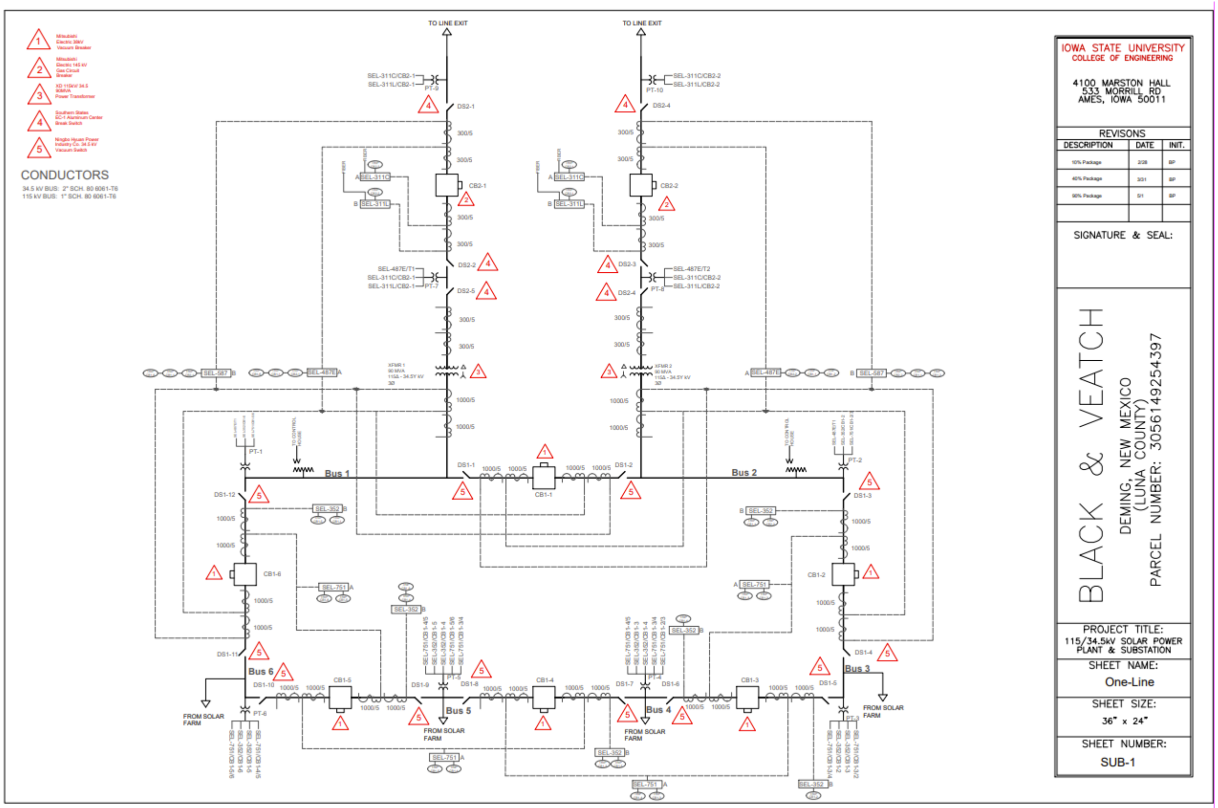
We selected each component to operate at the rated voltages and currents for our project. Some components like the transformers are oversized to allow for future expansion of the solar farm. We also implemented two transformers in the design so in the event one has an issue, power can still flow. We selected the CT ratios based on the maximum current that would flow through each bus section. The bus material was also selected for the correct ampacity on both the 34.5 and 115kV side.

Relays were selected based on the specific needs of each of each part of the substation. The low side of the substation has SEL 751 relays which is for feeder protection. The transformer has SEL 487E's and the transmission line exits have SEL 311's. Each relay requires at least one connection to a VT and CT. Some require multiple CTs or VTs, they are connected according to each relays data sheet. These connections can be seen on the following one-line diagram.

Using this drawing we were able to develop other drawings such as the key plan, three line, and section views. These drawings give much more insight into how the substation is configured and connected. Drawings such as the key plan give more insight into how the substation physically looks and is used in the construction of the site. The section views are also extremely useful for construction as they give side perspectives and more details into the actual construction of the equipment.

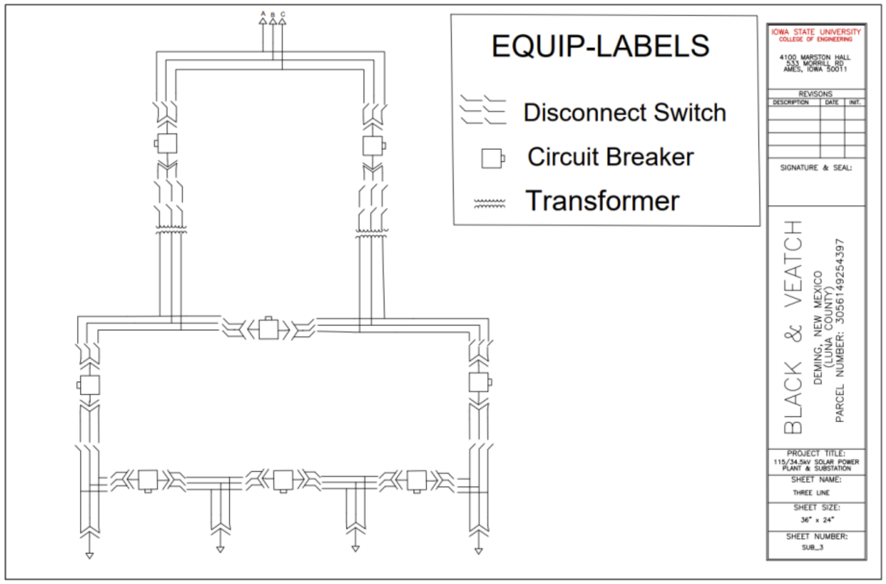
Visual Aids

One-Line Diagram:



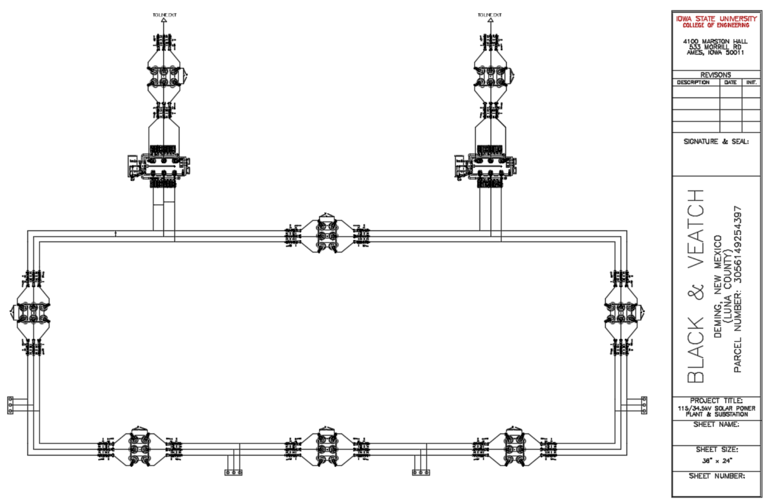
[Figure 4.3.4 One-Line Diagram]

Three-Line Diagram:



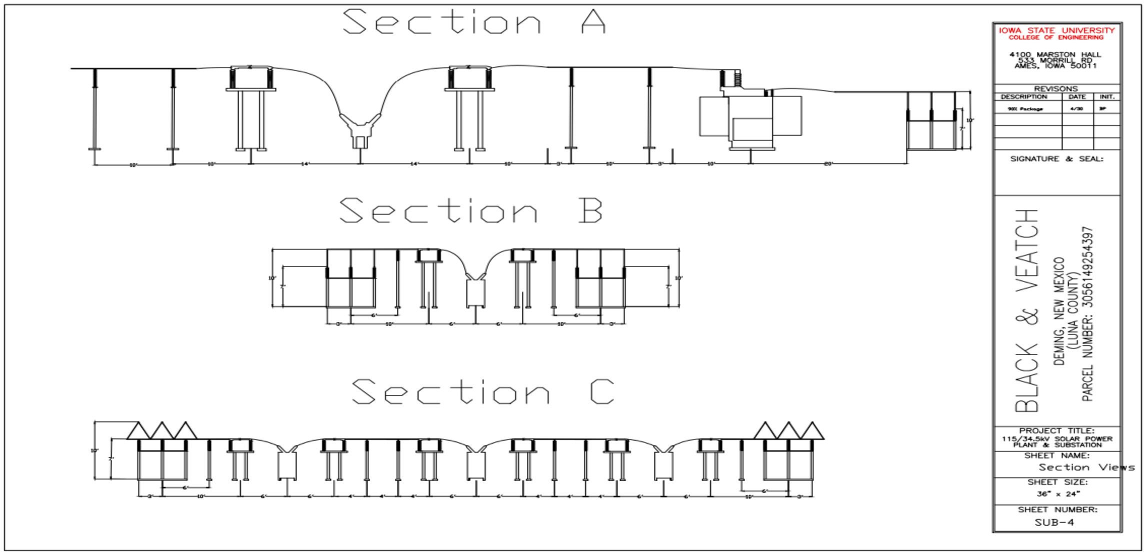
[Figure 4.3.5 Three-Line Diagram]

Physical Layout Drawing:



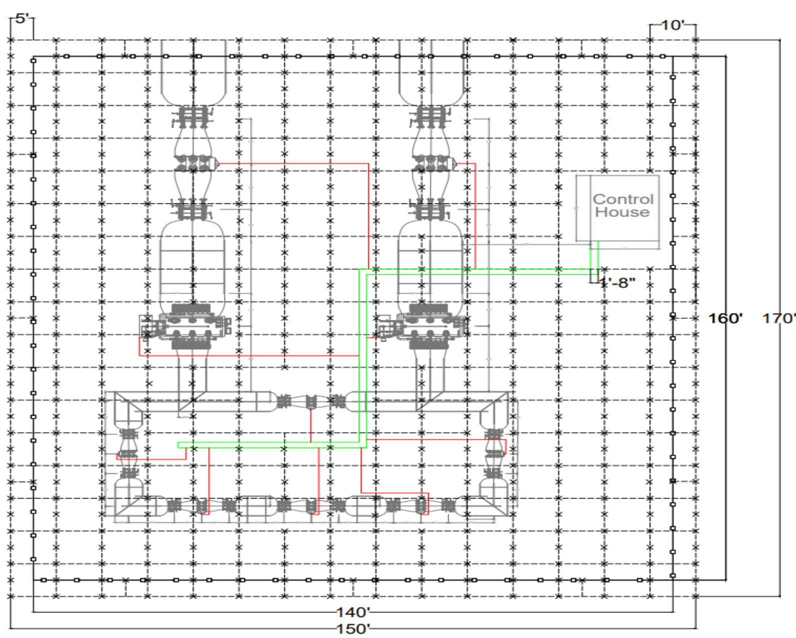
[Figure 4.3.6 Physical Layout Diagram]

Section View Drawing:



[Figure 4.3.7 Section View Drawing]

Grounding Plan:



[Figure 4.3.8 Grounding Plan]

4.3.3 Functionality

Fall Semester – Solar Array Design

Our design of the 115/34.5 kV Solar Plant and Substation aims to operate seamlessly in a real-world setting, providing clean energy to utility companies and local communities. Here's how it works:

How Users Interact: Utility companies and local residents benefit from the system through their own needs. The solar plant generates renewable energy that's fed into the local grid, offering these groups reliable, eco-friendly electricity.

How the System Works:

- **Solar Plant**: The solar panels capture sunlight and convert it into direct current (DC) electricity. This electricity then flows to inverters that convert it into alternating current (AC), making it compatible with the grid.
- **Substation**: Once converted to AC, the power reaches the substation, where it's stepped up to a higher voltage (115 kV). This step is crucial for long-distance transmission, as higher voltages reduce energy losses.
- **Real-World Responses**: On sunny days, the solar panels operate at peak efficiency, sending maximum power to the grid. When clouds roll in, the inverters adjust automatically to make the best use of available sunlight.

Spring Semester – Substation Design

Our substation design plays a key role in connecting the 60 MW solar array to the larger electrical grid. In real-world operation, it's responsible for stepping up the voltage from 34.5 kV (as produced by the solar panels and inverters) to 115 kV, which is a standard transmission-level voltage used by utility companies. The system also ensures that any faults or abnormal conditions are quickly detected and handled to protect equipment and maintain grid reliability.

How the System Operates

Once power is generated by the solar array, it flows into the substation. From there, two large 90 MVA transformers raise the voltage from 34.5 kV to 115 kV. This higher voltage makes it easier to send power over long distances without losing much of it as heat.

To make sure everything runs safely and efficiently, we use a combination of protection relays, circuit breakers, and disconnect switches. For example:

- The SEL 487E relay monitors the transformer and trips the breaker if there's a fault like a short circuit or abnormal current.
- The SEL 587 relay adds another layer of protection by comparing the current entering and exiting the transformer. If something seems off, it also sends a trip signal.
- Line protection is handled by relays like the SEL 311C and 311L, which protect the transmission lines leading out of the substation. These relays look for things like distance faults, breaker failure, and overcurrent.

All of this equipment works together in the background, constantly monitoring the system. If something goes wrong, the relays detect it in milliseconds and send a signal to circuit breakers to instantly disconnect the faulty section.

What the User (Operator) Does

The people interacting with the substation—usually utility engineers or control room operators—don't manage the system manually most of the time. Instead, they monitor the system through a SCADA interface, which shows real-time data like voltage, current, and breaker status. If something unusual happens, they can analyze logs, reset equipment, or schedule maintenance.

During planned maintenance, operators open disconnect switches to safely isolate specific equipment, allowing field crews to work without risk. Once the work is done, the equipment can be safely brought back online.

4.3.4 Areas of Challenge

How the Design Meets Requirements and User Needs:

Providing Clean, Reliable Power: The location in New Mexico, with its high solar exposure, allows us to generate the most power possible, so utility companies and the local community can count on a consistent, renewable energy source.

Seamless Grid Integration: With the substation in place to convert and transmit power effectively, our design meets industry standards, ensuring that energy flows safely and efficiently into the grid.

Primary Concerns:

Calculation Accuracy and System Efficiency: To make sure we meet power output and efficiency goals, it's essential that our calculations—like those for panel arrays and voltage drops—are spot-on. Any miscalculations here could compromise the system's ability to deliver the required 60 MW capacity.

Meeting Standards: We need to ensure our project complies fully with NEC, IEEE, and other industry standards, especially for things like grounding and safe grid connections.

Immediate Plans to Address These Concerns:

Frequent Validation and Testing: We'll be validating our calculations regularly and using specialized software to simulate performance. We're also setting up weekly review meetings with Black & Veatch to catch any issues early.

4.4 Technology Considerations

AutoCAD

- **Why We Use It**: AutoCAD helps us create detailed drawings of our design, showing every aspect clearly and precisely.
- **Pros**: It’s a professional tool widely used in the engineering field, so our design looks polished and meets industry standards.
- **Cons**: Only one person can work on the design at a time, which is challenging for teamwork. Plus, most of us aren’t familiar with CAD, so one team member handles most of it.
- **What We’d Like to Improve**: Ideally, we’d want a more collaborative version of CAD to allow multiple people to work on the drawings together.

Array Parameter Tool:

- **Why We Use It**: This tool is set up in Excel, so the whole team can access it and work on it together. It helps us decide on equipment and track settings for the solar array.
- **Pros**: Everyone can update it in real-time, and it has some formulas pre-set, saving us time and reducing errors.
- **Cons**: We can’t easily compare multiple setups at once. To test a different configuration, we have to create a new sheet each time.
- **What We’d Like to Improve**: A tool that lets us quickly compare different setups would make things faster and more flexible.

Voltage Drop Calculations Tool:

- **Why We Use It**: Also in Excel, this tool helps us calculate and organize the voltage drop in different parts of the solar setup, like between the panels and inverters.
- **Pros**: It’s organized, easy for everyone to access, and helps keep the calculations straight.
- **Cons**: Like the array tool, it can only handle one scenario at a time. Plus, it doesn’t show the calculation steps, so some of us double-check by doing parts by hand to understand better.
- **What We’d Like to Improve**: A more visual tool that shows the steps in calculations would be helpful for both accuracy and learning.

Solar Cost Analysis Tool:

- **Why We Use It**: This Spreadsheet, provided by Black & Veatch, helps us track costs and estimate how long it’ll take for the project to start making a profit.
- **Pros**: It’s very clear for projecting big-picture costs and when we’ll break even, which is useful for us and our clients.

- **Cons**: It doesn't give a detailed breakdown of costs, but we'll add that with a Bill of Materials later.
- **What We'd Like to Improve**: More detail in cost tracking would help us see exactly where the money is going.

4.4.1. Design Analysis

- **Fall 2024**

Progress So Far:

Choosing Components with the Array Parameter Tool: We started by analyzing different combinations of parts for the solar field using the Array Parameter Tool. We looked at factors like cost, how much equipment would be needed to reach our power output goal, and whether everything could fit within the land we have available. After comparing several setups, we settled on the best components (PV panels, combiner boxes, and inverters) and arranged them in a layout that met both our needs and the equipment specifications.

Creating Layouts in CAD and Getting Client Feedback: With our chosen configuration, we designed three different layouts in AutoCAD. After presenting these options to our client, we all agreed on the best layout and proceeded with voltage drop calculations to make sure power losses stayed within acceptable limits.

Voltage Drop Calculations and Adjustments: Initially, our voltage drop was too high, which would have impacted efficiency. Our client suggested moving the combiner boxes to the center of the array and choosing wires with a larger capacity. After making these changes, we achieved a voltage drop of 2.81% in the worst-case scenario, which was right on target.

Cost Analysis: Getting accurate cost estimates was a challenge since many companies don't post prices online and only provide quotes for confirmed purchases. However, Black & Veatch provided a spreadsheet to help us estimate costs and understand when the project might break even. This tool has been incredibly helpful in mapping out the project's financials.

Testing: We haven't started hands-on testing yet, but it's next on our list.

Next step:

Next semester, we'll work into the substation design, selecting more components and using tools like BlueBeam to collaborate and get feedback on layouts.

- **Spring 2025:**

Substation Design Development:

This semester, we shifted our focus from solar array design to substation development. Throughout the process, we collaborated with Black & Veatch (BV) in weekly meetings to gain insights into substation equipment, including transformers, disconnect switches, circuit breakers, and voltage transformers (CCVTs). These sessions provided us with valuable industry knowledge and helped us make informed design decisions.

Project Planning and Timeline Updates
To ensure a structured workflow, we revamped our Gantt chart, updating deadlines and deliverables to reflect the scope of the substation design phase. This allowed us to manage tasks effectively and maintain steady progress throughout the semester.

Component Selection and Bus Configuration
A key milestone was selecting the necessary substation components. We conducted a comparative analysis of data sheets for:

Transformers
Disconnect switches
Circuit breakers
CCVTs
Potential Transformers
Relays
Batteries

4.4.1.2 Cost

Estimating the cost of a solar farm and substation starts with creating a detailed Bill of Materials (BOM) that includes all the components needed for real-world implementation. By adding up the costs of these items, we can calculate the total project budget. This clear breakdown supports transparency and accuracy, helping project planners make well-informed decisions and manage resources effectively. Below are the BOMs for the solar farm, substation, and other related items.

Solar Component							
Component type	**Model Number**	**Quantity**	**Price**	**Datasheet link**	**Total Price**	**Pricing link**	
PV Panels	TOPBiHiKu7 CS7N-700TB-AG	113,100	$223.00	Link	$25,221,300.00		
Combiner boxes	CA1500-24-20S	360	$2,156.00	Link	$776,160.00		
Inverters	SLG-330-0279	15	$119,210.14	Link	$1,788,152.10		
Conduit	PVC4 SCH 40 4" 10' Conduit	1240	$37.34		$46,301.60	Link	451 ft
10 AWG Wire	10 AWG, Single Conductor 2500'	190	$1,126		$213,940.00	Link	
8 AWG Wire	8 AWG, Single Conductor 500'	150	$369		$55,350.00	Link	
3/0 Wire	3/0 Wire, 250'	1200	$1,508		$1,809,600.00	Link	298,350 ft
4/0 Wire	4/0 Wire, 250'	50	$1,729		$86,450.00	Link	12308 Ft
				Total Solar Farm Cost	$29,997,253.70		

Substation Component						
Component type	Model Number	Quantity	Price	Datasheet link	Total Price	Pricing link
SEL-311C	311#01	2	$6,590.67	Link	$13,181.34	Link
SEL-311L		2	$7,130.00	Link	$14,260.00	Link
SEL-352	352#01	6	$4,782.50	Link	$28,695.00	Link
SEL-751	751#12	4	$2,000.73	Link	$8,002.92	Link
SEL-487E	487E#01	2	$10,643.19	Link	$21,286.38	Link
SEL-587	587#01	2	$2,712.64	Link	$5,425.28	Link
T (POWER XMFR)	XD 115kV/34.5 90 MVA	2	$2,000,000		$4,000,000.00	
CB1	MT-DTCB-SF6-R7-3P-AC-DXF-1200A-40KA-6-FM-Z-Z-N4X-M1	2	$145,000.00	Link	$290,000.00	Link
CB2	LW36-40.5	6	$12,000	Link	$72,000.00	Link
DS1	ZW32	12	$8,000.00	Link	$96,000.00	Link
DS2	EC-1V	6	$8,000	Link	$48,000.00	
SSVT	100 kVA SSVT	2	$247,000		$494,000.00	Link
PT	MT-PT-R7-1P-DMD-46KV-SX.LM-CL3-60HZ	10	$6,521		$65,210.00	Link
Battery	5 Opzs 250	20	$646		$12,920.00	Link
Conduit	PVC4 SCH 40 4" 10' Conduit	50	$37.34		$1,867.00	
				Substation Total Cost	$5,170,847.92	

MIS Component						
Component type	Model Number	Quantity	Price	Datasheet link	Total Price	Pricing link
Fence	Solidlock® Pro 20 2096-6 12.5 ga 330' High Tensile Fixed Knot Game Fence	330	$643.00	Link	$212,190.00	Link
Low side bus	2" SCH. 80 6061-T6 8'	96	$125.55		$12,052.80	
High side bus	1" SCH. 80 6062-T6 8'	84	$74.35		$6,245.40	
				MIS Total Cost	$230,488.20	

[Figure 4.3.9 Bill of Materials]

The Bill of Materials (BOM) outlines all the essential components required for the installation, including solar panels, inverters, mounting structures, cables, transformers, switchgear, and other miscellaneous items. Each item is detailed with its type, model number, quantity, unit price, total cost, and includes links to relevant datasheets and pricing for easy reference. The estimated total cost for the solar farm is $29,997,253.70, the substation is $5,170,847.92, and the miscellaneous items amount to $230,488.20, bringing the overall project cost to $35,398,589.82.

4.4.2. Project Cost Analysis

Overall, our project design is both efficient and affordable. One of our main goals was to use high-efficiency monocrystalline solar panels, which produce more energy per panel. This allowed us to meet our 60 MW target while using less land, which helps reduce land-related costs such as site preparation, fencing, and long cable runs. We also selected reputable equipment that is highly reliable, so our long-term maintenance costs will be lower.

Our design decisions help reduce overall project costs by limiting the amount of land and materials needed, while still meeting energy production goals. Our team focused on making choices that would support a cost-effective and sustainable solar installation for the many years it will be in service.

4.5. Final Design Components

4.5.1. Solar Farm

We started by comparing possible locations for the solar farm, including Iowa and New Mexico. After looking at sunlight levels, land cost, and climate, we chose to place our solar farm in Deming, New Mexico. This location gets strong sunlight for most of the year and has lower land prices, which makes it a smart and cost-effective choice for a solar project. Once the location was selected, we researched and selected the solar panels, combiner boxes, and inverters that would work best for our site. We focused on equipment that was efficient and reliable. We also made sure all components were compatible in terms of voltage, current, and power ratings.

Using data from the equipment datasheets and the Array Parameter Tool provided by Black & Veatch, we estimated that our system would generate about 77.33 MW of DC power, which would result in about 60 MW of usable AC power after conversions and losses. This helped us size the number of panels and arrays we needed to meet the energy goal. Our final solar farm array design included 5 racks per row, 26 rows per array, with a module capacity of 700W and fixed solar panel tilt at 30 degrees.

		String Size		
	Location Dependent	Min Temp	4.44	C
	Datasheet (STC)	Voc	47.9	V
	Datasheet (STC)	Ref temp	25	C
	Datasheet	Temp Coeff of Voc	-0.0029	/C
		Temp delta	-20.56	
		temp correction	1.06	
		V0c corrected	50.75599	
Confirm possible with Panel type chosen	Designer Choice: 600, 1000, 1500, 2000V	string voltage	1500	V
		String size	29.55316	
		string size	29	
		Actual String Voltage	1471.9	
		Input Information =		

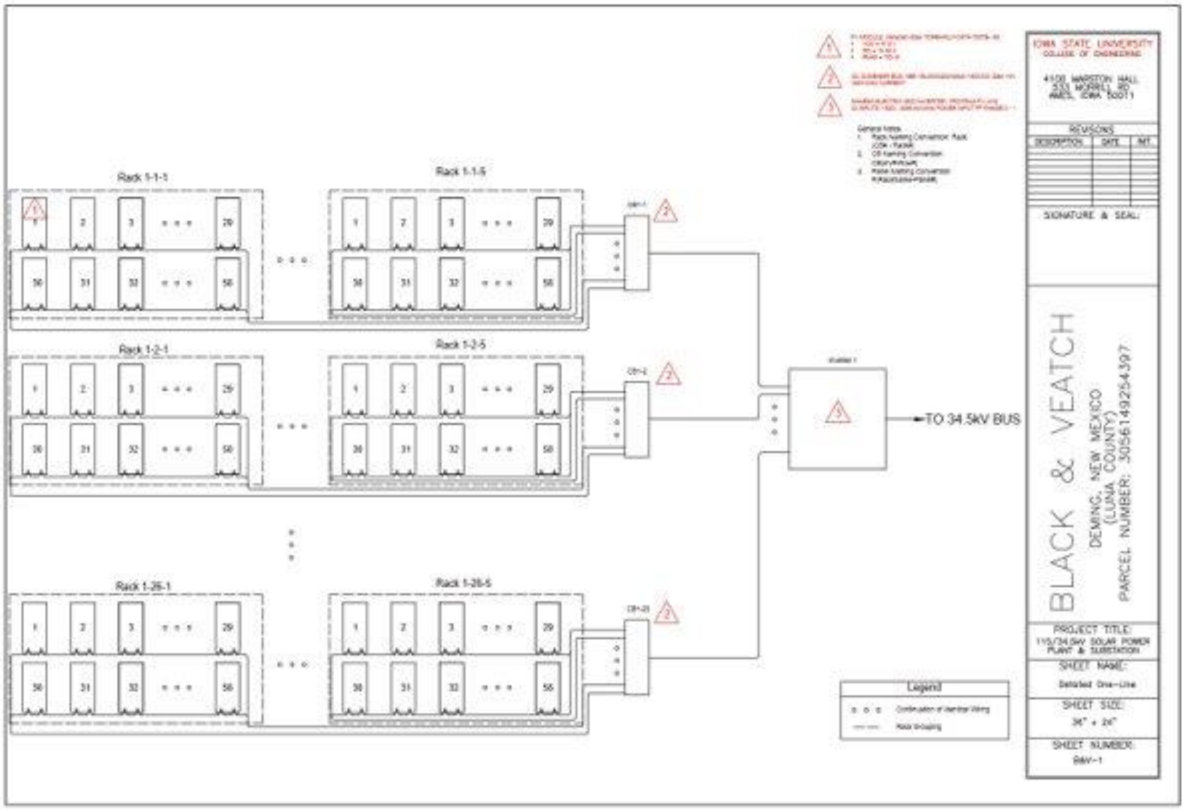
	Electrical Rack Size		
Designer Choice		Landscape	
Datasheet	Module width	7.82	ft
Datasheet	module height	4.27	ft
Designer Choice	Rack width	29	modules
Designer Choice	Rack height	2	modules
	Modules per rack		
	Rack width	226.78	ft
	Rack height	8.54	ft

	CB capacity		
Datasheet (STC)	mod/string Isc	18.49	A
NEC sectic	multiplier	1.25	
	nom Isc	23.1125	
Irr.	multiplier	1.25	
	max Isc	28.89063	A
Designer Choice: 200, 400A etc.	allowed current	320	A
	is this disconnect A?		
	strings per CB	11.07626	
	Round down:	11	
	racks per CB	5.5	

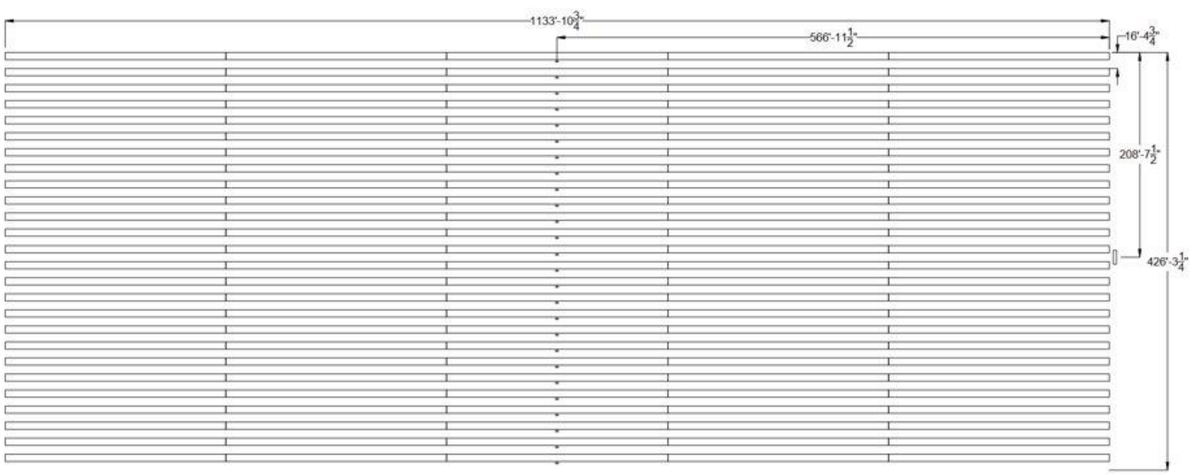
	Array Design		
Designer Choice	Racks per row	5	
Designer Choice	rows per Array	26	
Designer Choice	Racks removed	0	
	Total Racks/Array	130	
	Total modules	7540	
Datasheet (STC)	module capacity	700	W
	dc capacity	5278	kW
Designer Choice	inverter capacity	4095	kW
			MVA
Provided: Industry standard 1.3	ILR	1.288889	

	Array Size		
Designer Choice	tilt	30	
	table height proj	7.395857	ft
Designer Choice	row space	9	ft
	pitch	16.39586	ft
	Space for Inverter Maintenance		ft
	Array height	426.2923	ft
	Array width	1133.9	ft
	Ground Coverage Ratio	0.520863	

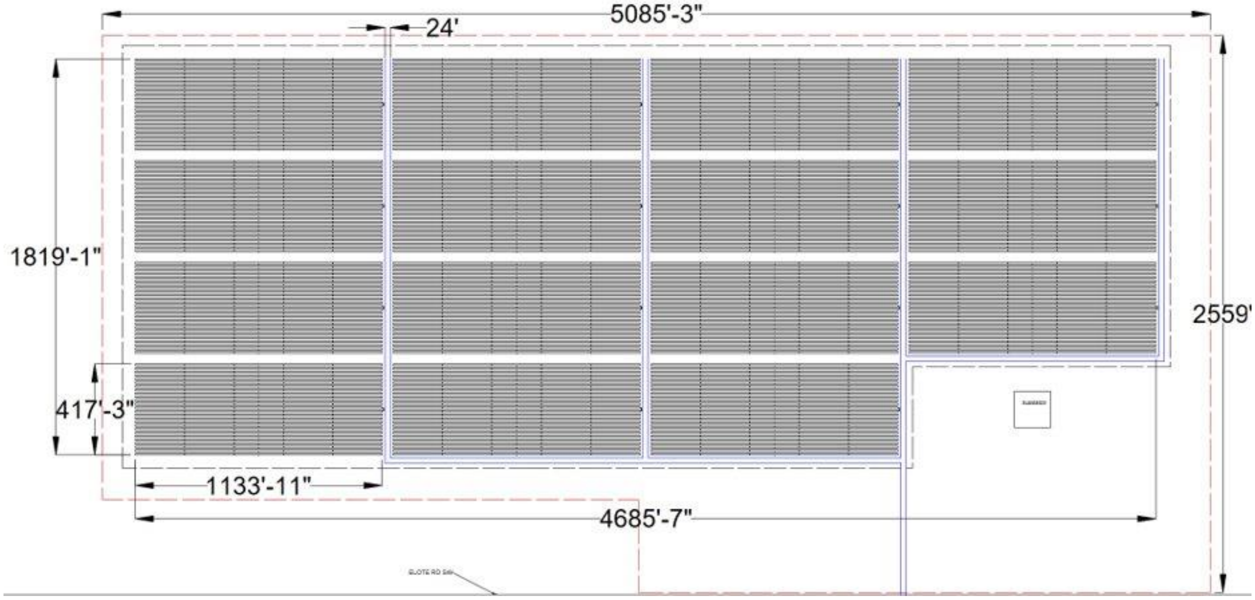
[Figure 4.5.1 Array Parameter Tool]



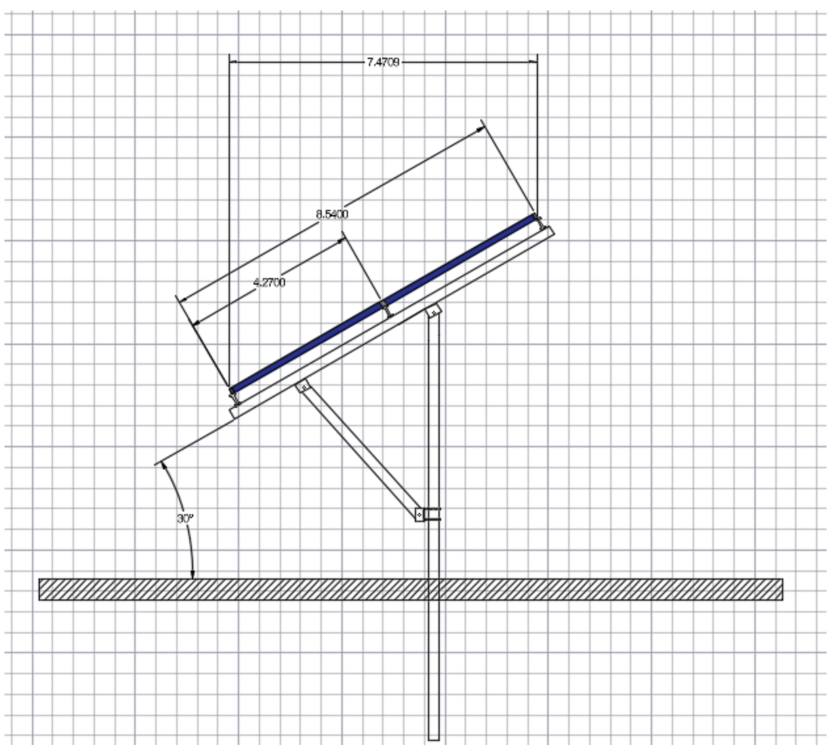
[Figure 4.5.2 Solar Array Overview]



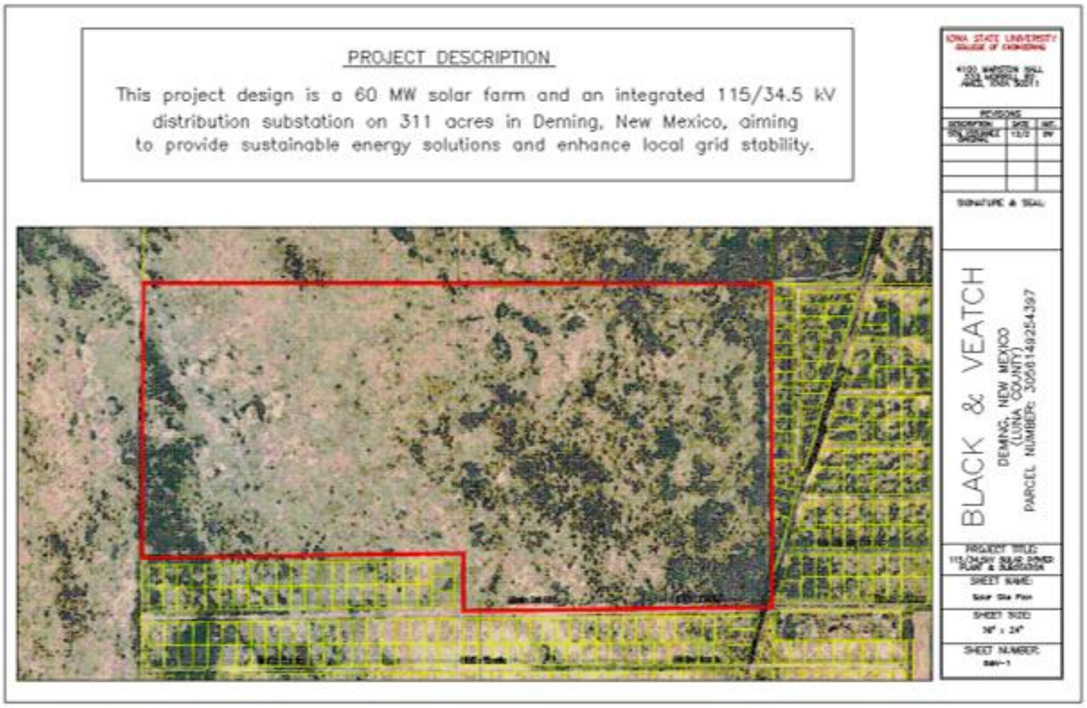
[Figure 4.5.3 PV Array]



[Figure 4.5.3 Solar Farm]



[Figure 4.5.4 OpSun Mounting & Side View]



[Figure 4.5.5 Solar Farm Site]

4.5.2 Design Calculation

Accurate calculations for AC and DC loads, battery sizing, bus design, and grounding are fundamental to the successful design of solar power plants and substations. AC load calculations determine the power needed to reliably supply all electrical appliances and systems, ensuring efficient operation. DC load calculations support the proper sizing of components that convert and distribute solar energy effectively. Battery sizing is equally important, as it guarantees adequate energy storage to cover periods of low solar irradiance or nighttime demand. Grounding calculations are essential for protecting both people and equipment, ensuring the system is safely grounded to prevent electric shocks and equipment damage. Together, these calculations form the foundation for a safe, reliable, and high-performing solar energy system that supports sustainable power generation and distribution.

4.5.2.1. AC Load Calculation

AC load calculations for a substation control house are essential to ensure the electrical system can support expected loads under all conditions. By analyzing conditions like a 115/34.5 kV transformer fault, engineers can determine peak tripping demands and design the system accordingly. Based on these figures, calculations for continuous 120/240VAC single-phase loads lead to recommendations such as a 80 kVA station service transformer and a 450A manual transfer switch (MTS). With total power and current values calculated at 79.25 kW and 376.22 A respectively, an additional 10% buffer is included to account for potential load surges. This detailed approach ensures the substation's electrical infrastructure remains reliable and safe during critical operations.

AC STUDY							
		Quantity	Load/Unit (W)	Amps (ea)	Voltage (V)	Total (W)	Amps Total
AC Panel - Control Building	Breaker Recepticle and Lights	8	210	1.75	120	1680	14.00
	Transformer Fans	2	24000	100	240	48000	200.00
	Transformer Sump Pump	2	2000	8.3333333	240	4000	16.67
	Control House Lighting	20	36	0.3	120	720	6.00
	Yard Lights (Assuming lights are off)	8	55	0.4583333	120	440	3.67
	HVAC System	1	10000	41.666667	240	10000	41.67
	Fire Detection Equipement	1	150	1.25	120	150	1.25
	Exhaust Fan	1	132	1.1	120	132	1.10
	AC Battery Charger	1		0	240	0	0.00
	Power Outlet	10	180	1.5	120	1800	15
	Breaker Heaters	8	640	5.3333333	120	5120	42.666667
				0	1	0	0
				0	1	0	0
	Worst Case Tripping						
	High Side Breaker Trip	1	720	3	240	720	3
	Low Side Breaker Trip	2	720	3	240	1440	6
	Total Worse Case AC Panel Load					72042	342.02
		Total Worst Case Load (+10%)				79246.2	376.21833

[Figure 4.5.6 AC Load Calculations]

4.5.2.2. DC load & Battery Sizing Calculation

DC load calculations for solar and substation design involve identifying the power demands of DC-powered devices, such as lighting, control circuits, communications equipment, and protective relays while considering how often and how long each device operates.

This load profile is crucial for accurately sizing solar panels and battery storage systems to meet energy demands efficiently. For example, devices like 34.5 kV and 115 kV breakers have unique tripping and closing current requirements, while protection and communication devices such as SEL-411L and SEL-311L contribute specific continuous and intermittent loads. Power supply burdens, such as those from a 60-cell system, are also factored in across defined time intervals. Summing the energy requirements of each component over time, we calculated a total DC load of 4.404 A for continuous operation and 19.8 A for discontinuous loads.

Components	Load Current (A)	Nominal Voltage (V) DC	Inception and Active Shutout Time	number of components	Total Load Current (A)	Power Requirement	Power (Units)
34.5kV Breaker:	Tripping Current: 3.3	70 – 140	0 -1	6	Tripping Current:19.8	343	W
	Closing Current: 2.6	90 - 140			Closing Current :15.6	364	W
115kV Breaker:	Tripping Current : 6.6	125	239- 240	2	Tripping Current: 13.2	1050	W
	Closing Current : 3.6	125			Closing Current : 7.2	950	W
SEL-311C	0.20	125	1 - 240	8	1.60	25	W
SEL-311L	0.20	125	1 - 240	8	1.60	25	W
SEL-587	0.044	125	1 - 240	2	0.08	6	W
SEL-487E	0.280	125	1 - 240	2	0.56	35	W
Battery Monitoring Equipment	0.024	50 -180	1 - 240	1	0.02	6	VA
DC Ammeter	0.048	125	1 - 240	1	0.048	3	VA
DC Voltmeter	0.048	120	1 - 240	1	0.048	3	VA
SACO Annunciator (L8)	0.150	125	1 - 240	2	0.30	15	W
Edwards Bell	0.012	125	1 - 240	1	0.012	1.5	VA
Power Line Indicating Lamps (LEDs)	0.017	125	1 - 240	8	0.136	2.125	W

60 Cell Sysem	Continuous Load	Discontinuous Load Current
	4.404A	19.8 A

Power Supply Burden (W)	t=240min	t = 1 min
	4.404 A	37.404

[Figure 4.5.7 DC Load Calculations]

To ensure reliable backup power, we utilized the Battery Sizing Programme (BSP) developed by Enersys, along with a custom Excel model, to accurately determine the appropriate battery size for our application. Both tools account for critical variables to recommend the most suitable battery type and capacity. This approach ensures the system remains operational during grid outages or periods of low solar generation. (Refer to the Appendix for detailed calculations.)

4.5.2.3. Grounding Calculation

The grounding calculations for our substation are shown below, detailing both the tolerable and maximum step and touch voltages. Tolerable limits are presented in Figure 4.5.8, while the maximum calculated values are illustrated in Figure 4.5.8 . Step voltage represents the potential difference between two points on the ground a person could span in a single step, caused by current flowing through the substation's grounding grid. Touch voltage refers to the potential a person might experience when touching grounded equipment while standing on the earth's surface. These calculations are critical for ensuring personnel safety and compliance with grounding standards.

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

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	1.005310832	
Ki	1.117543742	
Ls	1741.00297	
Es	1162.287431	V

6	Calculation for Maximum Touch Voltage

For no ground rod

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

$$K_{ii} = 1$$

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

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

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

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

Kii	1	
Kh	1.072380529	
Km	0.611012059	
Lm	3266.275925	
Em	376.5386862	V

Parameters to calculate/find					
Parameters	Value	Unit	Symbols	Value	Unit
Dimension of fence (x)	42.672	m			
Dimension of fence (y)	48.768	m			
Grid dimension (# x #)	20 x 20	m			
Number of parallel conductors	3.199619881		n		
Spacing between n parallel conductors	1.75	ft	D	0.5334	m
grid conductor diameter	0.05208	ft	d	0.015873984	m
Total length of conductor in the horizontal grid	278.70912	m	Lc		
Perimeter length of grid	195.072	m	Lp		
Area of the grid	2081.028096	m^2	A		
Max length in the x direction	150	ft	Lx	45.72	m
Max length in the y direction	170	ft	Ly	51.816	m
Max distance between any two points on the gric	69.10293956	m	Dm		m
Total length of rod needed	1802.318976	m	LR		m
Length of each rod	6.096	m	Lr		m
Number conductors	2.8575		na	0.870966	m
Number conductors	1.033946308		nb	0.315146835	m
Number conductors	1.082964351		nc	0.330087534	m
Number conductors	1		nd	0.3048	m
Number of grounding rods	295.656		r	90.1159488	m

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

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

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

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

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

Parameters to compare				
Parameter 1	Value 1	Parameter 2	Value 2	Comparison
E(step50)	1263.175554	Es	1162.287431	Design ok
E(touch50)	377.3121784	Em	376.5386862	Design ok

[Figure 4.5.8 Grounding Calculation]

5. Testing

5.1. Unit Testing

To make sure our system worked correctly, we ran power flow simulations using ETAP. These runs gave us feedback on potential issues or if our design was distributing the power how we were expecting it to. By implementing our one-line diagram into the ETAP software, a power flow analysis can be run to show potential overflow.

5.2 Interface Testing

There are different interfaces being tested within our design. There are smaller components that make up our solar farm and they are tested individually as well as together. The most important components we have tested are the array parameters (voltage, current, power) and the voltage drop in the solar farm. Both of these things impact the overall design of the array and they influence each other.

For testing of the array parameters, we used our array parameter tool which is an excel spreadsheet created by Black & Veatch. We input the component parameters into this spreadsheet and it gives us the array parameters. We are then able to verify these parameters by doing calculations by hand. In the future we will be able to verify both of these things using a simulation of our array.

For our voltage drop calculations we use a voltage drop calculator which is also an excel spreadsheet created by Black & Veatch. We are able to put in our array parameters, distance between components, and conductor sizes and it gives us the voltage drop across the conductor. We were able to add a percentage column to this document to ensure that the voltage drop is between 3 to 5%. This is a major factor in our testing for this component. The more current coming out of the array, the higher the voltage drop and the larger the conductor we need is. This is how the two components interact. We will be able to simulate the voltage drop using ETAP as well.

5.3 Integration Testing

Integration between the solar farm and substation is a key testing point in the future of our project. Without correctly integrating these two components the power generated by our solar farm will not be connected to the grid and therefore be an ineffective design. We will also need to test the integration of all of our individual arrays, combiner boxes, and inverters. If we are not able to integrate each individual array then we will not get our desired power output from the farm. This again will be tested using ETAP to ensure power is flowing correctly and there are no incorrect current or voltages throughout our design.

Another key integration point is from the substation to the transmission system. An incorrect connection to the grid can have catastrophic effects and would be a major design failure. We have to ensure all phases are connected properly and everything is grounded properly as well. If there is something within our design that causes the voltage and current to not be 60 Hz that would also need to be corrected. This will be done with calculations and simulation at the end of our design to ensure these needs are met. There are also various safety standards we will be included that will also be accounted for and tested.

5.4 System Testing

After testing individual parts and connections, we tested the entire system as a whole. We ran a full load flow simulation in ETAP to see how the system performed from start to finish—from power generation all the way to delivery at the 115 kV grid. We checked that the system delivered around 60 MW, voltage stayed within limits, and all protection devices functioned correctly. This system-level test confirmed that everything was working together and meeting our project goals.

Bus Input Data

Bus			Initial Voltage		Load							
					Constant kVA		Constant Z		Constant I		Generic	
ID	kV	Sub-sys	% Mag.	Ang.	MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar
Bus_1	34.500	1	100.0	0.0								
Bus_2	34.500	1	100.0	0.0								
Bus_3	34.500	1	100.0	0.0								
Bus_4	34.500	1	100.0	0.0								
Bus_5	34.500	1	100.0	0.0								
Bus_6	34.500	1	100.0	0.0								
Bus_7	115.000	1	100.0	0.0								
Bus_8	115.000	1	100.0	0.0								
Total Number of Buses: 8					0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Generation Bus				Voltage		Generation			Mvar Limits	
ID	kV	Type	Sub-sys	% Mag.	Angle	MW	Mvar	% PF	Max	Min
Bus_3	34.500	Mvar/PF Control	1	100.0	0.0	11.885	0.000	100.0		
Bus_4	34.500	Mvar/PF Control	1	100.0	0.0	15.846	0.000	100.0		
Bus_5	34.500	Mvar/PF Control	1	100.0	0.0	15.846	0.000	100.0		
Bus_6	34.500	Mvar/PF Control	1	100.0	0.0	15.846	0.000	100.0		
Bus_7	115.000	Swing	1	100.0	0.0					
Bus_8	115.000	Swing	1	100.0	0.0					
						59.423	0.000			

[Figure 4.6.1 ETAP Power Flow Simulation]

Short-Circuit Summary Report

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

Prefault Voltage = 100 % of the Bus Nominal Voltage

Bus		3-Phase Fault			Line-to-Ground Fault			Line-to-Line Fault			*Line-to-Line-to-Ground		
ID	kV	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.
Bus_2	34.500	1.997	-0.631	2.095	4.042	-1.434	4.289	-0.817	-2.307	2.447	-2.187	3.114	3.805

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

[Figure 4.6.1 ETAP Short-Circuit Simulation]

5.5 Regression Testing

To ensure new designs do not break our system or compromise any work we have already done we will be using our array parameter tool and voltage drop calculator to prove the design will work in theory before simulation. If we are diligent about what we choose to integrate and add it should not cause any problems if we don't make any mistakes. We have several people working on each design so things have a low chance of being overlooked. The critical features we need to ensure remain the same are the things required by our project. This is the output voltage and power from both our solar farm and substation. We also can't create any phase errors but this is unlikely to happen.

5.6 Acceptance Testing

Our team has weekly meetings with both our client (Black & Veatch) and our academic advisor Professor Ajjarapu. We present what we have worked on the previous week and discuss any questions or concerns we are having about the project. We receive lots of feedback and guidance from these meetings and it keeps us on track and ensured our project is moving in the right direction. Professor Ajjarapu helps us understand how this project connects to what we are learning in school and it allows us to know our hand calculations are being done the correct way. During our meetings with Black & Veatch we discuss our designs, standards, and how things are done in industry. We send them our calculations and drawings for review and receive feedback on how to do this better or more accurately.

5.7 User Testing

The main users of our project are utility companies that will operate the substation and solar plant, as well as local customers who will receive the electricity. We wanted to make sure our design met the needs of both groups. To do this, we worked closely with our client Black & Veatch. They gave us regular feedback during our weekly meetings and helped us understand what utility companies are looking for such as safety, reliability, and ease of maintenance. They also helped us design the project in a way that followed industry standards and best practices.

Although we didn't directly test the project with local customers, we kept their needs in mind. For example, we focused on making the system reliable and able to provide clean energy, which benefits the whole community. The feedback we got from Black & Veatch was very helpful. They pointed out ways we could improve our design, like how to arrange our equipment more efficiently and how to size key components correctly. We made changes based on their advice to make sure the design would work well in the real world.

5.8 Security Testing

For our project, we also considered physical security for both the solar farm and substation, which is important for protecting both the equipment and the people who work at the site. Our solar farm will be producing a large amount of power to put on the grid, so it's important to prevent unauthorized access and reduce the risk of potential grid outages from equipment damage or safety issues. We made sure to include features like fencing around the entire substation and solar plant area to keep out intruders and wildlife. We also included security cameras in key locations in our substation to monitor the site and help with incident response if needed. For the control room and any other restricted areas, we planned for badged access, so only trained and approved personnel can enter.

While we didn't physically test these features, we reviewed standard utility practices and followed guidelines for secure facility design. These security measures were also reviewed by engineers from Black & Veatch, who confirmed that they met real-world expectations for utility infrastructure.

5.9 Results

Our testing showed that the system we designed works well and meets the main goals of the project. Using ETAP, we ran simulations to see how power flows from the solar array through the substation and into the grid. The results showed that we delivered about 59.4 MW, which is very close to our target of 60 MW. Voltage levels stayed steady across all buses, which means the system was designed correctly and performs as expected.

We also tested how the system would respond to problems, like overcurrent or faults. The relays and breakers worked as they should, tripping in the right places and protecting the system. That gave us confidence that our protection setup is safe and reliable.

All parts of the system like the transformers, buses, and relays stayed within their safe operating limits. There were no major voltage drops or overloads, which shows the system is efficient and stable.

In the end, the results showed that our project not only works but is also safe, efficient, and meets both technical requirements and user expectations.

6. Implementation

Due to the large scope and budget of our project it will not be implemented by our team. We will leave our client with a completed design that is able to be implemented if wanted. Construction of a solar farm and substation can take long periods of time to complete. Should the project be implemented it would be after our graduation that construction would start, and be completed.

6.1 Design Analysis

Overall, our design works well and meets the main goals of the project. We created a plan for a 115/34.5 kV substation and a 60 MW solar plant that follows industry standards and is designed to be safe, reliable, and efficient. What worked well for our team was our ability to break down the project into smaller parts and approach each section step by step first with the solar farm and then the substation. Weekly meetings with Black & Veatch helped us stay on track and get feedback on our work from industry professionals. Our calculations, layouts, and simulations showed that the design works well and performs as intended under normal conditions. Our team utilized ETAP to simulate our design and perform a load flow analysis to confirm our work.

Some parts of the project were more challenging. Certain equipment choices or layout ideas had to be revised after we received feedback or found new information. In some cases, we had to go back and update our designs to better match real-world practices or cost considerations. One example is the decision between using more efficient solar panels versus using more land with cheaper panels. Our team had to weigh the pros and cons before making a final choice. If we could do anything differently, we would have started using design software and gathering equipment data earlier in the project. We believe that would have saved time later on and helped us explore more options before deciding on a final design.

7. Ethics and Professional Responsibility

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 Professional Responsibility/Code of Ethics

Area of Responsibility	**Definition**	**Relevant Item from IEEE Code of Ethics**	**Project Interaction/Adherence**
Work Competence	Ensuring all work is of high quality, integrating integrity, timeliness, and professionalism.	"Perform services only in areas of their competence; Avoid deceptive acts."	Our design calculations and system go through a process of being checked by our client, advisor, and by using simulation multiple times. Our work has been verified for accuracy and reliability.
Financial Responsibility	Delivering products and services that are cost-effective and	"Act for each employer or client	Our team has sourced material and compared multiple options, ensuring optimal cost-effectiveness

	hold realizable value.	as faithful agents or trustees."	without compromising quality and efficiency.
Communication Honesty	Upholding truthfulness and clarity in all project communications.	"Issue public statements only in an objective and truthful manner; Avoid deceptive acts."	Clear and honest updates are provided to our client, advisor, and team members frequently and regularly.
Health, Safety, Well-Being	Prioritizing the health and safety of the public in all engineering decisions.	"Hold paramount the safety, health, and welfare of the public."	Safety analyses are important to our project phases, making sure all designs meet safety standards.
Property Ownership	Respecting intellectual property and confidentiality.	"Act for each employer or client as faithful agents or trustees."	All software and design tools we are using are properly licensed.
Social Responsibility	Delivering benefits to society through engineering projects.	"Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession."	The project aims to improve energy efficiency, directly benefiting economic and environmental aspects of the community.

[Figure 7.1.1: Area of Responsibility]

Strength:

Communication Honesty

- Relevance to Our Project
  - Making sure we are effectively communicating is very important to ensure our client, advisor, and team members are all on the same page. This is important not only for efficiency, but also for functionality of our project.

- Team's Approach
    - Our team holds multiple regular weekly team meetings including meetings with our client, Black & Veatch, meetings with our faculty advisor, and team meetings.
    - Our team maintains very consistent reporting and progress updates. We also maintain a project website for clear documentation.
- Why Our Approach Upholds Ethical and Professional Responsibilities
    - Our communication practices follow the importance of truthful and accurate reporting in all professional interactions in accordance with the NSPE (National Society of Professional Engineers) Code of Ethics.
    - Maintaining communication in an honest matter helps build trust and ultimately prepares our team for long-term success.

Area for Improvement:

Financial Responsibility

- Relevance to Our Project
    - Financial responsibility is important for maintaining the project within a reasonable budget and ensuring a cost-effective solution for our client.
- Team's Approach
    - Our team updates an ongoing costs spreadsheet created using Microsoft Excel for various components of the project as well as a cost estimation tool with our client. Each and every week, we discuss costs in our meetings and modifications that may be needed.
    - Based on the weekly tasks required of us by our client, we continually update the cost estimation. It can be very difficult to find pricing for some components because they are strictly provided by commercial suppliers, making it hard to obtain a true cost.
- Why Our Approach Upholds Ethical and Professional Responsibilities
    - Our group will suggest not only continuing with our weekly cost meetings, but make mention of doing in-depth cost analysis more frequently with our client in order to make sure needs are met. We will also verify all components are included by cross-referencing our AutoCAD drawings.
    - These proposed changed will not only comply with ethical standards but also build trust with our client, including any future investors and the community, by demonstrating a commitment to financial responsibility.

7.2 Four Principles

Broader Context	**Beneficence**	**Nonmaleficence**	**Respect for Autonomy**	**Justice**
Public Health, Safety, and Welfare	Improves community well-being by providing cleaner energy and improving air quality.	Avoids harming the local community by not emitting pollutants.	We have designed our project to be minimally invasive and fully compliant with local land use and environmental regulations.	Ensures equitable access to the benefits of clean energy, improving local livelihoods.
Global, Cultural, and Social	Promotes global sustainability and cultural respect by using renewable resources.	Our approach focuses on maintaining the existing landscape ensuring and ensuring minimal impact on farming in the area.	Respects the local community including aesthetics and any farming operations.	Aims to distribute the benefits of renewable energy fairly across different contexts.

Environmental	Contributes to sustainability by reducing reliance on fossil fuels.	Reduces environmental impact by minimizing ecosystem disruption and not using non-renewable resources.	Provides transparency about environmental impacts.	Ensures future generations have access to natural resources and a clean environment.
Economic	Reduces energy costs, making sustainable energy accessible to more people.	Prevents economic harm by ensuring project viability and not overutilizing resources.	We are designing the solar farm to be economically beneficial by lowering energy costs and creating jobs, thereby supporting the community's economic well-being	Works to fairly distribute economic benefits from energy savings and job creation.

[Figure 7.2.1: Four Principles]

Important Pair: Environmental-Beneficence

Benefit: Our project is good for the environment because it uses solar energy instead of fossil fuels, which helps to reduce pollution and save natural resources.

Action Plan: To make sure we keep helping the environment, we will use efficient solar panels that will last for many years and provide abundant power. We'll also check the environmental impact regularly and make changes if we find any problems.

Lacking Pair: Economic-Nonmaleficence

Challenge: Our project costs a lot to start and uses many natural resources, which could be hard on the local economy if not handled well.

Improvement Strategy: To fix this, we need to better manage our resources and work closely with the community to make sure the benefits, like new jobs and cheaper energy, are greater than the costs. We could also look into different ways to help cover the initial costs for the community.

By focusing on these points, our project aims to be responsible and beneficial, balancing engineering solutions with ethical considerations to tackle real-world problems effectively. From the beginning of our project, we made it a priority to act responsibly and follow engineering ethics. We defined this as making decisions that protect public safety, are honest and fair, and follow professional standards. This includes designing a system that is safe, reliable, and environmentally responsible.

Nothing has changed in our approach to ethics and professional responsibility because we have continued to follow the same values throughout the project. We stayed committed to doing high-quality work, using accurate data, respecting deadlines, and being open to feedback. Our teamwork and communication with Black & Veatch also stayed professional and respectful from start to finish.

7.3 Virtues

In our senior design project, we emphasize virtues that guide our behavior and interactions both within the team and with external stakeholders. Here, we define three virtues central to our team dynamics and operational ethos, including actions we've taken to uphold these virtues:

1. **Integrity**
    a. **Definition:** Integrity ensures that every decision and action taken in the project aligns with ethical standards and promotes trust.
    b. **How Our Team Demonstrates Integrity:**
        i. **Clear Communication:** We regularly update our client, advisor, and team members with accurate information about project progress and any challenges.
        ii. **Compliance with Regulations:** We adhere strictly to all environmental, building, and safety regulations without taking shortcuts, ensuring all project aspects meet legal and ethical standards.
2. **Diligence**
    a. **Definition:** Diligence involves persistent effort and careful work to ensure the project's success and reliability.
    b. **How Our Team Demonstrates Diligence:**
        i. **Thorough Research and Testing:** We conduct extensive research and testing to validate our design choices and ensure they are the most effective and sustainable.
        ii. **Attention to Detail:** Each team member is responsible for meticulously reviewing their work to catch and correct any errors or potential problems before moving forward.
3. **Collaboration**
    a. **Definition:** Collaboration is the commitment to working synergistically with all stakeholders, valuing diverse perspectives and expertise to achieve the best project outcomes.

b. **How Our Team Demonstrates Collaboration:**
    i. **Regular Team Meetings:** We hold frequent meetings to discuss progress, share ideas, and solve problems collectively.
    ii. **Inclusive Decision-Making:** We ensure that all team members have a voice in key decisions, promoting a sense of ownership and mutual respect across the project.

Individual Reflections on Virtues

Team Member 1 – Andrew Chizek:

- Demonstrated Virtue: Flexibility
    - Importance: Being flexible about your role or task allows things to get done on time, and it can help improve team morale. Being able to work on multiple things and working with other teammates is beneficial to getting the task done correctly and up to standards.
    - Demonstration: All of us have had rotating roles, and we have been able to help each other out with different tasks while also completing our weekly assigned tasks.

- Undemonstrated Virtue: Leadership
    - Importance: Having a leader allows work to get done, especially on time. Even though I was not given the official role of leader this semester, I could have taken a prominent role instead of staying back.
    - Future Actions: When it becomes my turn to be the rotating leader, I will be in charge of setting up meeting time, assigning tasks to the others, and making sure all of these tasks will get done by the time they are supposed to. I will also attempt to be more vocal even when I am not the leader, as having a secondary leader can be beneficial as well.

Team Member 2 – David Ntako:

- Demonstrated Virtue: Leadership
    - Importance: Leadership keeps the team organized and focused on goals
    - Demonstration: Since there were a few things not in place yet, I first started by making sure that we had a fixed to meet outside of class to work on the project instead of the leader texting the group each week to set up a time to meet. Second, I guided the team, assigned tasks that way we know what each person is doing, and ensured we stayed on track to finish the project.

- Undemonstrated Virtue:
    - Importance: Flexibility allows the team to adapt to unexpected challenges or changes in the project.
    - Future Actions: I will remain open to new ideas and have back up plans when unexpected situations arise that way, I am staying on top of the situations as a leader instead of getting in trouble for not completing the work, and so forth.

Team Member 3 – Bennet Palkovic:

- Demonstrated Virtue: Industry
  - Importance: This virtue is important because it keeps you focused and efficient when working towards your goals. If your time is being taken up by unnecessary actions then it is not a good use of time when you could be using that time for something else. This virtue is especially important when working in a group project like ours, where certain tasks need to be done in order for another member to continue their work.
  - Demonstration: Time spent on the project is used efficiently and on the most important tasks. An effort was made to avoid repeating things when working on AutoCAD and all group projects to get them done quickly.

- Undemonstrated Virtue: Gratitude
  - Importance: Gratitude is important within a team as it can help build respect and relationships between the team. Gratitude helps team members feel more confident and better about their work and overall benefits everyone.
  - Future Actions: I plan to show more gratitude on teammates work and comment positively on things that have been achieved.

Team Member 4 – Mohamed Sam

- Demonstrated Virtue: Integrity
  - Importance: Being honest helps build trust and makes sure everyone knows what's going on. It also shows respect for the people we're working with, like our client and advisor.
  - Demonstration: I've made sure to communicate clearly with our client and advisor, setting up meetings on time and delivering all required documents when they're needed. This has kept the project on track and made sure everyone feels confident in our progress.

- Undemonstrated Virtue: Patience
  - Importance: Sometimes things don't go as planned, and patience helps me stay calm and focused so I can be more supportive of my team.
  - Future Actions: I'll listen more during discussions to understand everyone's perspectives and stay calm when problems arise, focusing on solutions instead of frustrations.

Team Member 5 – Sergio Sanchez Gomez:

- Demonstrated Virtue: Commitment
  - Importance: Commitment is important because it keeps everyone focused and accountable, helping the team push through challenges. It ensures that we stay dedicated to reaching our final goal.
  - Demonstration: I showed commitment by taking responsibility for the project's tasks and aiming to finish them ahead of schedule. I also made sure to be available

for team meetings whenever needed, helping us stay on track and work well together.

- Undemonstrated Virtue: Patience
  - Importance: It is crucial because it helps to stay focused and deal with challenges calmly.
  - Future Actions: I plan to be more flexible and adapt to each team member's strengths and weaknesses. I'll adjust how I communicate to ensure everyone's skills are utilized in the most effective way possible.

Team Member 6 – Dallas Wittenburg:

- Demonstrated Virtue: Integrity
  - Importance: Integrity is crucial to me because it fosters trust and respect among team members and our client.
  - Demonstration: I've ensured that all documentation I have handled was accurate and truthful. I've tried to maintain transparency about our project status and outcomes.

- Undemonstrated Virtue: Patience
  - Importance: Patience is important to me because it helps in dealing with unforeseen delays and issues calmly and effectively.
  - Future Actions: I plan to demonstrate patience by taking the time to understand the complexities of the project better and not rushing through problem-solving.

8. Closing Material

8.1 Conclusion

This project focused on designing a 115/34.5 kV Solar Plant & Substation to provide sustainable and efficient energy solutions. Our goal was to create a 60 MW solar farm and an integrated substation to meet the growing demand for renewable energy while minimizing environmental impact.

Our main objectives were to:

- Design a solar plant layout optimized for efficiency and minimal power loss.
- Integrate the solar plant with a substation for seamless grid connection.
- Evaluate costs and environmental impacts to ensure feasibility.

We successfully completed:

- **Validated Designs**: Ensured calculations, like voltage drop and power output, adhered to industry standards with input from Black & Veatch.
- **Optimized Layouts**: Achieved a low voltage drop (2.81%) in the worst-case scenario through strategic component placement.

Some constraints included:

- Limited access to up-to-date component costs, affecting early financial planning.

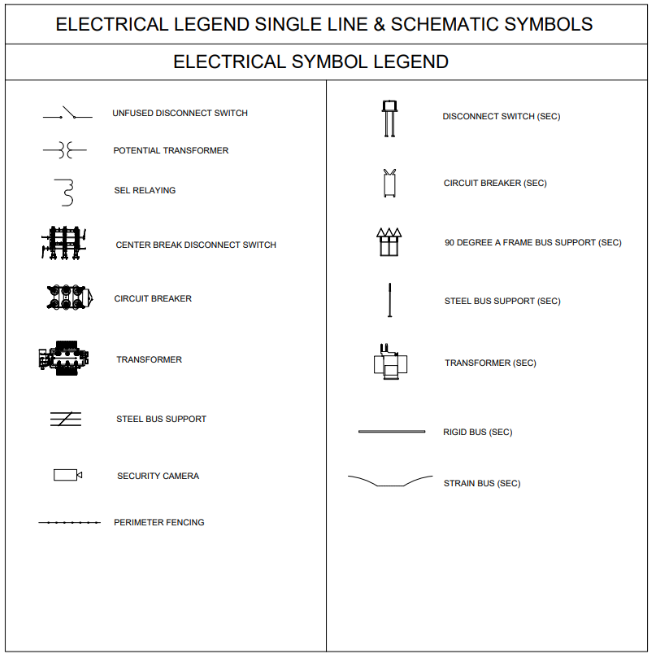
9. References:

IEEE Standards Association. **"IEEE 2778-2020: Standard for Grounding System Design for Utility-Scale Photovoltaic Solar Power Plants."** IEEE, 2020.

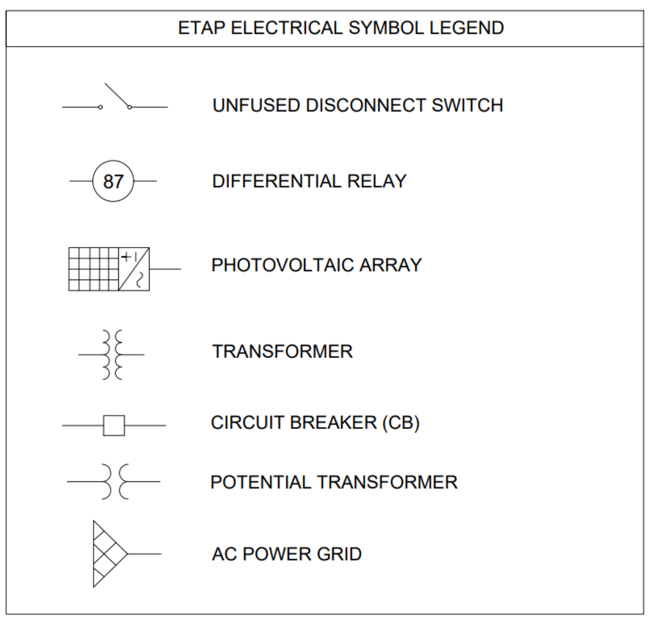
Bittrich, T. (2023, November 15). "2023 Update: How to Calculate PV String Size." *Mayfield Renewables*. [Online]. Available: https://www.mayfield.energy/technical-articles/2023-update-how-to-calculate-pv-string-size/

Mayfield, R., Miller, L., & van Almelo, N. (2020, August 28). "Analyzing the 2% DC Voltage Drop Rule." *Mayfield Renewables*. [Online]. Available: https://www.mayfield.energy/technical-articles/analyzing-the-2-percent-dc-voltage-drop-rule/

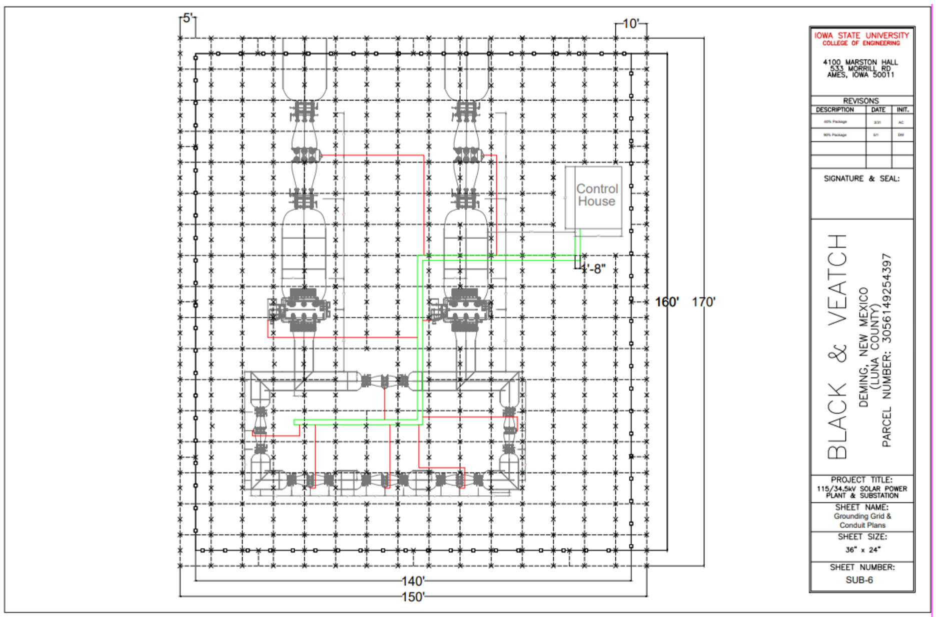
10. Appendices



[Figure 10.1 Electrical Legend Single Line & Schematic Symbols]



[Figure 10.2 ETAP Electrical Legend]



[Figure 10.3 Grounding Grid Layout]

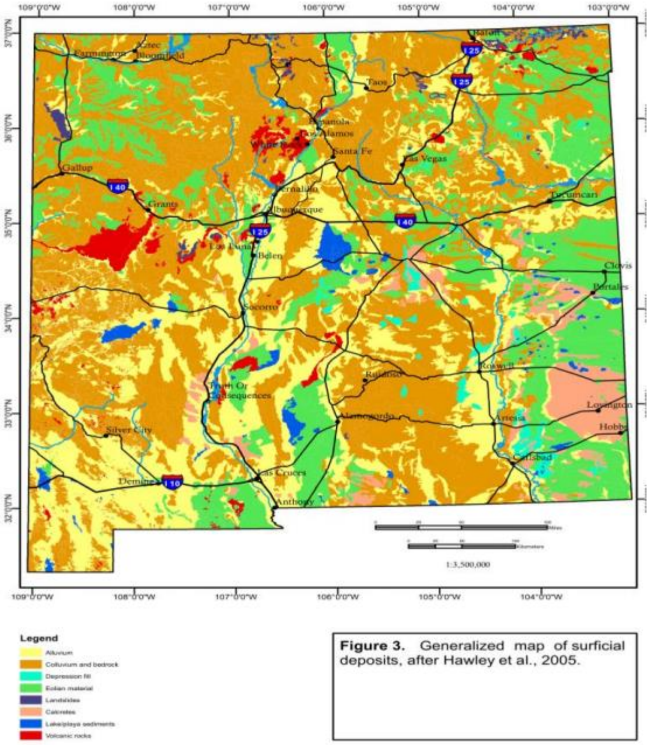
Components	Load Current (A)	Nominal Voltage (V) DC	Inception and Active Shutout Time	number of components	Total Load Current (A)	Power Requirement	Power (Units)
34.5kV Breaker:	Tripping Current: 3.3	70 – 140	0 - 1	6	Tripping Current:19.8	343	W
	Closing Current: 2.6	90 - 140			Closing Current :15.6	364	W
115kV Breaker:	Tripping Current : 6.6	125	239- 240	2	Tripping Current: 13.2	1050	W
	Closing Current : 3.6	125			Closing Current : 7.2	950	W
SEL-311C	0.20	125	1 - 240	8	1.60	25	W
SEL-311L	0.20	125	1 - 240	8	1.60	25	W
SEL-587	0.044	125	1 - 240	2	0.08	6	W
SEL-487E	0.280	125	1 - 240	2	0.56	35	W
Battery Monitoring Equipment	0.024	50 -180	1 - 240	1	0.02	6	VA
DC Ammeter	0.048	125	1 - 240	1	0.048	3	VA
DC Voltmeter	0.048	120	1 - 240	1	0.048	3	VA
SACO Annunciator (L8)	0.150	125	1 - 240	2	0.30	15	W
Edwards Bell	0.012	125	1 - 240	1	0.012	1.5	VA
Power Line Indicating Lamps (LEDs)	0.017	125	1 - 240	8	0.136	2.125	W

60 Cell Sysem	Continuous Load	Discontinuous Load Current
	4.404A	19.8 A

Power Supply Burden (W)	t=240min	t = 1 min
	4.404 A	37.404

(1)	(2)	(3)	(4)	(5)	(6)	(7)	
PERIOD	LOAD (A)	CHANGE IN LOAD (A)	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	4.404	4.404	4:00:00	4:00:00	4.807	21.170	0.000
					Sub Total	21.170	0.000
					Section 1 Total	21.170	
SECTION 2 - FIRST 2 PERIOD ONLY - IF A3 IS GREATER THAN A2. GO TO SECTION 3							
1	4.404	4.404	4:00:00	4:00:00	4.807	21.170	0.000
2	37.404	33.00	4:01:00	4:01:00	4.822	159.126	0.000
					Sub Total	180.296	0.000
					Section 2 Total	180.296	
		Aging factor		247.9070385	250 Ah		
		1.25					
		Design margin				nominal capacity	250
		1.1					

[Figure 10.4 DC Calculations]



[Figure 10.5 New Mexico Soil Type Map]

10.1 Team Members

1. Andrew Chizek
2. Sergio Sanchez Gomez
3. David Ntako
4. Bennet Palkovic
5. Mohamed Sam
6. Dallas Wittenburg

10.2 Required Skill Sets for Our Project

- **Solar Power Design**: Knowledge of PV system design and component selection.
- **Simulation Software Proficiency**: Expertise in AutoCAD and ETAP.
- **Team Collaboration**: Strong teamwork and communication skills to coordinate tasks and meet deadlines.

10.3 Skill Sets Covered by the Team

- **Ben:**

- Proficient in AutoCAD, creating detailed layouts for the solar plant.
- Effective team player with strong collaboration skills, ensuring smooth communication and task coordination.

- **Andrew:**
- Assists with refining layout designs using AutoCAD.
- Planning efficient PV systems and selecting the right components and cost analysis.

- **Dallas:**
  - Assists with refining layout designs using AutoCAD.
  - Planning efficient PV systems and selecting the right components and cost analysis.

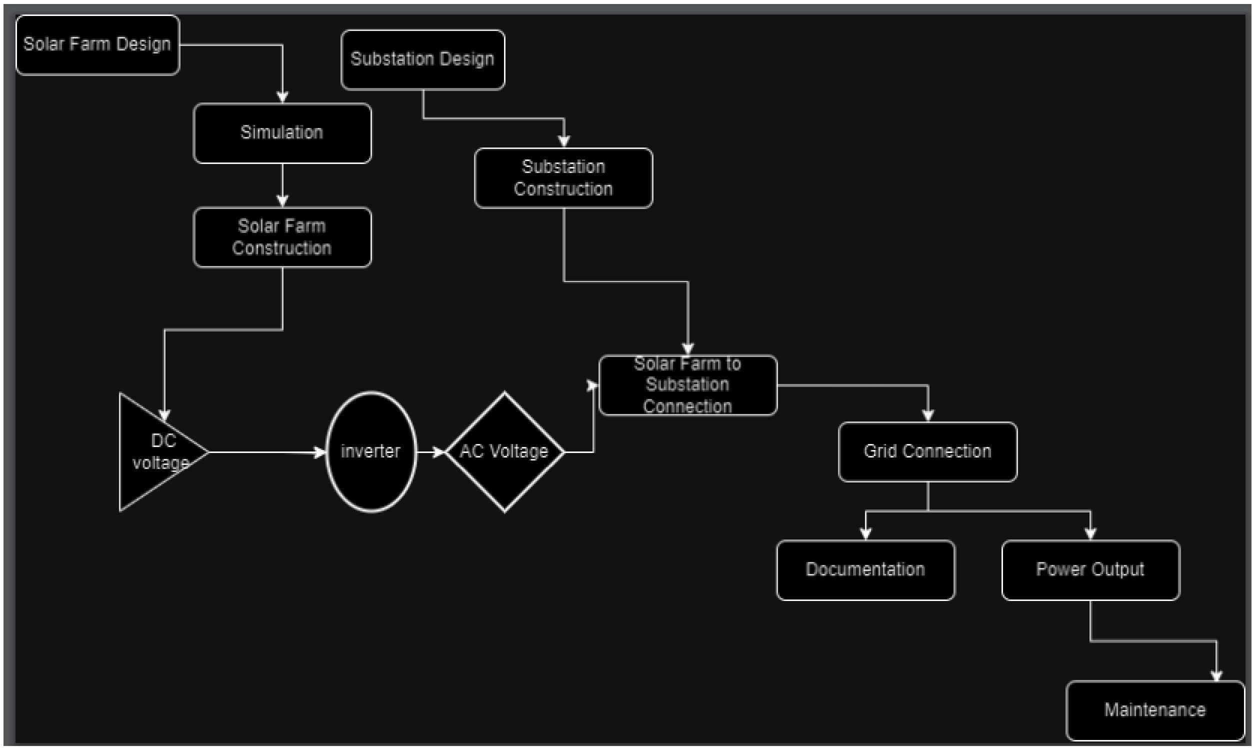
- **Mohamed:**
- Skills calculate and optimize voltage drops to minimize power loss.
- Communicates with the client and advisor, ensuring alignment with project goals and expectations.

- **Sergio:**
  - Handles documentation and presentation tasks, ensuring clear and concise reporting.
  - Assists with refining layout designs using AutoCAD.

- **David:**
  - Strong communication and coordination skills to ensure smooth teamwork.
  - Assist with voltage drop calculation and components selection.

10.4 Project Management Style Adopted by the Team

Our group utilized a waterfall management style because most of our tasks relied on a previous task getting done first. Since our project is split into two parts, our waterfall has two streams that eventually come back to one end point.



[Figure 10.6 Project Management Style]

10.5 Initial Project Management Roles

- Andrew Chizek: Rotating Leader/Group Member
- David Ntako: Rotating Leader/Group Member
- Bennet Palkovic: Rotating Leader/Group Member
- Mohamed Sam: Rotating Leader/Group Member
- Sergio Sanchez Gomez: Rotating Leader/Group Member
- Dallas Wittenburg: Rotating Leader/Group Member

10.6 Team Contract

Team Name sdmay25-41

Team Members:

1) Andrew Chizek
2) Sergio Sánchez Gomez
3) Mohamed Sam
4) David Ntako
5) Dallas Wittenburg
6) Bennet Palkovic

Team Procedures

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

   Friday, 1 pm, TLA (Face to face)

   Thursday, 1 pm, Zoom meeting with our client, Black and Veatch

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

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

   Group will decide what is best for all members

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

   Meeting minutes will be kept by group members on a rotating basis. The minutes will be on a document that will be shared with everyone so that anyone can access and see what was written down.

Participation Expectations

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

   All team members are expected to attend meetings and participate regularly and arrive on time. If any member is unable to attend a meeting, they must inform the rest of the team at least 24 hours in advance, providing a reason for their absence.

2. Expected level of responsibility for fulfilling team assignments, timelines, and deadlines:

   All team members are expected to alternate roles as well as alternate completing weekly tasks for our client, Black & Veach. Our client requires a weekly agenda to be sent to them at least 24hrs in advance of the meeting. Our client also requires the meeting minutes to be sent to them as soon as possible following the completion of the meeting. As a team, we will work together to meet the timelines and deadlines required by our client.

3. Expected level of communication with other team members:

   Communication should be used heavily. If a team member asks a question involving everyone, everyone should answer to make the best decision. Communicating any absence beforehand (24 hours) is expected. If any issues arise, communicating it with the others will hopefully for a resolution to said issues.

4. Expected level of commitment to team decisions and tasks:

The team members should attempt tasks and decisions with 100 percent effort. If they need help, they should ask others so that the finished work will be adequate to the effort the entire team desires. Each member should try to do the same amount of work and include everyone to limit work issues and ensure that every task gets accomplished.

Leadership

1. Leadership roles for each team member (e.g., team organization, client interaction, individual component design, testing, etc.): We will be rotating the role of leader throughout the year, so everybody has equal opportunities. We will decide as a group who will be working on what as we move through the project, working together whenever possible so we have equal opportunities to learn.

2. Strategies for supporting and guiding the work of all team members: As a group we should make sure that everybody has a role and isn't left out. Everybody should try to do work as well as try to include everyone in work that needs to be done. Teammates should invite each other to collaborate whenever possible and let others know what they are going to complete.
3. Strategies for recognizing the contributions of all team members: In the weekly reports all members will report their contributions and receive credit where it is due.

Collaboration and Inclusion

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

   All members are in electrical engineering with a focus in power systems. All members are currently taking EE456, Power Systems Analysis I and are studying the design and analysis of power generation and transmission systems. Some members have had internships with design firms as well as municipal utilities.
2. Strategies for encouraging and supporting contributions and ideas from all team members:

   During our weekly meetings, we will all contribute and talk about what we have been doing. If any advice is wanted, the members can reach out and talk about the support they'd like when asking a question. Everyone will maintain a positive attitude, which will keep morale high, and no one should be afraid to ask for support. If an idea is not liked, the group will discuss with each other why they think this, and everyone will pitch in to modify the original idea to get the best result for the project.

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

   To identify and resolve collaboration or inclusion issues, it's important to have a clear way to talk about problems. If at any time a member feels left out or unable to contribute, they are welcome to discuss this openly in weekly team meetings or to other members of the group individually.

Goal-Setting, Planning, and Execution

1. Team goals for this semester:
   The goal this semester is to get done the 115/34.5 KV Solar Plant part and work on the substation part for next semester. Good harmony throughout the project and everyone participates and does their assigned tasks on time. Getting done the first

Design solar plant

2. Strategies for planning and assigning individual and team work:

   Everyone will have roles, and specific roles, like leader or minutes keeper will be rotated throughout the design process to keep workload semi equal between all members. All members will communicate what they want to work on and discuss between us what gets assigned to whom.

3. Strategies for keeping on task:

   Monitor everyone's work and calmly push a potential member who is off task to get back on task. This calm approach should be used unless the issues keep happening, then more urgency will happen, and the group will meet to discuss how to move forward. Members should be held to a standard from the start that when working on our project, to be on task.

Consequences for Not Adhering to Team Contract

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

   - Address the Issue Privately: *The first step would be a private discussion (between the enforcer of the team and the student who violated the rules and guidelines) with the team member who committed the infraction to clarify the issue and ensure they understand the breach of the contract.*

-Collaborative Resolution: *The team would work together to resolve the issue, encouraging open communication to understand any challenges the member may be facing, and offering support or adjustments if needed.*

-Document the Incident: The enforcer of the team would document the infraction to ensure there's a record of the issue in case it escalates.

2. What will your team do if the infractions continue?

-Group Discussion*: The team will meet collectively to address the continued breach and seek a more formal resolution, such as establishing specific expectations or assigning additional responsibilities to make sure that the student who committed a penalty is still contributing to the project.*

-Escalation*: If unresolved, the team might escalate the issue to a higher authority (faculty advisor) for mediation or further action, such as reassignment of duties or penalties.*

****

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) Sergio Sánchez Gomez DATE: 09/19/2024

2) Andrew Chizek DATE: 09/19/2024

3) Mohamed Sam DATE: 09/19/2024

4) David Ntako DATE: 09/19/2024

5) Dallas Wittenburg DATE: 09/19/2024

6) Bennet Palkovic. DATE: 09/19/2024