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. For the fall semester, our focus was only the design process of the solar farm and the substation design will be implemented with the farm during the spring semester.

Our design process started with selecting our three 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 gets 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, we used a spreadsheet provided by our clients that helped us design our rack arrays, leading to telling 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. With our solar farm design meeting our requirements, we are on schedule and can focus on the substation design during the spring semester.

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 field. 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

New Skills/Knowledge acquired that was not taught in courses

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

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

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1. Introduction

1.1 Problem Statement

Nowadays, the world faces growing 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 a crucial solution. The 115/34.5 kV Solar Plant & Substation Senior Design Project will be implemented in Luna County, New Mexico. Our clients Black & Veatch aims to address the challenges associated with transitioning to cleaner energy. Black & Veatch is a consulting company and working in collaboration with us ISU students (group41) for designing this solar plant to generate clean, sustainable electricity that can be efficiently integrated into the local power grid. Luna County, with its abundant solar resources, provides the ideal environment for implementing solar energy on a large scale.

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. Black & Veatch Clients

- Description: Corporations, municipalities, or governments that engage Black & Veatch to develop renewable energy solutions.

- Need: These clients seek to invest in sustainable infrastructure projects that align with their environmental goals and corporate social responsibility initiatives. They also require innovative, cost-efficient designs that can be scaled or replicated for future projects.

- Benefit: Through this project, clients of Black & Veatch will gain a model for developing large-scale solar plants, benefiting from the company's engineering expertise and track record in renewable energy.

1.2.3. 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 files
- Electrical layout drawings (substation equipment) – Bluebeam/CAD/PDF editor
- Grounding analysis and ground-grid developed with IEEE-80 – Excel files
- Additional calculations (AC, DC, lightning protection, etc.) – Excel files
- Simulation of designed substation – SIMULATION SOFTWARE – STUDENT LICENSE [ETAP/SKM/ASPEN]
- Load Flow Analysis / AC Arc Flash Study / 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 has 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.

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, much like Agile's focus on adaptability.

Although our project flow remains rooted in the Waterfall method, this approach to leadership 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.

One of the key reasons we chose the Waterfall methodology is its structured, sequential approach through the project phases. 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.

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

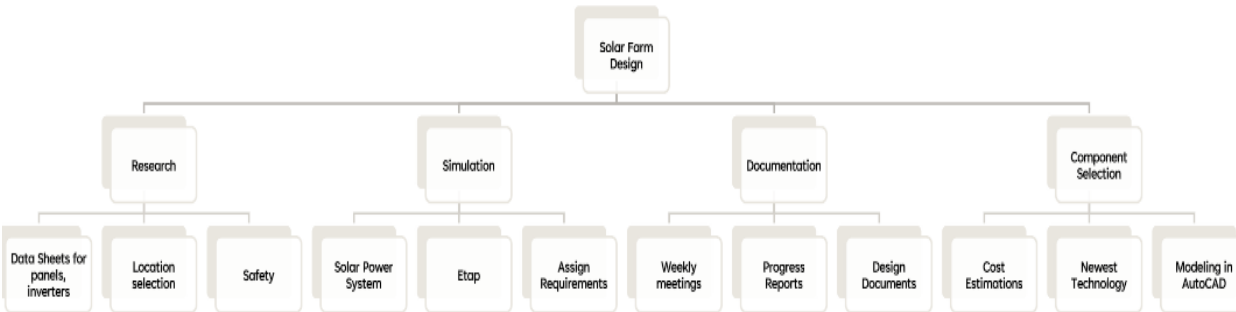
Our team has decomposed our project into many different tasks. These tasks can be applied throughout every step of our waterfall project management style. The decomposition of the tasks helps us understand what needs for the project. This includes: research, simulation, documentation, and component selection.

For the research component of our decomposition, we have broken it down into 3 parts: component data sheets, location, and safety. These are the main things that we have 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.



3.3. Project Proposed Milestones, Metrics, and Evaluation Criteria

Throughout our project we will be using many different milestones and metrics to track our progress. Many of these milestones apply to both the solar array and substation part of our project. There are some that are task specific but can still fall under the same categories. We are able to numerically evaluate many parts of our project and that gives us very specific metrics that we can follow.

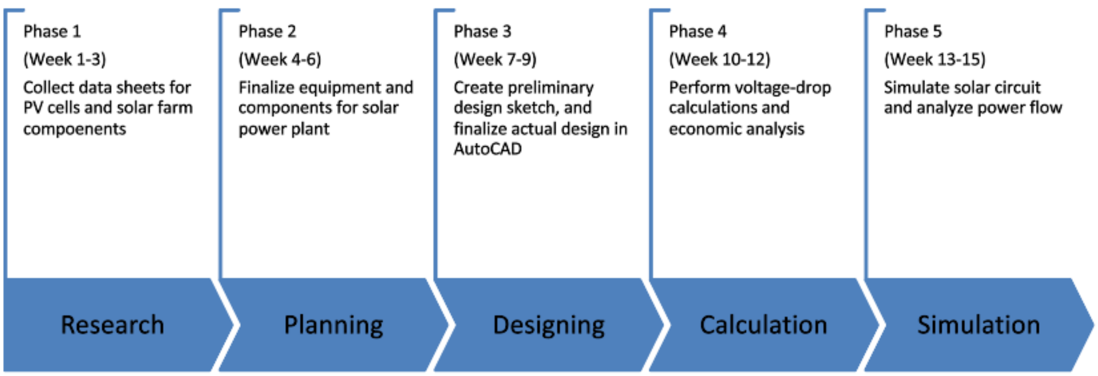
For the solar array we have requirements such as the power output, voltage drop throughout the array, and efficiency of our array. The solar array is required to output 60MW of AC power at peak production with less than a 5% voltage drop throughout the array. We also want to avoid losses of power so we want the array to be efficient. We do this through component selection, location selection, and site design. For example, we have chosen our site to be in Luna County, New Mexico. This provides us with higher irradiance which allows us to generate more power. The site also has a higher average of sunshine per year than other places in the U.S. such as Ames. We have also chosen to have our panels face south with a 30-degree tilt which optimizes the sunlight hitting the panels year-round. With these things together we are aiming to have a 75% efficiency of how much power the array is generating compared to if it was generating 60MW all the time.

For the substation part of the project, we have different milestones and metrics that we will be using. Our major milestones for this part include completion of detailed drawings, calculations, simulations, and cost and component analysis. We will be following similar metrics to the solar array part of the project such as efficiency, power, and voltage drop requirements. We don’t have exact numbers because we haven’t started this part of the project but as we work on it, we will be able to develop our metrics we want.

Finally, for our complete project we will be able to evaluate our work as it relates to IEEE standards and other industry standards. We will be following these standards as we work but we will want to ensure compliance with these for our final product. We also are able to have our industry and academic advisors review our work to ensure that it is standard for what is done by experienced engineers.

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.



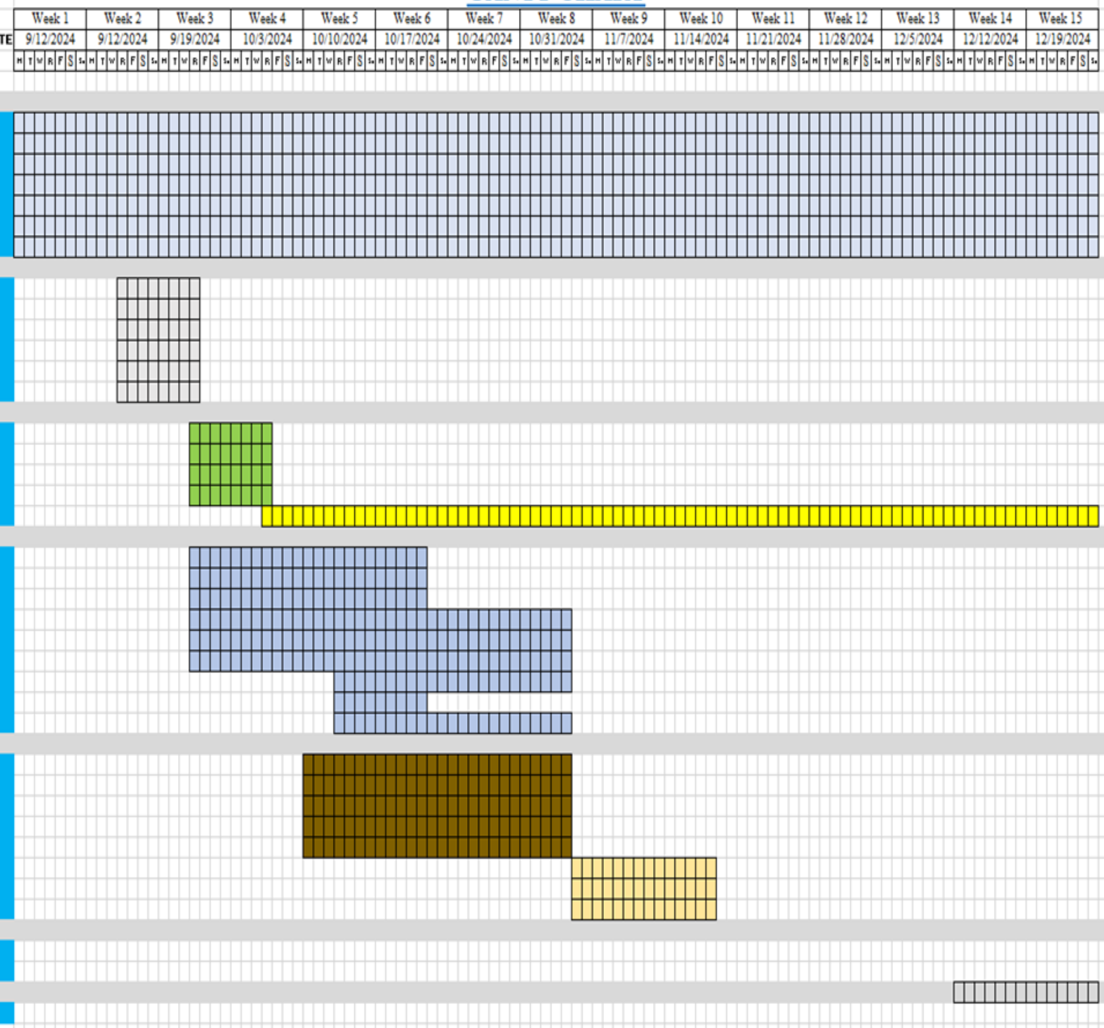
Fall 2024 – Solar Power Plant Design

Project: 115/34.5 kV Solar Power Plant & Substation | **Company Name** Black & Veatch

Project manag Adam Schroeder, Eli Schaffer, Utsavee Desai

GANTT CHART

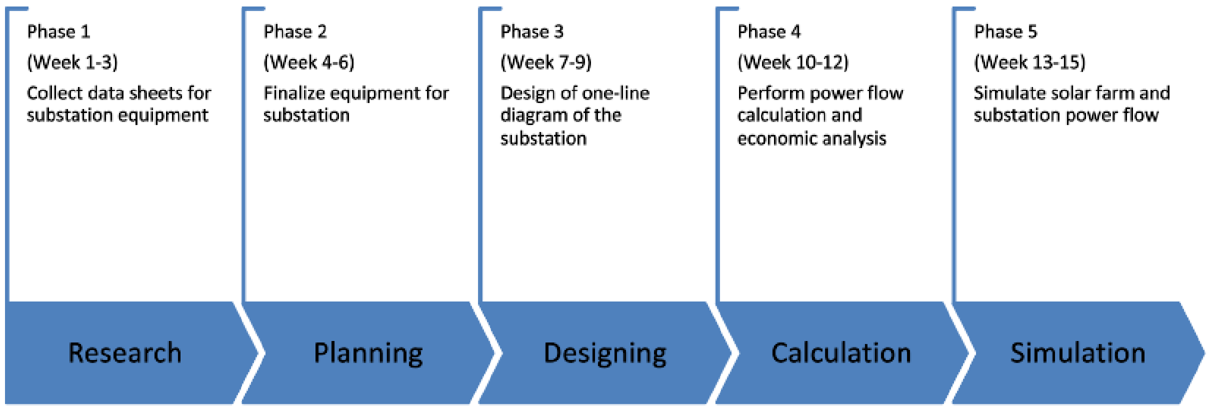
	TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION	TASK COMPLETE
	SOLAR PLANT					
1	**Documentation**					
	Weekly Agenda	All	9/12/2024	12/20/2024	99	☐
	Meeting Minutes	All	9/12/2024	12/20/2024	99	☐
	Weekly Report	All	9/12/2024	12/20/2024	99	☐
	Presentation Slides	All	9/12/2024	12/20/2024	99	☐
	Project Design Document	All	9/12/2024	12/20/2024	99	☐
	Final Report	All	9/12/2024	12/20/2024	99	☐
	Final Presentation	All	9/19/2024	12/20/2024	92	☐
2	**Research**					
	Utility-Grade Solar Panels	Sergio	9/12/2024	9/19/2024	7	☑
	Combiner Boxes	Mohamed	9/12/2024	9/19/2024	7	☑
	Utility-Grade Solar Inverters (skids)	Andrew	9/12/2024	9/19/2024	7	☑
	Safety Moment	Ben	9/12/2024	9/19/2024	7	☑
	Substation Design Overview	Sergio	9/12/2024	9/19/2024	7	☑
	Land Comparison	David	9/12/2024	9/19/2024	7	☑
3	**Component Selection**					
	Solar Component	David	9/19/2024	9/26/2024	7	☑
	Substation Component	All	9/19/2024	9/26/2024	7	☑
	Solar Farm and Substation Location	Sergio	9/19/2024	9/26/2024	7	☑
	Cost Estimation	All	9/19/2024	9/26/2024	7	☑
	Cost Analysis	Dallas	10/3/2024	12/20/2024	78	☑
4	**Array Parameter Calculations (Array parameter tool)**					
	String Size	All	9/19/2024	10/18/2024	30	☐
	Electrical Rack Size	All	9/19/2024	10/18/2024	30	☐
	CB Capacity	All	9/19/2024	10/18/2024	30	☐
	Array Design	Ben	9/19/2024	11/1/2024	53	☐
	Array Size	Ben	9/19/2024	11/1/2024	53	☐
	Total Equipment	David	9/19/2024	11/1/2024	43	☐
	Total Cost and Budget	Andrew	10/10/2024	11/1/2024	22	☐
	Total Power (AC & DC)	All	10/10/2024	10/18/2024	8	☐
	Voltage Drop Calculation	All	10/10/2024	11/1/2024	22	☐
5	**Solar Farm Design & AutoCAD Drawings**					
	Solar Panel Model	Dallas	10/10/2024	11/1/2024	22	☐
	Array	Ben	10/10/2024	11/1/2024	22	☐
	Rack	Ben	10/10/2024	11/1/2024	22	☐
	Solar Layout	Ben & Dallas	10/10/2024	11/1/2024	22	☐
	One Line Diagram	Ben	10/10/2024	11/1/2024	22	☐
	Mounting Structure	Dallas & Sergio	11/2/2024	11/15/2024	13	☐
	Site Plan w/ Measurements	Ben	11/2/2024	11/15/2024	13	☐
	Solar Panel Side View	Dallas & Sergio	11/2/2024	11/15/2024	13	☐
6	**Simulation**					
	Requirements	All				☐
	Simulation	All				☐
7	**Presentation**					
	Presentation	All				☐



Spring 2025 – Substation Design

Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
1/20/2025	1/27/2025	2/3/2025	2/10/2025	2/17/2025	2/24/2025	3/3/2025	3/10/2025	3/17/2025	3/24/2024	3/31/2025	4/7/2025	4/14/2025	4/21/2025	4/28/2025

	SUBSTATION					
1	**Documentation**					
	Weekly Agenda	All	1/20/2025	5/2/2025	102	☐
	Meeting Minutes	All	1/20/2025	5/2/2025	102	☐
	Weekly Report	All	1/20/2025	5/2/2025	102	☐
	Presentation Slides	All	1/20/2025	5/2/2025	102	☐
	Project Design Document	All	1/20/2025	5/2/2025	102	☐
	Final Report	All	1/20/2025	5/2/2025	102	☐
	Final Presentation	All	1/20/2025	5/2/2025	102	☐
2	**Research**					
	Substation Components	All	1/20/2025	1/31/2025	11	☐
	Safety Moment	All	1/20/2025	1/31/2025	11	☐
	One Line	All	1/20/2025	1/31/2025	11	☐
	Bus Layouts	All	1/20/2025	1/31/2025	11	☐
	Design Standards	All	1/20/2025	1/31/2025	11	☐
3	**Component Selection**					
	Circuit Breakers	All	2/3/2025	2/14/2025	11	☐
	Transformer	All	2/3/2025	2/14/2025	11	☐
	Switches	All	2/3/2025	2/14/2025	11	☐
	Control Building	All	2/3/2025	2/14/2025	11	☐
	Cables	All	2/3/2025	2/14/2025	11	☐
	Panels	All	2/3/2025	2/14/2025	11	☐
	Relays	All	2/3/2025	2/14/2025	11	☐
	Backup Service Batteries	All	2/3/2025	2/14/2025	11	☐
4	**Calculation & Design**					
	Additional Calculations (AC, DC, lightning protection, etc.)	All	2/16/2025	2/28/2025	12	☐
	Grounding Analysis and Ground-Grid Developed With IEEE-80	All	2/16/2025	2/28/2025	12	☐
	Electrical Layout Drawings (Substation Equipment)	All	2/16/2025	2/28/2025	12	☐
	Load Flow Analysis / AC Arc Flash Study / Protection Element Analysis	All	2/16/2025	2/28/2025	12	☐
	Backup Service Battery Calculations	All	2/16/2025	2/28/2025	12	☐
5	**Substation AutoCAD Drawings**					
	One Line	All	3/3/2025	4/4/2025	32	☐
	Three Line	All	3/3/2025	4/4/2025	32	☐
	AC Schematics	All	3/3/2025	4/4/2025	32	☐
	DC Schematics	All	3/3/2025	4/4/2025	32	☐
	Wiring Diagrams	All	3/3/2025	4/4/2025	32	☐
	Conduit Layout	All	3/3/2025	4/4/2025	32	☐
	General Arrangement	All	3/3/2025	4/4/2025	32	☐
	Building/Physcial Drawings	All	3/3/2025	4/4/2025	32	☐
6	**Simulation of designed substation**					
	ETAP Simulation	All	4/7/2025	4/18/2025	11	☐
	Creation of solar/substation conceptual design-optimizing tool					
7	**Presentation**					
	Faculty Presentation	All	4/21/2025	5/2/2025	11	☐



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 power plant, 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 one-line diagrams, 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.

3.6. Personnel Effort Requirements

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

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 technical drawings of the farm. We have drafted our sonar panels, the array layouts, and the farm layout. Our one-line drawings are also being implemented on AutoCAD. Bluebeam will be used for our clients to give us feedback on our AutoCAD drawings so it is easier to comment 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 and design.

4. Design

4.2. Design Exploration

4.2.1 Design Decisions

In designing our solar farm and substation in Deming, New Mexico, we've had to make several critical decisions to ensure the project's success. Here are three of the most important:

- Location Choice (Deming, New Mexico)

We started by comparing two proposed locations—Iowa and New Mexico—and ultimately chose Deming, New Mexico. It offers some of the best solar potential in the U.S., with high sunlight exposure and few cloudy days. The solar irradiance levels in Deming range from 5.75 to over 6.50 kWh/m^2 daily, making it one of the most promising areas for solar energy production. With more sunny days and a climate well-suited to solar, Deming provides both higher energy production and a better return on investment.

Additionally, land costs are low at $6,000 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.

- Proximity to High-Voltage Transmission Lines

One major advantage of the Deming site is its closeness to existing high-voltage transmission lines, which minimizes the infrastructure we'd need to connect to the grid. These connections make it easier to transport energy to nearby cities like Albuquerque and Santa Fe, lowering both transmission costs and logistical challenges. With quick access to major routes like I-10 and U.S. Route 180, getting materials and deploying the workforce is also simpler and more efficient.

- Site Layout and Room for Expansion

We're designing the layout to include space for the solar farm and a substation, along with room for future expansions. This flexibility is key for adapting to future demand. By planning for growth now, we ensure that the project can expand without significant restructuring later on. Deming's climate also brings a relatively low risk of hail, so with the right layout, we can improve the plant's durability and long-term reliability while keeping maintenance costs manageable.

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.

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 PROPOSED DESIGN

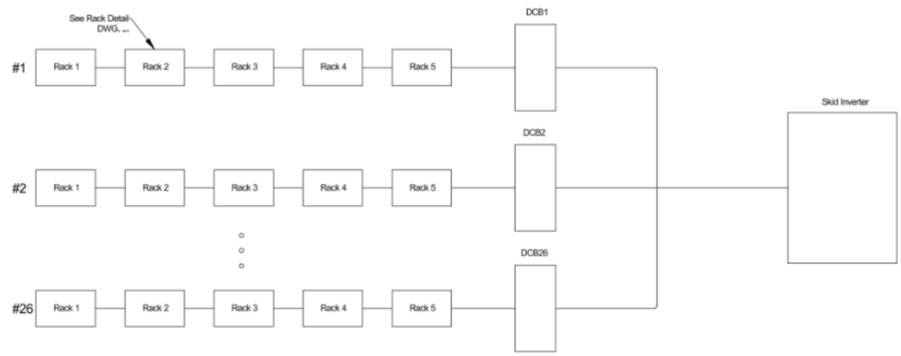
4.3.1 Overview

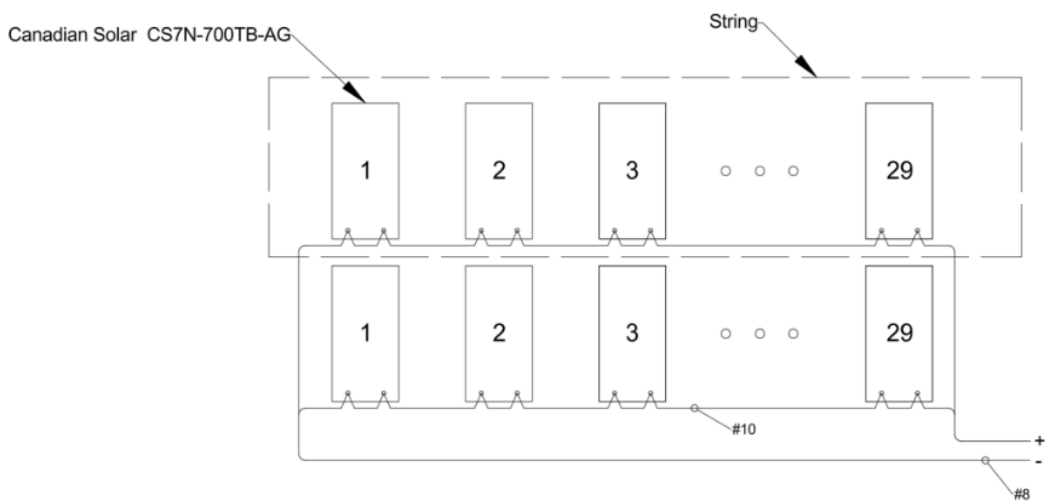
We are beginning our project by designing a solar array. This has many key components making it up. Starting at the lowest level you have a photovoltaic (PV) module. This is what makes up a solar panel. Solar panels can be connected in series or parallel to make a string. In our design we connected two strings to create a rack of panels. The rack is designed to have a certain voltage and current rating that relates to the DC combiner box. The DC combiner box takes multiple rack outputs and combines them into a single output. The array is designed to output a certain amount of power, in our case 60 MW. To reach this power requirement we have several arrays and therefor a large number of combiner boxes. The outputs of the combiner boxes are brought to a central inverter where the DC current and voltage is converted to AC. They are also combined into a single AC output. In our design we have 15 inverters, these 15 inverter outputs are brought together inside the substation.

Once the solar array design is completed, we will move into the substation design. We will be doing research on design philosophies for the substation. We know that we will be using circuit breakers, buses, switches, and transformers inside our substation. The main purpose is to step up the 34.5kV voltage to 115kV while also having protection elements for the rest of the power grid. To protect the rest of the grid we will have relays watching the currents flowing through the substation. If there is an overcurrent or current flowing in the wrong direction the circuit breakers will open to prevent problems in the rest of the grid.

4.3.2 Detailed Design and Visual(s)

There are a large number of calculations that go into designing a solar array. Black & Veatch has provided us with an array parameter tool to aid with the calculations. We start by selecting a solar panel and using its data sheet to extract key values we need for our design. We will use the open circuit voltage, and short circuit current to design our array. Based on the ratings of our combiner box we will design our rack to correspond to that. Our combiner box is rated for 1500V and 320A. We will design our string to have 1500V which takes 29 modules to achieve. Using the short circuit current we find that we can connect 11 strings to each combiner box (max current divided by short circuit current). Then we use the ratings of the inverter we selected we can find the number of racks we need in each array. Due to losses inside the inverter, we want the DC power the be 30% higher than the AC output we want. We achieve this by adding more racks into the array. In our design the inverter is rated for 4095 kW and our DC power per array is 5274 kW. To reach the 60 MW we want we will have 15 arrays and inverters in our total design.





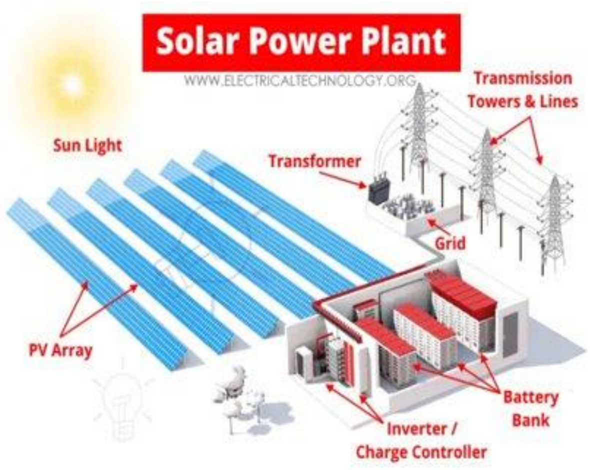
These two drawings give an idea into how the solar farm is laid out. It shows how the racks connect to the combiner box and then the combiners boxes go into the inverter. In the more detailed drawing, you can see how the panels are individually connected to make a string. You can also see the size of cable we will be using and the number of panels.

The cable sizing comes from the voltage drop calculations we will be performing. This will affect the placement of all the components in our array and it will help us decide what cable sizes we will be using to connect everything. We have another tool from Black & Veatch to do this. We input various parameters of our array like the number of racks per combiner box, and distances between components. Based on the voltage, current, and length we will be able to calculate the voltage drop through the cables. 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.

4.3.3 Functionality

Our design of the 115/34.5 kV Solar Plant and Substation in Luna County, New Mexico, 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, Black & Veatch clients, and local residents benefit from the system without directly managing it. 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. These inverters automatically adjust to changing sunlight conditions to keep power output stable and efficient.

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. The

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.

4.3.4 Areas of Concern and Development

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 Google Sheets, 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 Google Sheets, 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 Google Sheet, 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.

4.5 Design Analysis

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 Google Sheet tool 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.

5. Testing

5.1. Unit Testing

Testing of our designs will be conducted using ETAP. ETAP is a power flow software and we will use it to simulate and analyze power flow through our designed solar farm and substation. The main units we will pay attention to in our simulation are Volts, Current, Megawatts, and Megavars. We will be able to compare the results of our simulation to the expected result from our calculations to ensure the design works as intended. If there is a discrepancy between the results then we will know we have an error in our design and will need to fix it.

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

System testing will involve one large simulation of our completed design including both the solar farm and substation. This will give a large overview of our design and all the data we need to analyze. We can confirm that all calculations from the project are correct and everything works together as intended. The total system test should reflect our previous tests and show everything is working properly with the same values tested as before.

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 Results

The calculations we have done so far are correct and everything is working as intended. We have not done any simulation yet for our project but we are anticipating it will show our design works properly. Our calculations have been reviewed by our client and we have received feedback ensuring everything makes sense. Some examples of these calculations being correct include the power output of the array, and the voltage drop percentage within the farm. An industry standard is that the DC power going into the inverter is 1.3 times the desired AC output. This is something we have included in our project. The NEC (National Electric Code) says there should be no more than a 5% voltage drop and we have achieved a number lower than this.

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.

7. Ethics and Professional Responsibility

7.1 AREAS OF PROFESSIONAL RESPONSIBILITY/CODES 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 hold realizable value.	"Act for each employer or client as faithful agents or trustees."	Our team has sourced material and compared multiple options, ensuring optimal cost-effectiveness 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.

[Table 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 follows 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	Our approach focuses on maintaining the existing landscape	Respects the local community including aesthetics and	Aims to distribute the benefits of renewable energy fairly

	renewable resources.	ensuring and ensuring minimal impact on farming in the area.	any farming operations.	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.

[Table 7.2.1: Area of Responsibility]

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.

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.

8.2 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/

9. Team

9.1 TEAM MEMBERS

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

9.2 REQUIRED SKILL SETS FOR YOUR 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.

9.3 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.

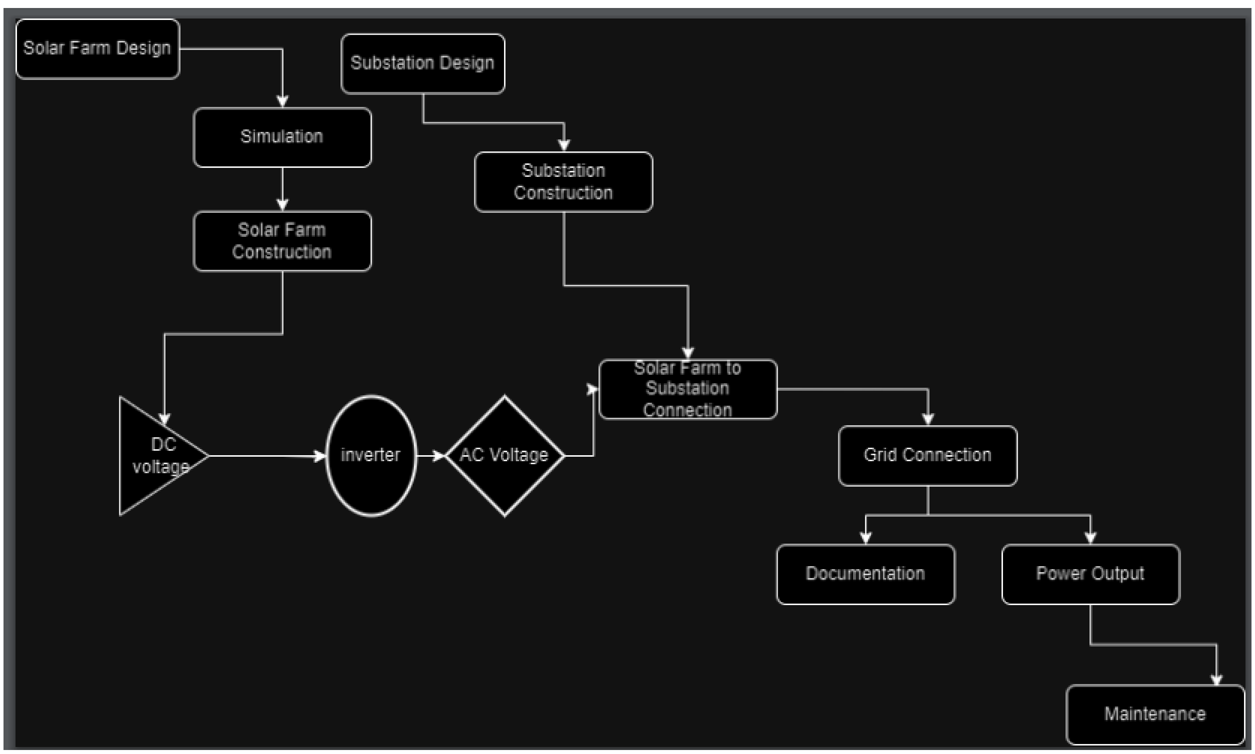
- Communicates with the client and advisor, ensuring alignment with project goals and expectations.

- **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.

9.4 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.



9.5 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

9.6 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