115/34.5kV Solar Power Plant & Substation Design Project

DESIGN DOCUMENT

Team Number: 18
Client: Black & Veatch
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Executive Summary

Development Standards & Practices Used

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

Summary of Requirements

List all requirements as bullet points in brief.

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

Applicable Courses from Iowa State University Curriculum

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

EE322 Semiconductor Devices

EE303 Power System

EE455 Distribution System

EE456 Power System 1

EE457 Power System 2

New Skills/Knowledge acquired that was not taught in courses

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

CAD – Computer-Aided-Design

ETAP – Electrical Transient Analysis Program

Solar and Substation Design

Table of Contents

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

1 Team

1.1 Team members

1.1.1 Baylor Clark

1.1.2 Eduardo Jimenez-Tzompaxtle

1.1.3 Eli Schaffer

1.1.4 Liam Gossman

1.1.5 Chicheng Tang

1.1.6 Siti Mohd Radzi

1.2 Required Skill Sets for Your Project

Technical Wise

CAD - Solar layout drawings

IEEE-80 - Grounding analysis and ground-grid calculations

Excel - Equipment sizing calculations, additional calculations (DC battery bank, lightning protection, etc), solar panel string sizing design. Grounding analysis and ground-grid calculations

ETAP/SKM/ASPEN- Solar Substation Simulation, Load flow scenario, Protection Element Analysis,

ETAP (Electric Transient Analysis Program) - Simulation software

Bluebeam - Electrical Layout drawings

1.3 Skill Sets covered by the Team

Everyone- Grounding and ground-grid circuit calculations/analysis

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

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

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

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

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

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

1.4 Project Management Style Adopted by the team

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

1.5 Initial Project Management Roles

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

2 Introduction

2.1 Problem Statement

Our team is attempting to design and simulate a 60 MW solar farm as well as the substation that connects it to the grid. We will design the solar farm during the first semester and the substation during the second semester.

2.2 Requirements and constraints

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

- Equipment sizing calculations (breakers, transformers, etc) using Excel files

- Solar layout drawings provided with Bluebeam/CAD/PDF editor
- Solar panel string sizing design done with Excel files
- Electrical layout drawings (substation equipment) printed using Bluebeam/CAD/PDF editor
- Grounding analysis and ground-grid developed with IEEE-80 also can be conducted using Excel files
- Bus calculations for substation design with Excel files
- Additional calculations of DC battery bank and lightning protection calculated using Excel files
- Creation of solar/substation design-optimizing tool can be done with ACAD/ETAP/new program
- Simulation of designed substation connection with a simulation software known as ETAP using the student license
- Coordination Study, AC Arc Flash Study, and Protection Element Analysis also using ETAP
- Load Flow Scenario Wizard and Configuration Manager done using ACAD/ETAP.

2.3 Engineering standards

Solar Power Plant Design Standards

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

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

Substation Standards

NEC 2020- (National Electrical Code)

2.4 Intended users and uses

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

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

3 Project Plan

3.1 Task Decomposition

To effectively address the prevailing issue, it is crucial to break it down into manageable tasks and subtasks while appreciating the intricate web of interdependencies among these tasks. This approach remains invaluable, even if you've embraced agile methodology, as it paves the way for a more structured and coherent problem-solving process. Notably, within the realm of agility, you can seamlessly overlay a linear progression of task completion in harmony with your project's sprint cycles.

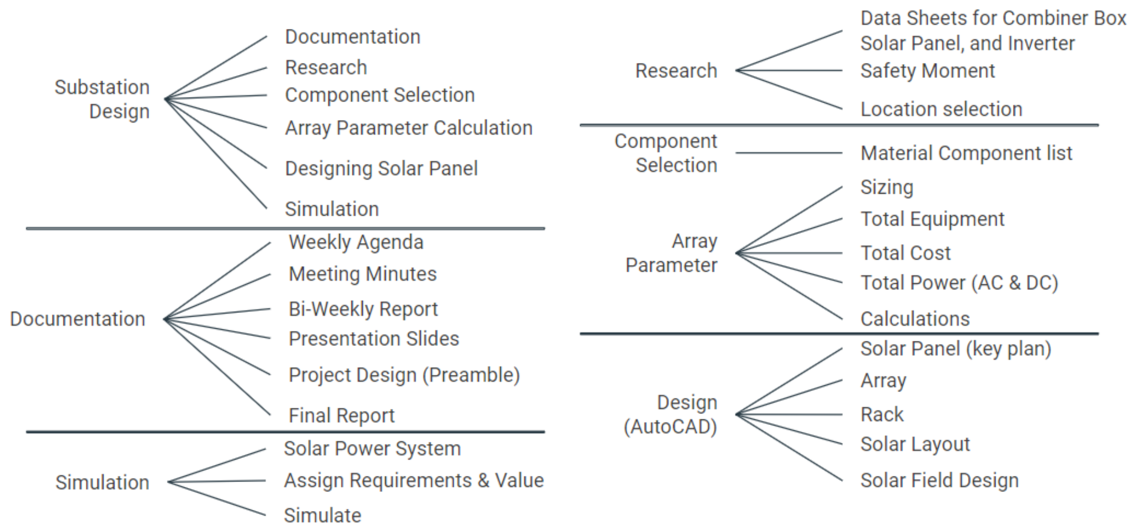
At its core, this section should encompass three key elements to elucidate the problem-solving framework:

1. **Task Dependence Graph:** Begin by constructing a task dependence graph, illustrating the sequential and parallel relationships between tasks. This visual representation will elucidate how each task influences and relies on others, fostering a holistic comprehension of the project's workflow.

2. **Task Descriptions:** For each task identified in the graph, furnish comprehensive descriptions. These descriptions should delve into the specifics of what each task entails, why it's vital to the overall project, and its place within the broader context of your objectives. Be sure to detail any particular skills, resources, or expertise required to execute the task effectively.

3. **Justification of Task Selection:** Rationalize the selection of these tasks with respect to your project's requirements. Elaborate on why these tasks are integral to achieving your objectives and how they collectively contribute to resolving the issue at hand. This justification should underscore the critical role of each task in the project's success.

Furthermore, consider the inclusion of sub-tasks, which can provide an additional layer of granularity to your task breakdown. Sub-tasks allow for a more nuanced understanding of the steps necessary to complete primary tasks and can assist in resource allocation and time management. In sum, this meticulous deconstruction of the problem into tasks and subtasks, coupled with an awareness of task interdependencies, enhances your problem-solving methodology and promotes clarity and transparency in project planning and execution. It is a robust foundation for effective project management, whether within an agile framework or other methodologies.



3.2 Project Management/Tracking Procedures

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

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

Our Gantt chart for tracking tasks and the design process loosely follows this waterfall style of design. The Gantt chart the group has created details the different phases of design and what is involved in each phase. Furthermore, a timeline outlines when different phases should be completed and deadlines are coming up in the future.

Additionally, the group will use GitHub to help keep track of design phases and assign tasks to each team member. The agile methodology involves frequent check-ins with group members and early detection of obstacles. This method of group collaboration allows for the most fluent progression through the phases of our senior design project.

3.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

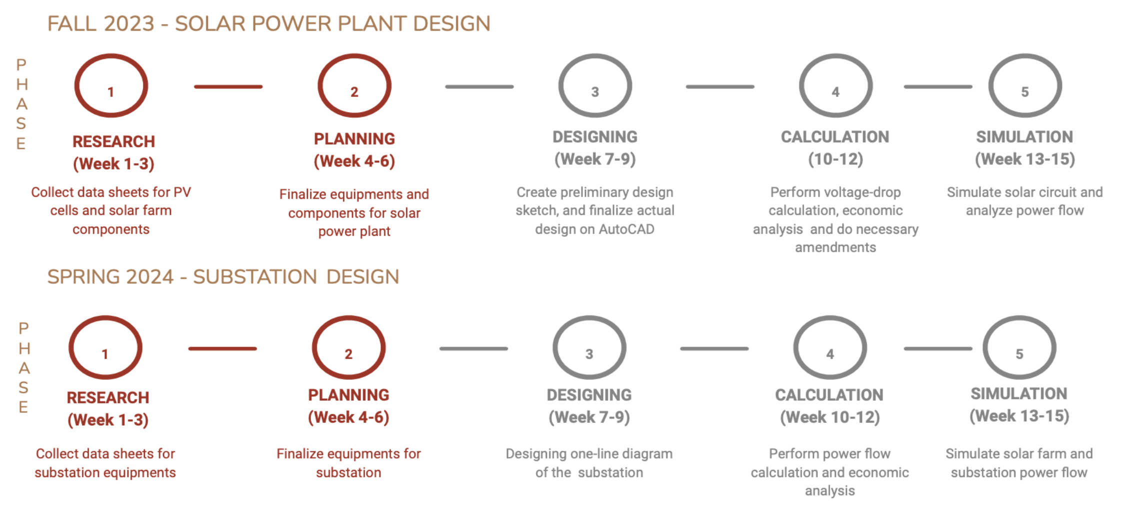
- Research Equipment
    - Collect 3 data sheets for PV panels, combiner boxes, and solar inverters
    - Research necessary components and present our understanding of them

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

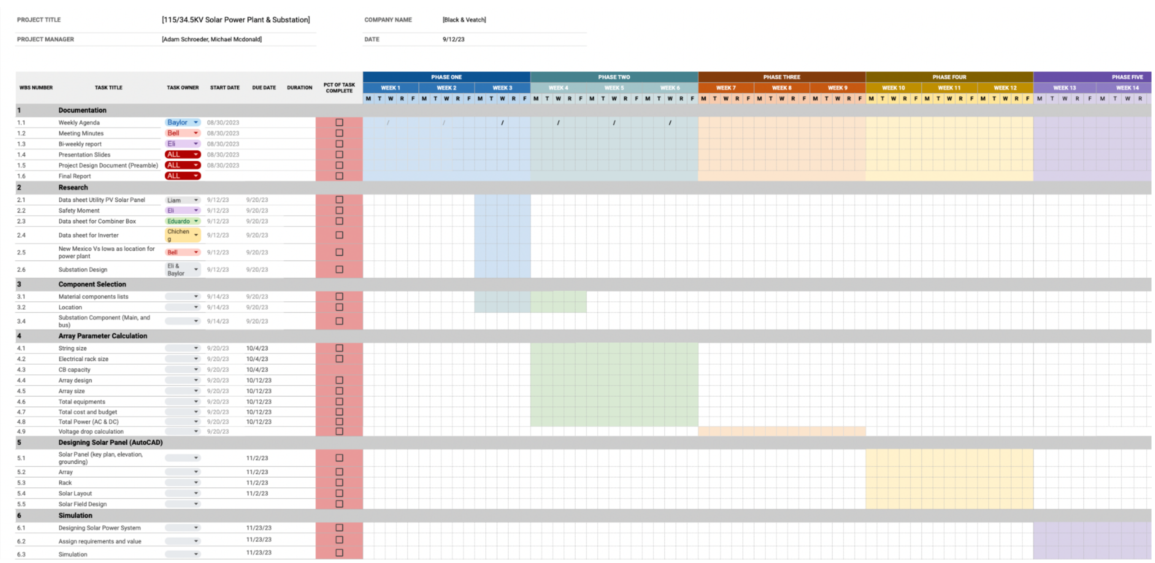
3.4 Project Timeline/Schedule

A realistic, well-planned schedule is an essential component of every well-planned project. Most scheduling errors occur due to either not properly identifying the necessary activities (tasks and/or subtasks) or not properly estimating the amount of effort required to correctly complete the activity. A detailed schedule is needed for the plan: Start with a Gantt chart showing the tasks (that you developed in 2.2) and associated subtasks versus the proposed project calendar. The Gantt chart shall be referenced and summarized in the text. Annotate the Gantt chart with when each project deliverable will be delivered. Project schedule/Gantt chart can be adapted to an Agile or Waterfall development model. For agile, a sprint schedule with specific technical milestones/requirements/targets will work.

Project Timeline/Schedule

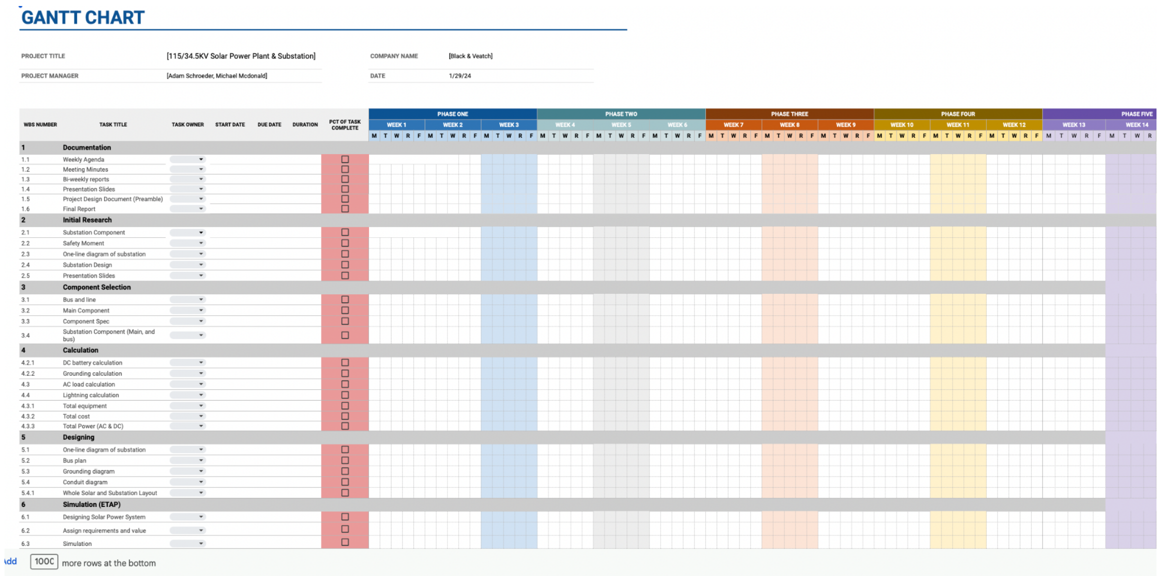


[Figure 3.4.1: Project Timeline]



WBS NUMBER	TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION	PCT OF TASK COMPLETE
1	**Documentation**					
1.1	Weekly Agenda	Baylor	08/30/2023			☐
1.2	Meeting Minutes	Bell	08/30/2023			☐
1.3	Bi-weekly report	Eli	08/30/2023			☐
1.4	Presentation Slides	ALL	08/30/2023			☐
1.5	Project Design Document (Preamble)	ALL	08/30/2023			☐
1.6	Final Report	ALL				☐
2	**Research**					
2.1	Data sheet Utility PV Solar Panel	Liam	9/12/23	9/20/23		☐
2.2	Safety Moment	Eli	9/12/23	9/20/23		☐
2.3	Data sheet for Combiner Box	Eduardo	9/12/23	9/20/23		☐
2.4	Data sheet for Inverter	Chicheng	9/12/23	9/20/23		☐
2.5	New Mexico Vs Iowa as location for power plant	Bell	9/12/23	9/20/23		☐
2.6	Substation Design	Eli & Baylor	9/12/23	9/20/23		☐
3	**Component Selection**					
3.1	Material components lists		9/14/23	9/20/23		☐
3.2	Location		9/14/23	9/20/23		☐
3.4	Substation Component (Main, and bus)		9/14/23	9/20/23		☐
4	**Array Parameter Calculation**					
4.1	String size		9/20/23	10/4/23		☐
4.2	Electrical rack size		9/20/23	10/4/23		☐
4.3	CB capacity		9/20/23	10/4/23		
4.4	Array design		9/20/23	10/12/23		☐
4.5	Array size		9/20/23	10/12/23		☐
4.6	Total equipments		9/20/23	10/12/23		☐
4.7	Total cost and budget		9/20/23	10/12/23		☐
4.8	Total Power (AC & DC)		9/20/23	10/12/23		☐
4.9	Voltage drop calculation		9/20/23			☐
5	**Designing Solar Panel (AutoCAD)**					
5.1	Solar Panel (key plan, elevation, grounding)			11/2/23		☐
5.2	Array			11/2/23		☐
5.3	Rack			11/2/23		☐
5.4	Solar Layout			11/2/23		☐
5.5	Solar Field Design					☐
6	**Simulation**					
6.1	Designing Solar Power System			11/23/23		☐
6.2	Assign requirements and value			11/23/23		☐
6.3	Simulation			11/23/23		☐

[Figure 3.4.2: Gantt Chart for Solar Power Plant Design for Fall 2023]



GANTT CHART

PROJECT TITLE	[115/34.5KV Solar Power Plant & Substation]	COMPANY NAME	[Black & Veatch]
PROJECT MANAGER	[Adam Schroeder, Michael Mcdonald]	DATE	1/29/24

PHASE ONE (WEEK 1, WEEK 2, WEEK 3) · PHASE TWO (WEEK 4, WEEK 5, WEEK 6) · PHASE THREE (WEEK 7, WEEK 8, WEEK 9) · PHASE FOUR (WEEK 10, WEEK 11, WEEK 12) · PHASE FIVE (WEEK 13, WEEK 14)

WBS NUMBER	TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION	PCT OF TASK COMPLETE
1	**Documentation**					
1.1	Weekly Agenda					☐
1.2	Meeting Minutes					☐
1.3	Bi-weekly reports					☐
1.4	Presentation Slides					☐
1.5	Project Design Document (Preamble)					☐
1.6	Final Report					☐
2	**Initial Research**					
2.1	Substation Component					☐
2.2	Safety Moment					☐
2.3	One-line diagram of substation					☐
2.4	Substation Design					☐
2.5	Presentation Slides					☐
3	**Component Selection**					
3.1	Bus and line					☐
3.2	Main Component					☐
3.3	Component Spec					☐
3.4	Substation Component (Main, and bus)					☐
4	**Calculation**					
4.2.1	DC battery calculation					☐
4.2.2	Grounding calculation					☐
4.3	AC load calculation					☐
4.4	Lightning calculation					☐
4.3.1	Total equipment					☐
4.3.2	Total cost					☐
4.3.3	Total Power (AC & DC)					☐
5	**Designing**					
5.1	One-line diagram of substation					☐
5.2	Bus plan					☐
5.3	Grounding diagram					☐
5.4	Conduit diagram					☐
5.4.1	Whole Solar and Substation Layout					☐
6	**Simulation (ETAP)**					
6.1	Designing Solar Power System					☐
6.2	Assign requirements and value					☐
6.3	Simulation					☐

Add 1000 more rows at the bottom

[Figure 3.4.3: Gantt Chart for Substation Design for Spring 2024]

3.5 Risks and Risk Management/Mitigation

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

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

3.6 Personnel Effort Requirements

Task	People	Expected Person-Hours
Solar Power System Sim	Eli	10
Requirements and Values	Baylor	5
Simulation	ALL	20
Data Sheets for Equipment	ALL	10
Safety Moment	ALL	3
Location Selection	Bell	6
Material Component List	Liam	3
Sizing	Chicheng	4
Total Equipment	Eduardo	6
Total Cost	Eli	10
Total Power (AC & DC)	Liam	6
Calculations	Bell/Chicheng	7
Solar Panel Plan	Eduardo	5
Array	Baylor	8
Rack	Eli/Baylor	3
Solar Layout	Liam/Chicheng	5
Solar Field Design	Bell/Eduardo	15

[Figure 3.6.1: Personnel Requirements]

3.7 Other Resource Requirements

Software (ETAP, AutoCAD, BlueBeam)

4 Design

4.1 Design Content

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

4.2 Design Complexity

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

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

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

4.3 Modern Engineering Tools

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

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

Bluebeam Revu: Sheet viewing software, markups from Industry professionals

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

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

4.4 Design Context

In any engineering design endeavor, a pivotal factor to bear in mind is the profound understanding of the design's contextual framework. This comprehension is vital for accurately pinpointing the target audience and purpose of the design. As engineers, it is our fundamental responsibility to encompass a holistic perspective, meticulously assessing the economic, environmental, and global ramifications that the design might invoke.

While crafting solutions tailored to address specific challenges is undoubtedly essential, its effectiveness reaches a critical juncture when considering the potential harm it may inflict upon the environment or adversely affect particular communities. A design, however innovative, falls short of its true potential if it inadvertently contributes to environmental degradation or disproportionately impacts a specific group of individuals. Thus, our design pursuits must align harmoniously with sustainability principles and social equity, ensuring that they not only serve their intended purpose but also foster positive contributions to our world.

Solar energy holds a significant and multifaceted position concerning the general public, its global ramifications, environmental effects, and economic implications. Solar energy and solar energy production affects any community that has an effect on.

1. Public Health:

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

2. Global Impact:

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

3. Environmental Impact:

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

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

4. Economical Impact:

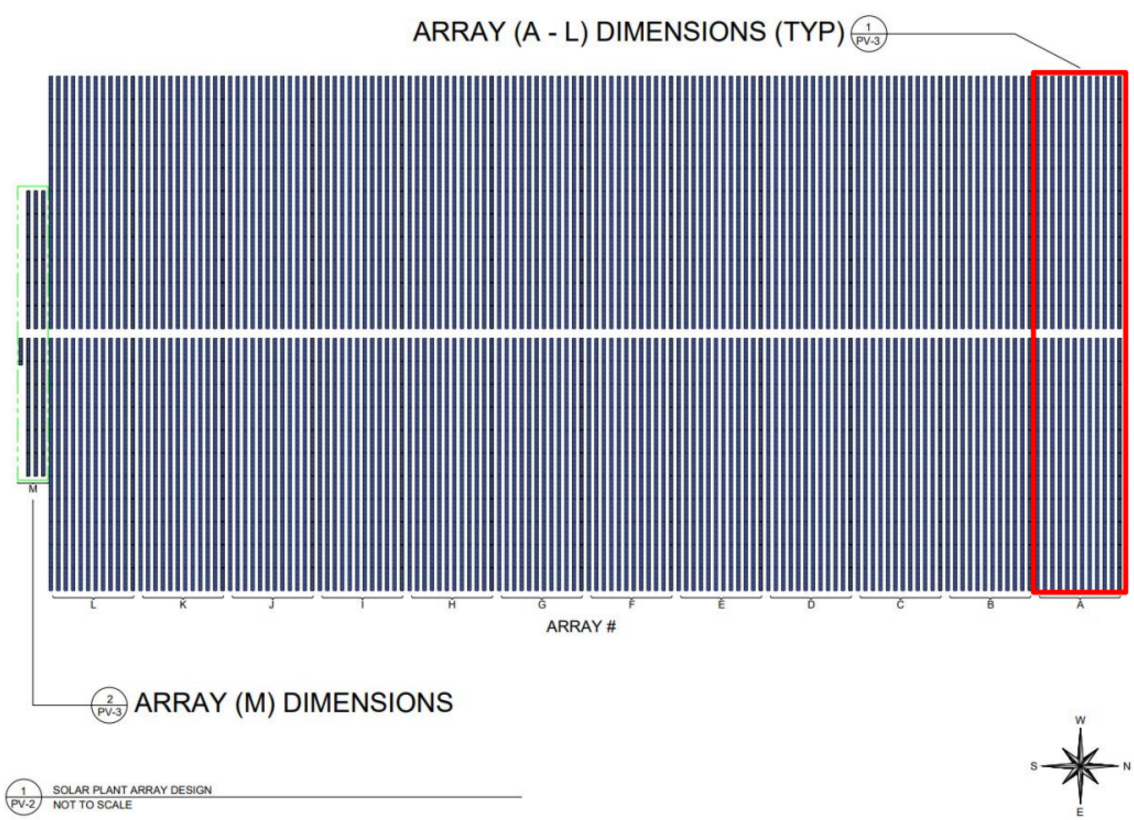
The transition to solar energy significantly increases the demand for jobs in various sectors. The construction phase of solar power plants and installations calls for a skilled workforce, including engineers, electricians, and laborers. Additionally, the operation and maintenance of these facilities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

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

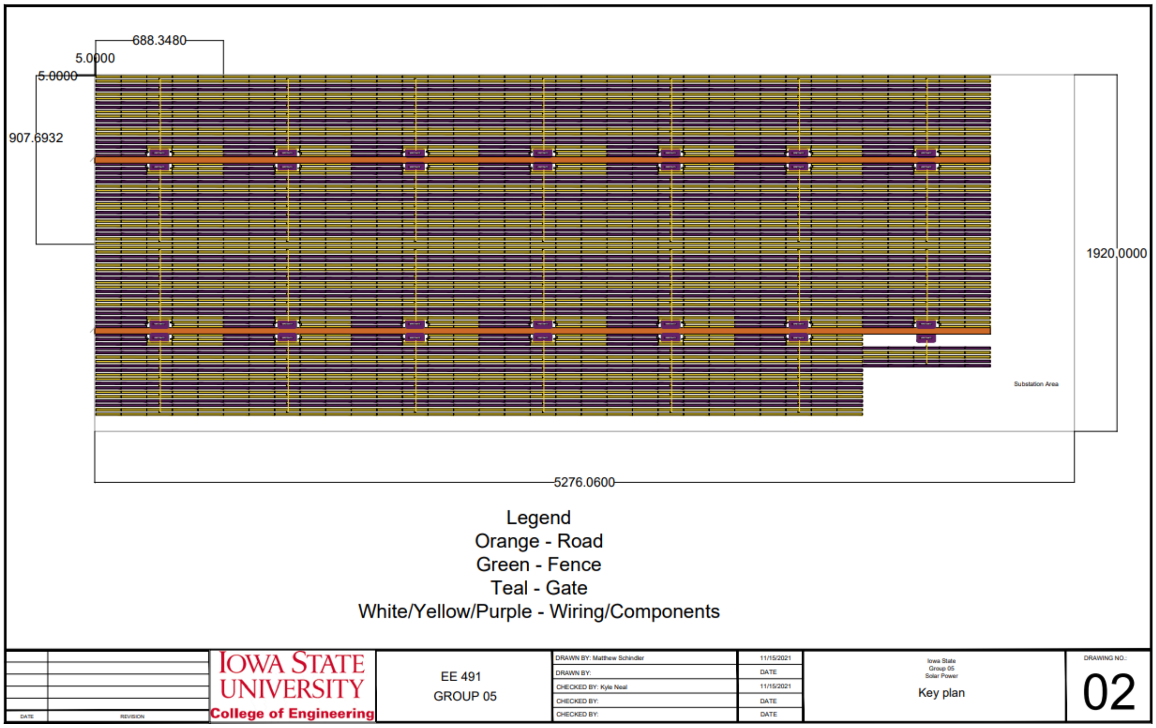
4.5 Prior Work/Solutions

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

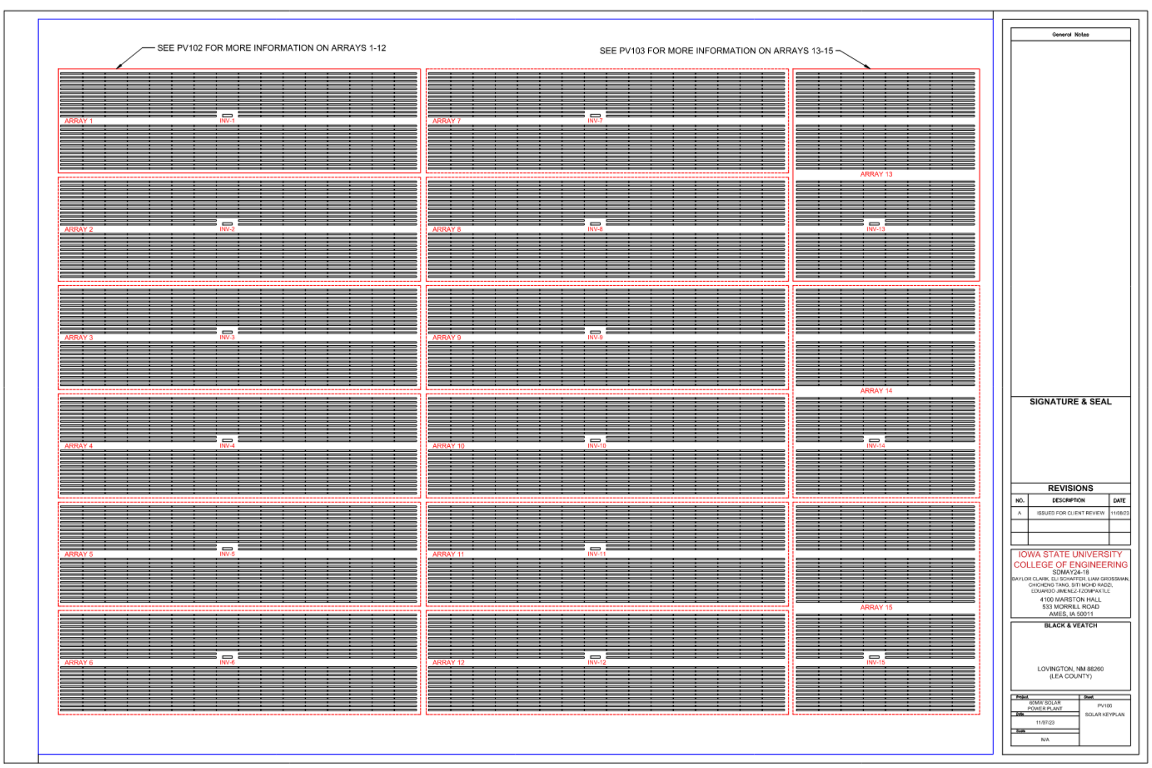
Some previous work that has been done for this company and senior design project can be viewed with these links, and we can compare some of their design choices with ours. Here are the links for the sdmay20-14 project, the sdmay21-37 project, the sdmay22-05 project, and the sdmay23-27 project. We can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



[Figure 4.5.1: sdmay23-27 Overall Array Layout]



[Figure 4.5.2: sdmay22-05 Overall Array Layout]



[Figure 4.5.2: sdmay24-18 Overall Array Layout]

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

[Figure 4.5.3: Pros and Cons For Our Design Choices]

We can see some topics as well as some pros and cons for those topics in figure 4.5.3. Some background that we needed for this project was the knowledge of solar panels and how they work. We also needed to understand how voltages and currents combine so we could rate the right equipment for the right purposes. There are many other solar farms and substation combos, but we can't use those designs because they belong to a company, and we don't have access to them. Our project differs from most solar farms because we will use one rack to one combiner box. We also will use a 4 MW skid inverter, which is uncommon in farms because of the size we need to achieve. There are many different options for designing a solar farm, which is why each design is unique.

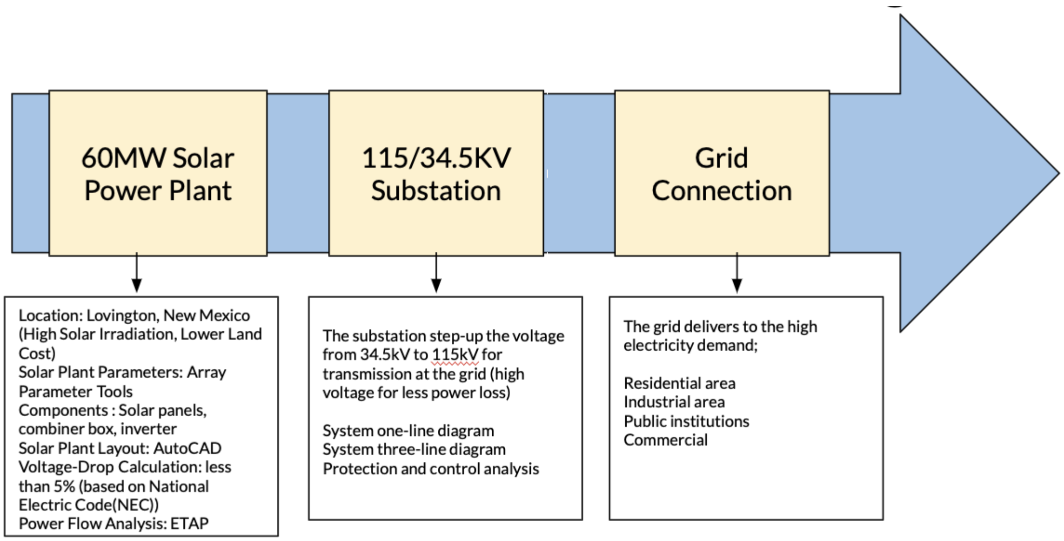
4.6 Design Decisions

The group has decided on some components and designs for the solar farm. The combiner box the group chose has the capacity of 1,500 V, 16 inputs, 1 output, and will cost about $1812 dollars. The skid has an inverter and a transformer in one system. The skid has a capacity of 1500 volts and can output 4600 kVA in AC. The solar panel changed from the original selection, but we decided to pick a panel with a capacity of 550 watts and an efficiency of 21.48%. The voltage for the panel is 41.1 volts with a short circuit current of 13.65 each. The cables connecting to the combiner box will be #10 AWG sizing. 400 MCM cable was also chosen for higher currents connecting the combiner box to the inverter.

The group also chose to have an input of 78 MW in DC to 60 MW AC since there will be a loss of power when converting from DC to AC. The connection of each component will be arranged in the order of a solar panel, combiner box, inverter, transformer, and to the grid/substation. The solar farm will consist of 15 array modules stacked in 2 columns with 6 rows for one set and 1 column with 3 rows for a different set due to constraints on the land the group has selected. The location for our project will be Lovington, New Mexico since it is a perfect candidate for producing power with a high level of sunlight and low amount of clouds throughout the year.

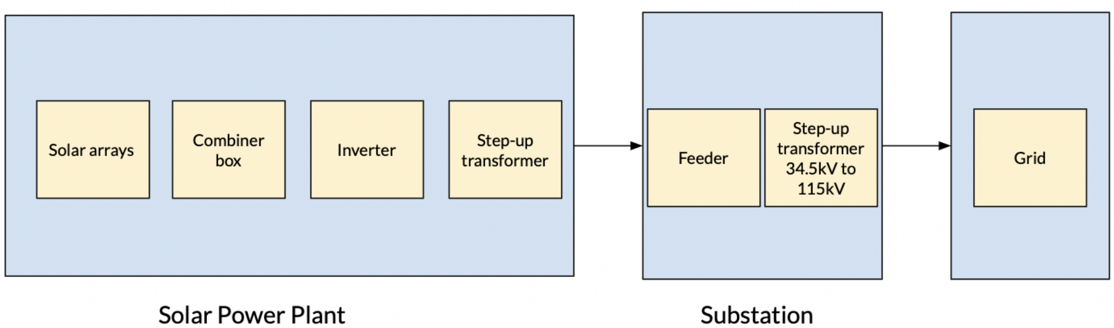
4.7 Proposed Design

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



[Figure 4.7: Solar Power Plant and Substation Design Process]

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



[Figure 4.7.1: Components of the design]

4.7.1 Design 0 (Initial Design)

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

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

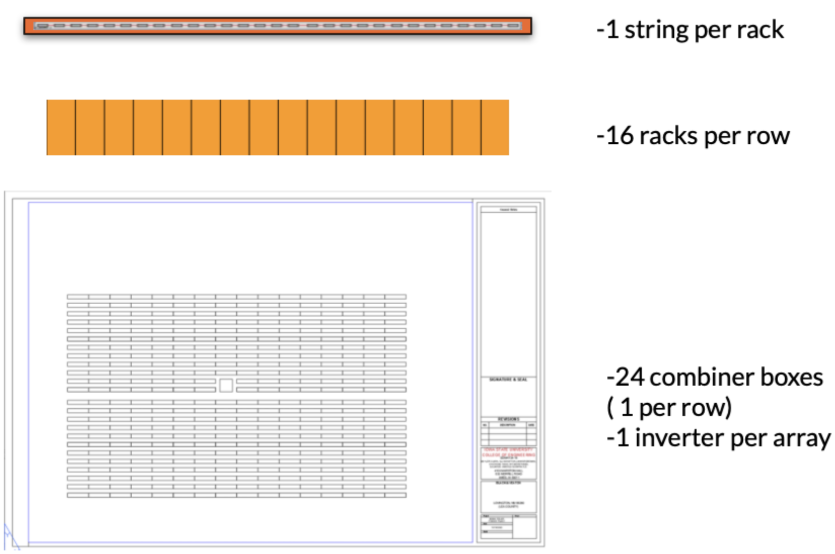
	Electrical Rack Size		
Designer Choice		portrait or Landscape	
Datasheet	Module width	3.72	ft
Datasheet	module height	7.474	ft
Designer Choice	Rack width	25	modules
Designer Choice	Rack height	1	modules
	Modules per rack		
	Rack width	93	ft
	Rack height	7.474	ft

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

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

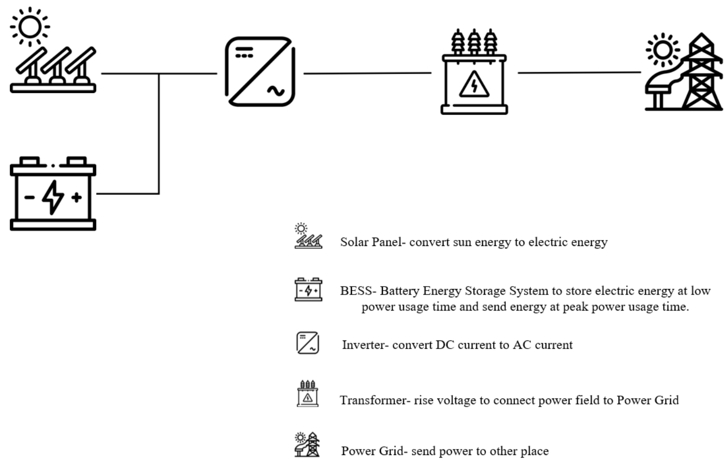
	Array Size		
Designer Choice	tilt	35	
	table height proj	6.122342	ft
Designer Choice	row space	10	ft
	pitch	16.12234	ft
	Space for Inverter Maintenance	35	ft
	Array height	386.9362	ft
	Array width	1488	ft
	Ground Coverage Ratio	0.463580	

[Figure 4.7.2: Array Parameter Tool]



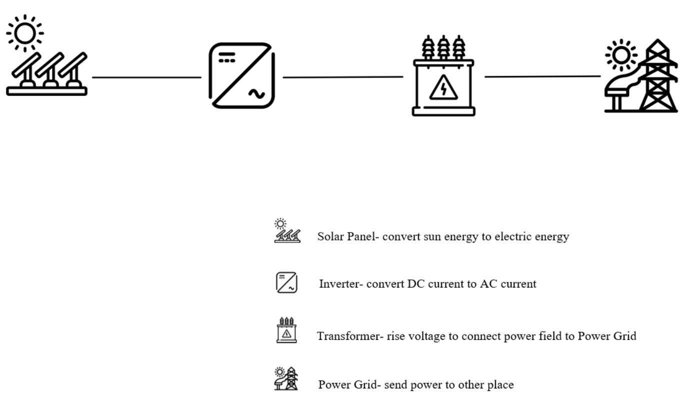
[Figure 4.72: Solar Rack Layout Design]

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



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

4.7.2 Design 1 (Design Iteration)



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

NOT NEEDED YET

4.8 Technology Considerations

Highlight the strengths, weakness, and trade-offs made in technology available.

Discuss possible solutions and design alternatives

4.9 Design Analysis

– Did your proposed design from 4.7 work? Why or why not?

The initial idea of having batteries for the solar array changed due to the cost of producing 2 hours of power. Mostly, everything has been kept the same for the general ideas on how to design the solar farm.

– What are your observations, thoughts, and ideas to modify or iterate further over the design?
I see that there is room for expandability in the future if more power is needed.

5 Testing

5.1 Unit Testing

For unit testing, the group will use software to confirm all the calculations of the design will be correct. The voltage, current, power, and safety systems, like circuit breakers, will be tested for each component. The group will use the eTap software to confirm the calculations. For the solar panels, combiner box, and cables, voltage and current will be measured, while the skid will be measured for voltage and power output.

5.2 Interface Testing

The design of our solar power plant and substation does not follow many of the same processes as software design and testing. The testing sections are harder to interpret in terms of our project. Our project is split up into two major phases of design. The solar power plant is being designed in the fall semester and the substation is going to be designed in the spring semester. Speaking in terms of our solar power plant design there are a couple "interfaces" that we are testing during design. One interface could be the wiring and design of the solar array itself. The second interface of the solar power system is the current inversion in the skid inverters and the feeders from the inverters to the substation.

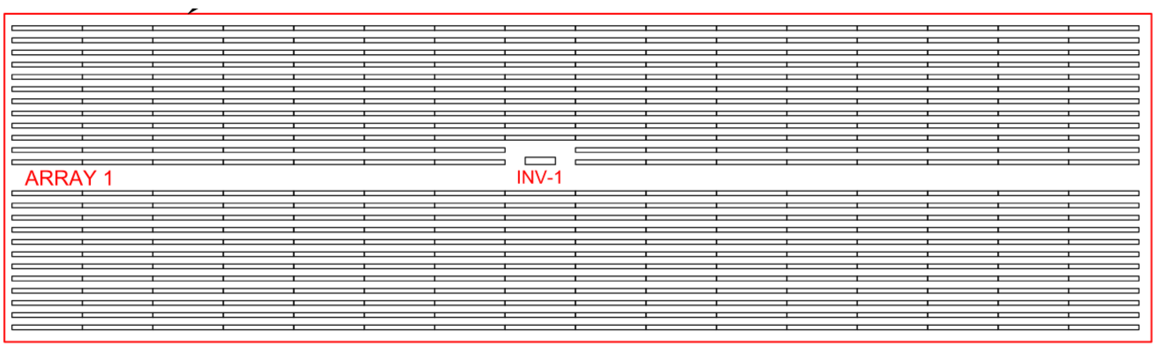
Calculations need to be made to determine voltage drop and power being delivered from the solar strings to the combiner box. Then the current and power being delivered to the inverter. After the current is inverted to AC. Voltage drop will need to be calculated from the feeder lengths between the substation and the inverters. There is very little the group can do to "test" the design of our solar power plant. However, the group does need to calculate voltage drop and voltage differences to ensure code compliance and maximum power usage of our system.

The tools we will be using will be calculation spreadsheets to find voltage drop and power flow. Furthermore, the group will be using eTap for power simulation to assure our calculations are correct. Ensuring calculations and simulations are important to ensure safety and maximum use of power available.

5.3 Integration Testing

Some important paths that we have in our project would be the paths from the solar panels to the inverters and the grid interconnection. We also have monitoring and control systems as well as safety and protection systems. For the path from the solar panels to the inverters, we have to test the efficiency of the panels, combiner boxes, and the inverters all under various conditions of input and other weather conditions. We also would test the durability of the panels if we were able to have a physical panel. For the grid interconnection, we plan on testing the power quality to see how well the substation would respond to a short circuit or some possible lightning strikes. We also will test the entire system for anti-islanding protection. Anti-islanding protection protects system elements from blackouts. We also will be testing our monitoring and control systems with data accuracy and communication reliability. Then we will test the safety and control systems with grounding calculations as well as adding some circuit breakers for voltage spike protection.

5.4 System Testing



[Figure 5.4.1: Single Array]

For the system testing, the group has decided to integrate all parts of the system into one large test. We will start with one array and then move to combining them. We start the system testing by calculating the voltage drop for each row, then we move onto combining the rows with each inverter. Once we have the full voltage drop for one array, we can then use those values to calculate the AC voltage drops from the inverters to the substation. After we have those units calculated out, we can start with the integration testing for the inverter efficiencies as well as the panel efficiencies for various weather conditions.

5.5 Regression Testing

In order to ensure that new features of our designs do not compromise previous ones, our team calculates new values to compare against the requirements of our project. Certain values of our project are set, such as the 60 MW output of the solar farm and operating voltages of the substation. Our team uses calculations from equipment specifications to ensure that the overall parameters of the project are met, as well as ensuring that each component fits within the acceptable operating range of every other component in the design. Values such as component voltage and current must combine to meet the overall requirements while also fitting within the requirements of each individual component. Any new components or layouts are tested via calculations to determine if they meet both of these requirements.

5.6 Acceptance Testing

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

5.7 Results

The results of the group testing will ensure that there will not be any additional work or redesign if someone wants to construct this solar array. The group cannot test physical components due to the size of the project, but ETAP will be used to compare the hand calculations of the voltage drops and currents of each component the group tests. One other result that we found from the system testing was the percentage of our voltage drops were in range with the NEC and what they expect from solar designs. We are happy that we were able to design something within specification on our first try.

ADD ADDITIONAL INFO NEXT SEMESTER WITH SUBSTATION RESULTS

6 Next Section