115kV / 34.5kV Solar Power Plant Substation Design

PROJECT PLAN

Team 26

Client: Black & Veatch

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TBD

Please include any definitions and/or acronyms the readers would like to know.

example: ASA: American Standards Association

1 Introductory Material

1.1 Project Scope

A steady increase in the use of renewable energy for larger scale power generation has been seen in recent years. Renewable energy standards have been improved, so Black & Veatch is sponsoring a senior design project for a 60 MW solar power plant with a 115 kV/34.5 kV substation. The design team will create designs for both the power plant and the substation, including layout designs, substation components and a man-hour budget. Deliverables include:

- Man-hour budget, schedule and cost estimates
- Solar plant layout drawings and conductor sizing
- AutoCAD drawings of schematics for plant and substation
- Component connections for plant and substation
- Substation single line diagram

In the first semester, the focus of the project will be the solar plant layout, sizing and budget. The substation one-line diagram will also be completed in the first semester. In the second semester, the substation design will be the priority and the final solar designs will be optimized in preparation for the final presentation.

1.2 Operating Environment

Our power plant will be located in either New Mexico, California or Arizona to maximise sunlight and power generated by the plant. The main concern with placing it in any of these states is the dusty conditions, which might cause an increase in maintenance to wipe excess dust off the panels. There have been a few other weather concerns but these have not been enough to have us choose another location.

1.3 Assumptions And Limitations

Assumptions

End product will be located in the United States of America. Locations in other parts of the world have different codes and standards from the ones we are working with in the design of our product.

Limitations

Total cost of solar plant and substation exceeds the budget. The total cost of the product at this moment is at $71,537,362.97. The design of the project will be reviewed as the project continues to reduce the cost.

1.4 Project Description

Solar Plant

The solar plant will be made up of about 117 acres of land. It will be made up of:

- 237,312 solar modules with a rating of 325W per module.
- 36 inverters with a rating of 1666 kW .
- 252 combiner boxes with a rating of 1500 V DC.

The total area of the plant will be approximately 244 acres. The deliverables related to this are:

- AutoCAD designs showing the layout of the panels and other components that will make up the solar plant. The importance of these drawing is that they show the wiring of things and positioning of components. Creating this schematic for our client helps us to perform power flow analysis on our plant and detect possible causes of concern . An estimated delivery date for the autocad drawing relating to the solar plant is October 20 2018.
- A detailed man-hour budget showing the amount of hours spent by the team each week as well as the charge for all hours spent in the first semester. This deliverable is also valid for the second semester.

Substation

The substation design will be made up of:

- The one-line diagram
- The key protection diagram
- The three-line diagram
- Protection and controls schematics

For the first semester, the main deliverable will be:

- A one-line diagram which is a simplified notation representing a three-phase power system. It will help us perform power flow studies and determine where electrical elements such as circuit breakers, transformers and conductors are located. The estimated delivery date for this has been set to November 29 2018.

2 Proposed Approach and Statement of Work

2.1 Objective of the Task

The end-product of the senior design project is to design a 60 MW solar power plant and a 115 kV/34.5 kV substation. To successfully conduct this project, a list of goals will need to be accomplished:

- Efficiently manage the scope of the project
- Provide documentation and justification for the design aspect of the project
- Follow the standards set by the NEC for all components of the project

2.2 Functional Requirements

For this project, we are required to have knowledge of power systems and solar plants, as this will be the basic information needed for our designs.Using this knowledge we will be able to utilize our functional requirements. These functional requirements for the project include:

- AutoCAD: All our design schematics will be created using this software
- Microsoft Word: Documents and simple diagrams will be drafted in this environment
- Microsoft PowerPoint: This software will be used for weekly presentations to the client/advisor
- Bentley View: This program allows us to view AutoCAD schematics of electrical systems that will be provided by the client
- Array Parameter Tool: A tool provided by the client to help us size the solar plant according to client specifications
- Google Hangout: This will be used to have weekly video conferences with the client

2.3 Constraints Considerations

Seeing that the students on the team have limited exposure to substation design, many things that they will encounter during the course of the project will be foreign to them. The adverse effects of the learning curve will be seen when students use AutoCAD as many of them have no prior knowledge of the program.

All the schematics will be in compliance with the National Electrical Code (NEC) and the Institute of Electrical and Electronics Engineers Power, Switchgear, Substations & Relays Standards Collection.

2.4 Previous Work And Literature

There are several existing project that are similar to our project, like miso solar project in Minnesota

- proper environment for our project
- 100 MW of solar pv capacity (440,000 modules)
- About 800 acres of agricultural land
- Single axis tracking to maximize production
- Grid connection at the Chicago substation 115kV

About the similar project we found in website, we saw that the past group who did this before have already done about structure designing and parameter computing. Although it is not completely same with our project, it still can be reference for us. Their group number is May1602. We found that element for every part in project or basic AutoCAD element in list. And we found that they did not make decision for location, because we think the location is important for solar energy.

2.5 Proposed Design

Through our researches from looking at the similar project that has been previously done, and following the new requirements of building the solar power plant and substation, we will be proposing the following design process:

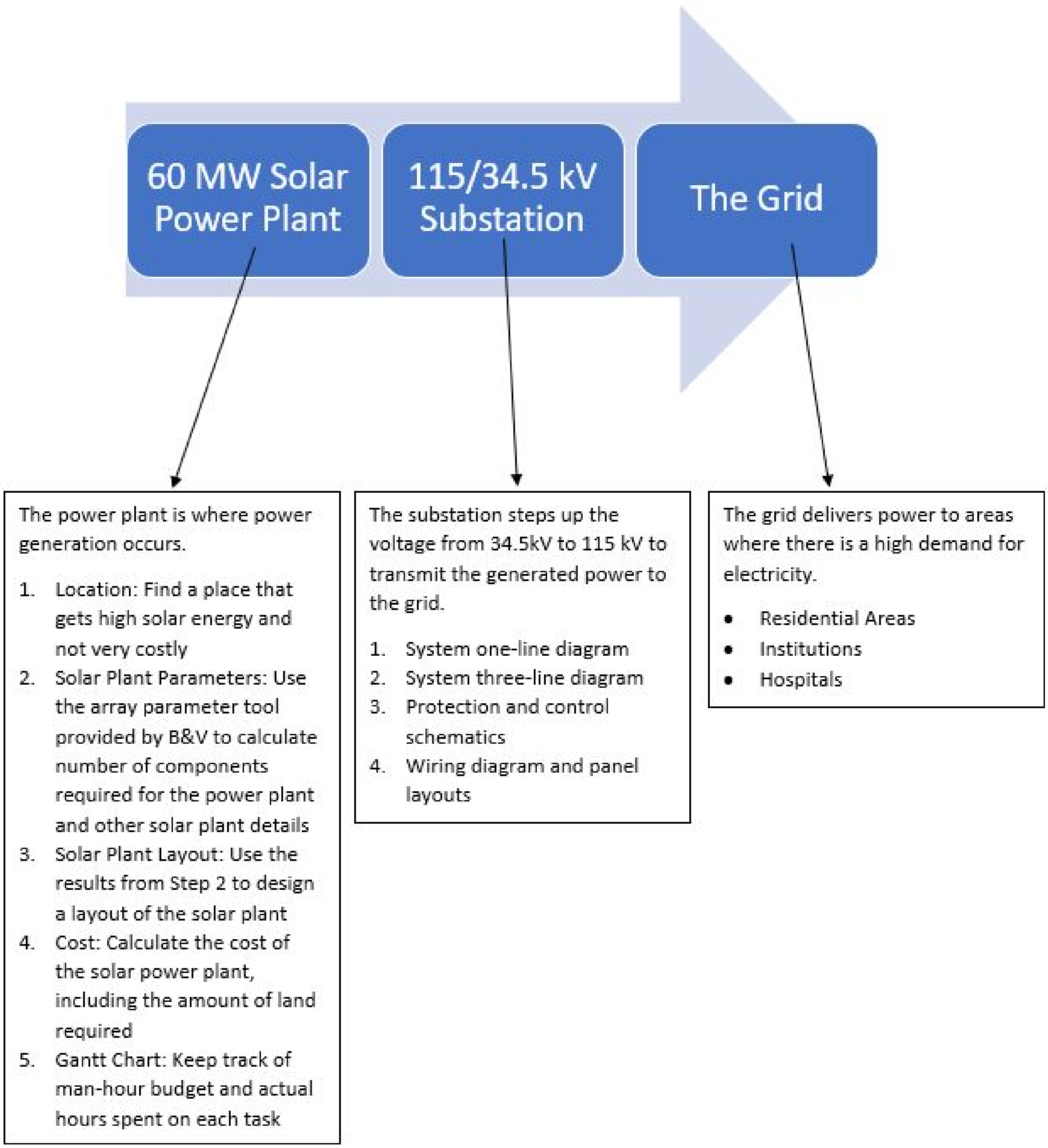

Figure A:: Solar Power Plant to Substation Design Connection

From that, we came out with a standard drawing of our solar power plant layout and we will be making changes based on the following design.

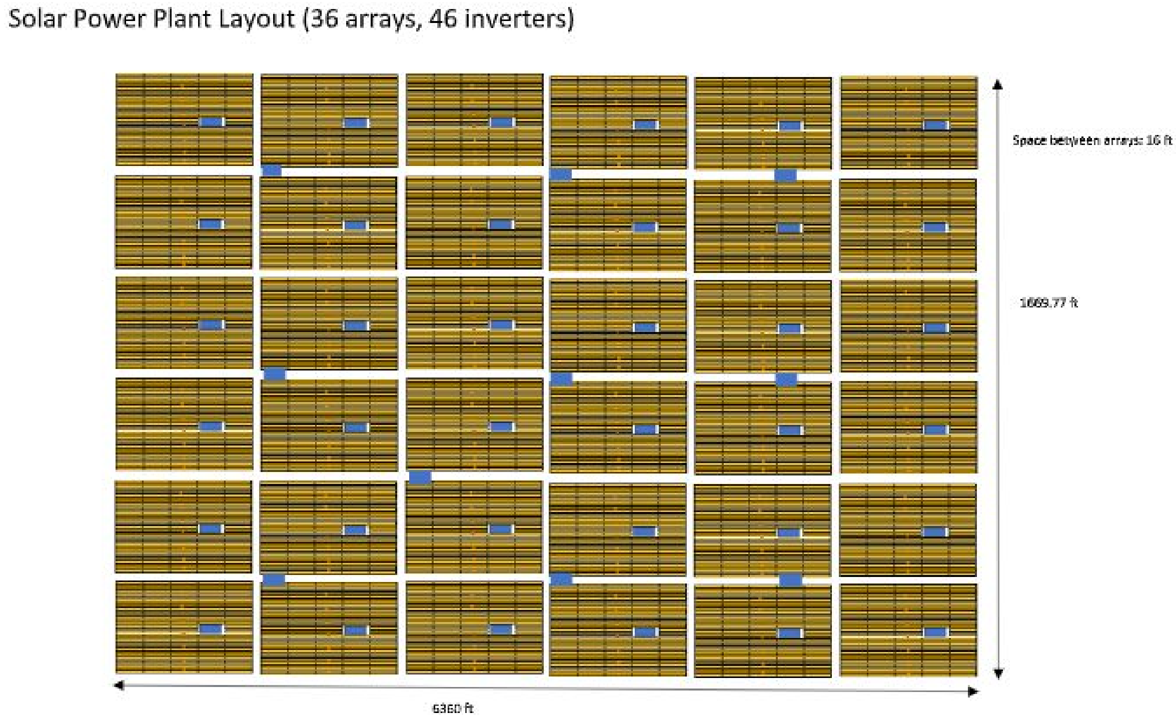

Figure 1: Solar Power Plant Overall Layout

Figure 1 above shown is the overall design draft of the solar power plant that we are going to build. It provides an AC output of 60MW after converting the current from DC to AC by running through the power inverters with inverter load ratio (ILR) of 1.3. Every big yellow boxes above indicate a solar array and we will be having 6x6 of 36 arrays and 46 power inverters for the whole design. Spacing between each array should be around 16ft, in accordance with NEC requirements and the total size of the solar power plant is about 1669.77 x 6360 ft, which is around 10,619,737ft^2 or 243.796 acres.

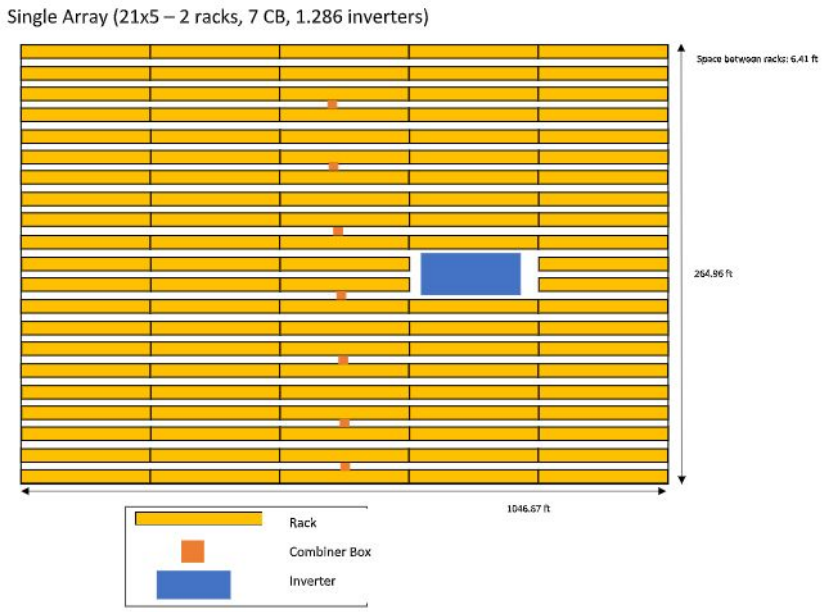

Figure 2: Solar Power Plant Single Array Layout

Figure 2 above shows the design of a single solar array. Each array contains about 103 racks of solar panels, 7 combiner boxes, and spacing between racks are about 6.41ft. The size of an array is 264.96 x 1046.67ft, which is about 277,325.7ft^2 or 6.37 acres.

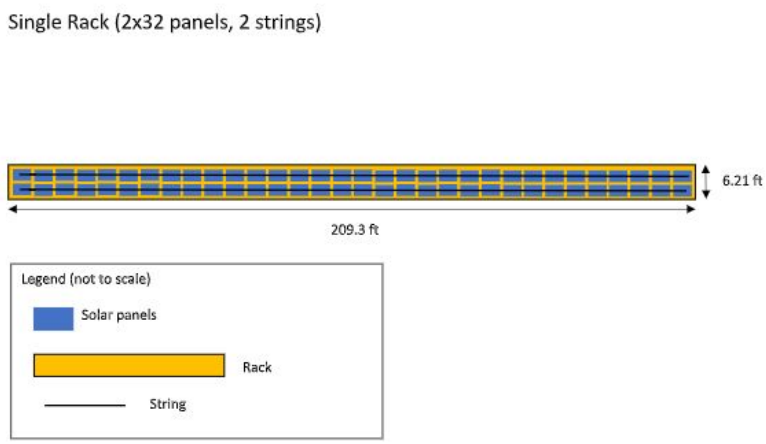

Figure 3: Solar Power Plant Single Rack Layout

Figure 3 shown is the design of a single rack of solar panels. It contains 64 solar panels in a rack with an arrangement of 2 rows and 32 columns. The dimension of a single rack is 6.21 x 209.3 ft, which is about 1299.75ft^2 or 0.0298acres.

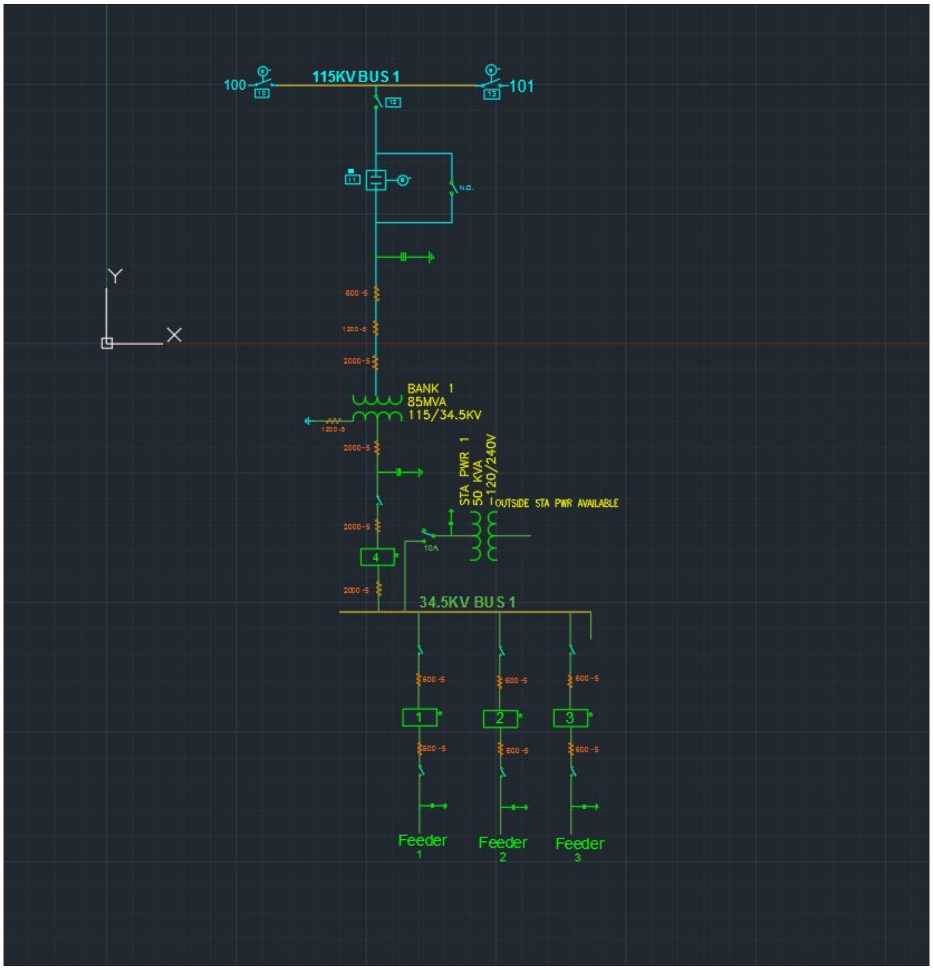

Figure 4: Single Line Diagram of 115/34.5kV Substation

Figure 4 shown is the design of 115/34.5kV substation generated from AutoCAD. It is a single line diagram that shows the components arrangement as well as their respective bus values.

2.6 Technology Considerations

The process of deciding the inverter load ratio (ILR), also known as the DC to AC ratio, that we want to use for our solar power plant design is a trade-off decision between total energy losses versus the design stability.

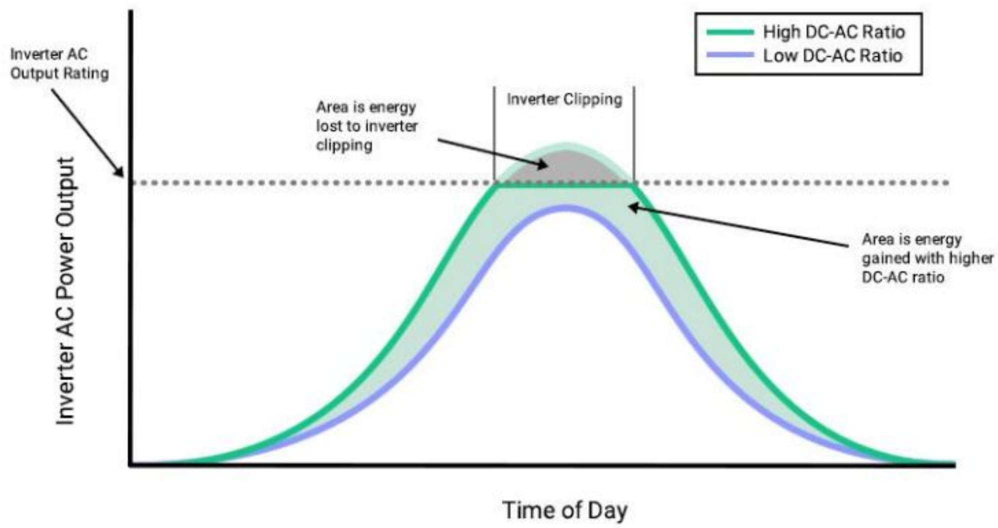

Figure 5: Graph of Energy Production or AC output vs Time of Day

Figure 5 shown is the graph that indicates the differences between solar power plant that has a lower ILR (or DC-AC ratio) versus power plant that has a higher ILR. A lower ILR has lower power losses because it utilizes most of the power generated by solar panels even under full standard condition while a higher ILR will cause more power losses due to clipping at the inverter AC output rating.

The reason that higher ILR is used is because it is rare that solar power plants work under full standard conditions. With a higher ILR, the solar power plant will provide a more stable and consistent AC power output even when it is not under full standard conditions. Since we are more in favor of designing a solar power plant with a much stable output, we set it to a slightly higher ILR (approximately 1.3) so that the power plant will generate about 60 MW of power under most conditions.

Another technological consideration that we will be taking in the process of designing the solar power plant is the types of solar panel that we should choose. Two common types of solar panels are monocrystalline and polycrystalline. A monocrystalline solar panel has a higher silicon purity and a higher efficiency level because it uses only the purest silicon material in the manufacturing process. On the other hand, a polycrystalline solar panel has a lower silicon purity and a lower efficiency level because it utilizes all silicon materials in the manufacturing process. Despite the fact that the monocrystalline solar panel provides a better efficiency level, it is a lot more expensive as compared to the polycrystalline solar panel (about 50% higher in price) while the efficiency level of polycrystalline solar panel is only about 1-3% lower than monocrystalline solar panel. Therefore, we have chosen polycrystalline solar panel in our design.

2.7 Safety Considerations

Danger of Electric Shock

Electric shock is the biggest safety concern when it comes to building power generator and substations, because we are dealing with high voltage and high power designs. The lowest voltage that could cause a person's death is only around 60 volts. It is important to know that each solar panel we use has an output voltage of about 46 volts, so just two solar panels could be fatal to a person. Our design consists of hundreds and thousands of solar panels, it could probably kill a person in seconds.

Danger of Fire

Fire usually happens when a connection wire hits an object such as trees or grass. Therefore, it is important to make sure all the connection wire are insulated and organized well to avoid hitting any object.

2.8 Task Approach

In the process of designing the solar power plant, we will be following the flowchart below:

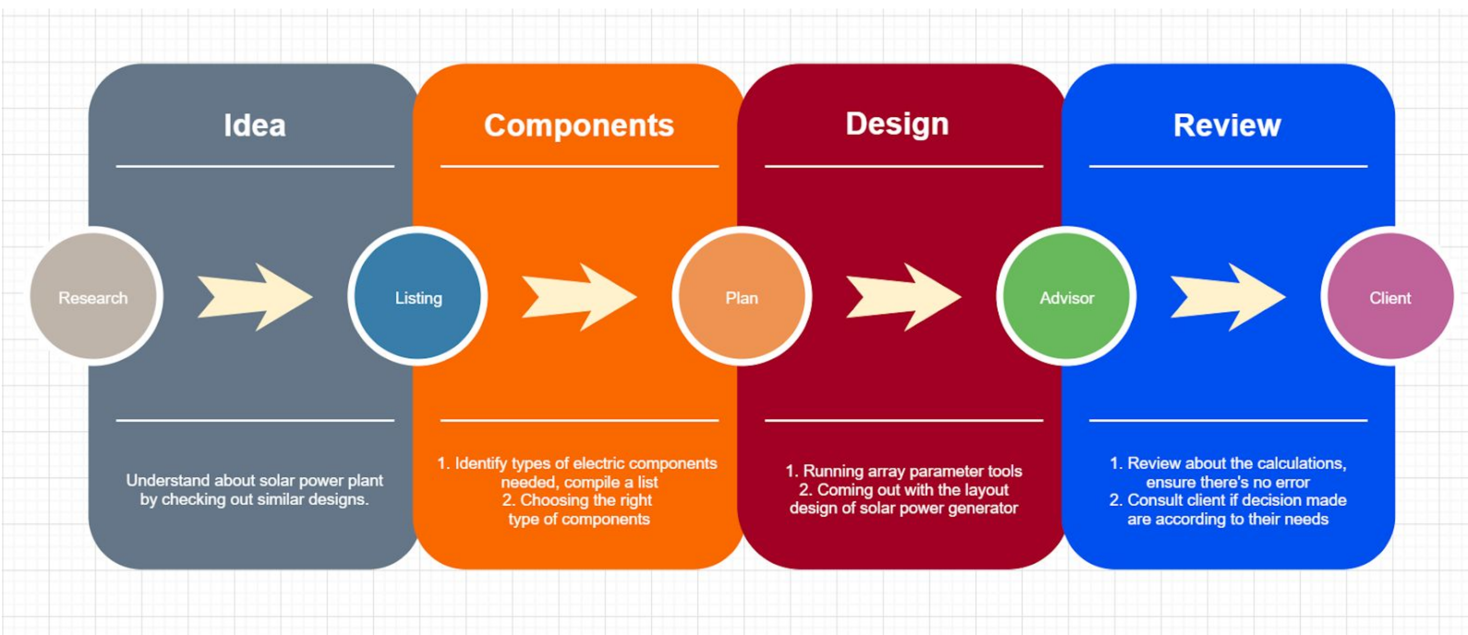

Figure 6: Flowchart of Project Task Approaches

2.9 Possible Risks And Risk Management

The inverter the client would like us to use has unfortunately been discontinued by the supplier. As such, we had difficulty finding the price of the inverter. To calculate the total cost of the project, we made estimations that we have no way of validating.

We were unsure of whether we would be purchasing the rack system from a supplier or designing one ourselves. If we design it, the project will be delayed since we didn't foresee this at the beginning of the project.

To find a good location for the solar power plant and substation, we need to do research on online because we are unable to travel around the United States to find a location. However, using google earth to find a location of at least 244 acres will be difficult as pictures differ from actual view. Besides, we do project for a year, and the land can change within one year.

We all are in senior year, and we need to spend a lot of time for studying. Therefore, we cannot put all of our effort in the project.

2.10 Project Proposed Milestones and Evaluation Criteria

Research:

- Location of solar power plant and substation
- Solar power plant parameters
- Justification of components and designs used
- Study the documents sent by the client

Rough draft of design:

- Look appropriate.
- Approval from the client.
- All members can understand the draft.

Final design:

- Everything is correct base on calculation.
- Approval from the client.
- All members can understand and read information from the design draft.

Finish:

- All design drafts, data, reports, and research are organized.

2.11 Project Tracking Procedures

Using Gantt chart to plan up what we will do every week. Then, using Groupme and meetings to keep everyone on the same track.

2.12 Expected Results and Validation

Expected results:

- Appropriate final drafts of solar power plant and substation.
- Accuracy parameters in final drafts.
- Accuracy calculations in voltage drop, current in each conductors.
- Suitable conductor for each connection.
- Satisfaction of the client.

Validation:

- Getting same and accurate calculated values after many calculation.
- Getting same values from client calculation.
- Satisfaction of the client.

2.13 Test Plan

1. **Functional Test Plan Scope**
- Solar power plant layout - Voltage drop calculation - Current calculation - Choosing conductors

2. **Functional Test Plan Assumptions and Constraints**
- None

3. **Functional Test Team Roles and Responsibilities**		
Name	**Roles**	**Responsibilities**
Ahmed Sobi	Leader	- Divide tasks to everyone in group. - Testing calculation and choosing conductor for collector.
Katayi Katanga	Tracker	- Making sure everyone do their responsibilities on time. - Testing calculation on voltage drop.
Nur Shuazlan	Tester	- Testing calculation on voltage drop.
Chufu Zhou	Tester	- Testing calculation and choosing conductors for collector.
Yao Cheah	Tester	- Testing calculation and choosing conductors for feeder.
Tam Nguyen	Tester	- Testing calculation and choosing conductors for feeder.
Everyone		- Testing the efficiency of the final layout.

4. Functional Test Criteria	
Scope	**Criteria**
Solar Power Plant Layout	- Least space need - Least cost need - Most power collected - Easy to connect components
Voltage Drop Calculation	- Less than 5% of original voltage
Current Calculation	- Be agreed by the client
Choosing conductors	- Based on National Electrical Code (NEC), given by the client

5. Functional Test Cases and Results			
Test Cases	**Pass/Fail**	**Test By**	**Date Tested**
N/A	N/A	N/A	N/A

3 Project Timeline, Estimated Resources, and Challenges

3.1 Project Timeline

The timeline for the entire project is shown in the Gantt Charts below. Throughout the two semesters, the senior design team will track how many hours they spend on each task and keep updating the Gantt Charts.

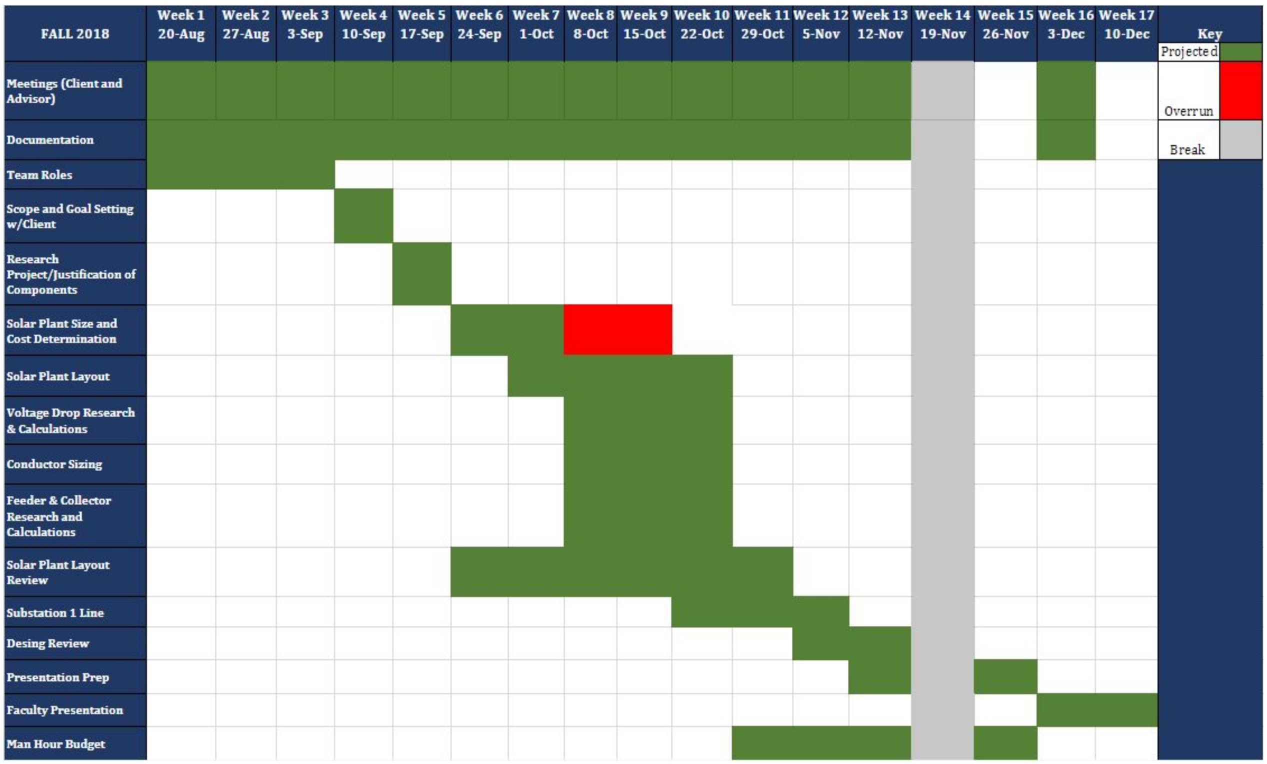

Figure 7: Fall 2018 Gantt Chart

For the first semester of the senior design project, the main focus is to design the 60 MW solar power plant. This includes using the Array Parameter Tool that was provided by the client to generate the parameters of the solar power plant and using the results to create layouts and schematics of the power plant. Then, the team used the voltage drop calculation template provided by the client to determine conductor sizes and to make sure that the total voltage drop of the entire system is less than 5% in compliance with the NEC. After finishing up the solar power plant part of the design, the team will move on to designing the 115 kV/34.5 kV substation based on the specifications set by the Arcadia single line diagram provided by the client. By the end of the semester, the team will have finalized the solar power plant design and wiring.

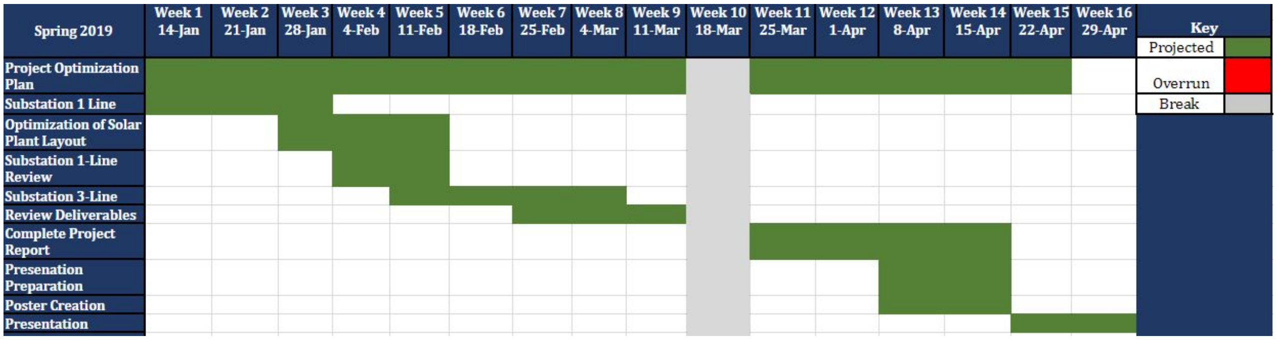

Figure 8: Spring 2019 Gantt Chart

For the second semester of the project, the main focus is to create the three-line diagram of the substation. The team will also keep optimizing and improving the schematics and layouts that were created in Fall 2018. At the end of the semester, the team will have their deliverables finalized and present the final project to the faculty members and Black & Veatch.

3.2 Feasibility Assessment

The feasibility of obtaining funding for a 60 MW solar power plant and a 115 kV/34.5 kV substation in Estancia, New Mexico is likely due to the cheap land and high solar radiation in the location. Even though the project costs over $69 million, the state of New Mexico has one of the best state incentives, which means that it is likely that Black & Veatch could receive funding or loans from the state, reducing the cost of the project. However, it is up to the company whether they want to actually build the power plant and substation or not.

3.3 Personnel Effort Requirements

The tables below show the tasks in Fall 2018 and Spring 2018 as well as the estimation of the total hours that will be spent on each task. Estimations are based on the difficulty of the task and the number of people estimated to take on the task.

Tasks	Description	Estimation of Total Hours
Solar Power Plant Parameters	Calculate the parameters of the power plant to figure out the total cost and size of the power plant	12
Solar Power Plant Layouts	Use the parameters to design layouts of the power plant	9
Voltage Drop Calculations and Conductor Sizing	Determine sizes of conductors and cables based on the IMP in the cable. Calculate voltage	25

	drops across each cable to make sure that the voltage drop percentage of the entire solar plant system is less than 5%	
Solar Power Plant AutoCAD Drawings	Create detailed drawings of the solar plant to show how different components are connected/wired together	5
Collector and Feeder Parameter Calculations	Calculate the parameters, such as currents and voltages, of the collectors and feeders based on the specifications set by the client	20
Collector and Feeder AutoCAD Drawings	Create detailed drawings of the collectors and feeders to show how they are connected to the solar power plant and substation	5
Substation One-line Diagram	Create a simplified drawing of the substation layout showing how different components are connected. Perform power flow study	10

Table 1: List of Fall 2018 tasks and estimation of total hours

Tasks	Description	Estimation of Total Hours
Substation Three-Line Diagram	Create a detailed diagram showing the actual components that will be used in the substation and the wiring of said components	20
Substation Key Protection Diagram	Create a detailed diagram showing the protection of each substation equipment	20

Table 2: List of Spring 2019 tasks and estimation of total hours

3.4 Other Resource Requirements

The resources needed to build the power plant and substation are shown in the tables below.

Components	Number/Amount of Resources
Solar Panel	238,032 units
Inverter	36 units
Combiner Box	792 units
Land	233.8 acres

Table 3: List of resources for the solar power plant

Components	Number/Amount of Resources
Circuit Breaker	TBD
Transformer	TBD
Lightning Arrester	TBD
Disconnect Switch	TBD
Land	TBD

Table 4: List of resources for the substation

4 Closure Materials

4.1 Conclusion

Our senior design team will design a 60 MW solar power plant and 115/34.5 kV substation in order to meet the increasing demand for renewable energy and reduce the dependency on non-renewable sources . The team will utilize all the resources have been provided by Black & Veatch to meet the specifications of the project. In the first semester, the team will come up with an optimal location, solar panels parameters, solar layout design, calculate the solar power plant cost, and create a substation one-line diagram. The team will also utilize a Gantt chart in order to keep track of the man-hours and the amount of time spent on tasks. In the second semester the team will dive deeper into the substation design and utilize AutoCAD to optimize the one-line diagram, three-line diagram and protection and control schematic.

4.2 References

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6. Frohlich , Thomas C, and Alexander Kent. "What US Land Is Really Worth, State by State." *20 Jobs That Will Be Replaced by Technology*, 7 Mar. 2015, www.msn.com/en-us/money/generalmoney/what-us-land-is-really-worth-state-by-state/ar-BBkTfZS#image=BBkGo1K%7C10

4.3 General Information form wikipedia

Substation

https://en.wikipedia.org/wiki/Electrical_substation

Inverter: Eaton 1666kW

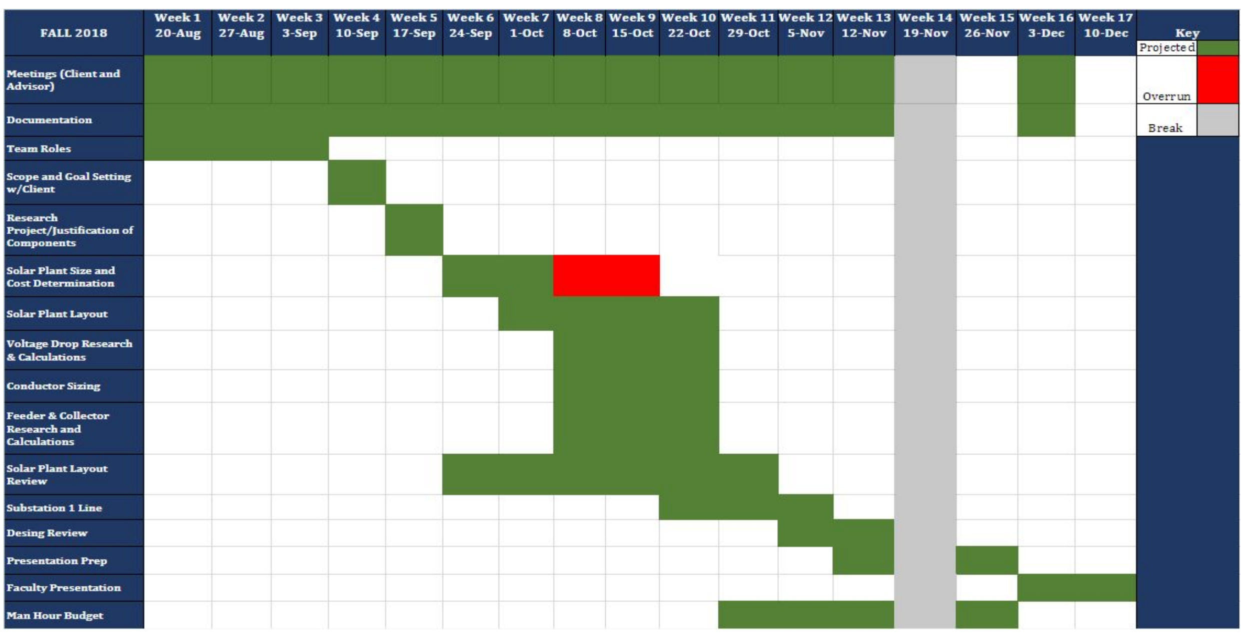
https://en.wikipedia.org/wiki/Power_inverter

Single line diagram

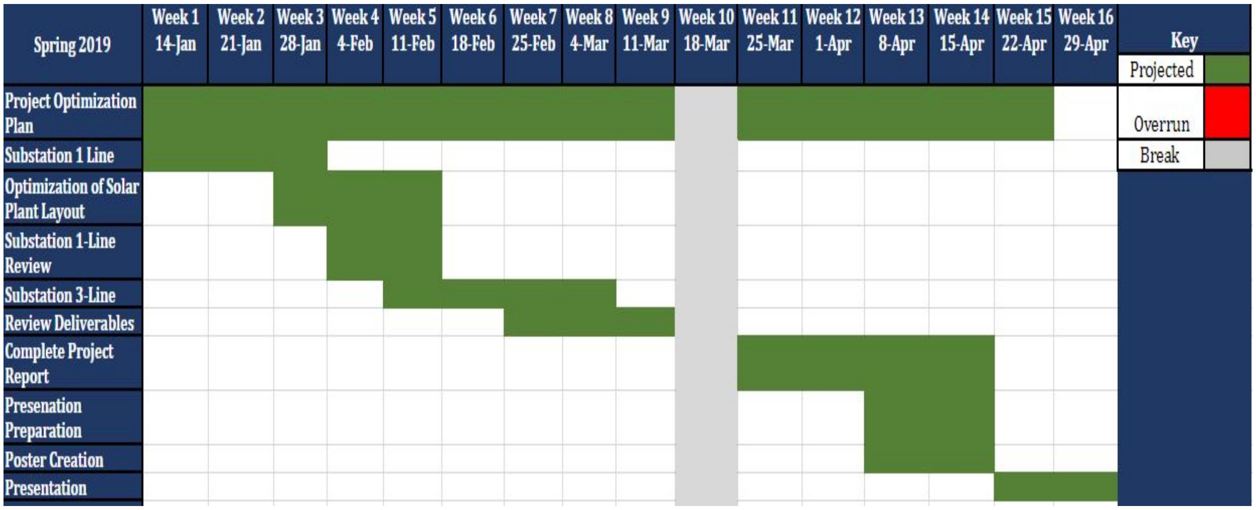
https://en.wikipedia.org/wiki/One-line_diagram

Appendices

fall Gantt-Chart



Spring Gantt-Chart


Spring 2019
Week 1 14-Jan
Week 2 21-Jan
Week 3 28-Jan
Week 4 4-Feb
Week 5 11-Feb
Week 6 18-Feb
Week 7 25-Feb
Week 8 4-Mar
Week 9 11-Mar
Week 10 18-Mar
Week 11 25-Mar
Week 12 1-Apr
Week 13 8-Apr
Week 14 15-Apr
Week 15 22-Apr
Week 16 29-Apr
Key
Projected
Overrun
Break
Project Optimization Plan
Substation 1 Line
Optimization of Solar Plant Layout
Substation 1-Line Review
Substation 3-Line
Review Deliverables
Complete Project Report
Presenation Preparation
Poster Creation
Presentation