115kV/ 34.5kV Solar Power Plant & Substation Design Project

Design Document

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Executive Summary

Development Standards & Practices Used

As this is primarily a design only project, we will be adhering to IEEE standards for reporting and documentation, as well as design layouts. We will also adhere to standard practice when coding using AutoCAD or Revit. We will also need to consider any limitations or requirements associated with construction in specific states, specifically New Mexico.

Summary of Requirements

- Design 60 MW Solar Farm (Fall 2020)
    - Select Panels
    - Select Combiner Boxes
    - Select Inverter Skids
    - Select Location
    - Design layout of Farm
- Design Substation to handle Output from Solar Farm (Spring 2021)

Applicable Courses from Iowa State University Curriculum

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

- EE 201, EE 230, EE 303, EE 456, EE 459/559

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/REVIT programming
- One line diagrams
- Solar farm layout and distribution

Table of Contents

1 Introduction

1.1 Acknowledgement

Black & Veatch will be guiding us as we work on this project.

1.2 Problem and Project Statement

This project sets out to develop a solar farm to increase the use of renewable energy at Black & Veatch. Additionally, a power substation must be created which will allow for the harnessing and distribution of the solar farm's energy. This project is very important because regulations pushing renewable energy on power companies are rapidly increasing and so Black & Veatch must begin to take the necessary steps towards avoiding penalties from these regulations. On the other side of this project, we can find importance through the students who are trying to learn about solar energy and power distribution. Through this project, the team of students will be gaining real world experience of what it would be like to work for a power company, using calculations that are produced from Black & Veatch's internal documents.

The final goal of this project is to create a 60MW Solar Power Plant and 115kV / 34.5kV Substation Design Project. This project will be split up into two semesters with the first semester being the creation of the solar plant and the second semester being the creation of the substation. In order to accomplish these creations, the team of students must work together in unison with the mentors giving deliverables that contain the following:

- Equipment sizing Calcs
- Solar layout drawings
- Solar panel string sizing design
- Electrical layout drawings (substation equipment)
- Grounding analysis and ground-grid developed with IEEE-80
- Bus calculations for substation
- Possibility of additional calculations (DC battery bank, Lightning protection, etc.)
- Creation of solar/substation design-optimizing tool

In order to stay on track with all of these deliverables, we will also be required to develop a detailed engineer man-hour budget and schedule for this project; this will be a very nice way to plan the overall project. Finally, the students will find a way to share their work with the Black & Veatch engineers who will analyze the work we have done through the two semesters.

General Problem Statement

We as a team, have been tasked with designing a 60 MW solar farm with accompanying substation in order to add clean, renewable energy to the American energy grid. This project is a “from scratch” design, and while we will be using resources provided to us, the overall design of the final project will be our own creation.

General Solution Statement

We will design a 60 MW solar farm and substation by selecting appropriate parts and land, and then decide the most cost effective way to combine and set up the farm. This consists of appropriately sizing solar panels, combiner boxes, and inverters for the solar farm, as well as necessary parts for the substation. We will accomplish this by using CAD or similar software to virtually build and assess our designs in order to produce a more ideal final product.

1.3 Operational Environment

This solar farm will operate outside, in typically hot, sunny weather, but must be able to withstand temperatures below freezing. It must also be resistant to common weather conditions of the area, such as thunderstorms or snow.

1.4 Requirements

Functional

- Must be able to operate in environmental conditions as described in section 1.3
- Power rating at the solar farm of 60 MW
- Adhere to IEEE standards
- Maintain reliability throughout lifespan of project

Environmental

- Parcel of land must be flat and continuous (i.e. no hills, creeks, ravines)
- High amount of average sunshine per year
- High irradiance on the land
- Must be near enough end users so energy produced is used

Economic

- Plant must be able to produce enough kWh per year over the course of 10 years to recover initial investment and operational costs

1.5 Intended Users and Uses

This solar farm will service the surrounding areas as a support to current infrastructure. This may include spikes in commercial or residential power usage during the daytime.

1.6 Assumptions and Limitations

Assumptions

- The sun will shine a consistent number of hours per year
- A consistent amount of energy will be generated and sold each year
- Power lost to inefficiencies in equipment/transmission will be constant

Limitations

- The plant can not operate at maximum power rating, as power is lost in wires, equipment, and to indirect sunlight
- The solar farm must be close to enough customers so that the power generated is used
- Land must be flat and continuous (no creeks/ravines/steep hills)

1.7 Expected End Product and Deliverables

There are deliverables for this project that will be required from both the mentors with Black & Veatch alongside the mentors/professors from Iowa State. The deliverables that will be required for our mentors from Iowa State include:

- Discussion posts covering various topics from the lectures
- Bi-weekly project reports
- Lighting talks
- Overall project Design Document

The weekly discussion posts will allow us to learn different processes that our mentors from Iowa State think will help throughout the process of this project. The Bi-Weekly reports helps our own group along with the mentors to keep track of where we are in the project. This involves us stating current problems and solutions that we are dealing with and current parts of the project that we are finishing and starting. The lightning talks are ways for us students to practice talking through our project and giving verbal updates for our mentors kind of like how we would in the real world to show our bosses our progress. This document is the last deliverable for our Iowa State mentors which will serve as an all-in-one project description.

From Back & Veatch we can expect to report the following deliverables:

- Equipment sizing Calcs
- Solar layout drawings
- Solar panel string sizing design
- Electrical layout drawings (substation equipment)
- Grounding analysis and ground-grid developed with IEEE-80
- Bus calculations for substation
- Possibility of additional calculations (DC battery bank, Lightning protection, etc.)
- Creation of solar/substation design-optimizing tool

The equipment sizing calcs will be excel documents that Black & Veatch have outlined for us to do. These outlines include built in formulas that will be completed throughout the semester as our group puts everything together. The solar layout drawing are 2D models that will be created in excel to give an easier-to-understand example of our project. The solar panel string sizing are a part of the same equipment sizing calc excel file as above and will help with knowing how to finish the 2d model. The rest of the calculations will be discussed in further length in the second semester. The students have not been presented with how these calculations should be completed yet.

All of these deliverables will help us to maintain a steady workflow resulting in a well documented and complete project by the end of this course.

At the end of the project, our client can expect to have a completed (2D) virtual model of the solar farm along with the power substation. This will include all of the deliverables listed above along with a presentation of the overall progress we made in this project. This presentation will include both a meeting with all of the students and mentors present in addition to this design document which lays out the project as a whole.

2 Project Plan

2.1 Task Decomposition

Parts Acquisition

- Select Solar Panels based on price, company, and power rating
- Select Combiner Boxes based on price, number of inputs, Amperage rating, and company
- Select Inverter skids based on capacity, inputs, cost, and company

Design

- Design high level model in order to better visualize final product
- Design farm layout within land requirements and accessibility
- Design component attachments based on part ratings and cost and power efficiency

2.2 Risks And Risk Management/Mitigation

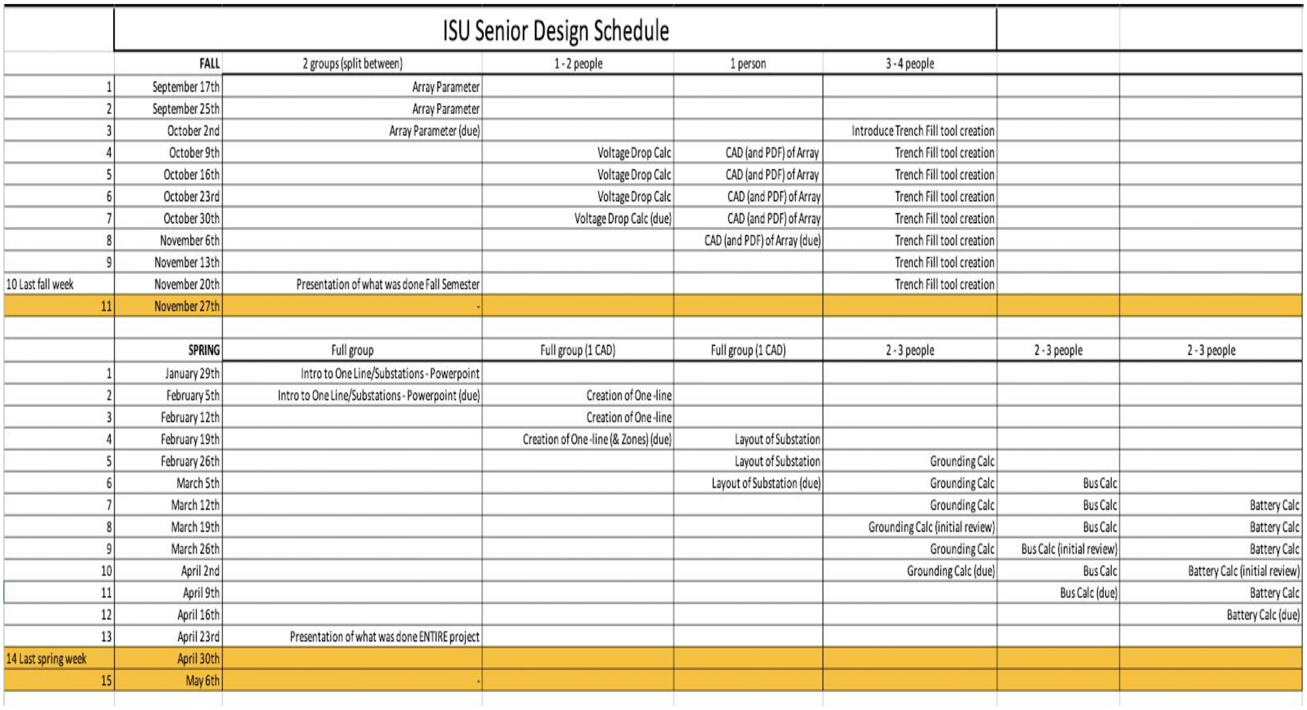
Because we are not physically building the 60MW solar plant, the risks will relate only to performance targets. We have assumed that the plot of land is perfectly flat, at the standard elevation of New Mexico, and will have enough room for all components of the solar plant. One possible risk is that the minimum temperature of the solar plant’s location will affect the solar string voltage. To compensate for this, we set the minimum temperature to -40 degrees Celsius. This ensures a risk factor of 0 because New Mexico simply does not get that cold at any point in the year. We have designed the system so that the combiner boxes and inverters will all be of adequate strength to handle all of their inputs, even with maximum solar output. The solar plant can also store excess power to keep up production on days with less than optimal amounts of sunlight. This means that projected solar output will not be a risk. The main risk is that we might not complete our design in time. I would evaluate this risk at a probability of 0.25 because we are currently ahead of schedule by at least 1 week. One way of making sure that this won’t happen is by asking our mentors for help whenever we feel that we are falling behind. Our mentors have been great about offering help when needed , and we are sure that they will try their best to answer any questions we might have.

2.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

Key Milestones in our project are part selection, high level layout design, AutoCAD/Revit initial Design, AutoCAD/Revit corrections, Autocad/Revit final draft. These milestones can be evaluated by percentage complete, as well as projected efficiency for the AutoCAD/Revit designs.

2.4 Project Timeline/Schedule

- Senior Design Team Schedule:



	ISU Senior Design Schedule						
	FALL	2 groups (split between)	1 - 2 people	1 person	3 - 4 people		
1	September 17th	Array Parameter					
2	September 25th	Array Parameter					
3	October 2nd	Array Parameter (due)			Introduce Trench Fill tool creation		
4	October 9th		Voltage Drop Calc	CAD (and PDF) of Array	Trench Fill tool creation		
5	October 16th		Voltage Drop Calc	CAD (and PDF) of Array	Trench Fill tool creation		
6	October 23rd		Voltage Drop Calc	CAD (and PDF) of Array	Trench Fill tool creation		
7	October 30th		Voltage Drop Calc (due)	CAD (and PDF) of Array	Trench Fill tool creation		
8	November 6th			CAD (and PDF) of Array (due)	Trench Fill tool creation		
9	November 13th				Trench Fill tool creation		
10 Last fall week	November 20th	Presentation of what was done Fall Semester			Trench Fill tool creation		
11	November 27th	-					
	SPRING	Full group	Full group (1 CAD)	Full group (1 CAD)	2 - 3 people	2 - 3 people	2 - 3 people
1	January 29th	Intro to One Line/Substations - Powerpoint					
2	February 5th	Intro to One Line/Substations - Powerpoint (due)	Creation of One -line				
3	February 12th		Creation of One -line				
4	February 19th		Creation of One -line (& Zones) (due)	Layout of Substation			
5	February 26th			Layout of Substation	Grounding Calc		
6	March 5th			Layout of Substation (due)	Grounding Calc	Bus Calc	
7	March 12th				Grounding Calc	Bus Calc	Battery Calc
8	March 19th				Grounding Calc (initial review)	Bus Calc	Battery Calc
9	March 26th				Grounding Calc	Bus Calc (initial review)	Battery Calc
10	April 2nd				Grounding Calc (due)	Bus Calc	Battery Calc (initial review)
11	April 9th					Bus Calc (due)	Battery Calc
12	April 16th						Battery Calc (due)
13	April 23rd	Presentation of what was done ENTIRE project					
14 Last spring week	April 30th						
15	May 6th	-					

- Senior Design Team Gantt Chart: Gantt Chart:

2.5 Project Tracking Procedures

Throughout this and next semester, our group plans to use Microsoft Teams and Google Drive to communicate and collaborate on all project materials. We will track progress by adhering to strict deadlines for the various tasks necessary to complete the project, and holding team meetings once per week to discuss progress on tasks and to determine if additional resources need to be reallocated to the completion of a specific task.

2.6 Personnel Effort Requirements

So far all tasks that have been completed by dividing work amongst team members via our weekly group meetings. The mentors have given the team tasks from the senior design schedule and they will provide upcoming specific tasks outlined in the schedule in the coming weeks. These tasks will be divided amongst the team members via the gantt chart linked in section 2.4, and the person-hours task table an example is below.

Time	Monday	Tuesday	Wednesday	Thursday	Friday
8:00am - 8:30am					
9:00am - 9:30am					
10:00am - 10:30am					
11:00am - 11:30am					
12:00pm - 12:30pm					
1:00pm - 1:30pm					
2:00pm - 2:30pm					
3:00pm - 3:30pm					
4:00pm - 4:30pm					
5:00pm - 5:30pm					

2.7 Other Resource Requirements

Aside from personnel effort requirements, there are some additional resources needed to complete this project. We will require access to solar field modeling tools, such as the Array Design Parameter Tool we used to model our initial solar field design. These will be provided by our mentors. We will also need access to AutoCAD software for designing things later in the semester. We can get free access as students so this will not pose a problem.

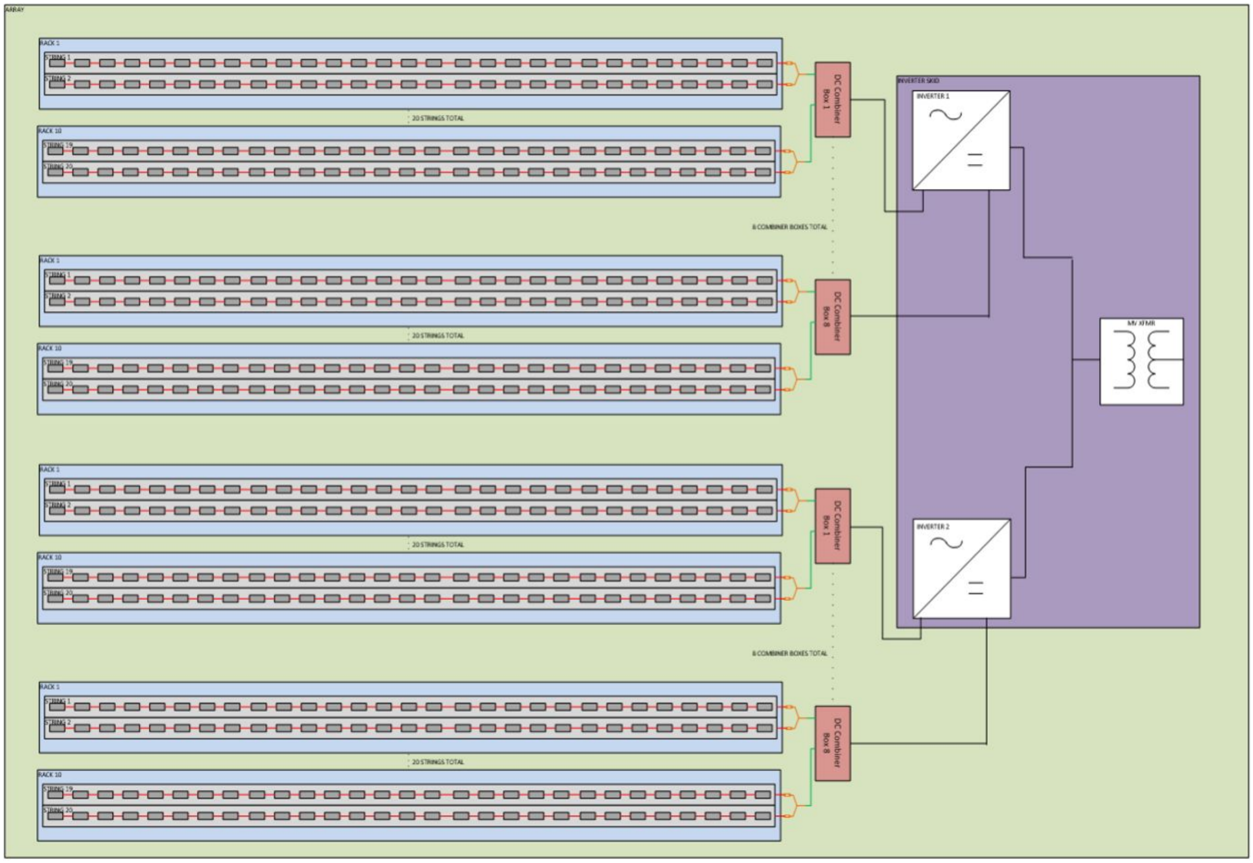
2.8 Financial Requirements

Given that our project is simply designing the solar field, the only financial requirement is possible future software costs. If our project was to completely build the solar plant, the cost would be upwards of millions of dollars.

3 Design

3.1 Previous Work And Literature

Solar farm and substation design is not as innovative or creative in it's own right; the farm is essentially a big grid of the same solar panels all hooked together. It was our job to figure out a highly efficient way of arranging solar panels and other components to get the maximum output possible while keeping losses low. In this way, we want to essentially imitate other successful solar farms. Typical designs seek to fill the ground area in the most efficient way possible, minimizing voltage drop losses when running cable. The image below is an example given to us by our peer mentors on a typical way solar modules are arranged in racks, rows, and arrays:



3.2 Design Thinking

So far, the driving factor in our solar farm layout is based on the array parameter tool and recommendations/guidance from our B&V peer mentors. Initial discussions within our group were centered around the array parameter tool where we threw out ideas and tested different combinations of numbers for string/rack size, panel tilt, average ambient temperature, and so on.

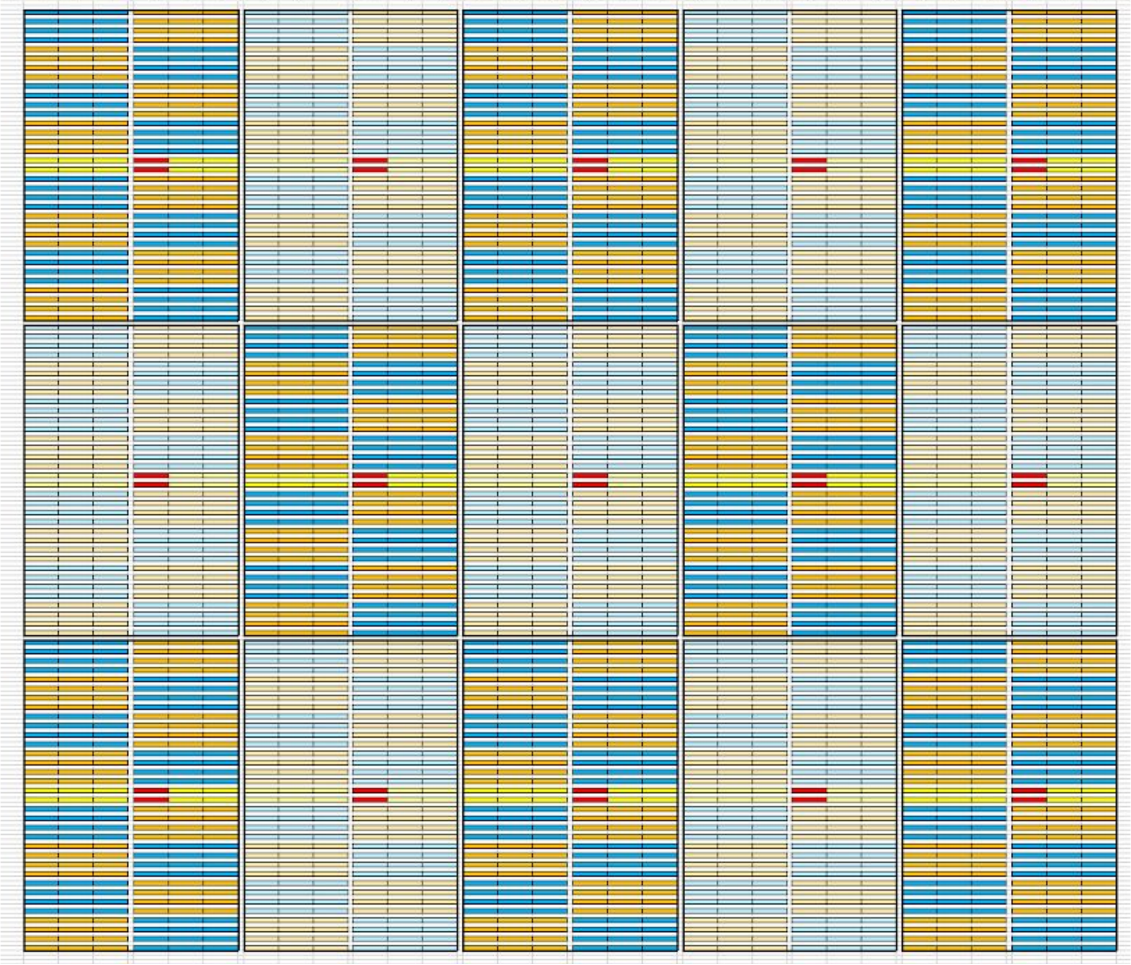
3.3 Proposed Design

So far, we have designated an initial layout of the panels, combiner boxes, and inverter skids.The basic idea behind our thinking was to maximize our efficiency on wiring and solar power collection. We made use of the array parameter tool with component choices to guide the layout we created. Below we can see the parameters used in our array parameter tool:

		String Size				Electrical Rack Size		
					Designer Choice		portrait or Landscape	
	Location Dependent	Min Temp	-40	C	Datasheet	Module width	3.36	ft
					Datasheet	module height	6.64	ft
	Datasheet (STC)	Voc	49.5	V				
	Datasheet (STC)	Ref temp	25	C	Designer Choice	Rack width	25	modules
					Designer Choice	Rack height	2	modules
	Datasheet	Temp Coeff of Voc	-0.0027	/C		Modules per rack		
		Temp delta	-65			Rack width	84	ft
		temp correction	1.18			Rack height	13.28	ft
		V0c corrected	58.18725					
Confirm possible with Panel type chosen	Designer Choice: 600, 1000, 1500, 2000V	string voltage	1500	V				
		String size	25.77884					
		string size	25					
		Actual String Voltage	1454.7					

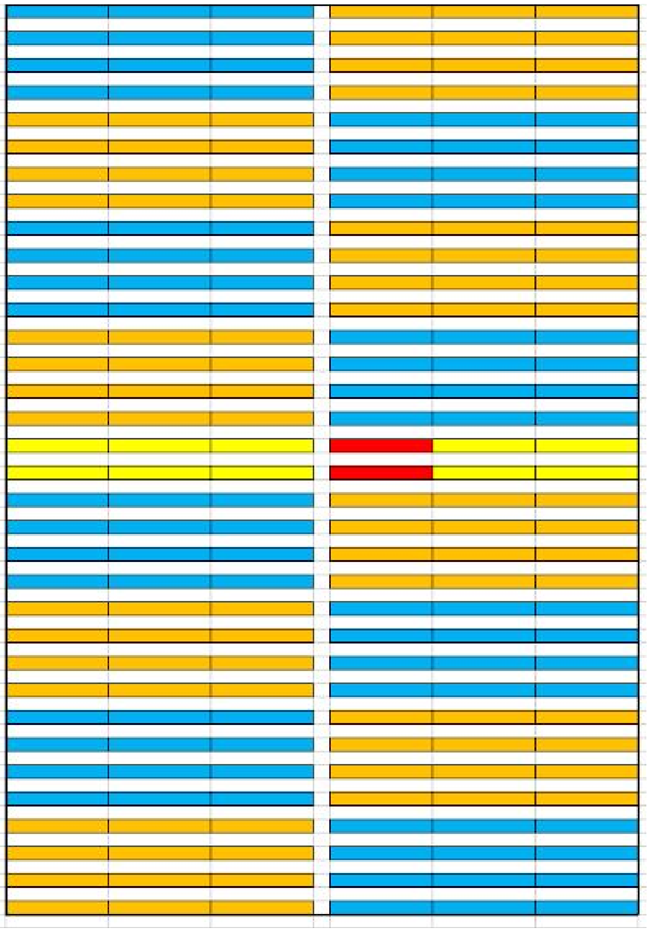
	CB capacity				Array Design				Array Size		
Datasheet (STC)	mod/string Isc	10.55	A	Designer Choice	Racks per row	6		Designer Choice	tilt	35	
NEC sectio	multiplier	1.25									
	nom Isc	13.1875		Designer Choice	rows per Array	34			table height proj	10.87834	ft
Irr.	multiplier	1.25									
	max Isc	16.48438	A	Designer Choice	Racks removed	2		Designer Choice	row spac	15	ft
Designer Choice: 200, 400A etc.	allowed current	400	A		Total Racks/Array	202			pitch	25.87834	ft
	is this disconnect A?								Space for Inverter Maintenance		ft
	strings per CB	24.2654			Total modules	10100			Array height	879.8635	ft
	Round down:	24									
	racks per CB	12		Datasheet (STC)	module capacity	410	W		Array width	504	ft
									Ground Coverage Ratio	0.51317	
	Total CB/Array	16.83333			dc capacity	4141	kW				
	Round up:	17									
				Designer Choice	Inverter capacity	3200	kW				
							MVA				
				Provided: Industry standard 1.3	ILR	1.294063					

Our design has not been finalized yet, but is looking very promising so far. The image below gives a basic idea of what the entire field will look like. The total outside dimensions as it stands are 2,520 feet wide by 2,640 feet tall.



There are 15 total arrays (outlined in black), each having their own set of inverter skids (red cells). All of these inverters will feed the substation where power will be sent out to the grid.

A close up of a single array is shown below:



Each highlighted cell in the image above represents a rack of panels 25 modules wide and two modules tall. For each array, two racks will be removed to make room for the inverter skids bringing the total number of solar panels in each array out to 10,100.

Having lots of well defined information on how to design a solar farm and substation has been very helpful for us. It allows us to focus more on getting this piece of infrastructure “built” in a timely manner - something important in a renewable energy industry that is innovating and creating more efficient products. However, one downside to having such rigid constraints is that it banishes creativity in a way - we can’t go out and create something in the same way that a fine artist might. Efficiency and conformity are rewarded in an industry like this; the most effective plant designs are ones that amalgamate all the best parts of other plans.

When we get to the design aspect of the substation, there are even more rigid constraints and pre-established norms to guide us in bus design configuration. It will be up to us to determine the correct configuration for our needs when we reach that point.

3.4 Technology Considerations

One thing we needed to consider when starting this project was the fast changing nature of the industry: solar panels are widely variable in their output characteristics and the technology is constantly evolving and improving. A major factor that allowed us to narrow our search was the scale of the project; we wouldn't want to buy consumer grade inverters meant for just a few solar panels on a house roof, we needed utility scale inverters that can handle thousands of amps coming from thousands of panels.

These component choices were made based upon the parameters given in data sheets and approved by peer mentors. We had to stay within constraints such as: how many panels we could have in series or parallel in a string or rack; how many racks we could hook up to one combiner box; and how big a panel array will be.

3.5 Design Analysis

So far, the feedback we have received has been very positive from our peer mentors. We initially had two potential designs, one with a 340 Watt panel and one with a 410 Watt panel but as we were going along, it became apparent that the 340 watt panel would not suit our needs for the large scale project.

So far we have not needed to iterate in any big ways - we played around with values until we were satisfied with ones that meet the necessary efficiency requirements laid out in our array parameter tool.

3.6 Development Process

We have adopted a Waterfall development process for this project. This makes sense for us as our requirements have been laid out specifically for us by our clients and Black & Veatch, and following with a high level design to detailed design is the most straightforward way to getting to a final product.

4 Testing

Within our project, individual unit testing is not directly related to the desired outcome. The kind of testing we will be doing is based more in iterative calculations that will meet predetermined constraints such as in the array parameter tool and the upcoming voltage drop calculation and cost analysis tools. Furthermore, because we are not actually physically building this project, no real world tests need to be run, we will merely gain an understanding of what kind of challenges arise when building and testing a utility scale solar farm in real life.

Some challenges we encountered while testing within the array parameter tool were misunderstanding of the terminology used because it is proprietary to the Black & Veatch. We were able to clear this up by asking our peer mentors questions and researching other plant designs.

4.1 Unit Testing

Under the category of unit testing, we will be working with the solar farm and substation design as sort of separate entities. Within the solar farm design, we have a few different “parts” that we will spend multiple weeks on each (array parameter tool, voltage drop calculator, and trench fill tool). For the purpose of our project these can be treated as individual units and will be continually tested and improved as they are not physical units but rather conceptual units.

4.2 Interface Testing

Interface testing has not been super important for us so far, but as we transition into next semester it will be important to synthesize our solar farm with the substation to ensure the designs work together to squeeze the most efficiency possible out of the panels.

4.3 Acceptance Testing

In order to show that we have met the design requirements, we will be presenting our findings, testing, and designs with our peer mentors in our weekly meetings. There, we will receive feedback and criticisms to ensure that we are moving forward in the right direction, implementing what is wanted from them (the customer).

4.4 Results

– Thus far, we have completed our iterative testing of the array parameter tool which determines the farm’s physical layout

- Two main obstacles we had to overcome at first were getting familiar with all the terminology and background information as well as getting an understanding of how the array parameter tool works

- Going forward, as we work on the other tools (voltage drop calculator and cost analysis tool) we will seek feedback and input from our mentors earlier and more often so that we do not waste time doing something not worth the time or effort

5 Implementation

We will not be directly involved with the implementation of this project. Our two semesters will be two different design projects, and as such, we will not have time to see a fully built solar farm of our design. Any implementation will be handled by Black & Veatch after Spring semester.

6 Closing Material

6.1 Conclusion

So far we have selected our components for the solar farm and have completed our high-level design. We are currently working on the detailed design portion of our process, and should soon be moving to coding. The final product for the semester will be the complete design specifications for a 60 MW solar farm located somewhere in New Mexico.

6.2 References

6.3 Appendices