Solar Power Plant and Substation Design Project

IOWA STATE UNIVERSITY and BLACK AND VEATCH

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IOWA STATE UNIVERSITY

Project Vision

- 60MW Solar Plant and 115kV/34.5kV Distribution Substation
- Black and Veatch
- Those impacted:
  - Surrounding communities
  - Those connected to the grid supplied by this plant
- Benefits:
  - Reduce reliance on fossil fuel/decrease carbon footprint
  - Economic benefits

Requirements

- 60MW Power Generation
  - Design solar array field for renewable energy production
    - Research into components
    - Voltage Drop Consideration
      - Meets or is below industry max of 3%
    - One-Line, Key Plan, & Grounding Plan
- Cost analysis of design
  - Components
  - Land
  - Labor
  - Solar cost analysis
    - Construction of solar power plant, internal rate of return, solar axis tracking
- Project Management
  - Schedule meetings for Team, Mentor, Client, and TA.
  - Creation of man-hour budgeting and Gantt Chart
    - Defines project timeline expectations
    - Tracks progress of project goals

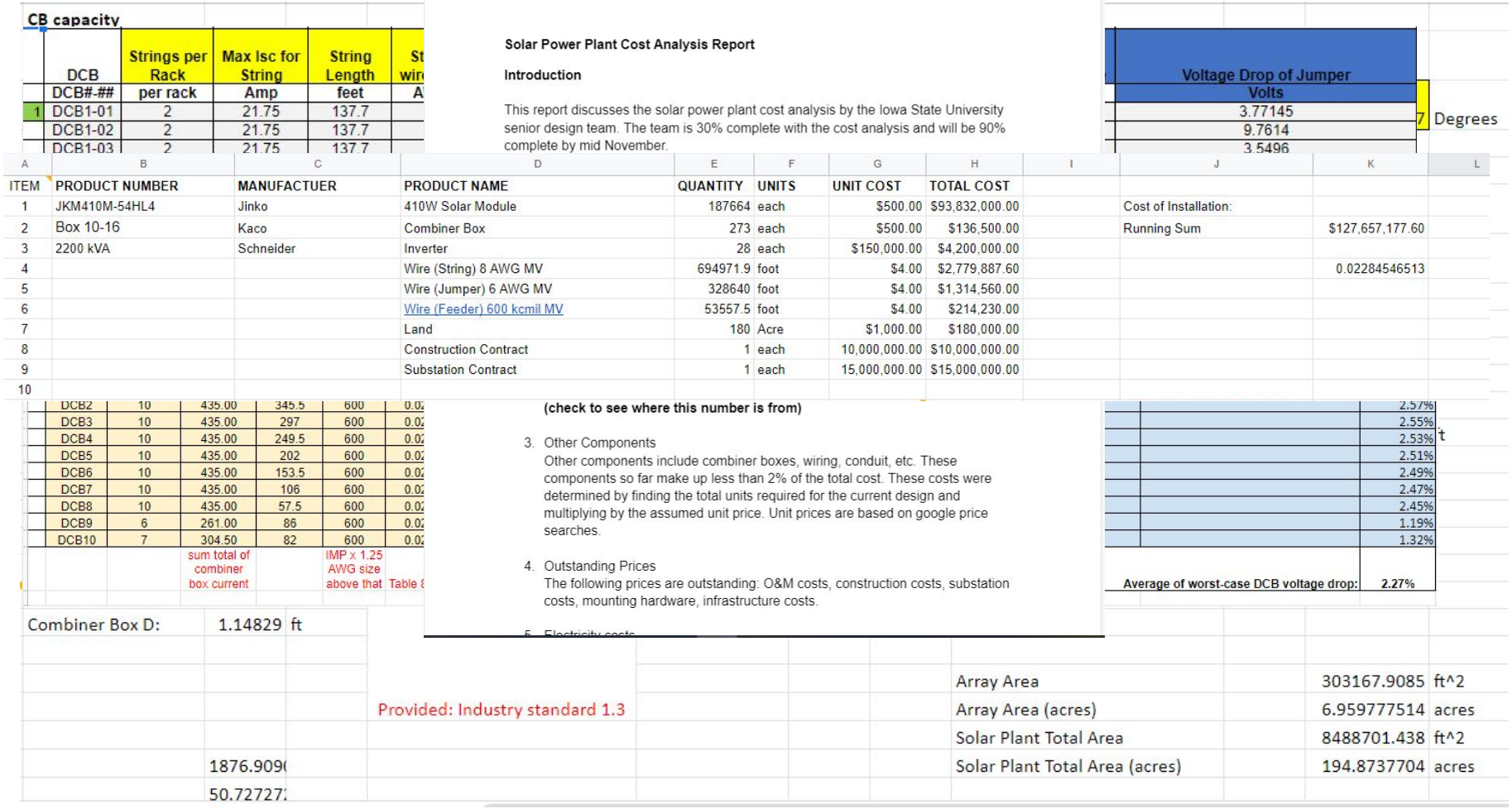
Functional Decomposition/System Architecture

115kV/34.5kV Solar Power Plant

Solar Array Components

- Solar Panel Module
- Rack Layout
- Combiner Box
- PV Skid
  - Inverter
  - Transformer

Software Architecture



CB capacity

	DCB	Strings per Rack	Max Isc for String	String Length	St wir
	DCB#-##	per rack	Amp	feet	A
1	DCB1-01	2	21.75	137.7	
	DCB1-02	2	21.75	137.7	
	DCB1-03	2	21.75	137.7	

Solar Power Plant Cost Analysis Report

Introduction

This report discusses the solar power plant cost analysis by the Iowa State University senior design team. The team is 30% complete with the cost analysis and will be 90% complete by mid November.

	Voltage Drop of Jumper
	Volts
	3.77145
	9.7614
	3.5496

7 Degrees

ITEM	PRODUCT NUMBER	MANUFACTUER	PRODUCT NAME	QUANTITY	UNITS	UNIT COST	TOTAL COST
1	JKM410M-54HL4	Jinko	410W Solar Module	187664	each	$500.00	$93,832,000.00
2	Box 10-16	Kaco	Combiner Box	273	each	$500.00	$136,500.00
3	2200 kVA	Schneider	Inverter	28	each	$150,000.00	$4,200,000.00
4			Wire (String) 8 AWG MV	694971.9	foot	$4.00	$2,779,887.60
5			Wire (Jumper) 6 AWG MV	328640	foot	$4.00	$1,314,560.00
6			Wire (Feeder) 600 kcmil MV	53557.5	foot	$4.00	$214,230.00
7			Land	180	Acre	$1,000.00	$180,000.00
8			Construction Contract	1	each	10,000,000.00	$10,000,000.00
9			Substation Contract	1	each	15,000,000.00	$15,000,000.00
10							

Cost of Installation:

Running Sum $127,657,177.60

0.02284546513

DCB2	10	435.00	345.5	600	0.02	2.57%
DCB3	10	435.00	297	600	0.02	2.55%
DCB4	10	435.00	249.5	600	0.02	2.53%
DCB5	10	435.00	202	600	0.02	2.51%
DCB6	10	435.00	153.5	600	0.02	2.49%
DCB7	10	435.00	106	600	0.02	2.47%
DCB8	10	435.00	57.5	600	0.02	2.45%
DCB9	6	261.00	86	600	0.02	1.19%
DCB10	7	304.50	82	600	0.02	1.32%
		sum total of combiner box current		IMP x 1.25 AWG size above that	Table 8	

Average of worst-case DCB voltage drop: 2.27%

(check to see where this number is from)

3. Other Components
   Other components include combiner boxes, wiring, conduit, etc. These components so far make up less than 2% of the total cost. These costs were determined by finding the total units required for the current design and multiplying by the assumed unit price. Unit prices are based on google price searches.

4. Outstanding Prices
   The following prices are outstanding: O&M costs, construction costs, substation costs, mounting hardware, infrastructure costs.

5. Electricity costs

Combiner Box D: 1.14829 ft

Provided: Industry standard 1.3

1876.909(

50.72727

Array Area	303167.9085	ft^2
Array Area (acres)	6.959777514	acres
Solar Plant Total Area	8488701.438	ft^2
Solar Plant Total Area (acres)	194.8737704	acres

Conceptual Design

Curret capacity		Number needed to Perform
	Combiner Box	
I-V curve		Allowed Current

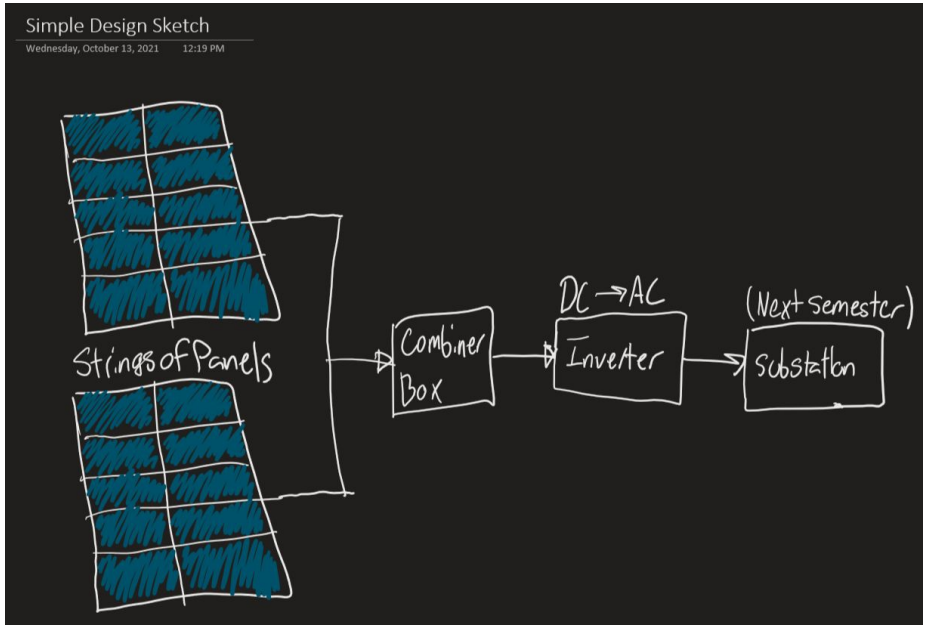
Cost		Inverter Load Ratio
	Inverter	
Inverter Capacity		Number needed to Perform

Number of rows		Rows per Array
	Racks	
Racks per row		Number of racks removed

Array Design		Array Size
	Arrays	
Racks		Modules

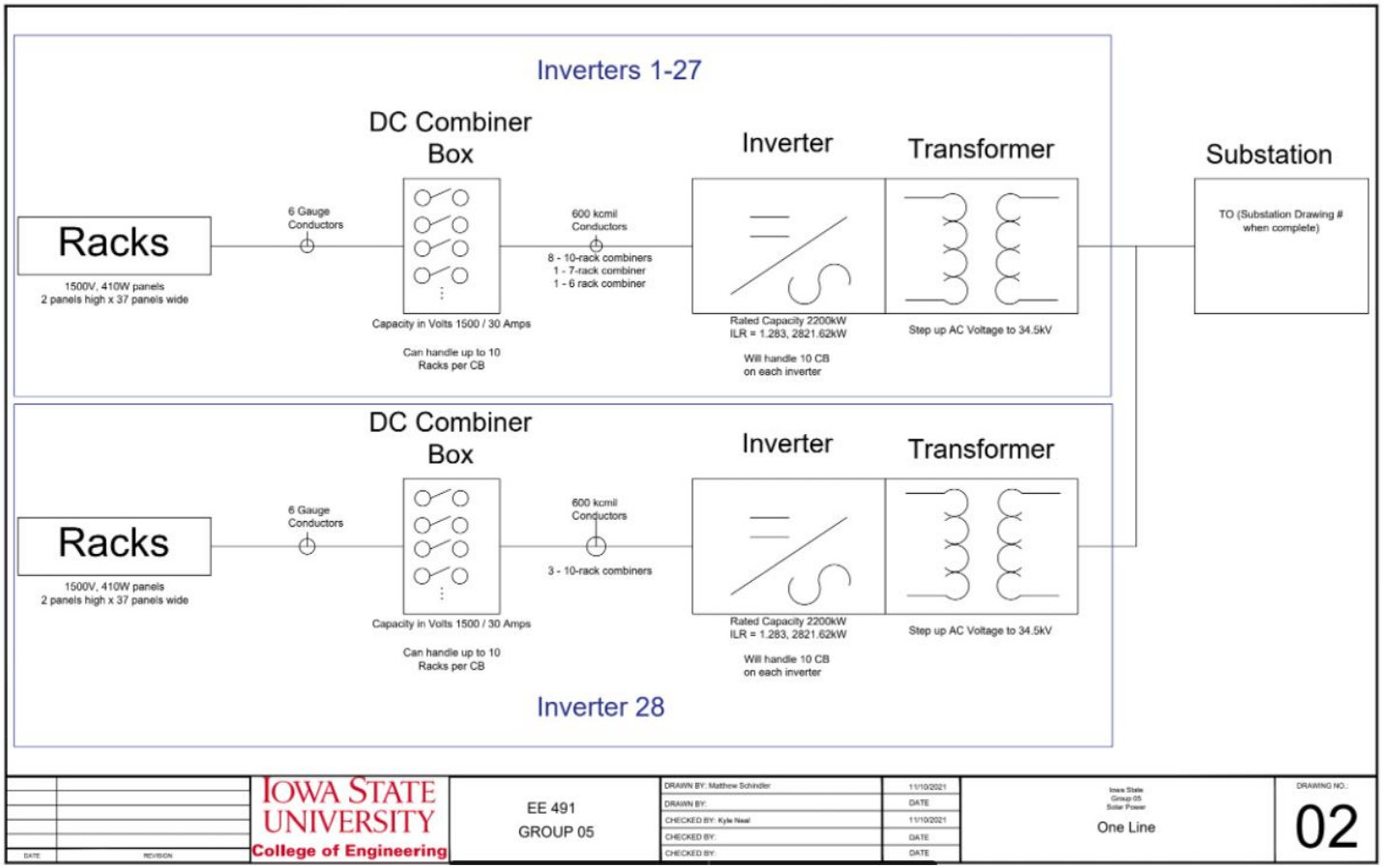
Combiner Box	Inverter	Racks
Arrays	Array Design	DataSheets
N/A	N/A	N/A

Organization		Company
	DataSheets	
Information on it		Relevancy

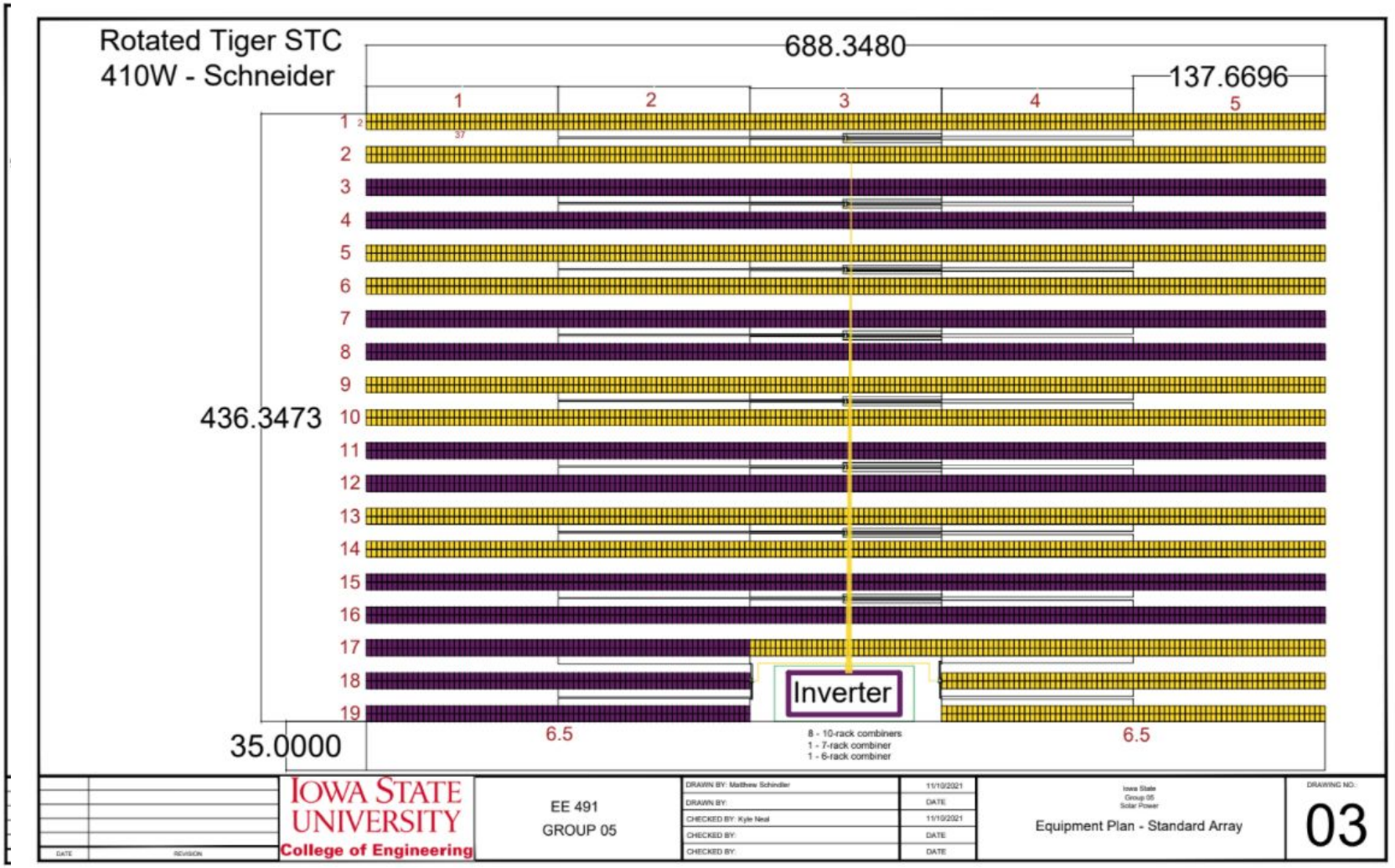


Detailed Design Diagram

Our Design



Prototype Implementations



Design Complexity

- Understanding of new concepts
  - Solar array layouts
  - Trench Fill
    - CAB System
  - Grounding Plans
- Growing Market Availability
  - 3 main components -- Product selection analysis (18 total designs)
- Array Efficiency
  - Most conservative use of space
    - Orientation of rack systems
      - Optimization of WxH can greatly reduce ft^2
      - Tilt
        - Affects Solar Irradiance collected
        - Impacts row spacing
    - Placement of Service Roads
- Cost Analysis
  - Is what we're designing cost effective or costly?
  - Our price estimate: $127,657,177.60

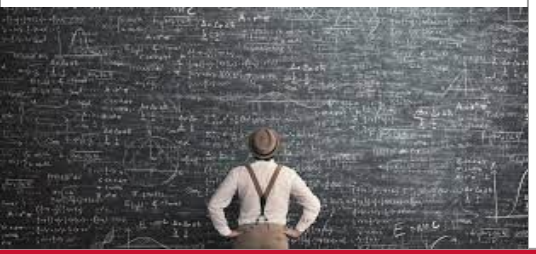
Project Plan - Management Style

Waterfall Management Style

- Four main parts
  - Schedule Management
  - Design Report Management
  - Calculations Management
  - Drawings Management.

- Each Team has a Team Lead
  - Team member will be responsible for delegating work
  - Ensuring quality and timeliness for that part of the project.
    - Gantt chart to track our progress throughout the year.
    - Our project documentation is tracked and organized in a shared google drive.
    - We use discord to set meetings, communicate online, and share research.

Project Plan - Risks and Mitigation

Risks	Issues that Arise	Level of Risk	Mitigation
Mis-timing some of the tasks 	Causes us to unknowingly fall behind schedule.	Low	Ensure we are on track with the assignments, clear any confusion and We constantly check each other's work with our weekly team, client, advisor and TA meetings.
Miscalculations in one of the parameters 	Causes us to deliver incorrect values to our client if this project was executed	Low	We have a large amount of oversight and checks to prevent this.

Project Plan - Tools and Requirements

- Gantt Chart
  - Displayed a good estimate of the amount of time each task will take us.
  - This chart was our guide to aid in the efficiency and accountability of the entire project.
  - Great tool for Black & Veatch to view our progress
- Various programs
  - AutoCad - Software
  - Bluebeam - Software
  - Microsoft Projects
  - Excel
  - PowerPoint

Project Plan - Schedule and Milestones

Project Task Decomposition

Solar Panel String Sizing Design
Initial Equipment Selection
Array Parameter Tool
Select Solar Panels, Inverters, Combiner Boxes
Cable List
Conduit List
Deliverable: Design Report

Equipment Sizing Calculation
Bus Calc
Grounding Calc
Lightning Protection
Ac Calc
Dc Calc
Trench Fill
Cable Tray Fill
Voltage Drop
Deliverable: Record Of Calculations

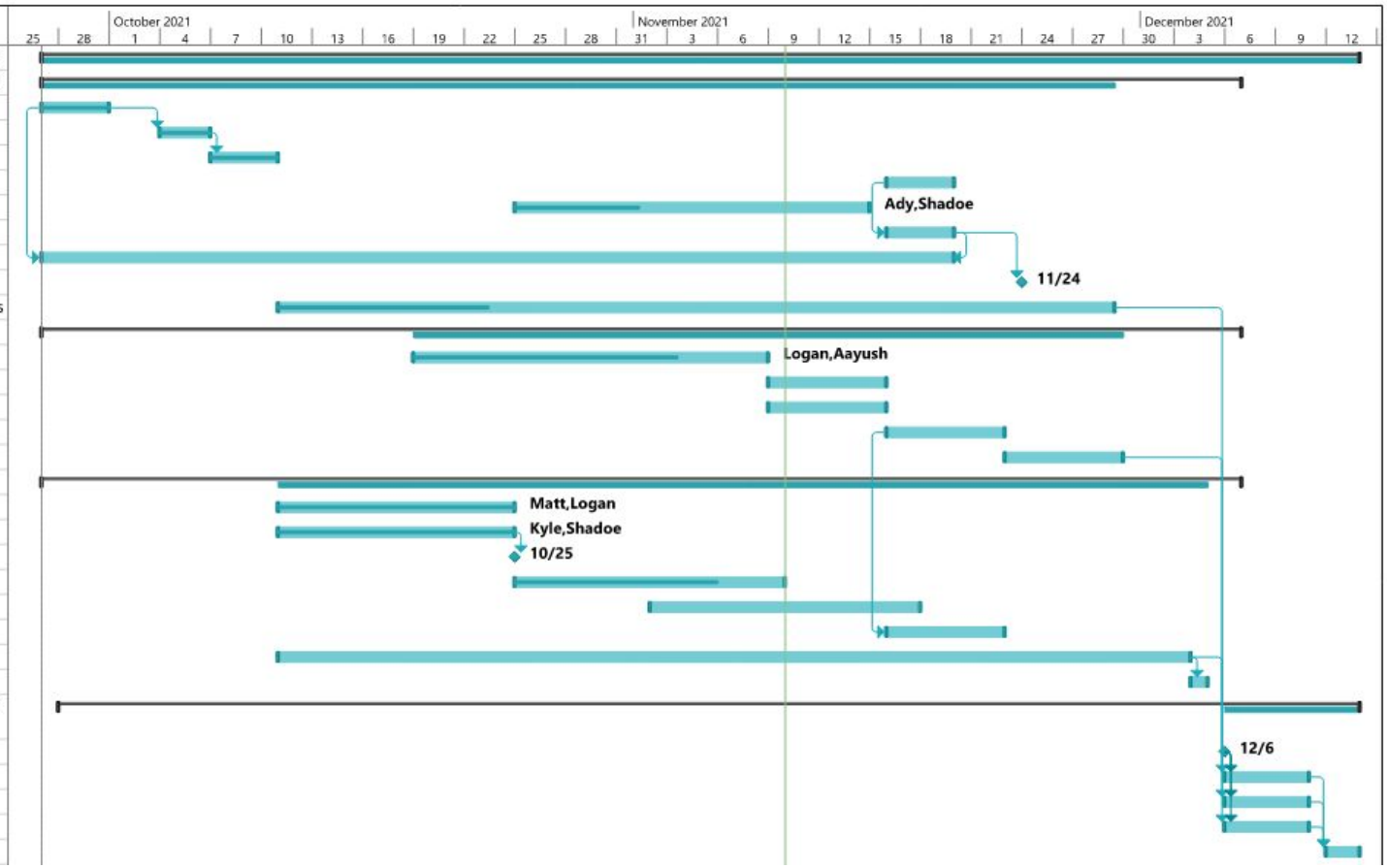
Solar Layout Drawings
grounding plan
key plan
Wiring diagram
DC Schematics
Conduit Plan
Equipment Plan
Elevations
Controls Drawing
Lighting Plan
AC Schematics
One lines
Three lines
Bus Plan
Drawing list
Deliverable: Drawing Package

Project Plan - Schedule and Milestones

- Project task decomposition was used to make Gantt chart and man-hour budget
  - Fall Semester: 175 man-hours
  - Spring Semester: 200 man-hours

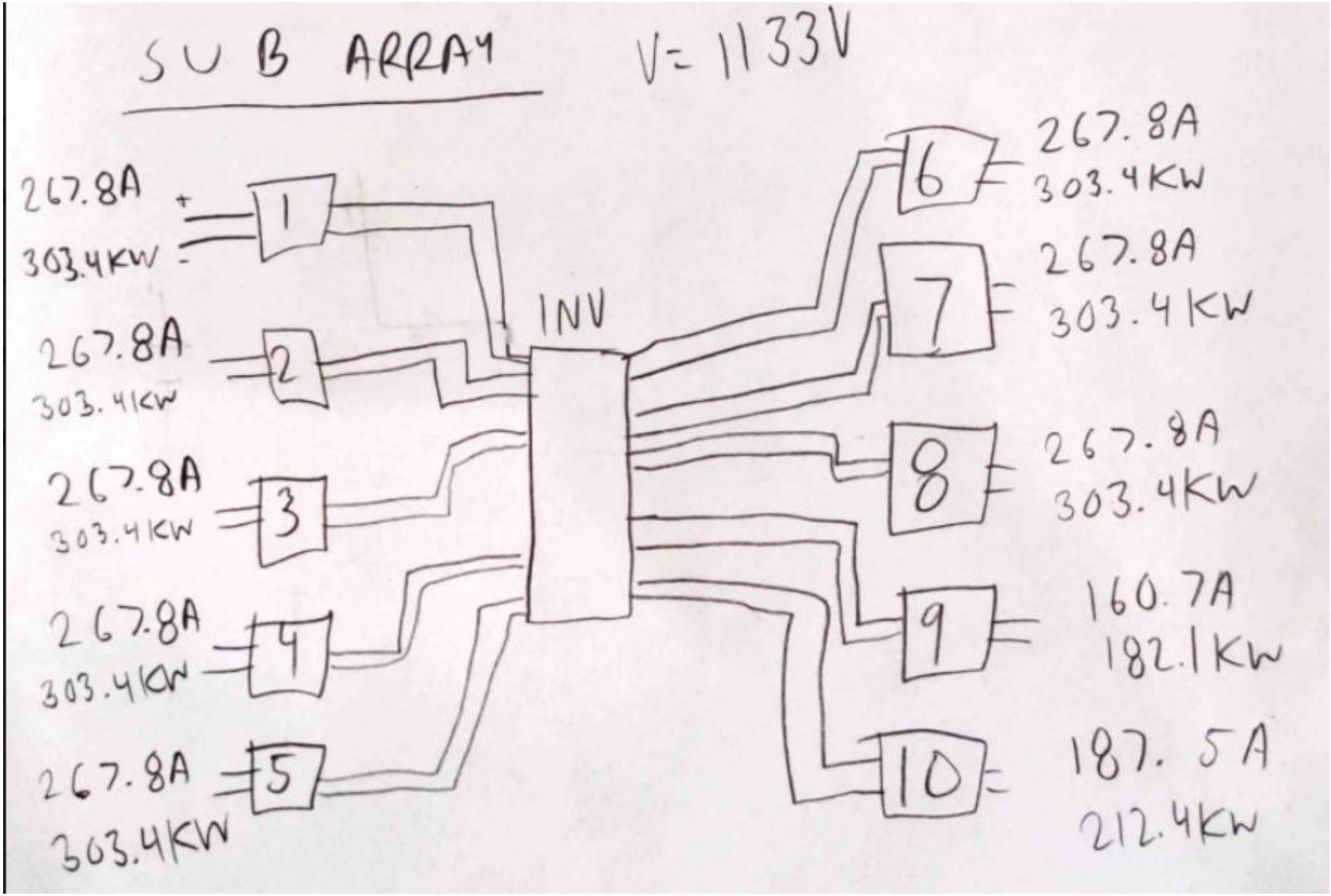
Project Plan - Schedule and Milestones

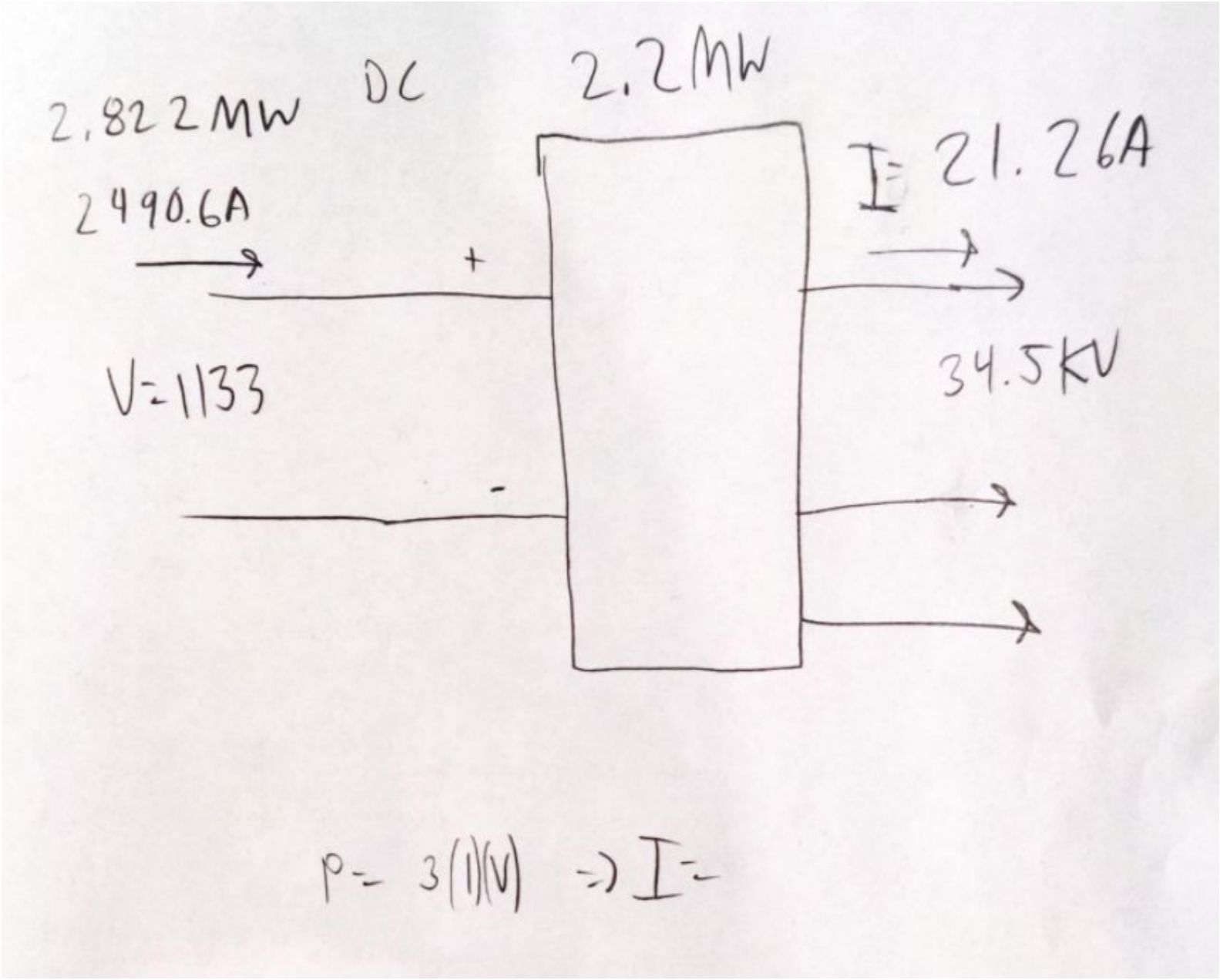
ID	Task Name	Work	Duration
1	**Solar Power Plant Design**	**175 hrs**	**78 days?**
2	**Solar Panel String Sizing Design**	**65 hrs**	**71 days?**
3	Initial Equipment Selection	4 hrs	4 days
4	Array parameter Tool	8 hrs	3 days
5	Select Solar Panels,Inverters, Co	2 hrs	4 days
6	Cable list	4 hrs	4 days
7	Solar Cost Analysis	21 hrs	21 days
8	Conduit list	4 hrs	4 days
9	Bill of Material	6 hrs	54 days
10	Finish cable and conudit list	0 hrs	0 days
11	Draft Report	16 hrs	49.5 days
12	**Equipment Sizing Calculation**	**36 hrs**	**71 days**
13	Voltage Drop	12 hrs	21 days
14	Electrical Ratings	6 hrs	7 days
15	Trench Fill	6 hrs	7 days
16	Lightning Protection	6 hrs	7 days
17	Calculation Summary Report	6 hrs	7 days
18	**Solar Layout Drawings**	**49 hrs**	**71 days**
19	One lines	12 hrs	14 days
20	key plan	12 hrs	14 days
21	Finish Key Plan Drawing	0 hrs	0 days
22	Equipmnent Plan	12 hrs	16 days
23	Elevations	6 hrs	16 days
24	grounding plan	6 hrs	7 days
25	Drawing list	1 hr	54 days
26	Finish Drawing Date	0 hrs	1 day
27	**1st Semester Delvirable Review and Submittal**	**25 hrs**	**77 days?**
28	All First Drafts Complete	0 hrs	0 days
29	Review Report	8 hrs	5 days
30	Review Calcualtions	8 hrs	5 days
31	Review Drawing Packege	8 hrs	5 days
32	Merge Documenets	1 hr	2 days



Test Plan

- Testing for this project means using quality management to ensure that designs will work as intended
- Review Procedure:
  1. Drawings and Calculations reviewed internally by team members
  2. Drawings and calculation sent to client and advisor for review
  3. Fix errors and incorporate feedback into updated design
- Example: Hand Calculations


SUB ARRAY
V= 1133V
267.8A
303.4KW
+
-
1
267.8A
303.4KW
2
267.8A
303.4KW
3
267.8A
303.4KW
4
267.8A
303.4KW
5
INV
6
267.8A
303.4KW
7
267.8A
303.4KW
8
267.8A
303.4KW
9
160.7A
182.1KW
10
187.5A
212.4KW

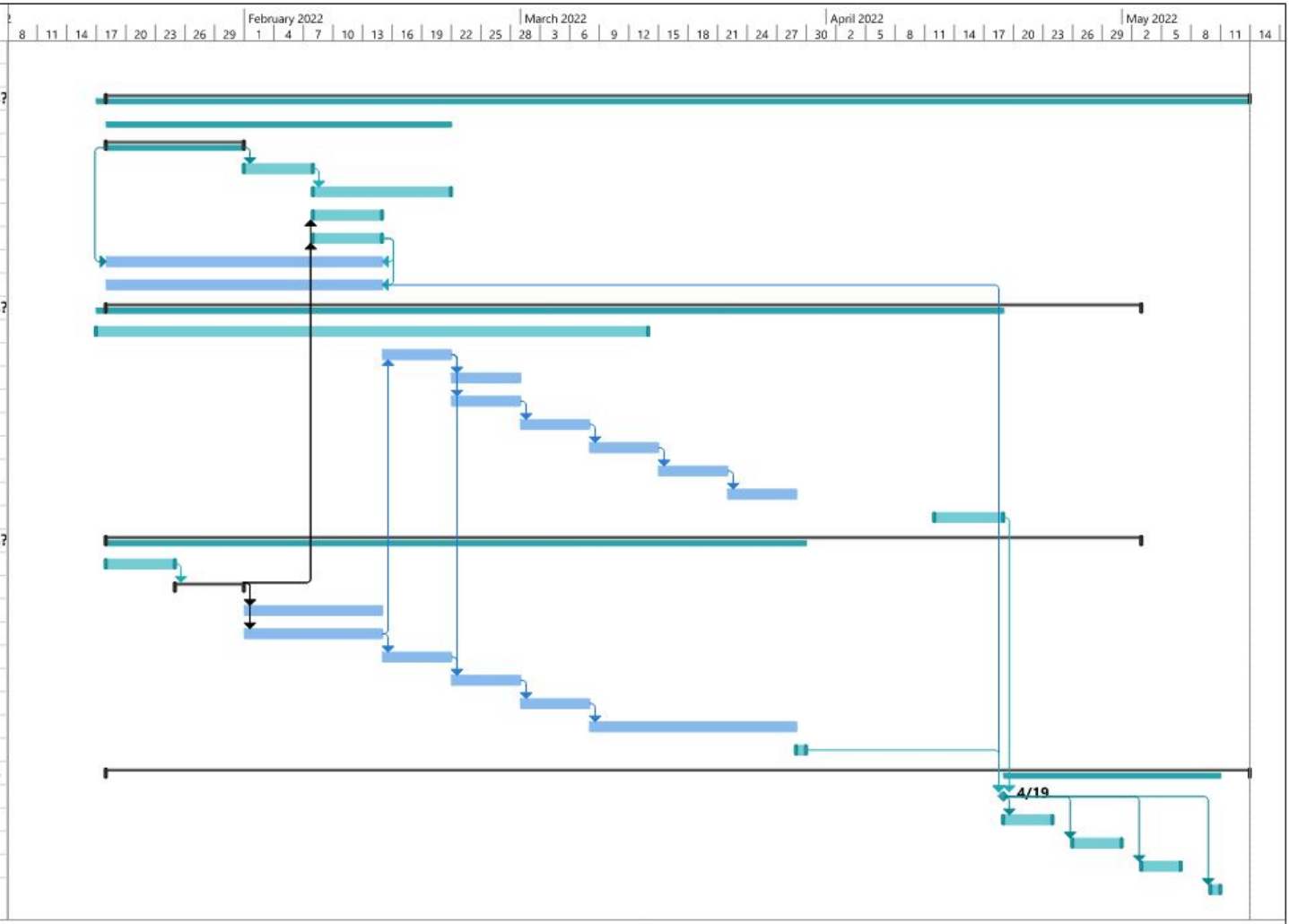

2.822MW
DC
2.2MW
2490.6A
I=21.26A
+
V=1133
34.5KV
-
P=3(I)(V) => I=

Conclusion

- Fall 2021 Schedule
  - In accordance with canvas and our client Black & Veatch we are ahead of schedule
    - Could potentially begin second semester material
    - Client schedule and Finals Week didn't allow for us to start
- Spring 2022 Plan
  - Completed Next semester’s gantt chart
  - Plan to start Transformer calculations and design to allow for our solar array to be connected to the grid
  - Re-distribute Individual roles to best suit the team’s goal

Second Semester Gantt Chart

ID	Task Name	Work	Duration
1	**Solar Power Plant Design**	**175 hrs**	**78 days?**
33	**EE 491 Canvas Weeklys**	**94.5 hrs**	**63 days**
43	**Substation Design**	**200 hrs**	**116 days?**
44	**Substation Planning**	**60 hrs**	
45	**Equipment selection**	**16 hrs**	**14 days?**
54	Bus Design	8 hrs	7 days
55	Control House Design	8 hrs	14 days
56	Conduit List	4 hrs	7 days
57	Cable List	4 hrs	7 days
58	Bill of Materials	4 hrs	28 days
59	Draft Report	16 hrs	28 days
60	**Calculations**	**62 hrs**	**105 days?**
61	Bus Calc (Tentative)	12 hrs	56 days
62	Grounding Calc	6 hrs	7 days
63	AC Calc	6 hrs	7 days
64	DC Calc	6 hrs	7 days
65	Voltage Drop	6 hrs	7 days
66	Lightning Protection	6 hrs	7 days
67	Trenchfill	6 hrs	7 days
68	Cable Tray Fill	6 hrs	7 days
69	Draft Calculation Report	8 hrs	7 days
70	**Drawings**	**52 hrs**	**105 days?**
71	Bus Plan	0 hrs	7 days
72	**Key Plan**	**14 hrs**	**7 days**
75	One Lines	6 hrs	14 days
76	Three Lines	6 hrs	14 days
77	Elevations	6 hrs	7 days
78	Grounding Plan	6 hrs	7 days
79	Lighting Plan	6 hrs	7 days
80	Controls Drawing	6 hrs	21 days
81	Drawing List	2 hrs	1 day
82	**Review and Submittal**	**26 hrs**	**116 days**
83	All First Drafts Complete	0 hrs	0 days
84	Review Report	8 hrs	5 days
85	Review Calcualtions	8 hrs	5 days
86	Review Drawing Packege	8 hrs	4 days
87	Merge Documenets and Submit	2 hrs	1 day



Project: Project Schedule Fall 20
Date: Wed 11/10/21

Task | Split | Milestone | Summary | Project Summary | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | External Tasks | External Milestone | Deadline | Progress | Manual Progress

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References

- "2021 electricity rates by state (updated July 31, 2021)," *Payless Power*, 31-Jul-2021. [Online]. Available: https://paylesspower.com/blog/electric-rates-by-state/. [Accessed: 2021].
- A. Diehl, "Determining module inter-row spacing," *CED Greentech*, Mar-2020. [Online]. Available: https://www.cedgreentech.com/article/determining-module-inter-row-spacing. [Accessed: Sep-2021].
- B. Ludt, "What is a solar tracker, how does it work, and how many types are there?," *Solar Power World*, 16-Jan-2020. [Online]. Available: https://www.solarpowerworldonline.com/2020/01/what-is-a-solar-tracker-and-how-does-it-work/. [Accessed: 2021].
- C. Lane, "What is a solar tracker and is it worth the investment?," *Solar Reviews*, 02-Jan-2021. [Online]. Available: https://www.solarreviews.com/blog/are-solar-axis-trackers-worth-the-additional-investment. [Accessed: 2021].
- "DC-Combiner Box," 2021. [Online]. Available: https://kaco-newenergy.com/index.php?eID=dumpFile&t=f&f=8198&token=abf0049c8de689975ec47671c032d182cfa9c947. [Accessed: 2021].
- "Electricity bills by State Monthly Report: Saveonenergy.com®," *Save On Energy Blog*, 05-Nov-2021. [Online]. Available: https://www.saveonenergy.com/learning-center/post/electricity-bills-by-state/. [Accessed: 2021].
- "New Mexico," *Global Solar Atlas*. [Online]. Available: https://globalsolaratlas.info/detail?c=34.218616%2C-106.026306%2C8&r=USA%3AUSA.32_1. [Accessed: Sep-2021].
- P. Grana, "What DC to AC inverter load ratio is ideal for your application?," *Solar Power World*, 08-Jul-2016. [Online]. Available: https://www.solarpowerworldonline.com/2016/07/solar-inverters-clipping-dcac-inverter-load-ratio-ideal/. [Accessed: Sep-2021].
- "PV Skid." [Online]. Available: https://solar.schneider-electric.com/wp-content/uploads/2015/06/pv-skid-datasheet-20160826.pdf. [Accessed: 2021].
- "Sunshine & Daylight Hours in Albuquerque, New Mexico, USA," *Sunshine & Daylight Hours in Albuquerque, New Mexico, Usa Sunlight, Cloud & Day length*. [Online]. Available: http://www.albuquerque.climatemps.com/sunlight.php#:~:text=There%20is%20an%20average%20of,sunny%2078.9%25%20of%20daylight%20hours. [Accessed: 2021].
- "Tiger Pro 54HC 395-415 Watt Mono-Facial Module," 2020. [Online]. Available: https://jinkosolarcdn.shwebspace.com/uploads/JKM395-415M-54HL4-(V)-EN-F2.1.pdf. [Accessed: 2021].