115/34.5 kV Solar Power Plant & Substation

Elymus Schaffer - ***Team Lead***
Baylor Clark - ***Team Organizer***
Liam Gossman - ***Client Correspondent***
Eduardo Jimenez-Tzompaxtle - ***Submission, Research, and Testing Leader***
Siti Mohd Radzi - ***Recorder and Testing***
Chicheng Tang - ***Research and Testing Leader***

Client- Black & Veatch: Adam Schroeder, Michael McDonald
Project Advisor- Dr. Venkataramana Ajjarapu
Faculty Advisor - Dr. Akhilesh Tyagi

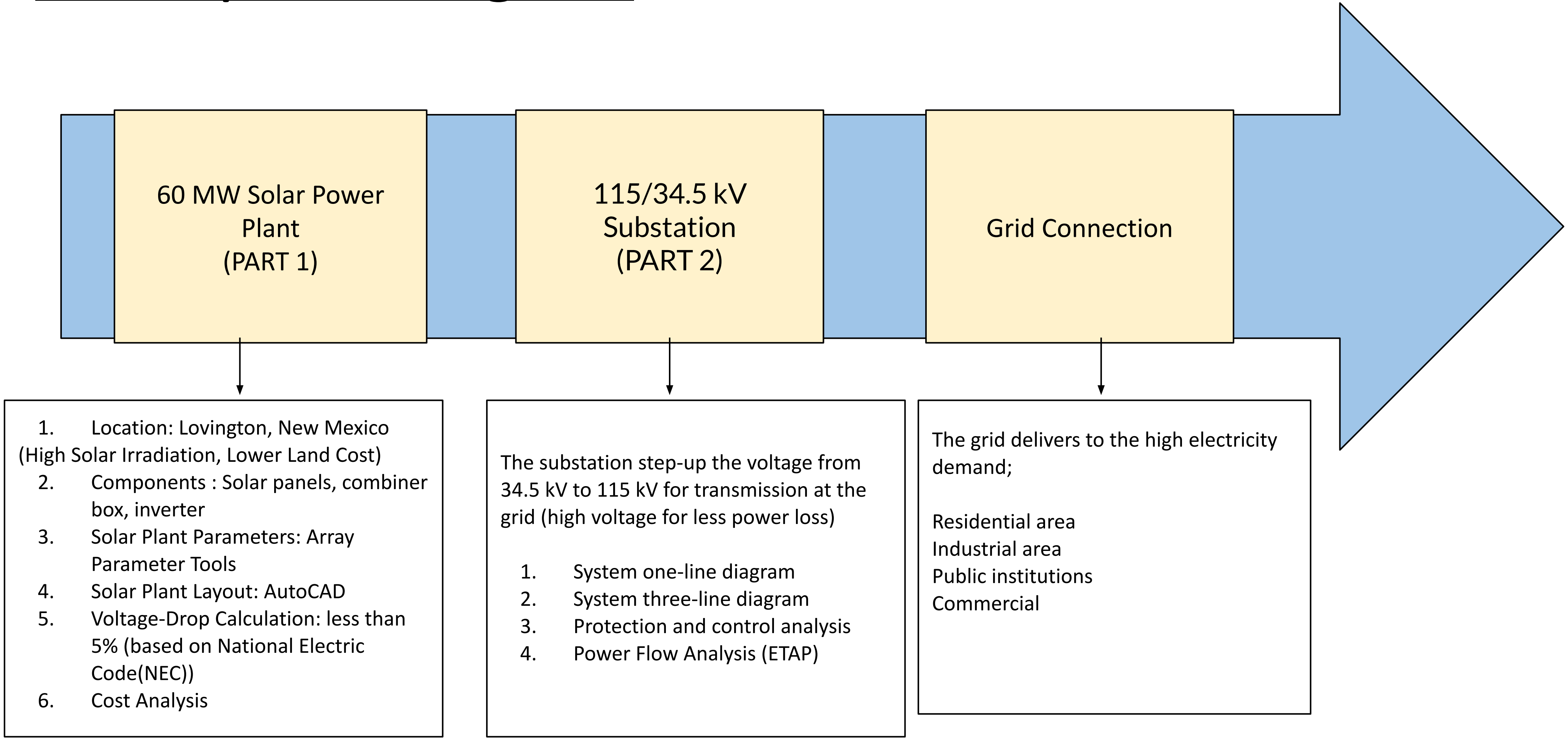
BLACK & VEATCH

STATE

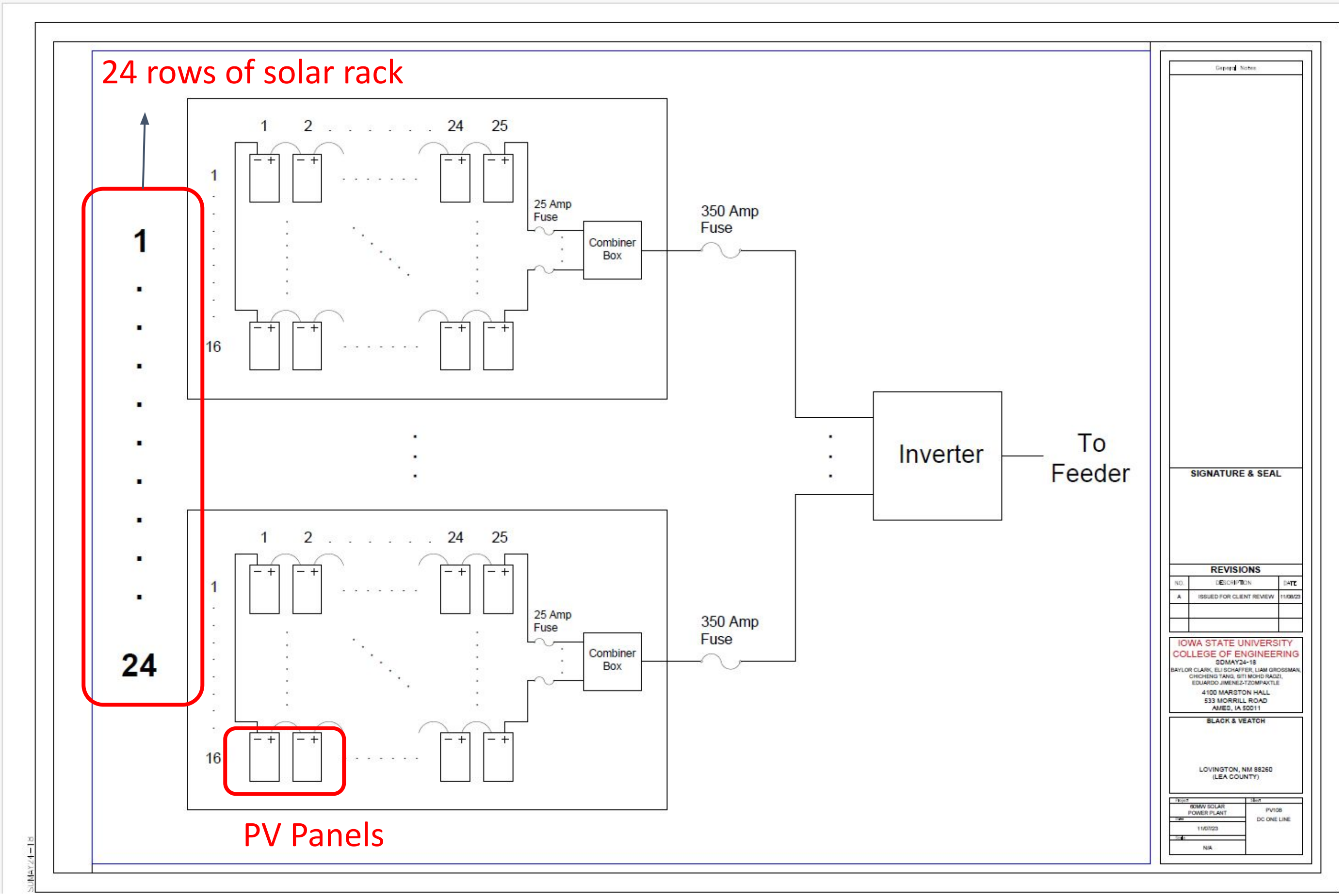
Project Vision

- Our project is to design a 60 MW solar farm as well as a 115/34.5 kV substation to go along with it.
- Our solar farm would be used by people in New Mexico as well as Texas because we would connect it to the power grid (SPP interconnection).
- Our project location is located on the border of New Mexico and Texas, northeast of Lovington, NM.

Conceptual Diagram



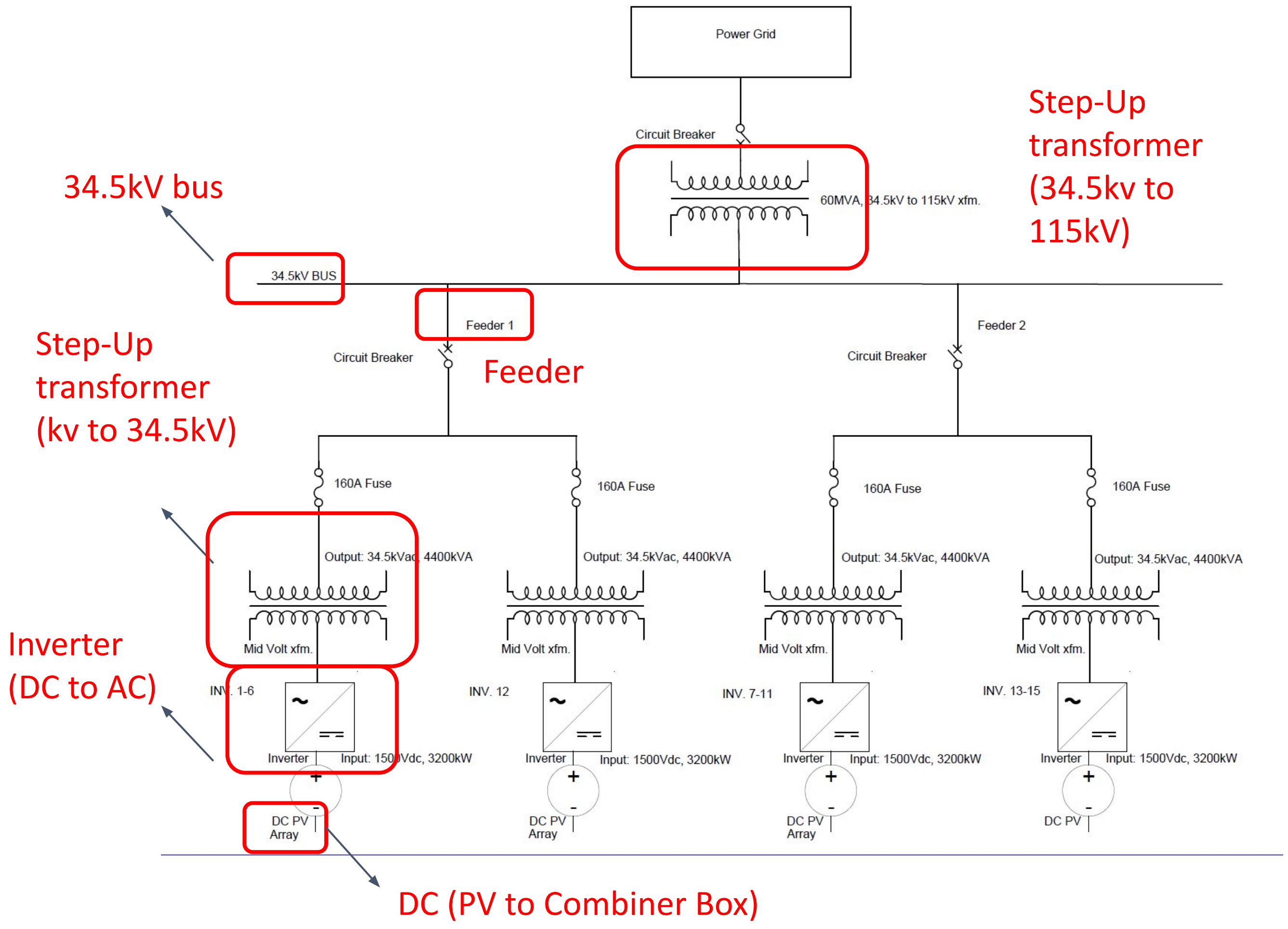
Overview of Solar Power Plant - 60MW



1 array of solar panels

In a 60 MW solar farm, the solar panels connected in series for a string, to the total voltage of the string. Then, they are connected parallel into racks connected to the combiner box. The combiner box combines the power to the inverter, inverted into AC electricity. The inverter includes skids, where the power will be step-up to 34.5kV, before carried to the feeder to the substation.

Overview of Substation- 115/34.5kV



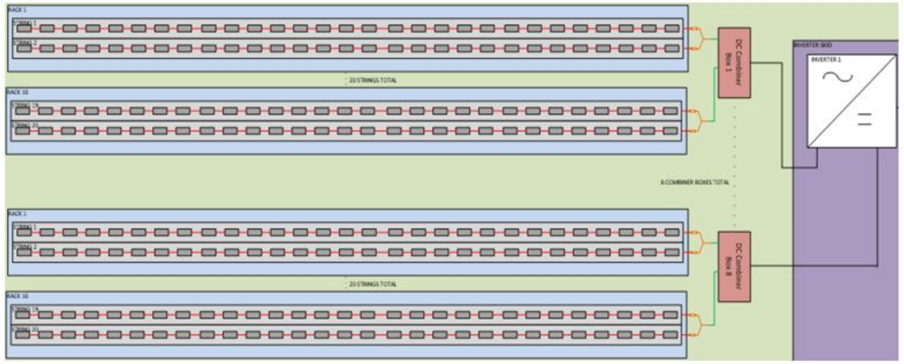
Direct current converted to alternating current (AC) by inverters and then boosted by step-up transformers within the solar plant, raising it to 34.5 (kV). The electricity travels through transmission lines to a substation, where another step-up transformer boosts the voltage further to 115 kV. This elevated voltage is suitable for seamless integration into the broader electrical grid. The electricity is fed into the grid, facilitating its distribution to various consumers, including homes and businesses. The step-up transformers ensure efficient transmission of power across the grid.

The circuit diagram to the left shows an overview of a typical substation circuit. This shows a 115/34.5kV system and transformer.

Requirements- Functional

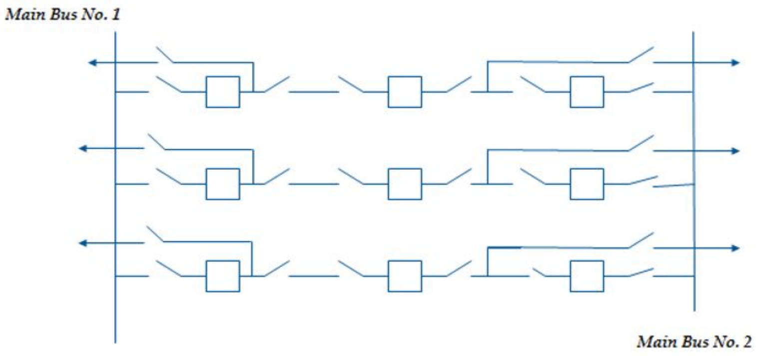
First Semester (Fall 2023)

- Research and select components
- Calculate equipment parameters, sizing, and layout
- Calculate voltage drops up to the substation
- Create solar layout drawings in AutoCAD
- Simulate solar farm in ETAP



Second Semester (Spring 2024)

- Research and select substation equipment
- Calculate equipment parameters, sizing, and layout
- Perform fault/grounding analysis
- Create substation drawings in AutoCAD/BlueBeam
- Simulate power flow of the overall system



Requirements- Non-Functional

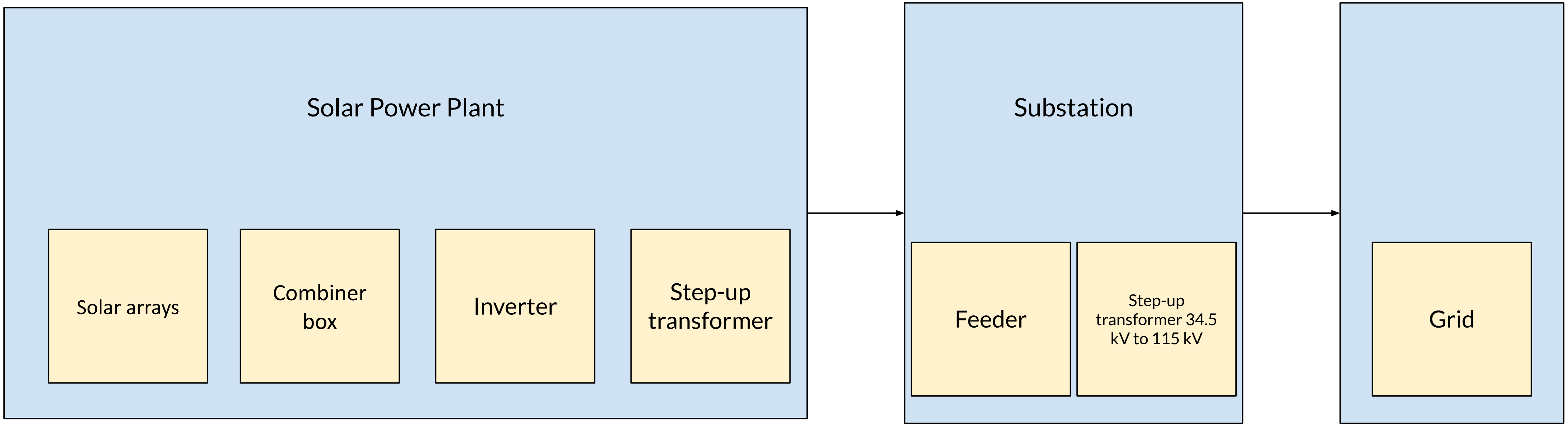
Environmental

- Flat and continuous land
- High annual sunshine and irradiance
- Safe substation power for nearby communities
- Efficient land use

Economic

- Our solar plant must be able to produce enough power per year to recover initial investment and operational costs over 10 years.

Components of the design



PV Panels

- 550 W
- 50.2 Voc
- 13.89 Isc

Combiner Boxes

- Supports 1500 VDC
- 16 Inputs
- 1 Output

Inverters

- 1500 VDC Inputs
- Converts DC to AC
- Transformer steps up voltage

Development Standards & Practice

Code	*Standards Description*
NEC690.8(B)	Overcurrent ratings shall not be less than 125% of the max current calculated
NEC690.8(A)	The maximum current shall be the sum of the short-circuit current ratings of the PV modules connected in parallel multiplied by correction multiplier, 125 percent.
NEC690.9	PV system dc circuit and inverter output conductors and equipment must be protected against overcurrent.
NEC 240.6	240.6(A) Fuses and Fixed-Trip Circuit Breakers: The standard ampere ratings for fuses and inverse time circuit breakers shall be considered 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110, 125, 150, 175, 200, 225, 250, 300, 350, 400, 450, 500, 600, 700, 800, 1000, 1200, 1600, 2000, 2500, 3000, 4000, 5000, and 6000 amperes.
NEC 210.19	Voltage drop would be 2% from DC, and 1% from AC side
NEC Table 8 Conductor Properties & NEC AWG Chart	Provides information on conductor properties, including ampacity, insulation types, and other specifications. NEC AWG Chart provides information on the ampacity of conductors based on their size (gauge) and the type of insulation which is crucial for ensuring that the conductors used in electrical installations can safely carry the expected current without overheating.
IEEE-80	Guide for Safety in AC Substation Grounding
Lovington & Lea County Ordinance	The fence, wall or barrier required by [this subsection] shall not be less than eight (8) feet in height with no openings, holes or gaps larger than four (4) inches measured in any direction. Gates and doors opening directly into the area enclosed by a fence, wall or barrier, as required by this section, shall be equipped with a lock to keep the doors or gates securely closed and locked at all times. Tower sites located within industrial yard areas with existing secure fencing of the entire yard may construct secure fencing six (6) feet in height.

Array Parameter Tools

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	
Designer Choice: 600, 1000, 1500, 2000V	string voltage	1500	V
	String size	25.14133	
	string size	25	
	Actual String Voltage	1491.6	
	Input Information =		

Confirm possible with Panel type chosen

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
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

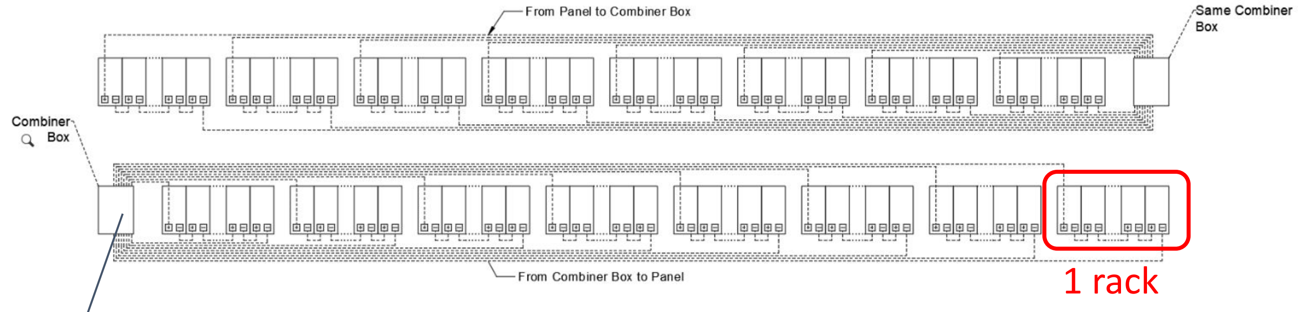
Designer Choice	Racks per row	16	
Designer Choice	rows per Array	24	
Designer Choice	Racks removed	2	
	Total Racks/Array	382	
	Total modules	9550	
Datasheet (STC)	module capacity	550	W
	dc capacity	5252.5	kW
Designer Choice	inverter capacity	4000	kW
		4	MVA
: Industry standard 1.3	ILR	1.313125	

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	0.46358	

System Design - Solar Layout

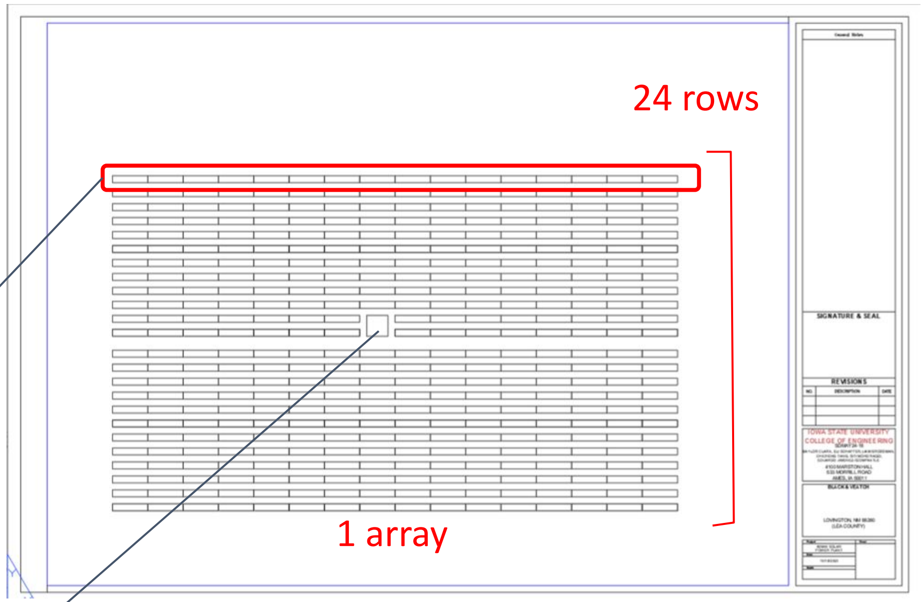
-25 modules
-1 string per rack



Not to Scale

a row of 16 racks

Combiner box



Inverter

1 array layout:

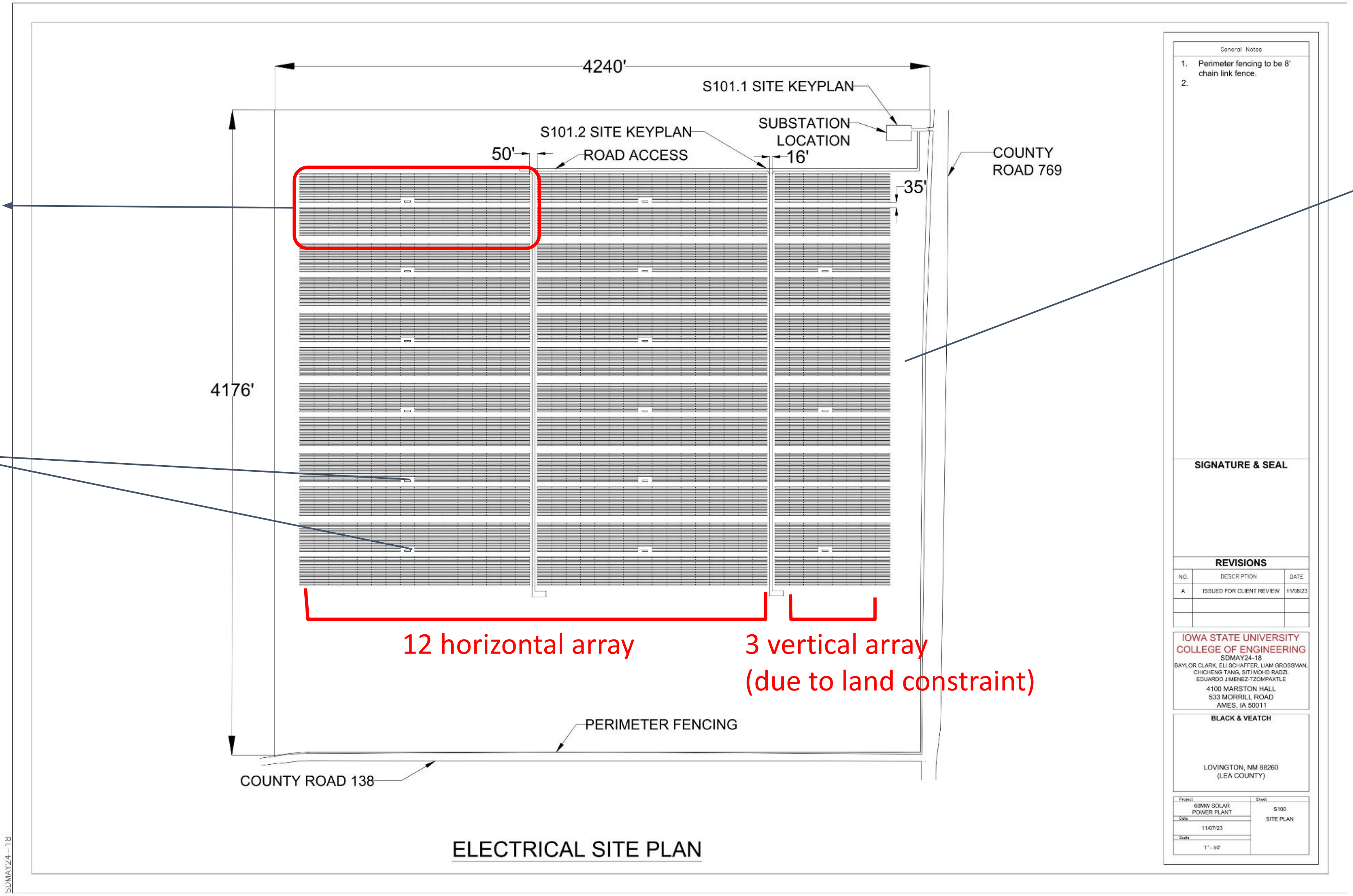
a. One string of 25 series module per rack
b. 16 racks in 1 row (16-input combiner box)
c. 24 rows of racks (24 combiner box)
d. 1 AC inverter

Estimated DC Power Output: 78.79MW
Estimated AC Power Output: 60MW

Conceptual Final Design Diagram

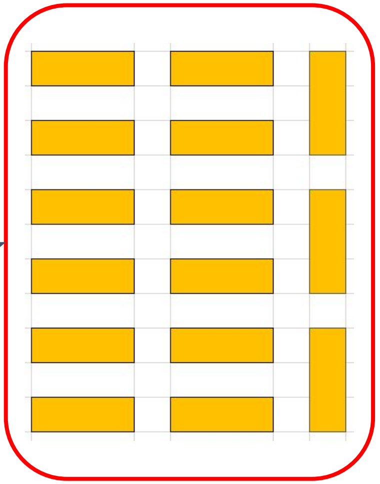
1 horizontal array

Inverter



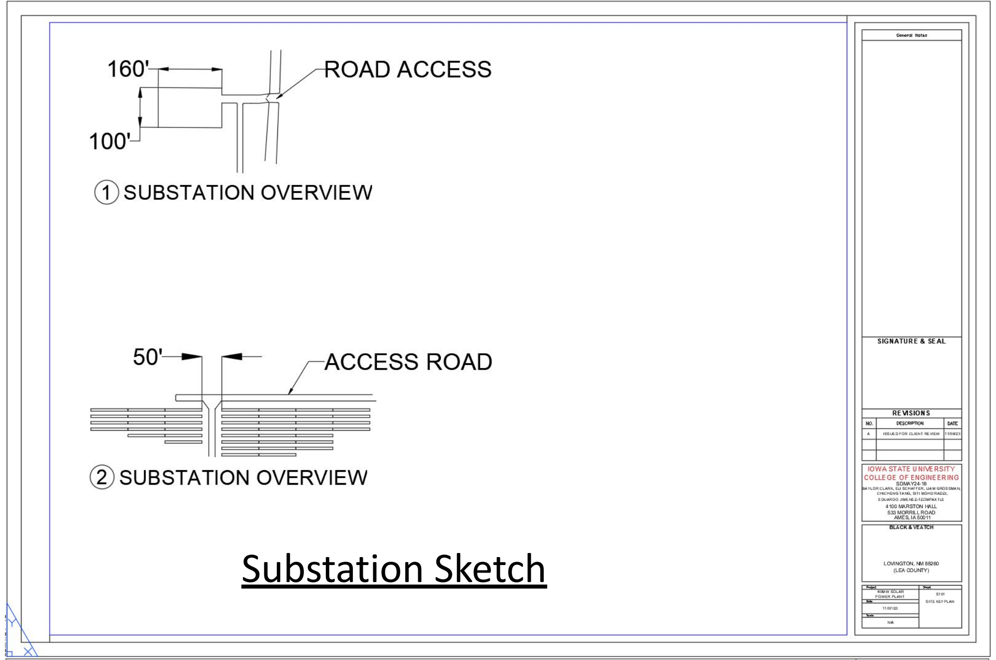
12 horizontal array

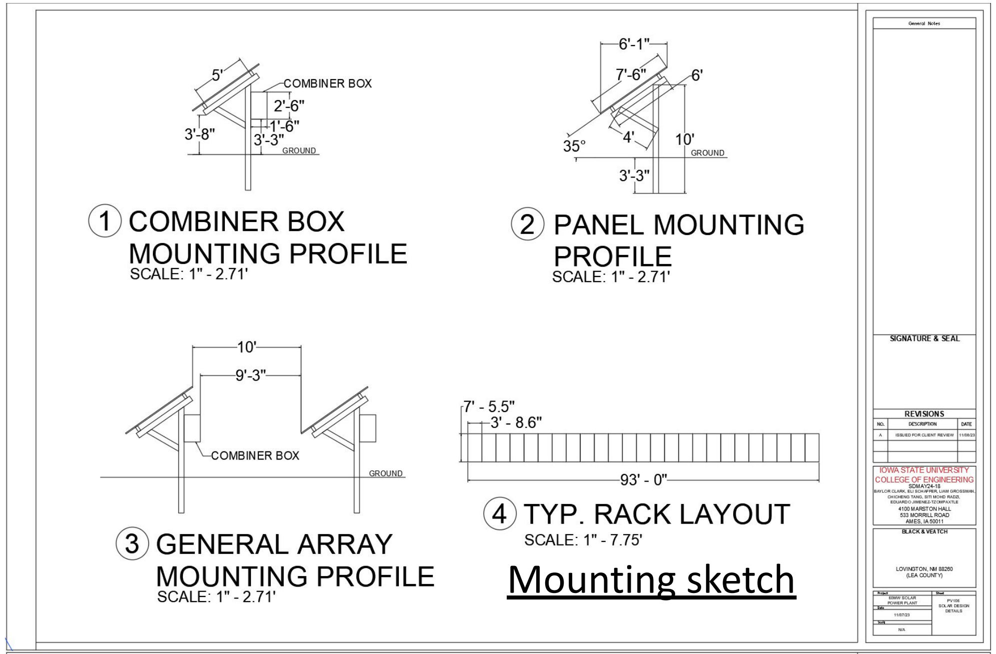
3 vertical array
(due to land constraint)

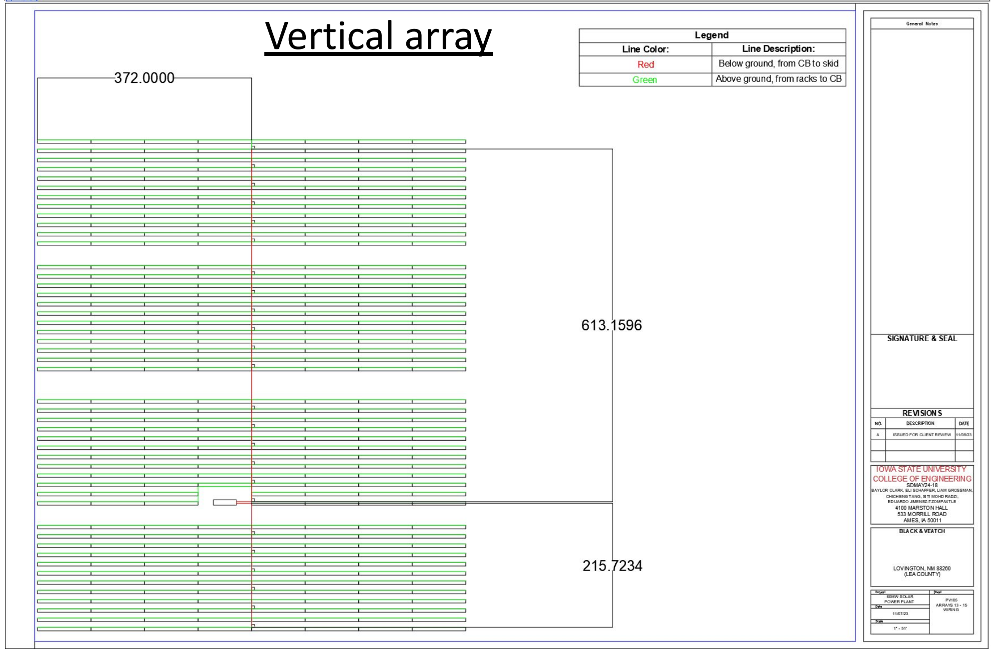


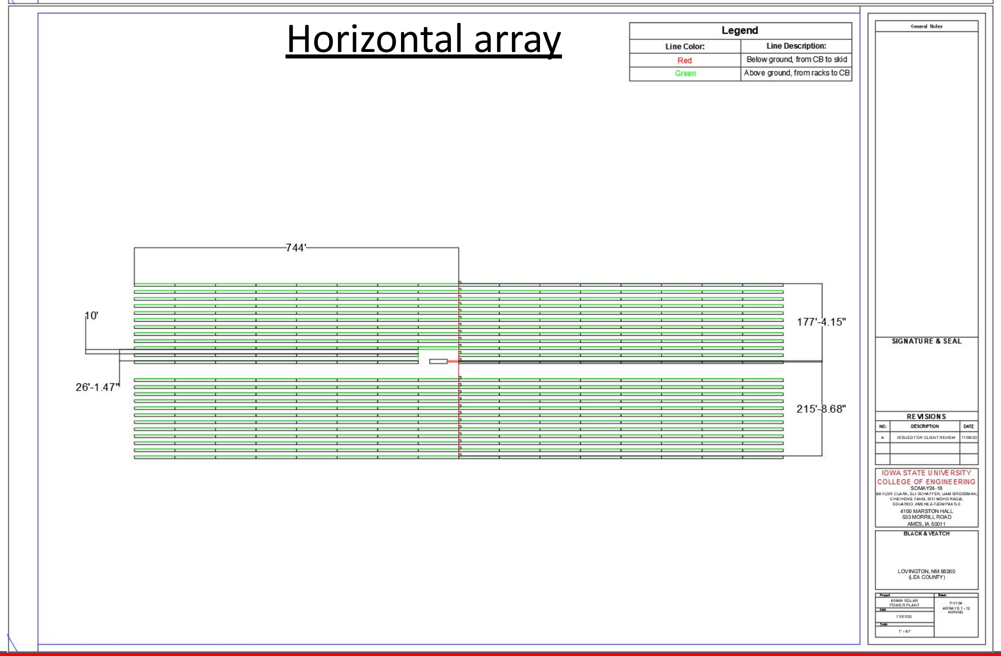
Preview

15 array
15 inverter
406 acres land

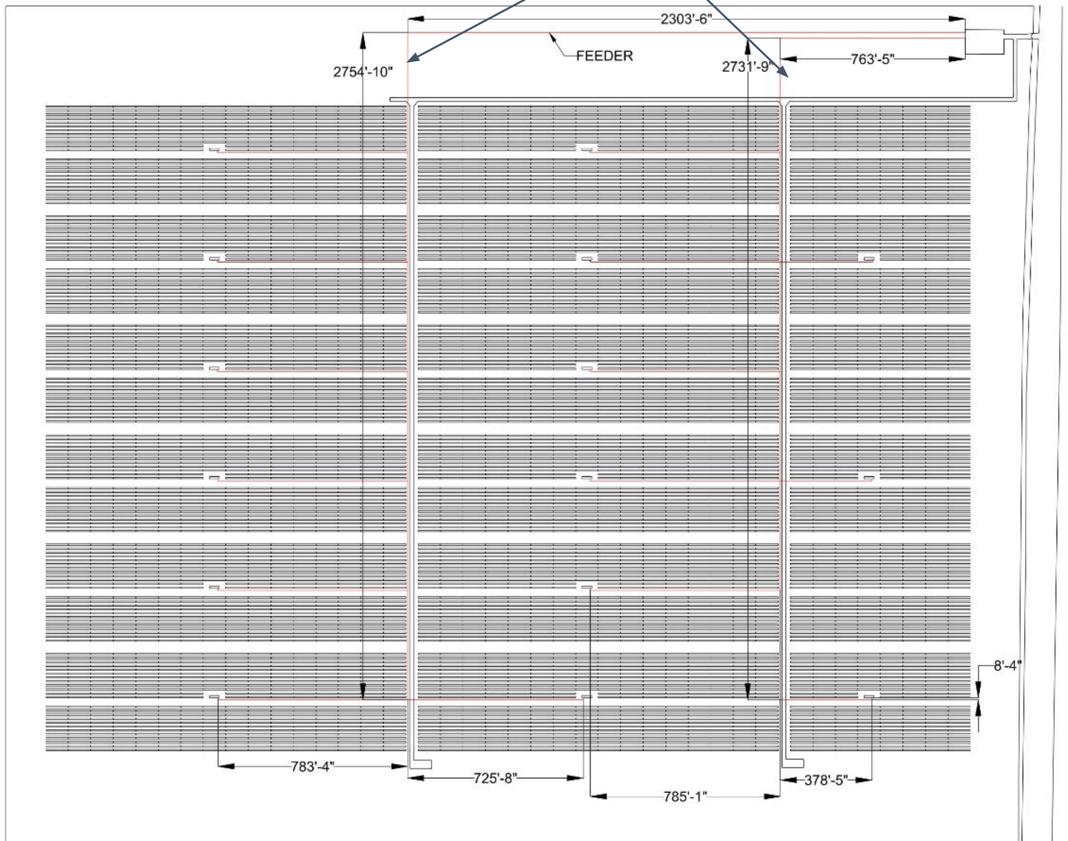

160'
100'
ROAD ACCESS
1 SUBSTATION OVERVIEW
50'
ACCESS ROAD
2 SUBSTATION OVERVIEW
Substation Sketch
SIGNATURE & SEAL
REVISIONS
IOWA STATE UNIVERSITY
COLLEGE OF ENGINEERING
BLACK & VEATCH
LOVINGTON, NM 88260
(LEA COUNTY)


5'
COMBINER BOX
2'-6"
1'-6"
3'-8"
3'-3"
GROUND
1 COMBINER BOX MOUNTING PROFILE
SCALE: 1" - 2.71'
6'-1"
7'-6"
6'
35°
4'
10'
GROUND
3'-3"
2 PANEL MOUNTING PROFILE
SCALE: 1" - 2.71'
10'
9'-3"
COMBINER BOX
GROUND
3 GENERAL ARRAY MOUNTING PROFILE
SCALE: 1" - 2.71'
7' - 5.5"
3' - 8.6"
93' - 0"
4 TYP. RACK LAYOUT
SCALE: 1" - 7.75'
Mounting sketch
SIGNATURE & SEAL
REVISIONS
IOWA STATE UNIVERSITY
COLLEGE OF ENGINEERING
BLACK & VEATCH
LOVINGTON, NM 88260
(LEA COUNTY)


Vertical array
Legend
Line Color: | Line Description:
Red | Below ground, from CB to skid
Green | Above ground, from racks to CB
372.0000
613.1596
215.7234
SIGNATURE & SEAL
REVISIONS
IOWA STATE UNIVERSITY
COLLEGE OF ENGINEERING
BLACK & VEATCH
LOVINGTON, NM 88260
(LEA COUNTY)


Horizontal array
Legend
Line Color: | Line Description:
Red | Below ground, from CB to skid
Green | Above ground, from racks to CB
744'
10'
177'-4.15"
26'-1.47"
215'-8.68"
SIGNATURE & SEAL
REVISIONS
IOWA STATE UNIVERSITY
COLLEGE OF ENGINEERING
BLACK & VEATCH
LOVINGTON, NM 88260
(LEA COUNTY)

2 feedder line



Legend	
Line Color:	Line Description:
Red	Below ground, from skid to substation

FEEDER SITE PLAN

General Notes

SIGNATURE & SEAL

REVISIONS

NO.	DESCRIPTION	DATE
A	ISSUED FOR CLIENT REVIEW	11/08/23

IOWA STATE UNIVERSITY
COLLEGE OF ENGINEERING
SDMAY24-18
BAYLOR CLARK, ELI SCHAFFER, LIAM GROSSMAN, CHICHENG TANG, SITI MOHD RADZI, EDUARDO JIMENEZ-TZOMPAXTLE
4100 MARSTON HALL
533 MORRILL ROAD
AMES, IA 50011

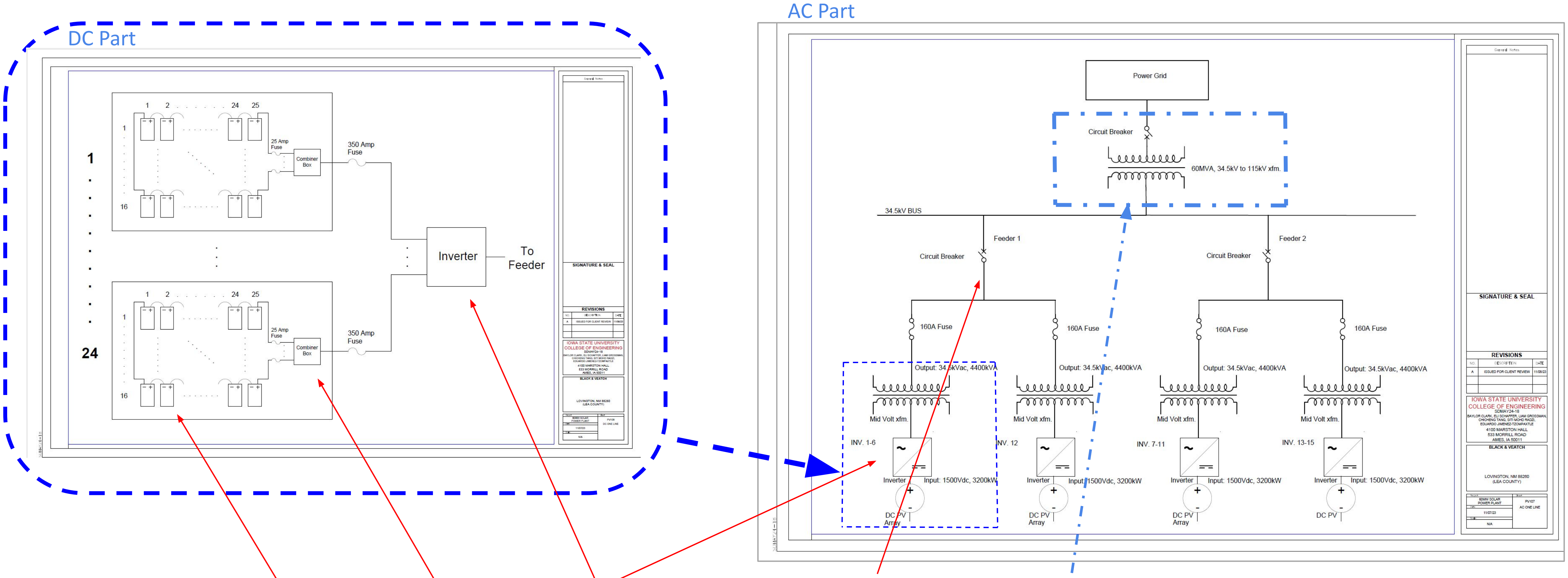
BLACK & VEATCH

LOVINGTON, NM 88260
(LEA COUNTY)

Project	Sheet
60MW SOLAR POWER PLANT	S102 SITE WIRING
Date: 11/07/23	
Scale: 1"-60'	

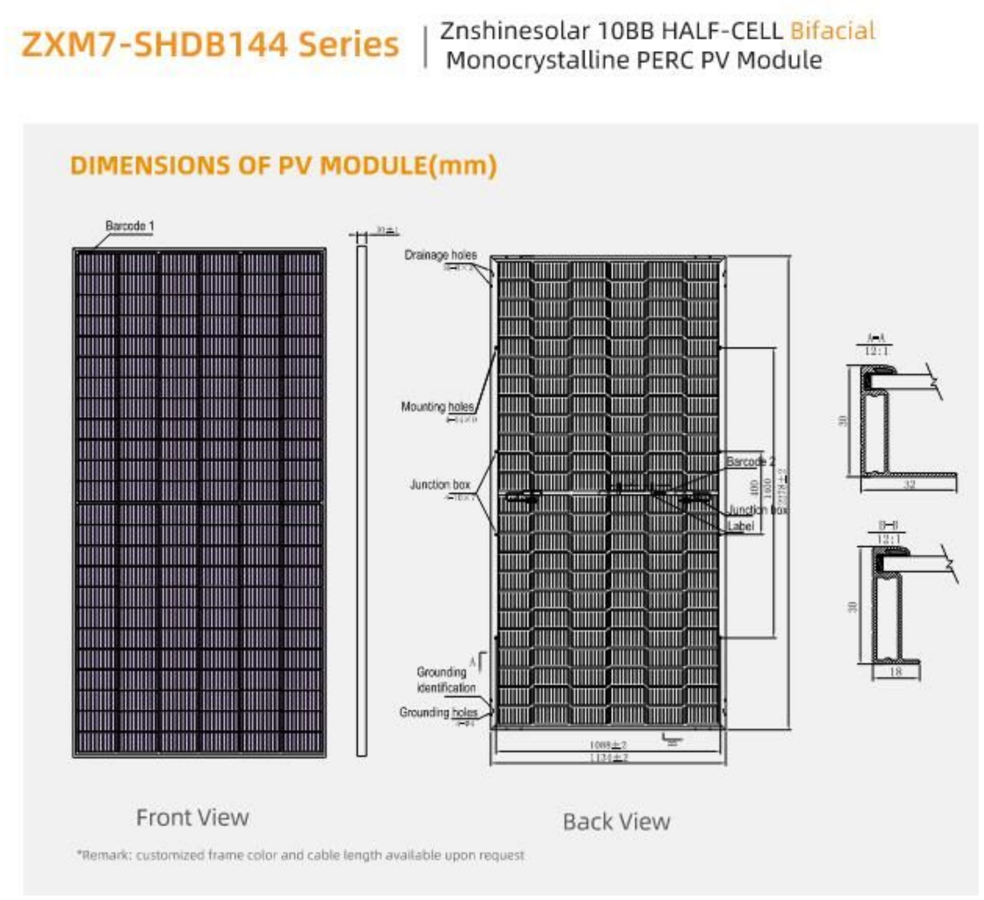
ELI SCHAFFER

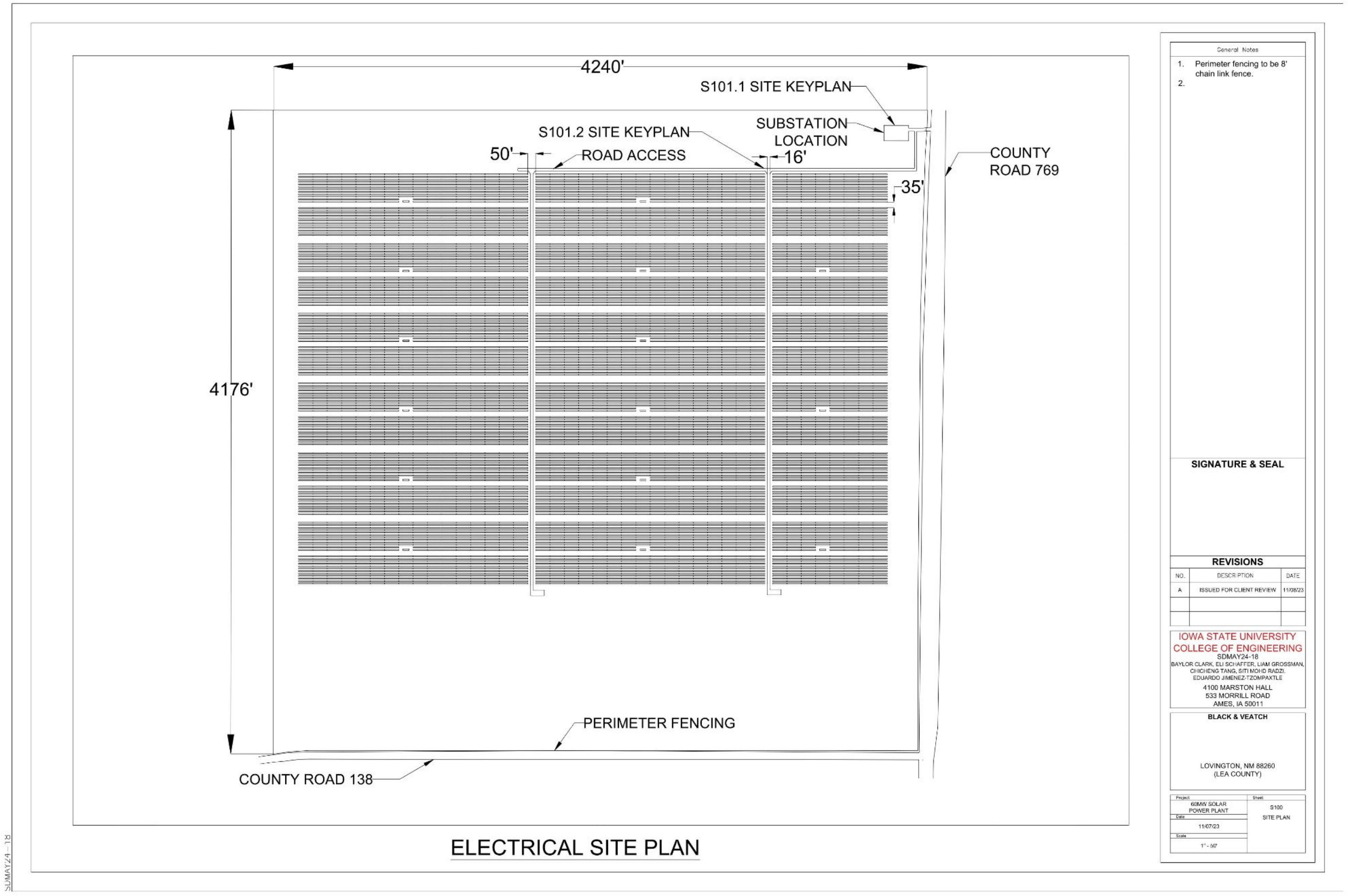
Overall Conceptual/Visual Sketch



Solar panel -> Combiner Box -> Inverter skids (34.5kV) ->Feeder (34.5kV) -> Substation (115kV)(Next semester) -> Grid
(DC convert to AC)

Design Complexity





Project Plan

Lovington Solar Power Information & Peak Sun Hours

Solar Green Energy Summary for Lovington, New Mexico

Lattitude: 32.9457

Sunlight

Fixed Tilt Sunlight Hours: 6.6 hours per day

1-Axis Tilt Sunlight Hours: 7.5 hours per day

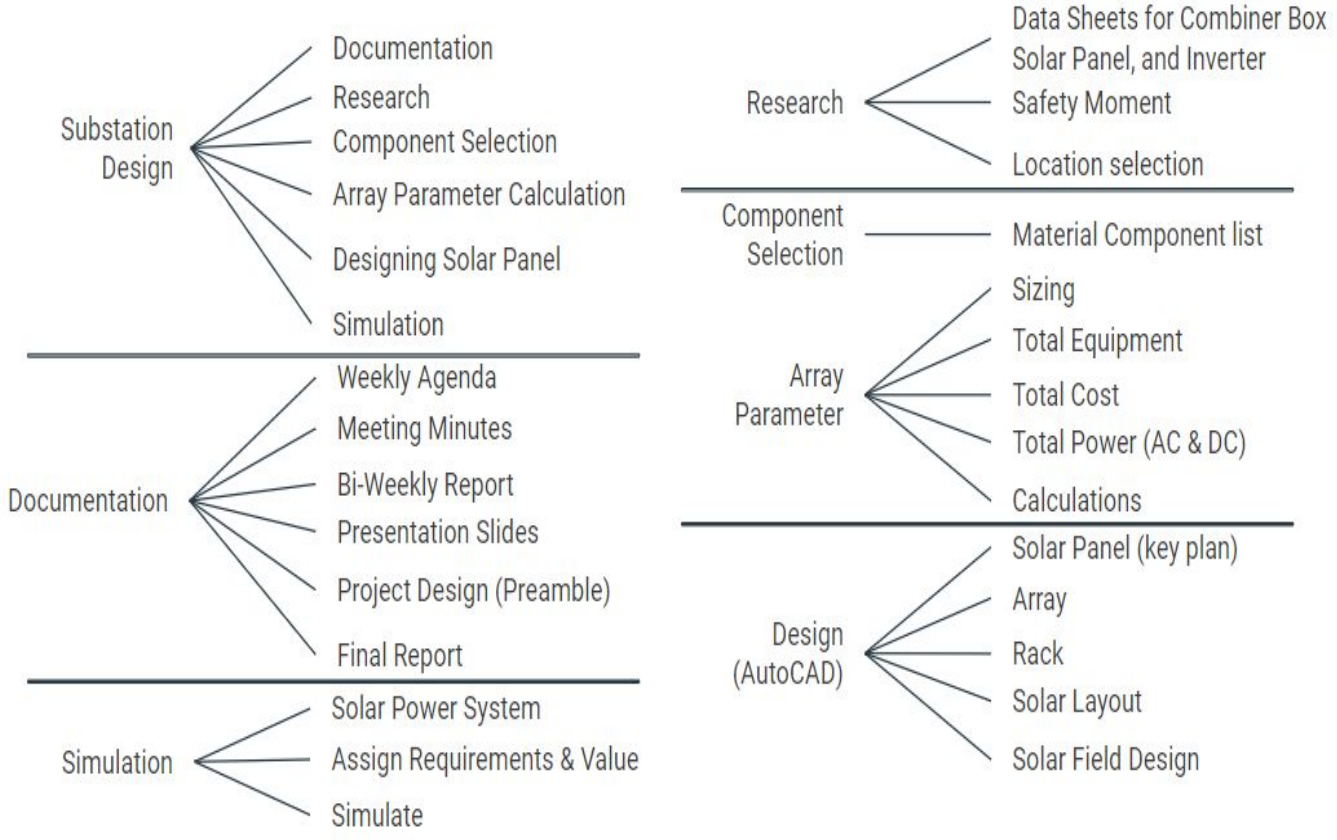
2-Axis Tilt Sunlight Hours: 8.8 hours per day

Realistic average daily solar insolation by month (kWh/m²/day)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2.835	3.592	4.645	5.587	5.932	6.321	5.954	5.503	4.460	3.792	2.885	2.410

Project Plan

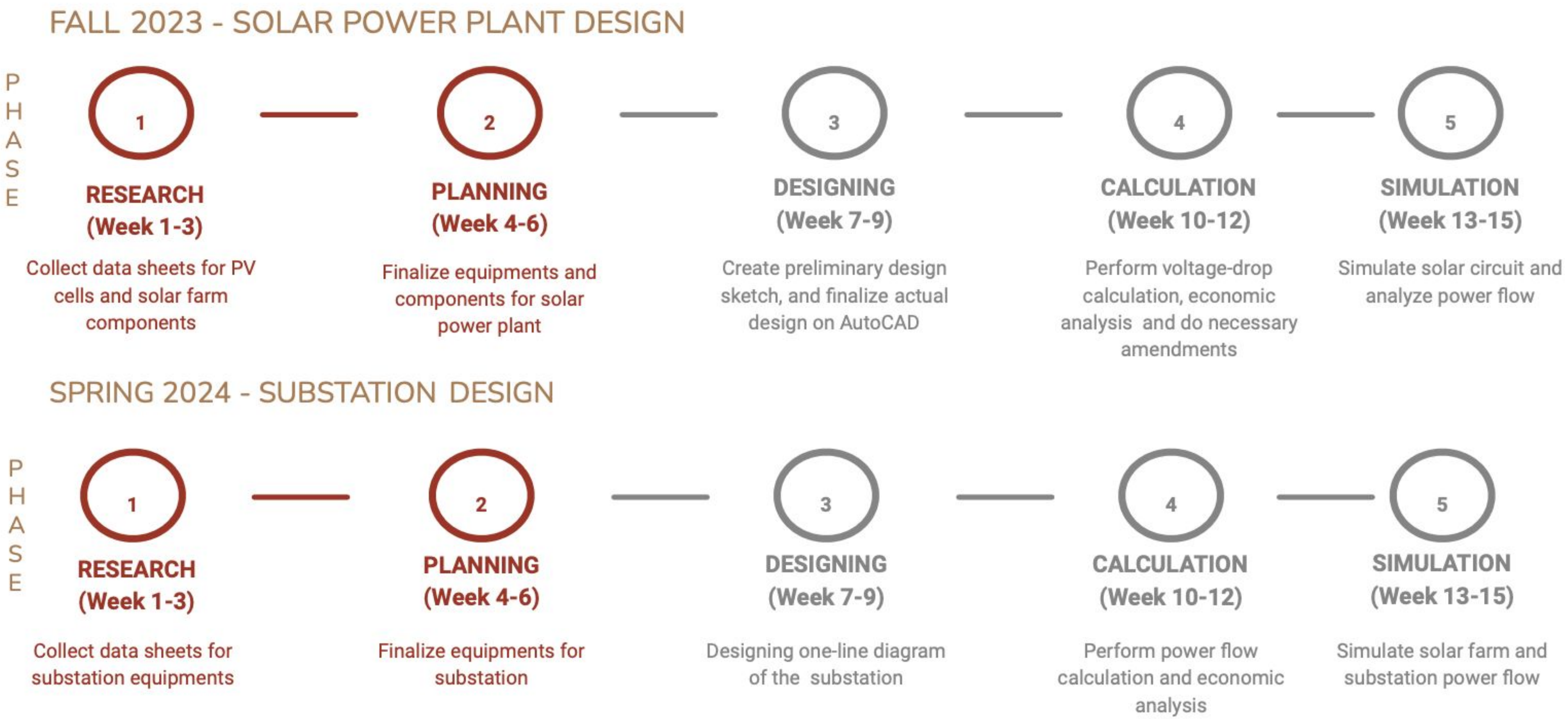
Task Decomposition



Risks and Risk Mitigation

- Electrical code adherence
- Local construction code and law adherence
- Correct electrical calculations for design
- Safety/Grounding
- Financial Risks
- File management and project organization

Project Plan

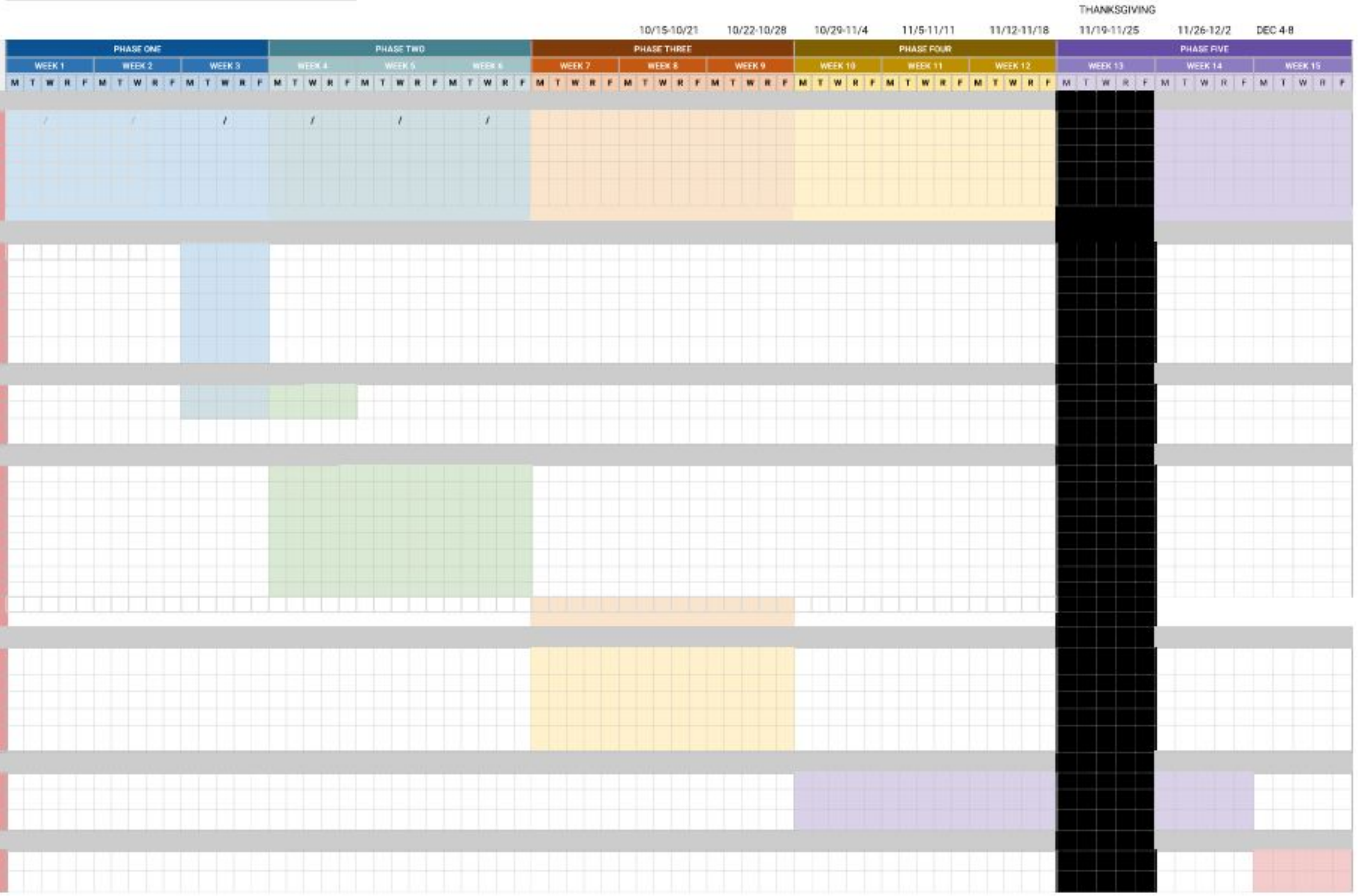


Fall Gantt Chart

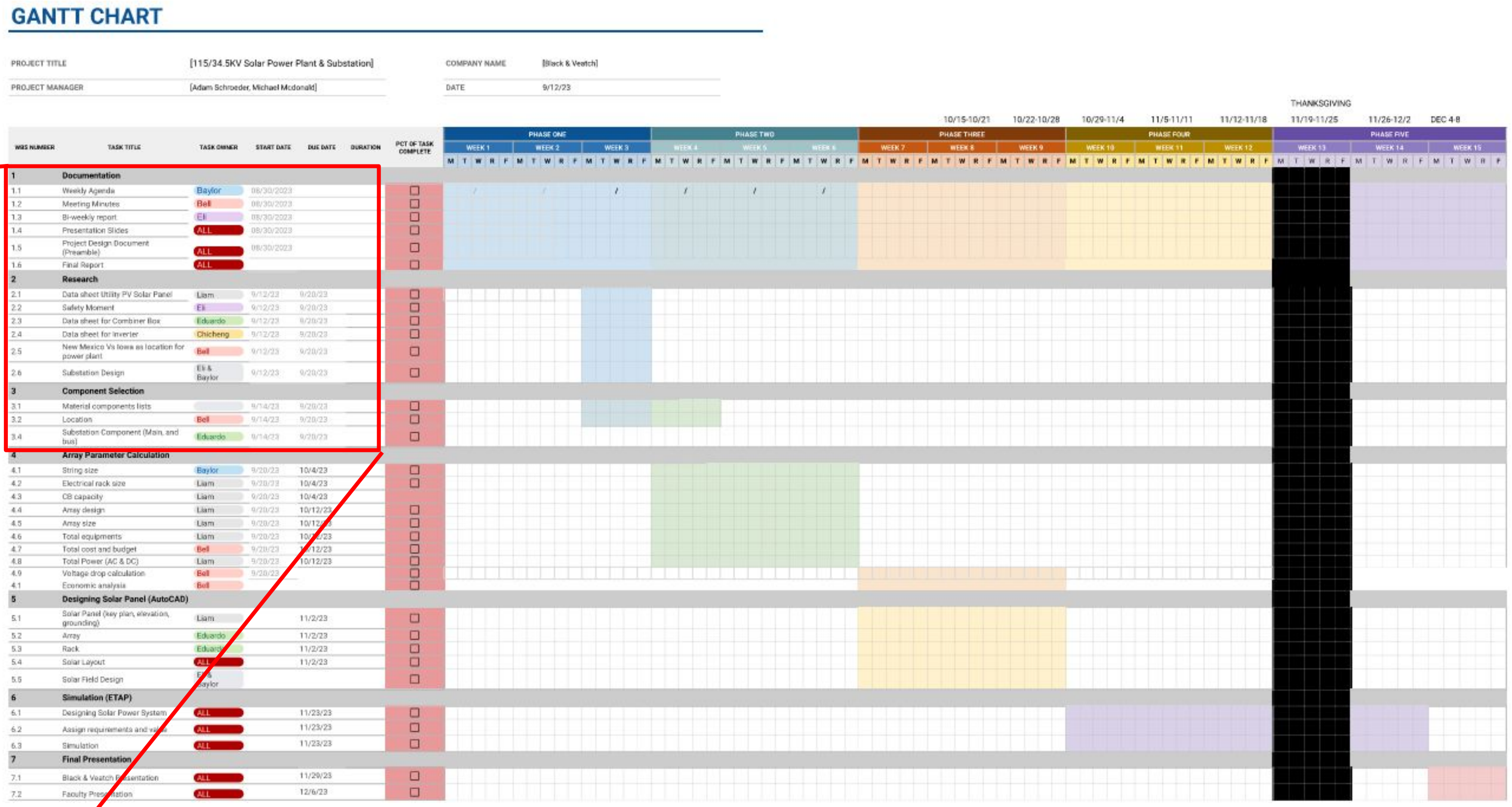
GANTT CHART

PROJECT TITLE	[115/34.5KV Solar Power Plant & Substation]	COMPANY NAME	[Black & Veatch]
PROJECT MANAGER	[Adam Schroeder, Michael Mcdonald]	DATE	9/12/23

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	Bell	9/14/23	9/20/23		☐
3.4	Substation Component (Main, and bus)	Eduardo	9/14/23	9/20/23		☐
4	**Array Parameter Calculation**					
4.1	String size	Baylor	9/20/23	10/4/23		☐
4.2	Electrical rack size	Liam	9/20/23	10/4/23		☐
4.3	CB capacity	Liam	9/20/23	10/4/23		
4.4	Array design	Liam	9/20/23	10/12/23		☐
4.5	Array size	Liam	9/20/23	10/12/23		☐
4.6	Total equipments	Liam	9/20/23	10/12/23		☐
4.7	Total cost and budget	Bell	9/20/23	10/12/23		☐
4.8	Total Power (AC & DC)	Liam	9/20/23	10/12/23		☐
4.9	Voltage drop calculation	Bell	9/20/23			☐
4.1	Economic analysis	Bell				☐
5	**Designing Solar Panel (AutoCAD)**					
5.1	Solar Panel (key plan, elevation, grounding)	Liam		11/2/23		☐
5.2	Array	Eduardo		11/2/23		☐
5.3	Rack	Eduardo		11/2/23		☐
5.4	Solar Layout	ALL		11/2/23		☐
5.5	Solar Field Design	Eli & Baylor				☐
6	**Simulation (ETAP)**					
6.1	Designing Solar Power System	ALL		11/23/23		☐
6.2	Assign requirements and value	ALL		11/23/23		☐
6.3	Simulation	ALL		11/23/23		☐
7	**Final Presentation**					
7.1	Black & Veatch Presentation	ALL		11/29/23		☐
7.2	Faculty Presentation	ALL		12/6/23		☐



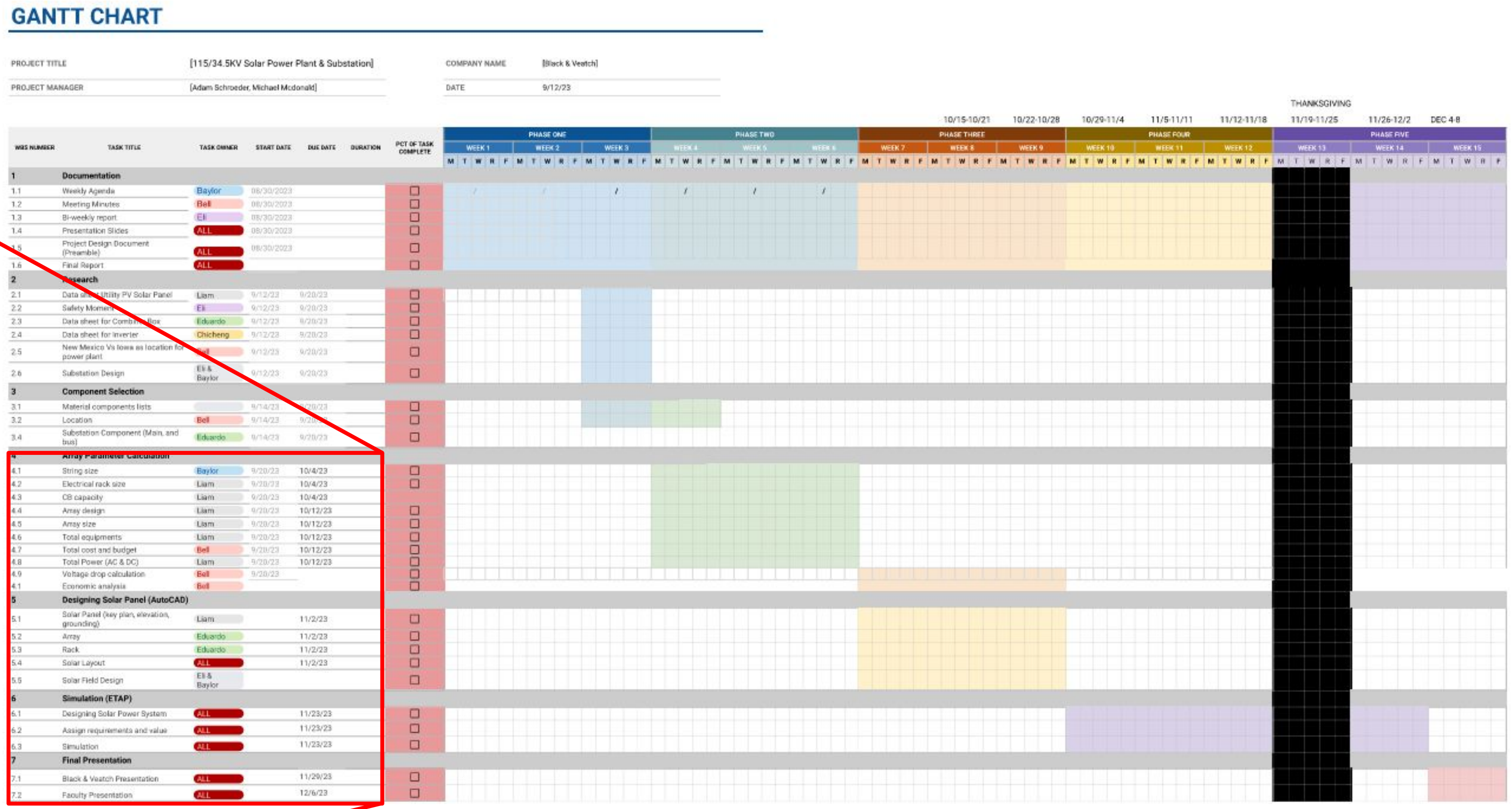
Fall Gantt Chart



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	Bell	9/14/23	9/20/23
3.4	Substation Component (Main, and bus)	Eduardo	9/14/23	9/20/23

Fall Gantt Chart

4	**Array Parameter Calculation**			
4.1	String size	Baylor	9/20/23	10/4/23
4.2	Electrical rack size	Liam	9/20/23	10/4/23
4.3	CB capacity	Liam	9/20/23	10/4/23
4.4	Array design	Liam	9/20/23	10/12/23
4.5	Array size	Liam	9/20/23	10/12/23
4.6	Total equipments	Liam	9/20/23	10/12/23
4.7	Total cost and budget	Bell	9/20/23	10/12/23
4.8	Total Power (AC & DC)	Liam	9/20/23	10/12/23
4.9	Voltage drop calculation	Bell	9/20/23	
4.1	Economic analysis	Bell		
5	**Designing Solar Panel (AutoCAD)**			
5.1	Solar Panel (key plan, elevation, grounding)	Liam		11/2/23
5.2	Array	Eduardo		11/2/23
5.3	Rack	Eduardo		11/2/23
5.4	Solar Layout	ALL		11/2/23
5.5	Solar Field Design	Eli & Baylor		
6	**Simulation (ETAP)**			
6.1	Designing Solar Power System	ALL		11/23/23
6.2	Assign requirements and value	ALL		11/23/23
6.3	Simulation	ALL		11/23/23
7	**Final Presentation**			
7.1	Black & Veatch Presentation	ALL		11/29/23
7.2	Faculty Presentation	ALL		12/6/23

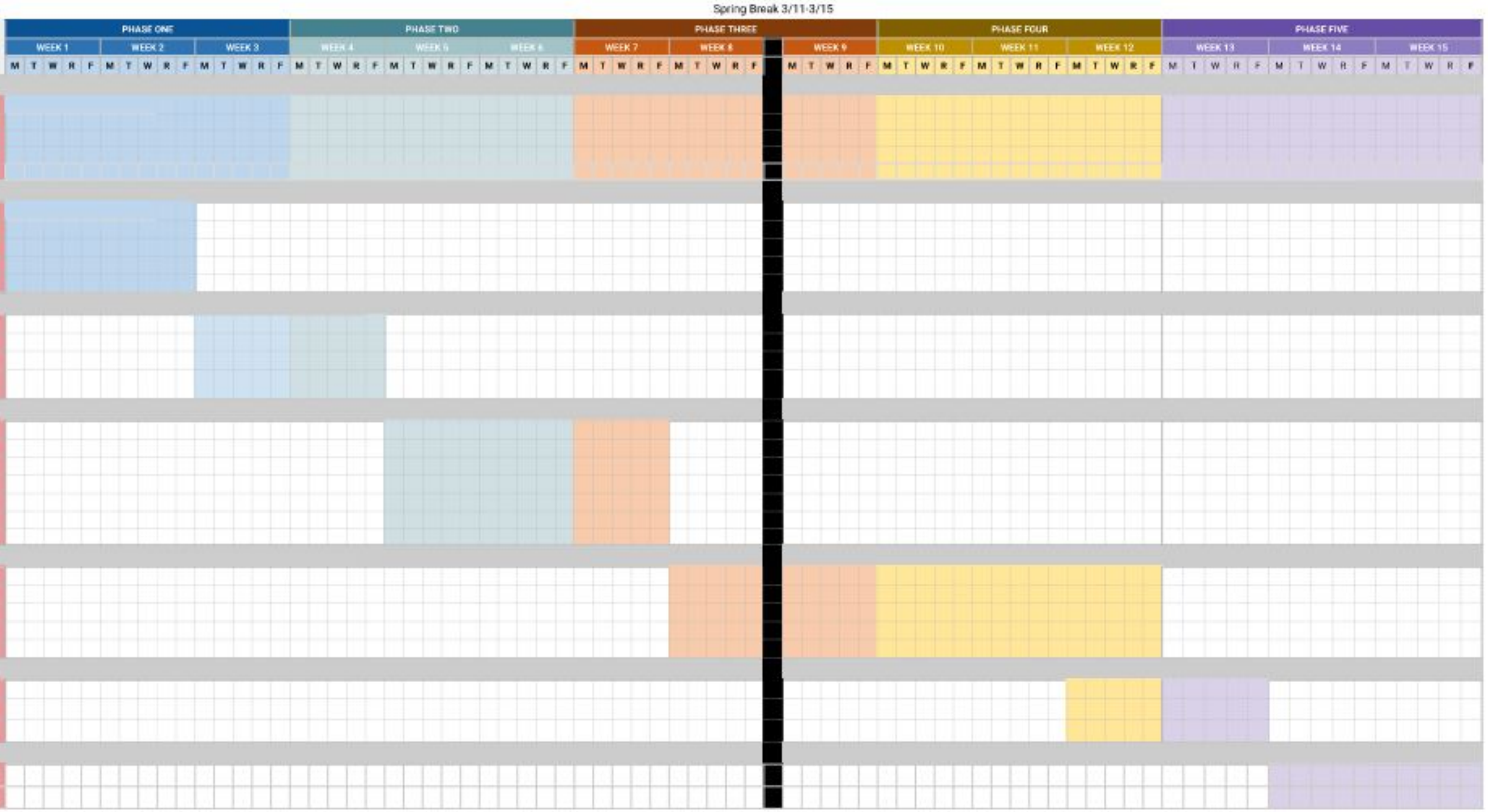


Spring Gantt Chart

GANTT CHART

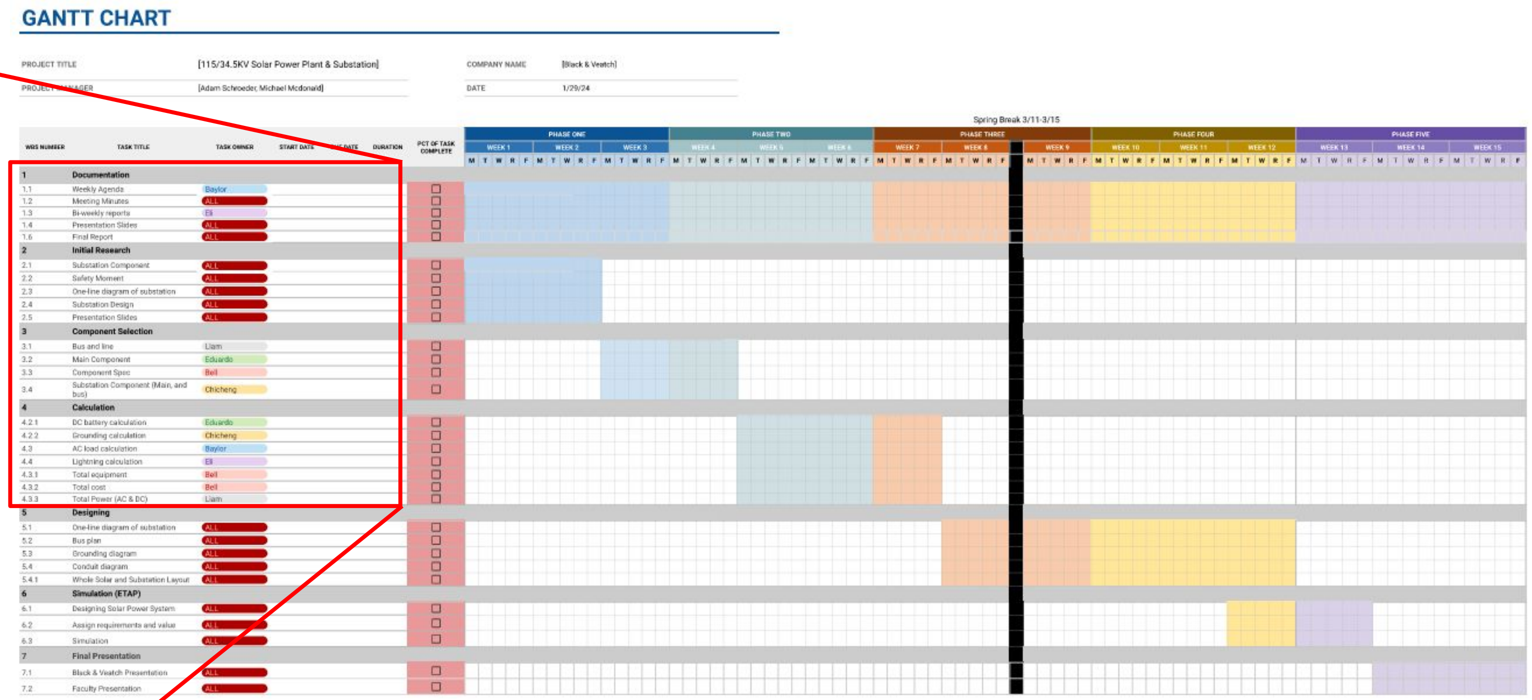
PROJECT TITLE	[115/34.5KV Solar Power Plant & Substation]	COMPANY NAME	[Black & Veatch]
PROJECT MANAGER	[Adam Schroeder, Michael Mcdonald]	DATE	1/29/24

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



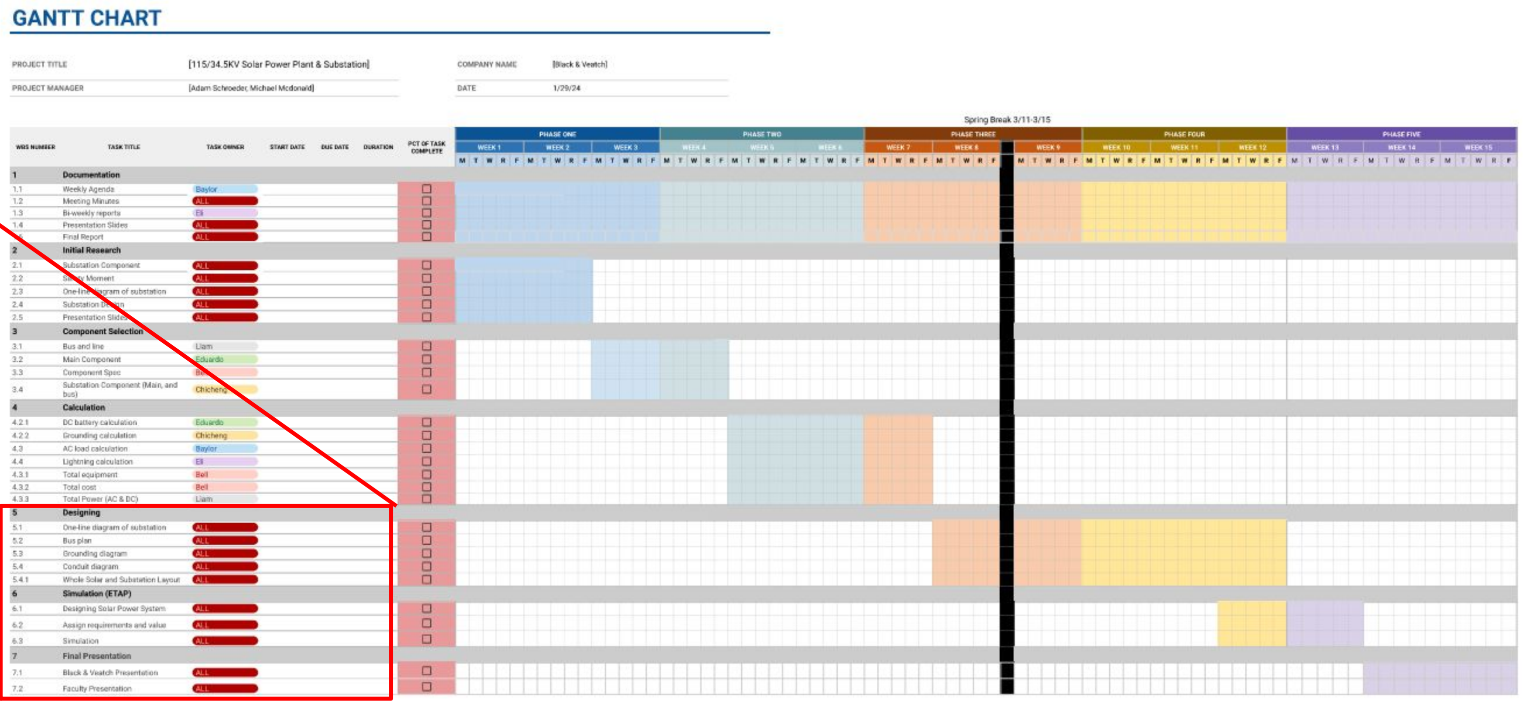
Spring Gantt Chart

1	**Documentation**	
1.1	Weekly Agenda	Baylor
1.2	Meeting Minutes	ALL
1.3	Bi-weekly reports	Eli
1.4	Presentation Slides	ALL
1.6	Final Report	ALL
2	**Initial Research**	
2.1	Substation Component	ALL
2.2	Safety Moment	ALL
2.3	One-line diagram of substation	ALL
2.4	Substation Design	ALL
2.5	Presentation Slides	ALL
3	**Component Selection**	
3.1	Bus and line	Liam
3.2	Main Component	Eduardo
3.3	Component Spec	Bell
3.4	Substation Component (Main, and bus)	Chicheng
4	**Calculation**	
4.2.1	DC battery calculation	Eduardo
4.2.2	Grounding calculation	Chicheng
4.3	AC load calculation	Baylor
4.4	Lightning calculation	Eli
4.3.1	Total equipment	Bell
4.3.2	Total cost	Bell
4.3.3	Total Power (AC & DC)	Liam



Spring Gantt Chart

5	**Designing**	
5.1	One-line diagram of substation	ALL
5.2	Bus plan	ALL
5.3	Grounding diagram	ALL
5.4	Conduit diagram	ALL
5.4.1	Whole Solar and Substation Layout	ALL
6	**Simulation (ETAP)**	
6.1	Designing Solar Power System	ALL
6.2	Assign requirements and value	ALL
6.3	Simulation	ALL
7	**Final Presentation**	
7.1	Black & Veatch Presentation	ALL
7.2	Faculty Presentation	ALL



Test Plan

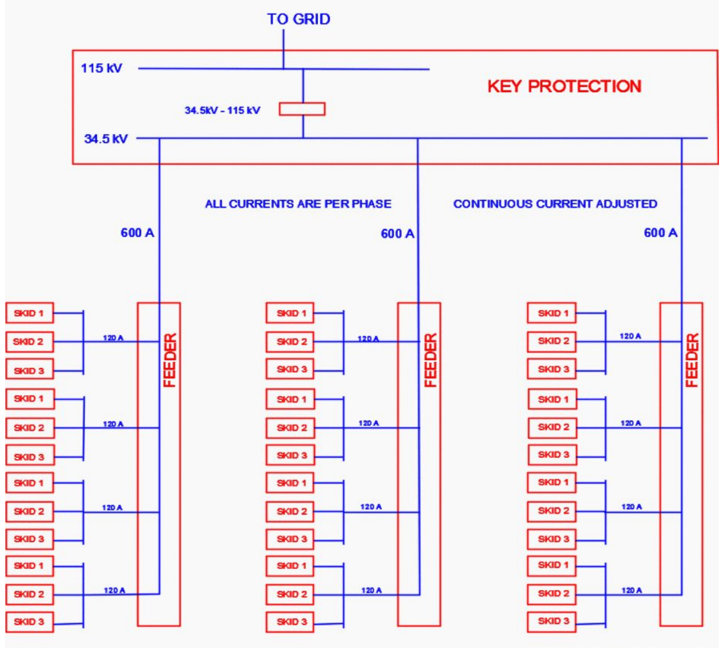
What will be tested: Voltage, Current, Power, Safety Systems

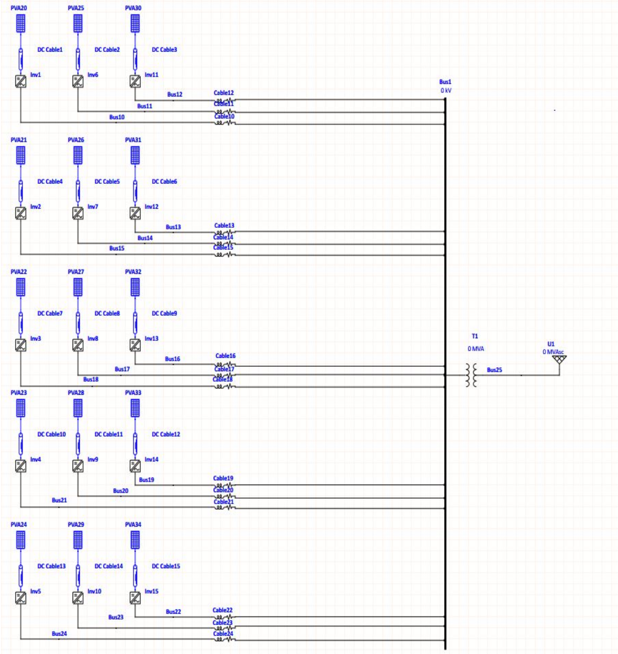
How: Etap will be used which is a software that will show the output of each component to determine if the group needs to change parts of the design.

Test Plan

Interface Testing: voltage and power output from solar array to inverters. Also, will be testing output from inverter to substation, and all will be compared to the calculations made.

Integration testing: There will be other testing for efficiency, grounding and power quality.





Link

Conclusions

Schedule Progress

Group Member Contributions

Bell: Meeting Minutes, Project Plan, Site Location Research, Project Cost, Voltage Drop Calculations
Eduardo: Combiner Box Research, AutoCAD Design Work
Chicheng: Inverter Research, ETAP Research and Design
Eli: Bi-Weekly Reports, AutoCAD Research, ETAP Research, Website Design
Liam: Solar Module Research, Array Calculations/Sizing, Client Correspondent
Baylor: Weekly Agenda, AutoCAD Site Drawings, Wiring Research

All Members: Weekly Presentations/Reports, AutoCAD Drawings

Plans for next semester

Q&A Session