115/34.5 kV Solar Power Plant & Substation

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

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



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Overview of Solar Power Plant - 60MW



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.

1 array of solar panels

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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.

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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



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Requirements- Non-Functional

Environmental

<u>Economic</u>

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

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 lsc •
- Combiner Boxes
- Supports 1500 VDC
- 16 Inputs
- 1 Output

Inverters

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

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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.

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Array Parameter Tools

		String Size			Electrical Rack Siz	e			CB capacity			Array Design			Array Size	
				Designer Choice		portrait or Landscap e										
	Location Dependent	Min Temp	-40 C	Datasheet	Module width	3.72	ft	Datasheet (STC)	mod/string lsc	13.89	A Choic	er Racks per row	16	Designe Choice	r tilt	35
			5	Datasheet	module height	7.474	ft	NEC sect	i multiplier	1.25			2			
	Datasheet (STC)	Voc	50.2 V						nom lsc	17.3625	Design Choic	er rows per Array	24		table height proj	6.122342 ft
	Datasheet (STC)	Ref temp	25 C	Designer Choice	Rack width	25	modules	Irr.	multiplier	1.25						
				Designer Choice	Rack height	1	modules		max lsc	21.70312	A Choic	er Racks removed	2	Designe Choice	row space	10 ft
	Datasheet	Temp Coeff of Voc	-0.0029 /C		Modules per rack									1		
		Temp delta	-65		Rack width	93	ft	Choice:	allowed current	350	A	Total Racks/Arra	iy 382		pitch	16.12234 ft
		temp correction	1.19		Rack height	7.474	ft	200,	is this disconnec	t A?					Space for Inverter Maintenance	35 ft
		V0c corrected	59.6627					400A	strings per CB	16.12670		Total modules	9550)	Array height	386.9362 ft
								etc.	Round down:	16				-		
onfirm		string voltage	1500 V						racks per CB	16	Datashe (STC)	et module capacity	550	w	Array width	1488 ft
ossible		String size	25.14133												Ground Coverage Ratio	0.463580
with	Designer	string size	25									dc capacity	5252.5	kW		
Panel	Choice: 600,	Actual String Voltage	1491.6										-	19		
type chosen	1000, 1500, 2000V										Design	er inverter capacit	y 4000	kW		
													4	MVA		
											:	ILR	1.313125			
		Input Information =									Indust standa	ry rd				
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Conceptual Final Design Diagram



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Iowa State University

Eduardo Jimenez-Tzompaxtle





Eduardo Jimenez-Tzompaxtle

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Eduardo Jimenez-Tzompaxtle

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Overall Conceptual/Visual Sketch



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Chicheng Tang

Design Complexity



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Baylor Clark

Project Plan



Lovington Solar Power Information & Peak Sun Hours

Solar Green Energy Summary for Lovington, New Mexico

Lattitude: 32.9457

<u>Sunlight</u>

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

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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

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Project Plan



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Fall Gantt Chart

GANTT CHART

	PROJECT	TITLE	[115/34.5KV	Solar Power	Plant & Substation)		COMPANY NA	ME	Black & Ver	atch]														
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Iowa State University 115/34.5kV Solar Power Plant & Substation Design Project

Fall Gantt Chart

GANTT CHART

						PROJECT	TITLE	[115/34.5KV S	Solar Power Plant & Substa	tion]	COMPANY NAME	[Black & Veatch]												
						PROJECT	MANAGER	(Adam Schroeder,	r, Michael Mcdonald]		DATE	9/12/23												
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						1.2	Meeting Minutes Ri-weekly report	Bell	08/30/2023															
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1.1	Weekly Agenda	Baylor	▼ 08/	30/2023		2.2	Data sheet for Combiner Box	Ellando	9/12/23 9/20/23															
1.2	Meeting Minutes	Rell	 08/ 	30/2023		2.4	Data sheet for inverter New Maxim Valoase as location	Chicheng	9/02/28 9/28/28															
1.2	Meeting Minutes	Den	00/	50/2025		2.5	power plant	Bel	9/12/25 9/28/23															
1.3	Bi-weekly report	Eli	08/	30/2023		2.6	Substation Design	Baylor	9/12/23 9/20/23														_	
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1 5	Project Design Document	-	00/	20/2022		3.4	bus)	Eduardo	9/14/28 9/20/28															
1.0	(Preamble)	ALL	- 00/	30/2023		4.1	Array Parameter Calculation String size	Baylor	9/20/23 10/4/23															-
1.6	Final Papart	ALL	-			4.2	Electrical rack size	Liam	9/20/29 10/4/23															
1.0	Final Report	ALL				4.4	Array design	Liam	9/20/23 10/12/23															
2	Research					4.5	Array size Total eculoments	Liam	9/28/23 10/12/3															
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2.1	Data sheet Utility PV Solar Panel	Liam	• 9/1	2/23	9/20/23	4.8	Voltage drop calculation	Bell	9/20/23	La														
2.2	Safety Moment	Eli	• 9/1	2/23	9/20/23	41 5	Economic analysis Designing Solar Panel (AutoC	AD)																
2.3	Data sheet for Combiner Box	Eduardo	• 9/1	2/23	9/20/23	5.1	grounding) Array	Liam Eduardo	11/2/23															
2.4	Data sheet for Inverter	Chicheng	• 9/1	2/23	9/20/23	5.3	Ratk Solar Layout	Eduard	11/2/23 11/2/23															
		omonong		-1-0	5/20/20	5.5	Solar Field Design	Fa																
2.5	New Mexico Vs Iowa as location for	Rell	• 9/1	2/23	9/20/23	6	Simulation (ETAP)			-					10 M 11 M 1	115 IV. 1977	10000	101 101 101						
2.0	power plant	Den		2120	3720720	6.1	Assign requirements and value	ALL	11/23/23															
1202		Eli &				6.3	Simulation	ALL	11/23/23															
2.6	Substation Design	Baylor	• 9/1	2/23	9/20/23	7	Final Presentation		11/05/02	-														
		Daylor				7.1	Black & Veatch Unsentation Faculty Presentation	ALL	12/6/23															-
3	Component Selection																							
3.1	Material components lists		• 9/1	4/23	9/20/23																			
3.2	Location	Bell	• 9/1	4/23	9/20/23																			
3.4	Substation Component (Main, and bus)	Eduardo	• 9/1	4/23	9/20/23	_/																		

Iowa State University 115/34.5kV Solar Power Plant & Substation Design Project

Fall Gantt Chart

GANTT CHART

PROJECT M	ANAGER	(Adam Schroes	ler. Michael Mcd	mald		Dé	TE		9/12	23																						
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1.1	Weekly Agenda	Baylor	08/30/2023								1		,	'	1		1															
1.2	Meeting Minutes	Bell	01/30/2023																													
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1.6	Final Report	ALL				51 - 14 - 14																										
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2.1	Data since Utility PV Solar Panel	Liam .	0/12/22	9/20/23		1 - L																										
2.2	Safety Moment	El	9/12/29	9/20/23		3																							_			
2.3	Data sheet for Combine Box	Eduardo	9/12/23	0/20/23	0	-																							- 2			
2.4	Data sheet for inverter	Chicheng	9/32/28	9/20/23																									- 2			
2.5	power plant	1	0/12/25	9/20/23		3																										
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3.2	Location	Bel	9/14/23	9/20	ä	8																										
2.4	Substation Component (Main, and	Educatio	8/14/19	Relation .		3																								ور کے اور		
3.4	bus)	LONGSO	W 190-24			2							_			_	_		_						_			_	-5			÷
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6.1	String size	Baylor	9/20/23	10/4/23		-																							- 2			
4.2	Electrical rack size	Liam	0/20/23	10/4/23																												
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4.5	Array size	Liam	9/28/23	10/17/23	ä																											
4.6	Total equipments	Liam	9/20/23	10/12/23	ä																											
4.7	Total cost and budget	Bel	9/20/23	10/12/23	ō																									ين کا کا تھ		
4.8	Total Power (AC & DC)	Liam	9/20/23	10/12/23		5 10																										
4.9	Voltage drop calculation	Bell	9/28/23			-																										
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5.3	Rack	Eduardo		11/2/23																												
5.4	Solar Layout	ALL		11/2/23																										يوحد عر		
5.5	Solar Field Design	El & Bankor				1																										
6	Simulation (ETAP)																															
6.1	Designing Solar Power System	ALL		11/23/23		11										1.1.1					1 1 1											
4.9	Assist maximumate and store	-	1	11/23/23																												
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·	Final Presentation	1000			10000																											į.
7.1	Black & Veatch Presentation	ALL		11/20/23																												
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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 (AutoCA	D)			
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	P		11/29/23
7.2	Faculty Presentation	ALL	-		12/6/23

Iowa State University 115/34.5kV Solar Power Plant & Substation Design Project

Spring Gantt Chart

GANTT CHART

PROJECT TI	TLE	[115/34.5KV Sol	ar Power Plant 8	Substation]		COMPANY	NAME	[Black	& Veatch)																								
PROJECT M	ANAGER	[Adam Schroeder, N	fichael Mcdonaid]			DATE		1/29/2	14																								
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1	Documentation																			1													
1.1	Weekly Agenda	Baylor																															
1.2	Meeting Minutes	ALL																															
1.3	Bi-weekly reports	E																															
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	AUL																															
3	Component Selection																																
3.1	Bus and line	Llam					1.1.1									1.1										1111							
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	Eduardio									TIT	1.1									1.1.											1.1	
4.2.2	Grounding calculation	Chicheng																															
4.3	AC load calculation	Baylor)																														
4.4	Lightning calculation	El																															
4.3.1	Total equipment	Bell																															
4.3.2	Total post	Bell			ā																												
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	Brounding diagram	ALL																															
5.4	Conduit diagram	ALL																															
5.4.1	Whole Solar and Substation Layout	ALL			ā																												
6	Simulation (ETAP)																																
6.1	Designing Solar Power System	ALL									1 1 1																						
6.2	Assign requirements and value	ALL																															
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7.1	Black & Veatch Presentation	Alle									TEE							TT										1.1					
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Iowa State University 115/34.5kV Solar Power Plant & Substation Design Project

Spring Gantt Chart

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	•	/



Iowa State University 115/34.5kV Solar Power Plant & Substation Design Project

Spring Gantt Chart

GANTT CHART

		PROJECT TITLE	[115/34.5KV Solar Power Plant & Substation]	COMPANY NAME	[Black & Vestch]											
		PROJECT MANAGER	[Adam Schroeder, Michael Mcdonaid]	DATE	1/29/24											
									Spring Break 3/11-3	3/15						
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2	Designing	1 Documentation	Bastr	1					1 1 1							
5.1	One-line diagram of substation 🛛 🚺 🚽 🚽	1.2 Meeting Minunes 1.3 Bi-weekly reports	(Ef)													
5.2	Bus plan ALL	1.4 Presentation Slates Final Report		3					111							
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5.4	Conduit diagram 🛛 🖌 🥄 🔿	2.4 Substation Distant 2.5 Presentation Sides		3												
5.4.1	Whole Solar and Substation Layout 🛛 🖌 🚽	3 Component Selectio 3.1 Bus and line	uan Can	3												
6	Simulation (FTAD)	3.2 Main Component 3.3 Component Spec	Eduardo Bit													
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		4.2.2 Grounding calculation	Chicheng													
6.2	Assign requirements and value ALL	4.3 AC load calculation 4.4 Lightning calculation	ES C]												
		4.3.1 Total equipment 4.3.2 Total cost	Rol Rol	2												
5.3	Simulation ALL	4.3.3 Total Power (AC & DC)	Dam	5												
		5 Designing 5.1 One-line diagram of su	station Alternation													
7	Final Presentation	5.2 Bus plan														
		5.3 Grounding diagram 5.4 Conduit diagram														
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		6 Samuration (ETAP) 6.1 Designing Solar Power	System ALCONTROL	1												
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0.49.40		6.3 Simulation														
		7 Final Presentation												an anna		
		7.1 Black & Veatch Prease	toton	7												
		7.2 Faculty Presentation	ALL													

Iowa State University 115/34.5kV Solar Power Plant & Substation Design Project

<u>Test Plan</u>

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.



SERVICE PROVIDER

Iowa State University 115/34.5kV Solar Power Plant & Substation Design Project

<u>Test Plan</u>

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.



Iowa State University 115/34.5kV Solar Power Plant & Substation Design Project

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

Liam Gossman

Q&A Session

Iowa State University 115/34.5kV Solar Power Plant & Substation Design Project

Liam Gossman