IOWA STATE UNIVERSITY

Solar Power Plant and Substation Design

Final Presentation

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Team Introduction

Omer Karar
Madissen Lawrence
Brooke Nelson
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Project Overview

Problem Statement

- The United States has become more aware of its carbon footprint and is taking measures to minimize emissions. The greenhouse gas with the highest atmospheric emissions, carbon emissions, significantly impacts the environment.

- Local utilities have contracted Black & Veatch to implement a solar plant to increase their renewable energy sources. Our project will focus on Roswell, New Mexico, to implement a new generation system. We are designing a large-scale 60 MW utility solar power plant, along with a 34.5/115 kV substation, to provide more clean energy to the area.

Project Requirements

- Design 80 MW DC/ 60 MW AC Solar Farm (Fall 2022)
- Select Location
- Select Panels
- Select Combiner Boxes
- Select Inverter Skids
- Voltage drop calculation
- The codes and Standards NED, IFC, UL
- Design layout of the Farm
- One-line diagram (Protection & Relaying
- Design Substation to handle Output from Solar Farm (Spring 2023)

User Needs

Intended Users and Uses

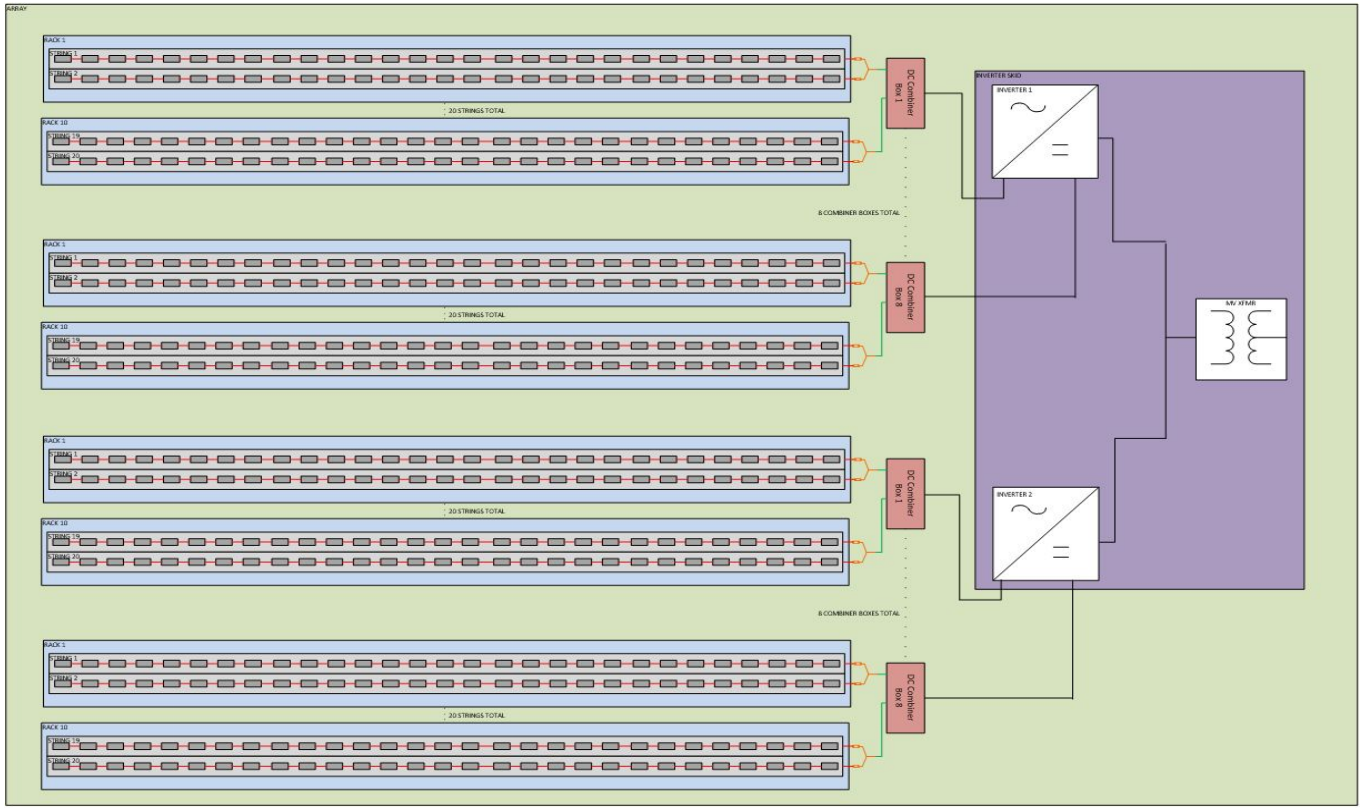
- Anyone who uses electricity in New Mexico
  - Homeowners
  - Renters
  - Small businesses
- Utility companies

Specific User Needs

- User: Utility
  - Values clean & consistent energy, efficiency
  - Needs:
    - Quality design
    - Proper location
      - High irradiance
      - Low humidity
      - Flat
      - Low cost land
- User: Electricity Consumer
  - Values consistent and reliable energy powering their homes
  - Needs:
    - Clean energy
    - Cheap energy
    - Reliability

Components

Components


ARRAY
RACK 1
STRING 1
STRING 2
20 STRINGS TOTAL
RACK 10
STRING 19
STRING 20
8 COMBINER BOXES TOTAL
DC Combiner Box 1
DC Combiner Box 8
INVERTER SKID
INVERTER 1
INVERTER 2
MV XFMR

Array Parameter Tool

		String Size				Electrical Rack Size				CB capacity				Array Design		
					Designer Choice		Portrait	41.1								
	Location Dependent	Min Temp	-1.11	C	Datasheet	Module width	3.425	ft	Datasheet (STC)	mod/string Isc	11.26	A	Designer Choice	Racks per row	22	Designer Choice
					Datasheet	module height	7.267	ft	NEC section	multiplier	1.25					
	Datasheet (STC)	Voc	53.61	V						nom Isc	14.075		Designer Choice	rows per Array	12	
	Datasheet (STC)	Ref temp	25	C	Designer Choice	Rack width	26	modules	Irr.	multiplier	1.25					
					Designer Choice	Rack height	2	modules		max Isc	17.59375	A	Designer Choice	Racks removed	0	Designer Choice
	Datasheet	Temp Coeff of Voc	-0.0027	/C		Modules per rack										
		Temp delta	-26.11			Rack width	89.050	ft	Designer Choice: 200, 400A etc.	allowed current	400	A		Total Racks/Arra	264	
		temp correction	1.070497			Rack height	14.533	ft		is this disconnect A?						
		Voc corrected	57.38934417							strings per CB	22.73534636			Total modules	13728	
							41.1			Round down:	22					
Confirm possible with Panel type chosen	Designer Choice: 600, 1000, 1500, 2000V	string voltage	1500	V			87.2			racks per CB	11		Datasheet (STC)	module capacity	480	W
		String size	26.13725634													
		string size	26		Mod	Q-Cells	480W			Total CB/Array	24			dc capacity	6589.44	kW
		Actual String Voltage	1492.122948		CB	Shaol	400A			Round up:	24					
					Inverter	ABB	1500V/5MW						Designer Choice	inverter capacity	5000	kW
																MVA
													Provided: Industry standard 1.3	ILR	1.317888	
		Input Information =									https://codes.iccsafe.org/content					
		Final =														

Solar Panels

Q Peak Duo XL - G10.2

- 480W
- 53.61 Voc/11.26 Isc
- 44.81 Vmp/10.71 Imp
- 20.7% efficiency
- 12 year warranty

Combiner Box

Shoals 1500V Standard Combiner

- 1500 VDC
- Output Current of 400 A
- 70 lbs

Inverter

ABB central inverter: PVS980-58

- 1500 V (DC) / 690 V (AC)
- Output Current of 4184 A
- 13,000 lbs

Step Up Transformer

ABB medium voltage pad mounted solution

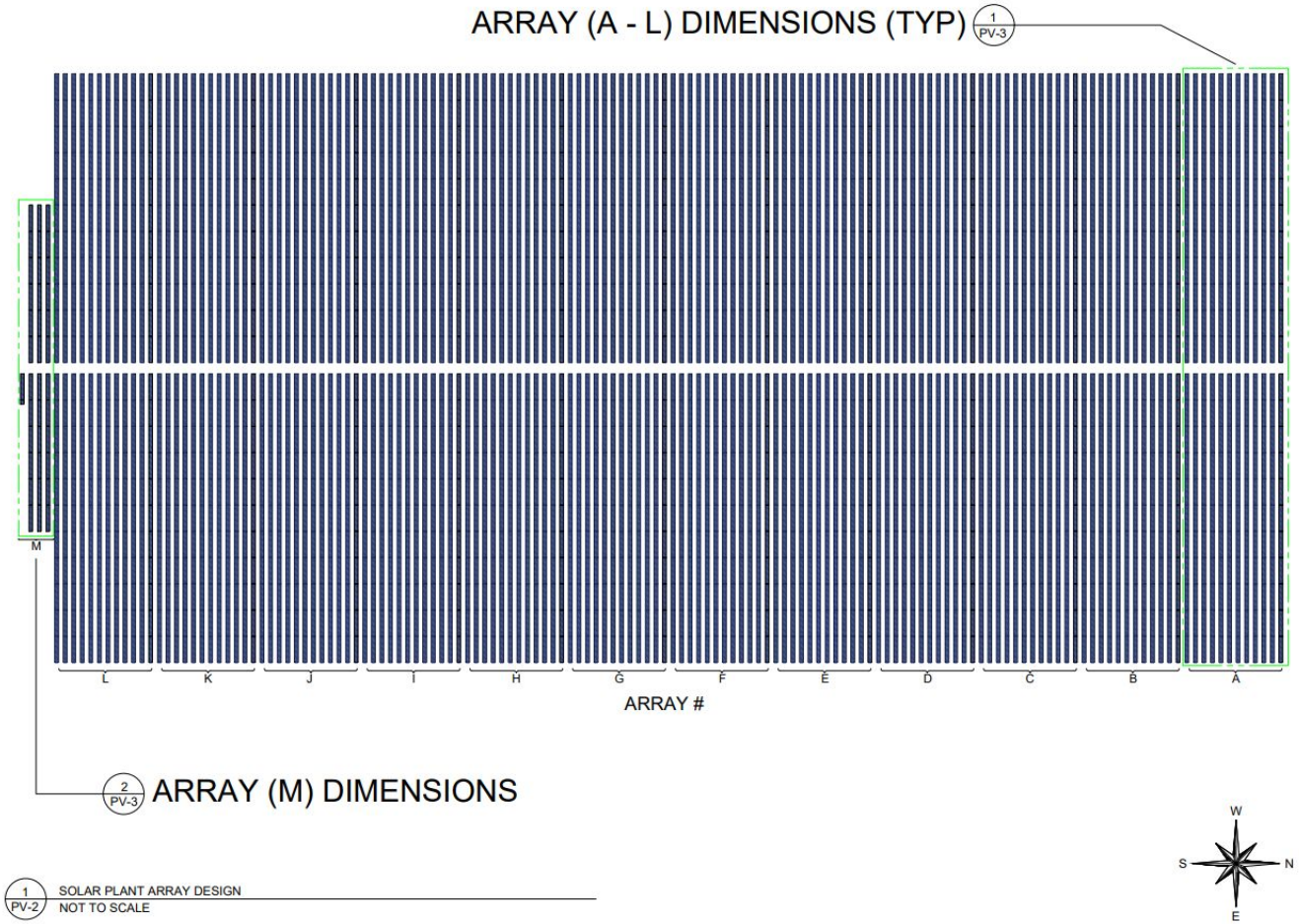
PVS980-MVP – 2.0 to 4.6 MVA

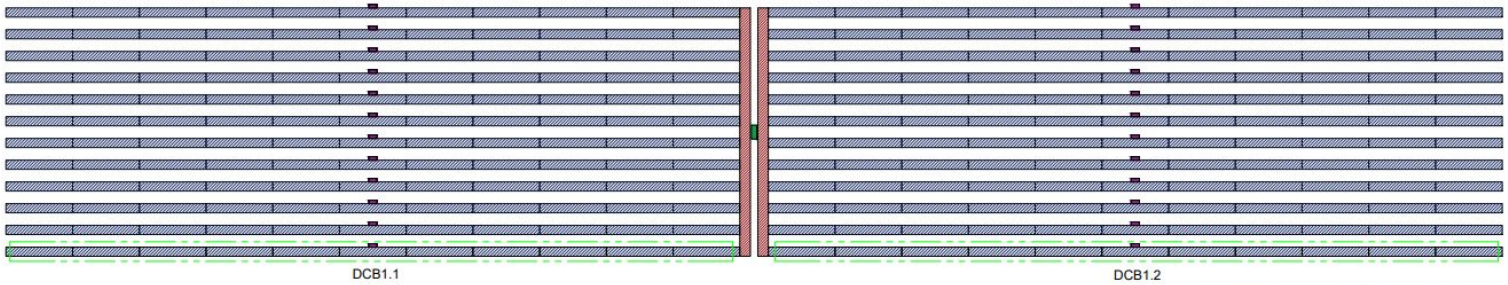
- 690V - 34.5kV Transformer
- Nominal output voltage (U N(AC)) 12 kV to 36 kV 2)
- Ambient temperature range (nominal ratings) 3) -25 °C to +50 °C

CAD Layout

4 Major Decisions

- Orientation
- Tilt
- Row Spacing
  - Shading
  - Land Use
- Solar Farm Layout

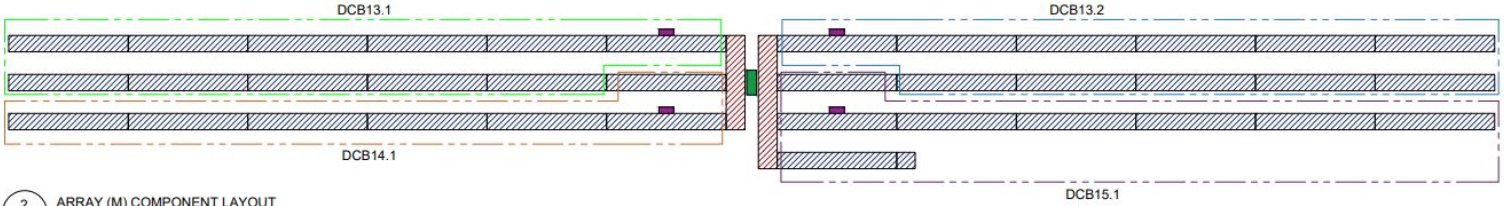




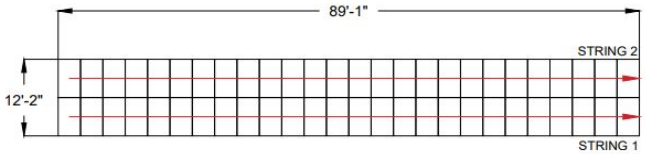
1 PV-4 ARRAY (A) COMPONENT LAYOUT (TYPICAL)
NOT TO SCALE

NOTE 1: ELECTRICAL DETAIL FOR ARRAY (A) IS SHOWN IN E-1 & E-2. EACH COMBINER BOX IS LABELED DCBX.X

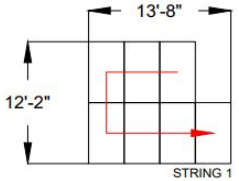
NOTE 2: ELECTRICAL DETAIL FOR ARRAY (M) IS SHOWN IN E-3. EACH COMBINER BOX IS LABELED DCBX.X



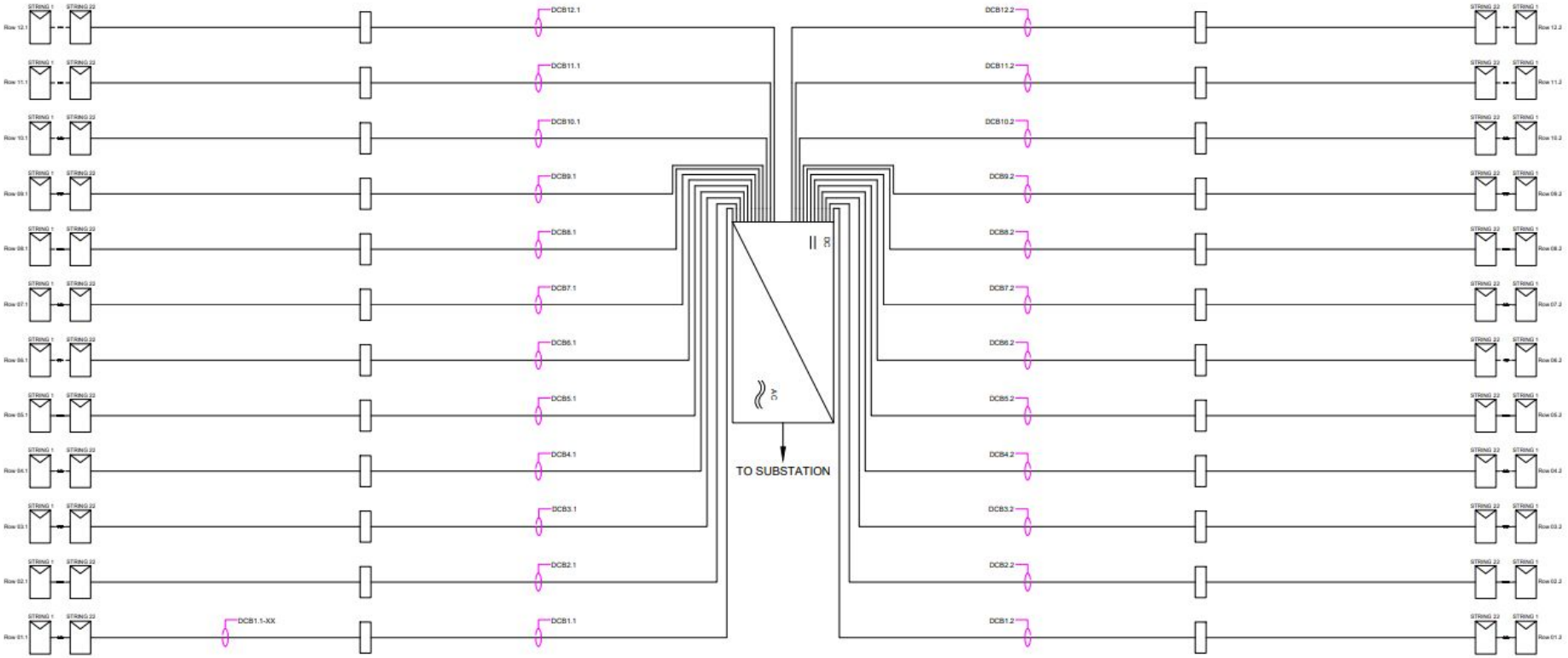
2 PV-4 ARRAY (M) COMPONENT LAYOUT
NOT TO SCALE



3 PV-3 RACK/STRINGING DETAIL (TYPICAL)
NOT TO SCALE



4 PV-3 RACK/STRINGING DETAIL
NOT TO SCALE


DCB12.1
DCB11.1
DCB10.1
DCB9.1
DCB8.1
DCB7.1
DCB6.1
DCB5.1
DCB4.1
DCB3.1
DCB2.1
DCB1.1
DCB1.1-XX
DCB12.2
DCB11.2
DCB10.2
DCB9.2
DCB8.2
DCB7.2
DCB6.2
DCB5.2
DCB4.2
DCB3.2
DCB2.2
DCB1.2
DC
AC
TO SUBSTATION

Voltage Drop Calculations

Normal Array Voltage Drop Calculations

JUMPER VOLTAGE DROP CALCULATIONS: ARRAY A - L (TYP)													
DCB	Strings per Rack	IMP for String	String Length	String wire size	String Conductor resistance	String resistance	Voltage Drop of String	IMP for Jumper	Jumper Length	Jumper wire size	Jumper resistance	Jumper resistance	Voltage Drop of Jumper
DCB#-##	per rack	Amp	feet	AWG	Ohm/kft	Ohm	Volts	Amp	feet	AWG	Ohm/kft	Ohm	Volts
DCB1-01	2	10.7	85.7	10	2.000	0.332	3.668	21.4	490.00	6	0.808	0.766	16.945
DCB1-02	2	10.7	85.7	10	2.000	0.332	3.668	21.4	400.95	6	0.808	0.627	13.866
DCB1-03	2	10.7	85.7	10	2.000	0.332	3.668	21.4	311.90	6	0.808	0.488	10.786
DCB1-04	2	10.7	85.7	10	2.000	0.332	3.668	21.4	222.85	6	0.808	0.348	7.707
DCB1-05	2	10.7	85.7	10	2.000	0.332	3.668	21.4	133.80	6	0.808	0.209	4.627
DCB1-06	2	10.7	85.7	10	2.000	0.332	3.668	21.4	44.75	6	0.808	0.070	1.548
DCB1-07	2	10.7	85.7	10	2.000	0.332	3.668	21.4	44.75	6	0.808	0.070	1.548
DCB1-08	2	10.7	85.7	10	2.000	0.332	3.668	21.4	133.80	6	0.808	0.209	4.627
DCB1-09	2	10.7	85.7	10	2.000	0.332	3.668	21.4	222.85	6	0.808	0.348	7.707
DCB1-10	2	10.7	85.7	10	2.000	0.332	3.668	21.4	311.90	6	0.808	0.488	10.786
DCB1-11	2	10.7	85.7	10	2.000	0.332	3.668	21.4	400.95	6	0.808	0.627	13.866

$$V_d = \frac{2LR_2I}{1000}$$

Where:
V_d = voltage drop over circuit length (volts)
L = length of circuit (ft)
R_2 = resistance of conductor from Equation (ohm/kft)
I = maximum power current of circuit (amps)

Requirement Threshold = 5%

Hand Calculation Check - Design Document 3.2.2.4

DCB	No. of Rack Inputs	IMP for DCB circuit	Feeder length	Feeder wire size	Feeder resistance	Feeder resistance	Voltage drop for feeder	Voltage drop for feeder	Voltage drop for circuit	VMP for circuit	Voltage drop for circuit
DCB#-##	#	Amp	feet	kcmil	Ohm/kft	Ohm	Volt	per cent	Volt	Volt	per cent
DCB1.1	11	235.40	641	600	0.035	0.044	10.653	0.91%	48.338	1165.00	4.15%
DCB1.2	11	235.40	641	600	0.035	0.044	10.653	0.91%	48.338	1165.00	4.15%
DCB2.1	11	235.40	612	600	0.035	0.042	10.171	0.87%	48.177	1165.00	4.14%
DCB2.2	11	235.40	612	600	0.035	0.042	10.171	0.87%	48.177	1165.00	4.14%
DCB3.1	11	235.40	583	600	0.035	0.040	9.689	0.83%	48.016	1165.00	4.12%
DCB3.2	11	235.40	583	600	0.035	0.040	9.689	0.83%	48.016	1165.00	4.12%
DCB4.1	11	235.40	553	600	0.035	0.038	9.190	0.79%	47.850	1165.00	4.11%
DCB4.2	11	235.40	553	600	0.035	0.038	9.190	0.79%	47.850	1165.00	4.11%
DCB5.1	11	235.40	524	600	0.035	0.036	8.708	0.75%	47.689	1165.00	4.09%
DCB5.2	11	235.40	524	600	0.035	0.036	8.708	0.75%	47.689	1165.00	4.09%
DCB6.1	11	235.40	494	600	0.035	0.034	8.210	0.70%	47.523	1165.00	4.08%
DCB6.2	11	235.40	494	600	0.035	0.034	8.210	0.70%	47.523	1165.00	4.08%
DCB7.1	11	235.40	494	600	0.035	0.034	8.210	0.70%	47.523	1165.00	4.08%
DCB7.2	11	235.40	494	600	0.035	0.034	8.210	0.70%	47.523	1165.00	4.08%
DCB8.1	11	235.40	524	600	0.035	0.036	8.708	0.75%	47.689	1165.00	4.09%
DCB8.2	11	235.40	524	600	0.035	0.036	8.708	0.75%	47.689	1165.00	4.09%
DCB9.1	11	235.40	553	600	0.035	0.038	9.190	0.79%	47.850	1165.00	4.11%
DCB9.2	11	235.40	553	600	0.035	0.038	9.190	0.79%	47.850	1165.00	4.11%
DCB10.1	11	235.40	583	600	0.035	0.040	9.689	0.83%	48.016	1165.00	4.12%
DCB10.2	11	235.40	583	600	0.035	0.040	9.689	0.83%	48.016	1165.00	4.12%
DCB11.1	11	235.40	612	600	0.035	0.042	10.171	0.87%	48.177	1165.00	4.14%
DCB11.2	11	235.40	612	600	0.035	0.042	10.171	0.87%	48.177	1165.00	4.14%
DCB12.1	11	235.40	641	600	0.035	0.044	10.653	0.91%	48.338	1165.00	4.15%
DCB12.2	11	235.40	641	600	0.035	0.044	10.653	0.91%	48.338	1165.00	4.15%

Average of worst-case DCB voltage drop:	**4.11%**

Small Array Voltage Drop Calculations

DCB	Strings per Rack	IMP for String	String Length	String wire size	String Conductor resistance	String resistance	Voltage Drop of String	IMP for Jumper	Jumper Length	Jumper wire size	Jumper resistance	Jumper resistance	Voltage Drop of Jumper
DCB#.##	per rack	Amp	feet	AWG	Ohm/kft	Ohm	Volts	Amp	feet	AWG	Ohm/kft	Ohm	Volts
DCB13.x-01	2	10.7	85.7	10	2.000	0.332	3.668	21.4	396	6	0.808	0.619	13.695
DCB13.x-02	2	10.7	85.7	10	2.000	0.332	3.668	21.4	310	6	0.808	0.485	10.721
DCB13.x-03	2	10.7	85.7	10	2.000	0.332	3.668	21.4	224	6	0.808	0.350	7.746
DCB13.x-04	2	10.7	85.7	10	2.000	0.332	3.668	21.4	138	6	0.808	0.216	4.772
DCB13.x-05	2	10.7	85.7	10	2.000	0.332	3.668	21.4	52	6	0.808	0.081	1.798
DCB13.x-06	2	10.7	85.7	10	2.000	0.332	3.668	21.4	43	6	0.808	0.067	1.487
DCB13.x-07	2	10.7	85.7	10	2.000	0.332	3.668	21.4	468	6	0.808	0.732	16.185
DCB13.x-08	2	10.7	85.7	10	2.000	0.332	3.668	21.4	382	6	0.808	0.597	13.210
DCB13.x-09	2	10.7	85.7	10	2.000	0.332	3.668	21.4	296	6	0.808	0.463	10.236
DCB13.x-10	2	10.7	85.7	10	2.000	0.332	3.668	21.4	210	6	0.808	0.328	7.262
DCB13.x-11	2	10.7	85.7	10	2.000	0.332	3.668	21.4	74	6	0.808	0.116	2.559
DCB14.1-01	2	10.7	85.7	10	2.000	0.332	3.668	21.4	396	6	0.808	0.619	13.695
DCB14.1-02	2	10.7	85.7	10	2.000	0.332	3.668	21.4	310	6	0.808	0.485	10.721
DCB14.1-03	2	10.7	85.7	10	2.000	0.332	3.668	21.4	224	6	0.808	0.350	7.746
DCB14.1-04	2	10.7	85.7	10	2.000	0.332	3.668	21.4	138	6	0.808	0.216	4.772
DCB14.1-05	2	10.7	85.7	10	2.000	0.332	3.668	21.4	52	6	0.808	0.081	1.798
DCB14.1-06	2	10.7	85.7	10	2.000	0.332	3.668	21.4	43	6	0.808	0.067	1.487
DCB14.1-07	2	10.7	85.7	10	2.000	0.332	3.668	21.4	74	6	0.808	0.116	2.559
DCB15.1-01	2	10.7	85.7	10	2.000	0.332	3.668	21.4	396	6	0.808	0.619	13.695
DCB15.1-02	2	10.7	85.7	10	2.000	0.332	3.668	21.4	310	6	0.808	0.485	10.721
DCB15.1-03	2	10.7	85.7	10	2.000	0.332	3.668	21.4	224	6	0.808	0.350	7.746
DCB15.1-04	2	10.7	85.7	10	2.000	0.332	3.668	21.4	138	6	0.808	0.216	4.772
DCB15.1-05	2	10.7	85.7	10	2.000	0.332	3.668	21.4	52	6	0.808	0.081	1.798
DCB15.1-06	2	10.7	85.7	10	2.000	0.332	3.668	21.4	43	6	0.808	0.067	1.487
DCB15.1-07	2	10.7	85.7	10	2.000	0.332	3.668	21.4	74	6	0.808	0.116	2.559
DCB15.1-06	2	10.7	85.7	10	2.000	0.332	3.668	21.4	74	6	0.808	0.116	2.559
DCB15.1-07	1	10.7	13.7	10	2.000	0.053	0.586	10.7	74	6	0.808	0.116	1.280

DCB13.1	11	235.40	106.5	600	0.035	0.007	1.770	0.15%	43.930	1165.00	3.77%
DCB13.2	11	235.40	106.5	600	0.035	0.007	1.770	0.15%	43.930	1165.00	3.77%
DCB14.1	7	235.40	69.5	600	0.035	0.005	1.155	0.10%	23.203	1165.00	1.99%
DCB15.1	9	235.40	69.5	600	0.035	0.005	1.155	0.10%	25.901	1165.00	2.22%

Average of worst-case DCB voltage drop:	**2.94%**

Bill of Materials

Wiring Materials & Components

"Wiring" Material	Normal Array(ft)	Small Array (ft)	Total length (ft)	Cost ($/ft)	Total ($)
10 AWG Al THWN	90500	8941	99,441.00	$1.40	$139,217.40
6 AWG Al THWN	130488	10430	140,918.00	$1.40	$197,285.20
600kcmil Al THWN	327072	704	327,776.00	$6.42	$2,104,321.92
Sub Total($)					$2,440,824.52

Components	Amount			Cost per ($)	Total ($)
Inverters	13			$303,763.00	$3,948,919.00
Combiner Boxes	292			$250.00	$73,000.00
Solar Panels	166667			$460.00	$76,666,820.00
Sub Total($)					$80,688,739.00

Racking Material

Racking Material	Part #	Qnty		Cost per ($)	Total ($)
Ground Rail, 172IN, SILVER	232-02542	1489	112 per bundle	$122.29	$182,089.81
Ultra Rail MID Clamp, Silver	242-02070	166660		$4.43	$738,303.80
Universal End Clamp	242-02215	333320		$6.28	$2,093,249.60
Bonding Pipe Clamp Assembly for 1-1/2 IN	242-09004	333320		$7.48	$2,493,233.60
Ground Rail End Cap, Black	232-01043	333320		$2.87	$956,628.40
Ground Lug Assemply, 6-12 AWG	242-02101	3205		$6.01	$19,262.05
5EXT-8, Single Socket Tee, 1-1/2IN, AL-MG	172-05818	192300		$33.37	$6,417,051.00
17-8, Single Adjustable Socket Tee, 1-1/2IN, AL-MG	172-05803	192340		$30.87	$5,937,535.80
62-8, Plug End, 1-1/2IN, AL	172-05808	205120		$7.85	$1,610,192.00
Junction Box	242-01104	3205		$35.11	$112,527.55
Sub Total($)					$20,560,073.61
Total ($)					$103,689,637.13

Cost Analysis

No Axis Tracking			
$13/kW			
Installation Cost	O+M/yr	Inflation Rate	Yearly Revenue
$ 103,689,637.13	$ 585,000.00	3.22%	$ 11,510,246.23

$1767/kW

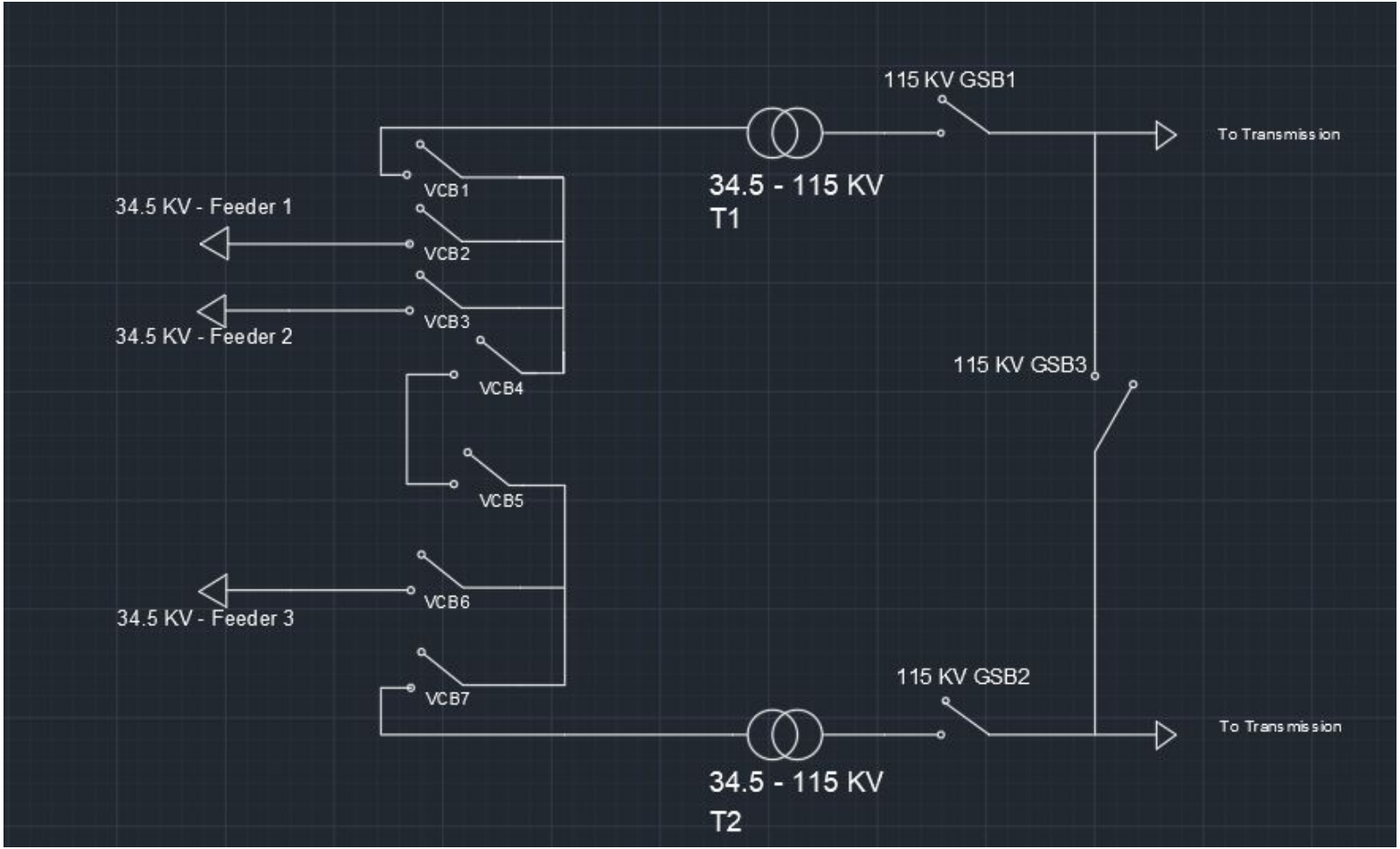
Cash Flow										
Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
$ (103,689,637.13)	$ 10,925,246.23	$ 11,277,039.16	$ 11,640,159.82	$ 12,014,972.96	$ 12,401,855.09	$ 12,801,194.83	$ 13,213,393.30	$ 13,638,864.56	$ 14,078,036.00	$ 14,531,348.76

Present Value				
Years	Installation Cost	O+M	Revenue	Profit
10	$ (103,689,637.13)	($4,934,606.35)	$ 126,522,110.71	$ 17,897,867.22

Moving Forward

Substation Design

- Substation Key Plan
- Grounding System
- Cable Trenching Calculations
- Cables, Bus, Breaker, Switches, Transformers
- Monitoring and Protection


115 KV GSB1
To Transmission
34.5 - 115 KV
T1
VCB1
34.5 KV - Feeder 1
VCB2
VCB3
34.5 KV - Feeder 2
VCB4
115 KV GSB3
VCB5
VCB6
34.5 KV - Feeder 3
VCB7
115 KV GSB2
To Transmission
34.5 - 115 KV
T2

Questions?