Iowa State University
Department of Electrical and Computer Engineering

115/34.5kV Solar Plant & Substation

Client: Black & Veach: Adam Schroeder, Elymus Schaffer, Utsavee Desai
Faculty Advisor: Venkataramana Ajjarapu

Andrew M Chizek, David W Ntako, Ben Palkovic, Mohamed A Sam, Sergio Sanchez Gomez & Dallas R Wittenburg

| Senior Design Team 41

| 05/09/2025

Iowa State University
Department of Electrical and Computer Engineering

Group Roles

- Andrew Chizek: Researcher and Drafter
- David Ntako: Researcher and Drafter
- Ben Palkovic: Meeting Recorder and Drafter
- Mohamed Sam: Testing and submission
- Sergio Sanchez Gomez: Technical Writer and Editor
- Dallas Wittenburg: Client and Advisor Communications

IOWA STATE UNIVERSITY
Department of Electrical and Computer Engineering

Project Overview

Fall Semester: Solar Farm

Spring Semester: Substation

- Make a complete design of a solar farm and substation including all drawings, calculations, and tests needed for construction

Project Motivation

Users

- Utility companies
- Citizens who use electricity

Needs

- Clean energy
- Uninterrupted supply of power
- Optimal use of land and budget
- Adhere to all safety codes and regulations
- Sustainable

IOWA STATE UNIVERSITY
Department of Electrical and Computer Engineering

Project Plan

Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
(Week 1-3)	(Week 4-6)	(Week 7-9)	(Week 10-12)	(Week 13-15)
Collect data sheets for PV cells and solar farm compoenents	Finalize equipment and components for solar power plant	Create preliminary design sketch, and finalize actual design in AutoCAD	Perform voltage-drop calculations and economic analysis	Simulate solar circuit and analyze power flow
Research	Planning	Designing	Calculation	Simulation

Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
(Week 1-3)	(Week 4-6)	(Week 7-9)	(Week 10-12)	(Week 13-15)
Collect data sheets for substation equipment	Finalize equipment for substation	Design of one-line diagram of the substation	Perform power flow calculation and economic analysis	Simulate solar farm and substation power flow
Research	Planning	Designing	Calculation	Simulation

| Sergio

Iowa State University
Department of Electrical and Computer Engineering

Deliverables

Fall Semester: Solar Farm

- Array Parameter Tool
- String, Rack, and Array Layouts
- Plant Characteristics
- Voltage Drop Calculations
- Datasheets
- Site Selection

Spring Semester: Substation

- One-Line
- Equipment Layout
- Grounding Study and Calculations
- AC and DC Calculations
- ETAP Simulations

| David

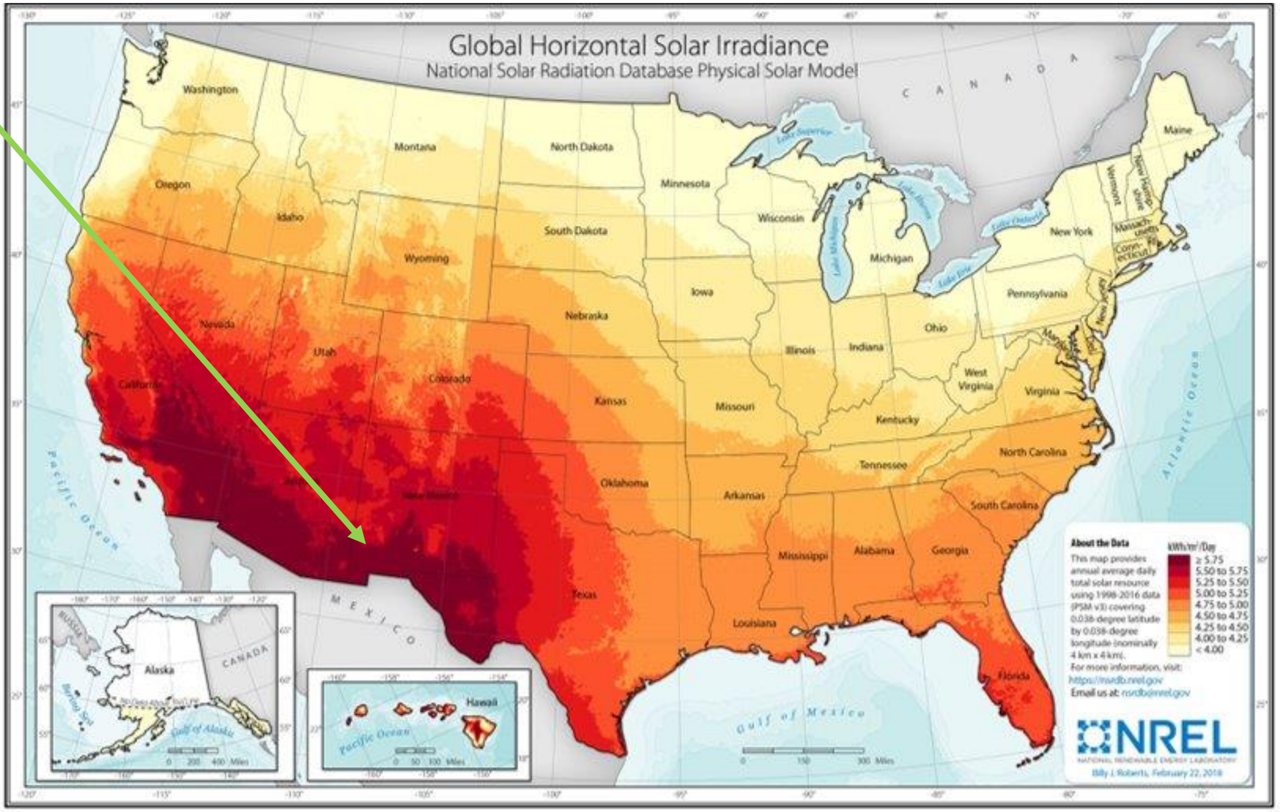
| 05/09/2025

IOWA STATE UNIVERSITY
Department of Electrical and Computer Engineering

Solar Site Selection

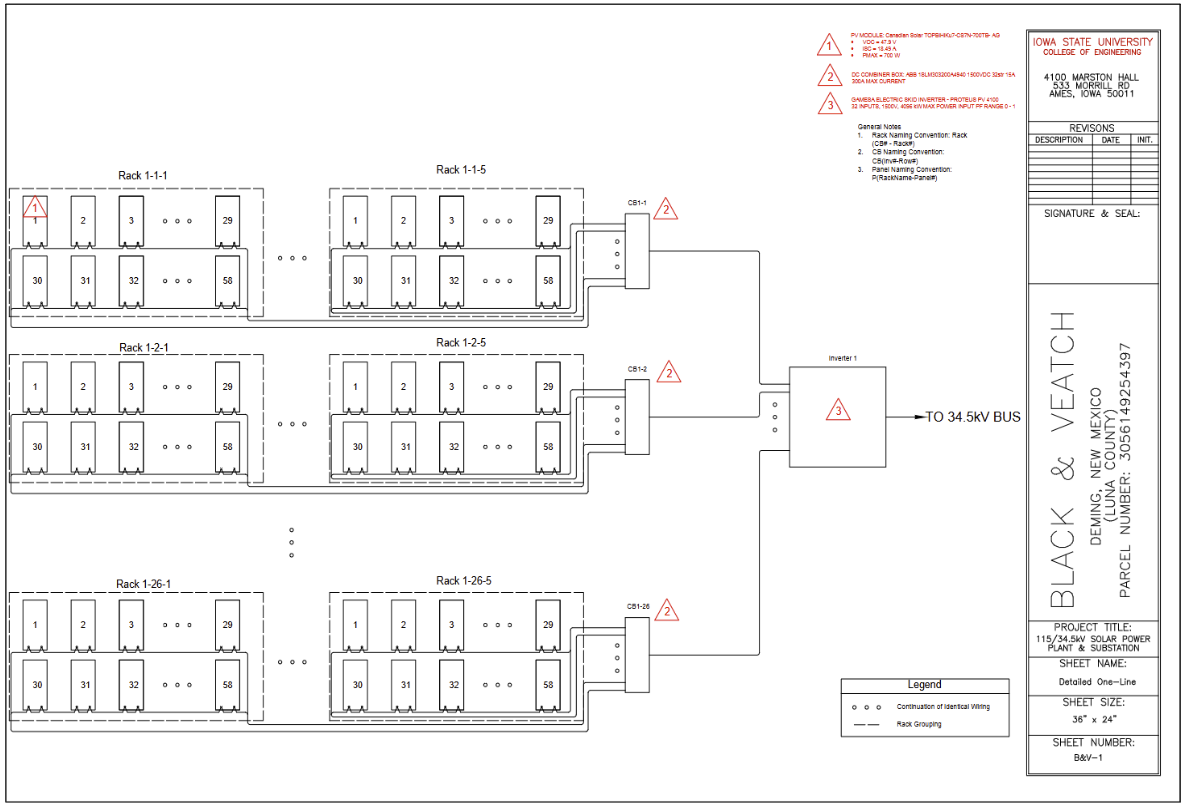
Deming, New Mexico

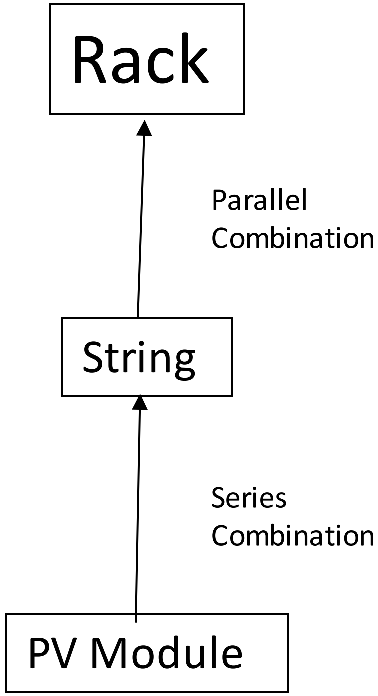
- Optimal cost
- High solar irradiance
- Barren, useless land
- Nearby high voltage transmission lines



Iowa State University
Department of Electrical and Computer Engineering

Solar Array Overview





PV Modules	Combiner Box	Inverter
700W	1500 V	1500 V input
Voc: 47.9 V	320 A	4095 kW
Isc: 18.49 A		

David

05/09/2025

Iowa State University
Department of Electrical and Computer Engineering

Solar Array Overview

Array Parameter Tool

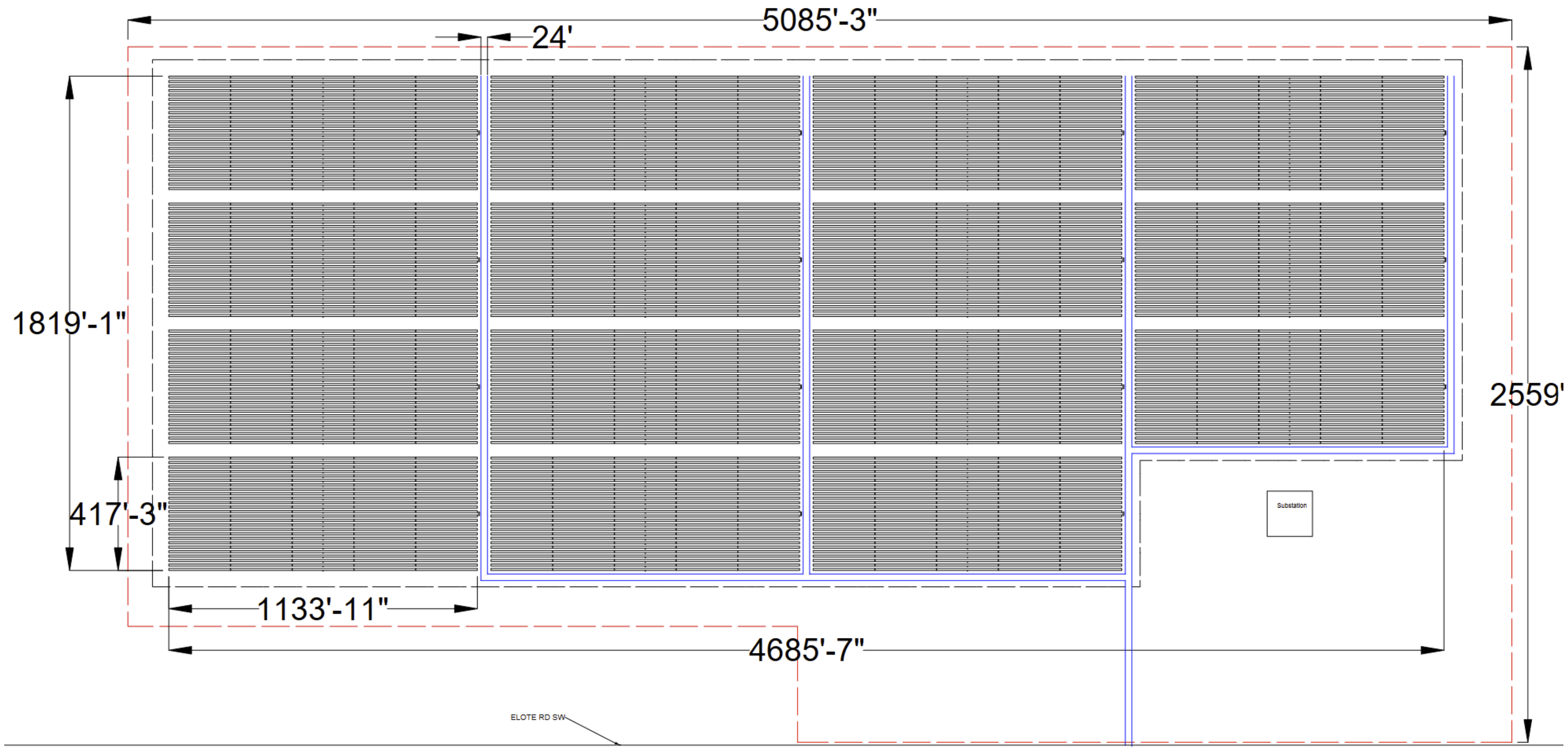
		String Size				Electrical Rack Size				CB capacity				Array Design				Array Size		
					Designer Choice		Landscape													
	Location Dependent	Min Temp	4.44	C	Datasheet	Module width	7.82	ft	Datasheet (STC)	mod/string Isc	18.49	A	Designer Choice	Racks per row	5	Designer Choice	tilt	30	
					Datasheet	module height	4.27	ft	NEC sectic	multiplier	1.25								
	Datasheet (STC)	Voc	47.9	V						nom Isc	23.1125		Designer Choice	rows per Array	26		table height proj	7.395857	ft
	Datasheet (STC)	Ref temp	25	C	Designer Choice	Rack width	29	modules	Irr.	multiplier	1.25								
					Designer Choice	Rack height	2	modules		max Isc	28.89063	A	Designer Choice	Racks removed	0	Designer Choice	row space	9	ft
	Datasheet	Temp Coeff of Voc	-0.0029	/C		Modules per rack													
		Temp delta	-20.56			Rack width	226.78	ft	Designer Choice: 200, 400A etc.	allowed current	320	A		Total Racks/Array	130		pitch	16.39586	ft
		temp correction	1.06			Rack height	8.54	ft		is this disconnect A?							Space for Inverter Maintenance		ft
		V0c corrected	50.75599							strings per CB	11.07626			Total modules	7540		Array height	426.2923	ft
										Round down:	11								
Confirm possible with Panel type chosen		string voltage	1500	V						racks per CB	5.5		Datasheet (STC)	module capacity	700	W	Array width	1133.9	ft
	Designer Choice: 600, 1000, 1500, 2000V	String size	29.55316														Ground Coverage Ratio	0.520863	
		string size	29											dc capacity	5278	kW			
		Actual String Voltage	1471.9																
													Designer Choice	inverter capacity	4095	kW			
																MVA			
													Provided: Industry standard 1.3	ILR	1.288889				
		Input Information =																	

David

05/09/2025

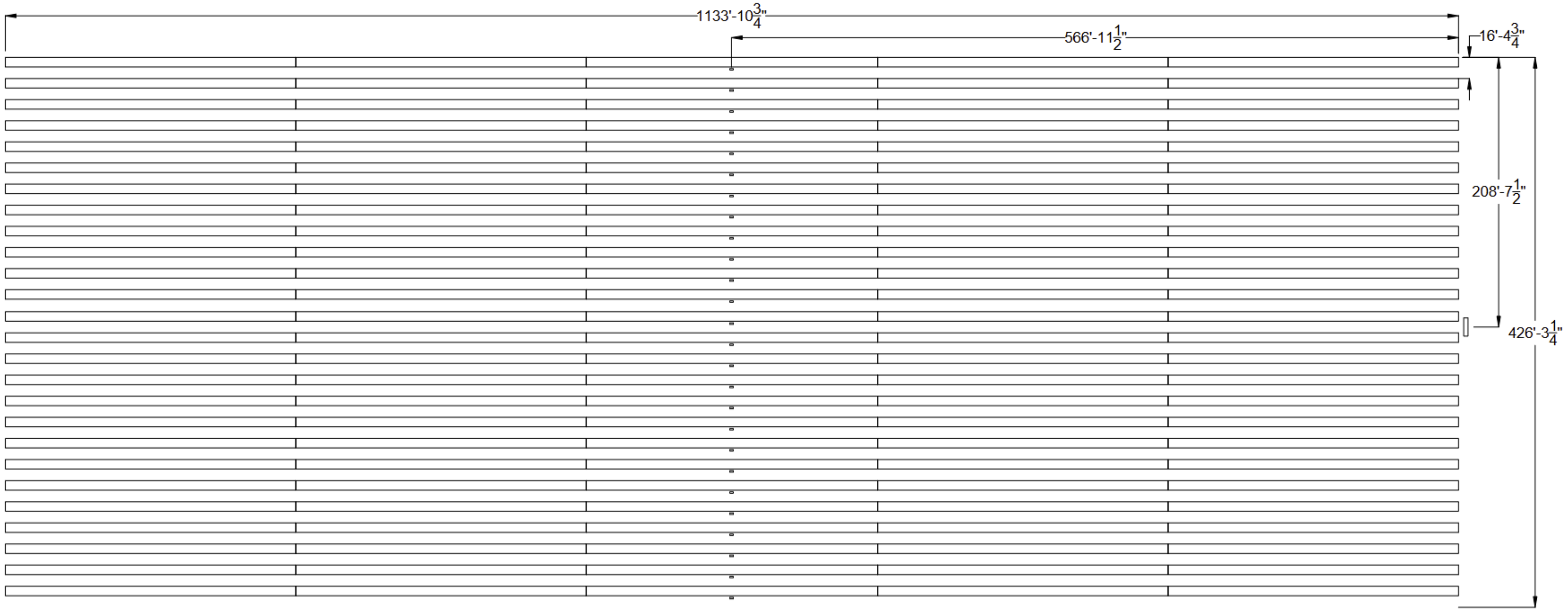
Iowa State University
Department of Electrical and Computer Engineering

Solar Farm Overview



IOWA STATE UNIVERSITY
Department of Electrical and Computer Engineering

Solar Array Overview



| Mohamed

| 05/09/2025

Iowa State University

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	Voltage Drop of String	Voltage Drop of Jumper
DCB#-##	per rack	Amp	feet	AWG	Ohm/kft	Ohm	Volts	Amp	feet	AWG	Ohm/kft	Ohm	Volts	percent	percent
DCB1-01	2	14	226.87	10	1.2400	0.5448151	7.8769264	28	569	8	0.7640	0.8409313	24.344096	0.525128427	1.622939733
DCB1-02	2	14	226.87	10	1.2400	0.5448151	7.8769264	28	342	8	0.7640	0.5061071	14.632128	0.525128427	0.9754752
DCB1-03	2	14	226.87	10	1.2400	0.5448151	7.8769264	28	115	8	0.7640	0.1703152	4.92016	0.525128427	0.328010667
DCB1-04	2	14	226.87	10	1.2400	0.5448151	7.8769264	28	342	8	0.7640	0.5061071	14.632128	0.525128427	0.9754752
DCB1-05	2	14	226.87	10	1.2400	0.5448151	7.8769264	28	569	8	0.7640	0.8409313	24.344096	0.525128427	1.622939733
Combiner Name		from Array Parameter	panels in string * panel width	IMP x 1.25 AWG size above that	Table 8 NEC						Table 8 NEC				

$$V_d = \frac{I \times 2 \times d}{1000\, ft/kft} \times \left(\frac{\Omega}{kft} \right)$$

Where:

V_d	= voltage drop
d	= route length of dc cable in feet (2 x adjusts for total circuit wire length)
I	= dc current in amperes (commonly I_{mp})
Ω//kft	= ohms/thousand feet (resistance)

$$\text{Voltage drop (in percentage)} = \frac{V_d}{V_{MAX}} \times 100$$

Iowa State University
Department of Electrical and Computer Engineering

Substation Overview

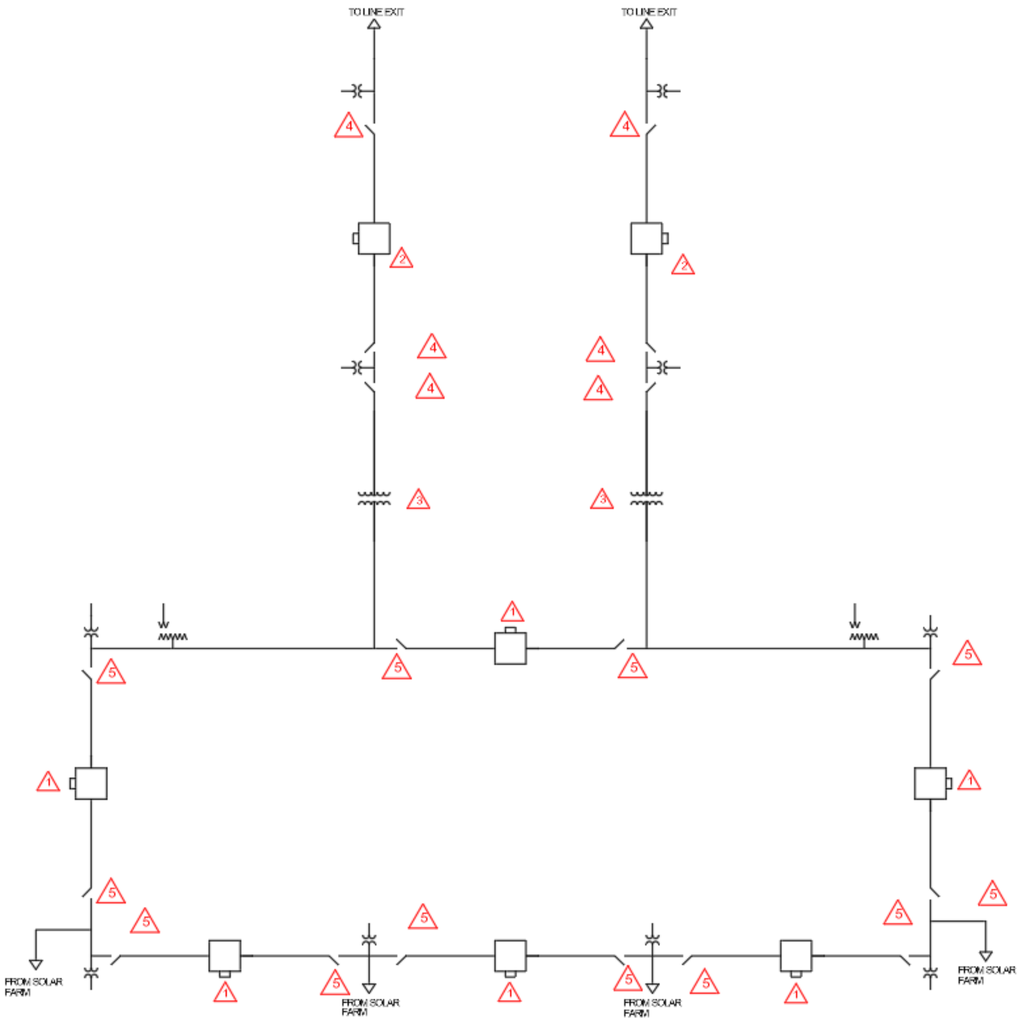
Ring Bus Configuration

Pros

- Very Reliable
- Flexible

Cons

- Complex relaying
- More land
- More expensive

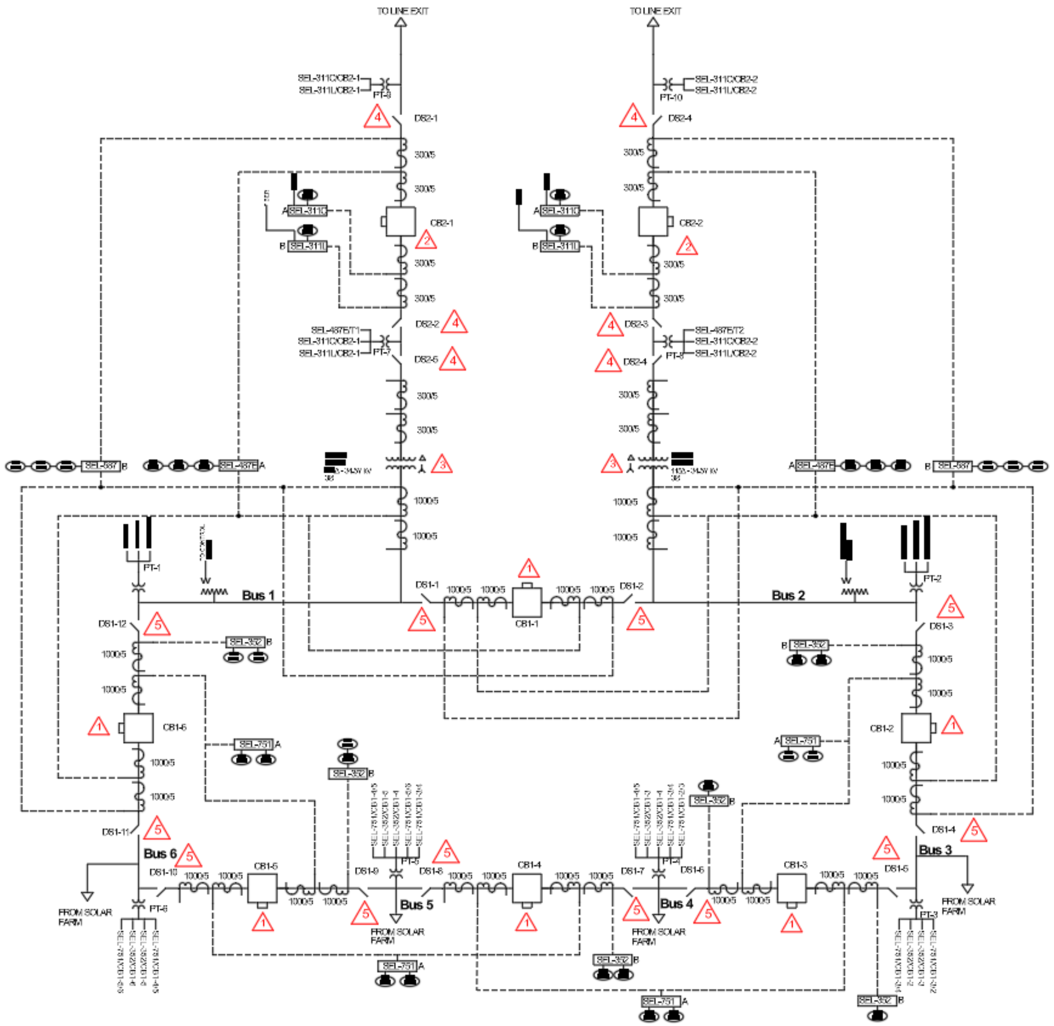


IOWA STATE UNIVERSITY
Department of Electrical and Computer Engineering

Relaying Plan

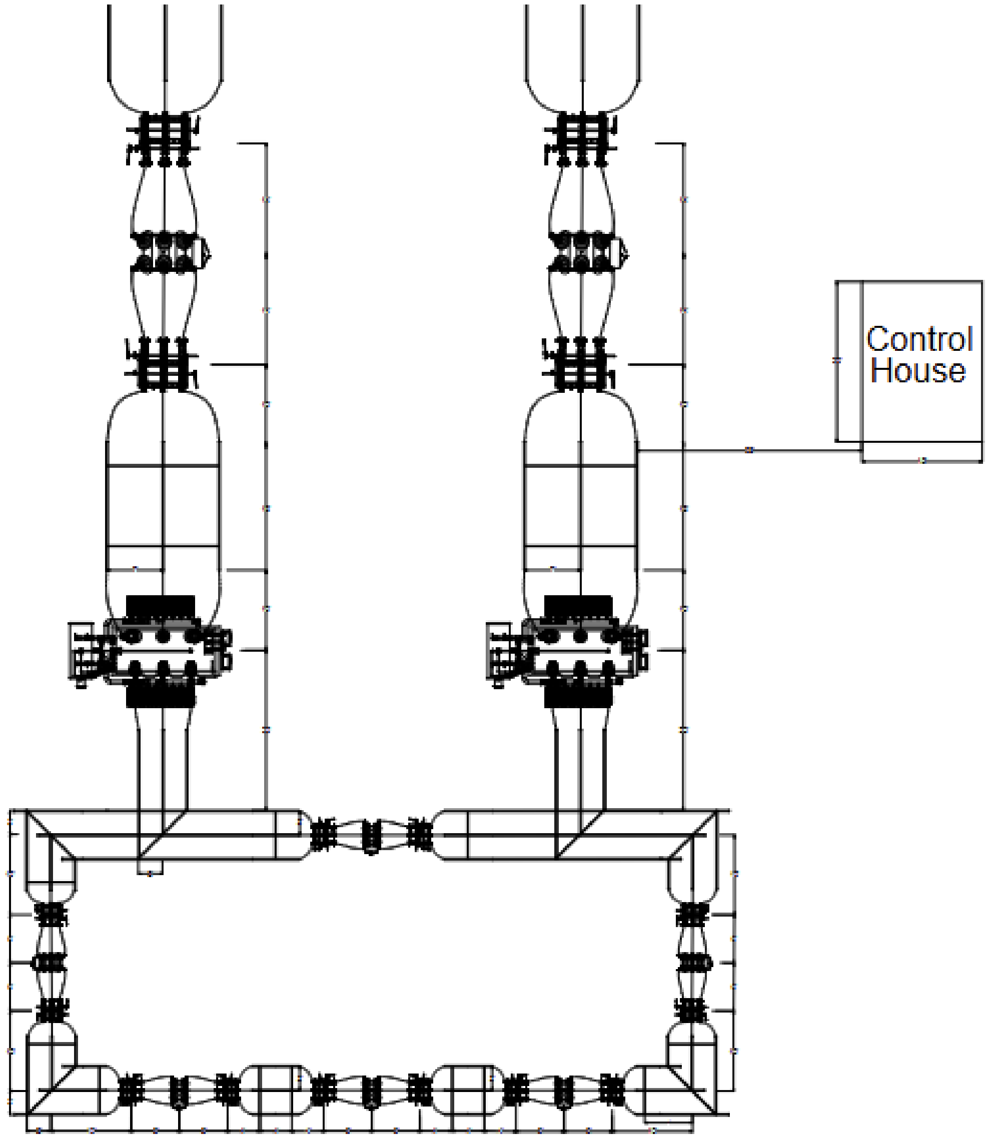
Key Components

- Voltage Transformer (VT)
- Current Transformer (CT)
- Relays
  - **Line Protection**:
    SEL 311L and 311C
  - **Feeder and BF**:
    SEL 751 and 352
  - **Transformer Prot:**
    487E and 587



Iowa State University
Department of Electrical and Computer Engineering

Key Plan



| Andrew

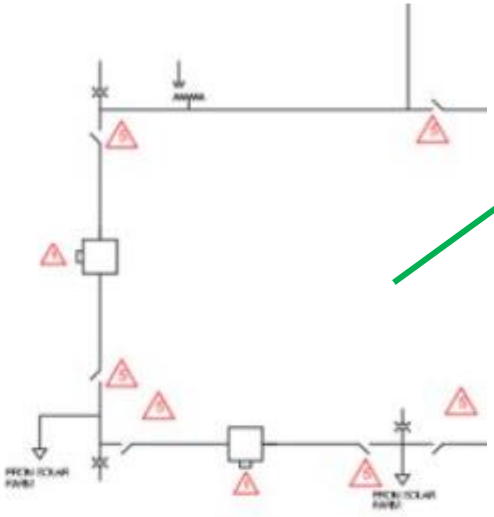
| 05/09/2025

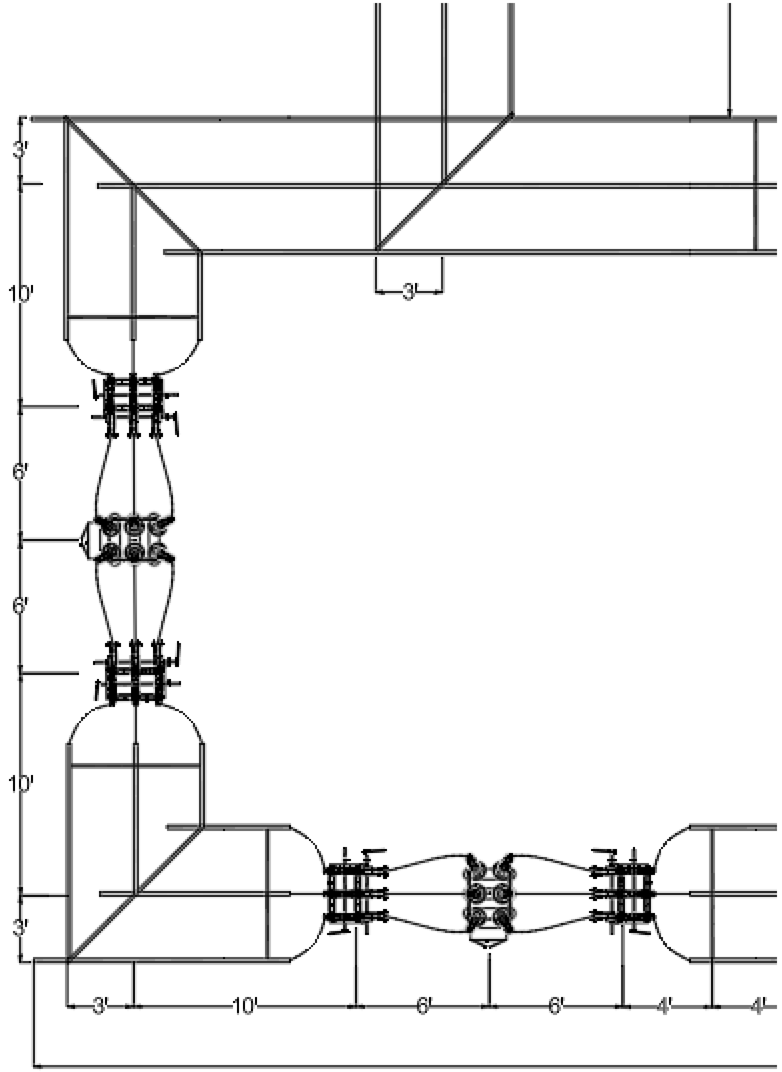
IOWA STATE UNIVERSITY
Department of Electrical and Computer Engineering

Key Plan

Things to Consider

- Bus spacing
- Phasing
- Land constraints





| Andrew

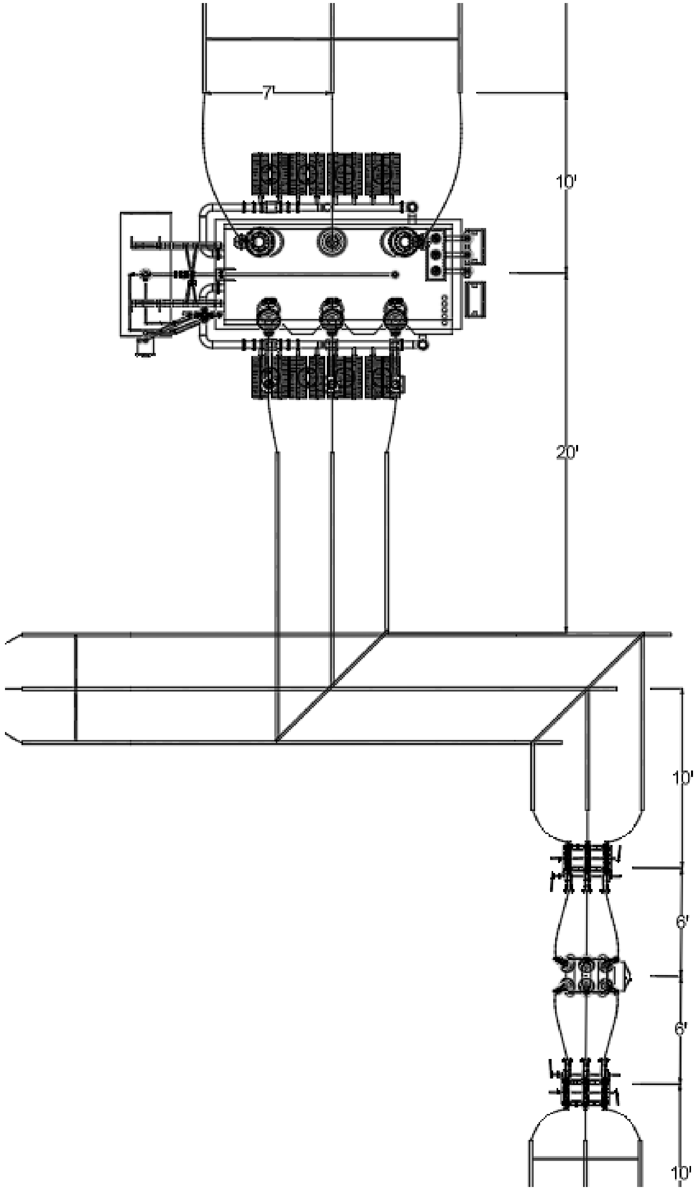
| 05/09/2025

Iowa State University
Department of Electrical and Computer Engineering

Key Plan

Things to Consider

- Bus spacing
- Phasing
- Component sizes



Andrew

05/09/2025

Iowa State University
Department of Electrical and Computer Engineering

AC calculations

AC STUDY							
		Quantity	Load/Unit (W)	Amps (ea)	Voltage (V)	Total (W)	Amps Total
AC Panel - Control Building	Breaker Recepticle and Lights	8	210	1.75	120	1680	14.00
	Transformer Fans	2	24000	100	240	48000	200.00
	Transformer Sump Pump	2	2000	8.333333	240	4000	16.67
	Control House Lighting	20	36	0.3	120	720	6.00
	Yard Lights (Assuming lights are off)	8	55	0.458333	120	440	3.67
	HVAC System	1	10000	41.66667	240	10000	41.67
	Fire Detection Equipement	1	150	1.25	120	150	1.25
	Exhaust Fan	1	132	1.1	120	132	1.10
	AC Battery Charger	1		0	240	0	0.00
	Power Outlet	10	180	1.5	120	1800	15
	Breaker Heaters	8	640	5.333333	120	5120	42.666667
				0	1	0	0
				0	1	0	0
	Worst Case Tripping						
	High Side Breaker Trip	1	720	3	240	720	3
	Low Side Breaker Trip	2	720	3	240	1440	6
	Total Worse Case AC Panel Load					72042	342.02
		Total Worst Case Load (+10%)				79246.2	376.21833

80 kVA station service transformer
450 A MTS

IOWA STATE UNIVERSITY
Department of Electrical and Computer Engineering

DC calculations

Components	Load Current (A)	Nominal Voltage (V) DC	Inception and Active Shutout Time	Number of components	Total Load Current (A)	Power Requirement	Power (Units)
34.5kV Breaker:	Tripping Current: 3.3	70 – 140	0 -1	6	Tripping Current:19.8	343	W
	Closing Current: 2.6	90 - 140			Closing Current :15.6	364	W
115kV Breaker:	Tripping Current : 6.6	125	239- 240	2	Tripping Current: 13.2	1050	W
	Closing Current : 3.6	125			Closing Current : 7.2	950	W
SEL-311C	0.20	125	1 - 240	8	1.60	25	W
SEL-311L	0.20	125	1 - 240	8	1.60	25	W
SEL-587	0.044	125	1 - 240	2	0.08	6	W
SEL-487E	0.280	125	1 - 240	2	0.56	35	W
Battery Monitoring Equipment	0.024	50 -180	1 - 240	1	0.02	6	VA
DC Ammeter	0.048	125	1 - 240	1	0.048	3	VA
DC Voltmeter	0.048	120	1 - 240	1	0.048	3	VA
SACO Annunciator (L8)	0.150	125	1 - 240	2	0.30	15	W
Edwards Bell	0.012	125	1 - 240	1	0.012	1.5	VA
Power Line Indicating Lamps (LEDs)	0.017	125	1 - 240	8	0.136	2.125	W

60 Cell Sysem	Continuous Load	Discontinuous Load Current
	4.404A	19.8 A

Power Supply Burden (W)	t=240min	t = 1 min
	4.404 A	37.404

IEEE-485

Iowa State University
Department of Electrical and Computer Engineering

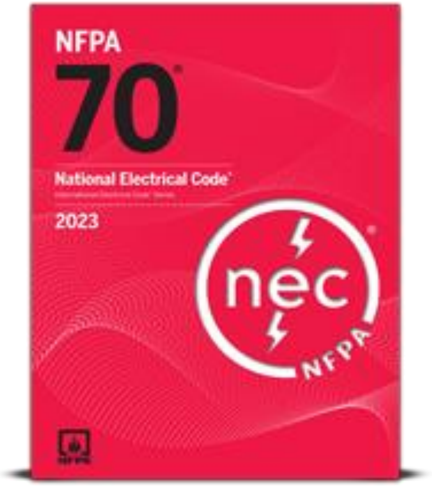
Standards

IEEE Standards

- IEEE 80 - Grounding
- IEEE 485 – Lead acid battery sizing
- IEEE 605 – Bus design

NEC Standards

- Section 210-20(a) - Overcurrent protection devices
- Section 110-14(c) - Conductor Sizing



Iowa State University
Department of Electrical and Computer Engineering

Testing

Generation Bus				Voltage		Generation			Mvar Limits	
ID	kV	Type	Sub-sys	% Mag.	Angle	MW	Mvar	% PF	Max	Min
Bus_3	34.500	Mvar/PF Control	1	100.0	0.0	11.885	0.000	100.0		
Bus_4	34.500	Mvar/PF Control	1	100.0	0.0	15.846	0.000	100.0		
Bus_5	34.500	Mvar/PF Control	1	100.0	0.0	15.846	0.000	100.0		
Bus_6	34.500	Mvar/PF Control	1	100.0	0.0	15.846	0.000	100.0		
Bus_7	115.000	Swing	1	100.0	0.0					
Bus_8	115.000	Swing	1	100.0	0.0					
						59.423	0.000			

The generation totals to **59.423 MW**, which is nearly the target **60 MW** design goal.

All voltages are regulated at **100%**, and reactive power is **0.000 MVAR**, confirming the power factor is 1.0 across all generator buses.

IOWA STATE UNIVERSITY
Department of Electrical and Computer Engineering

Conclusions

<u>Group Member Contributions</u>

- Andrew Chizek: Component Selection, Section Views, Grounding Physical Drawings
- David Ntako: Component Selection, DC Calculation
- Ben Palkovic: One-Line Diagram, Physical and Relaying, Key Plan, Section Views
- Mohamed Sam: ETAP, Load Flow & Short Circuit, Three-Line Diagram
- Sergio Sanchez Gomez: DC Calculation, Battery Sizing, BOM
- Dallas Wittenburg: Substation Grounding, Layout, Conduit Plan, ETAP

<u>All Members:</u> Weekly Meetings, Rotating Leadership Roles

Iowa State University

Department of Electrical and Computer Engineering

THANK YOU

| Senior Design Team 41

| 05/09/2025