115kV / 34.5kV Solar Power Plant/Substation Design Project

Team sdmay19-26

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Advisor: Dr. Ajjarapu
Client: Black & Veatch

http://sdmay19-26.sd.ece.iastate.edu/

Safety Moment: Elevator Safety

Do:

- Hold handrail, stay away from door
- Use alarm button
- Stay calm + Stay stuck in elevator

Don’t:

- Use in event of fire
- Get on if overcrowded
- Engage in horseplay
- Rest on/push someone against doors

Black & Veatch Information

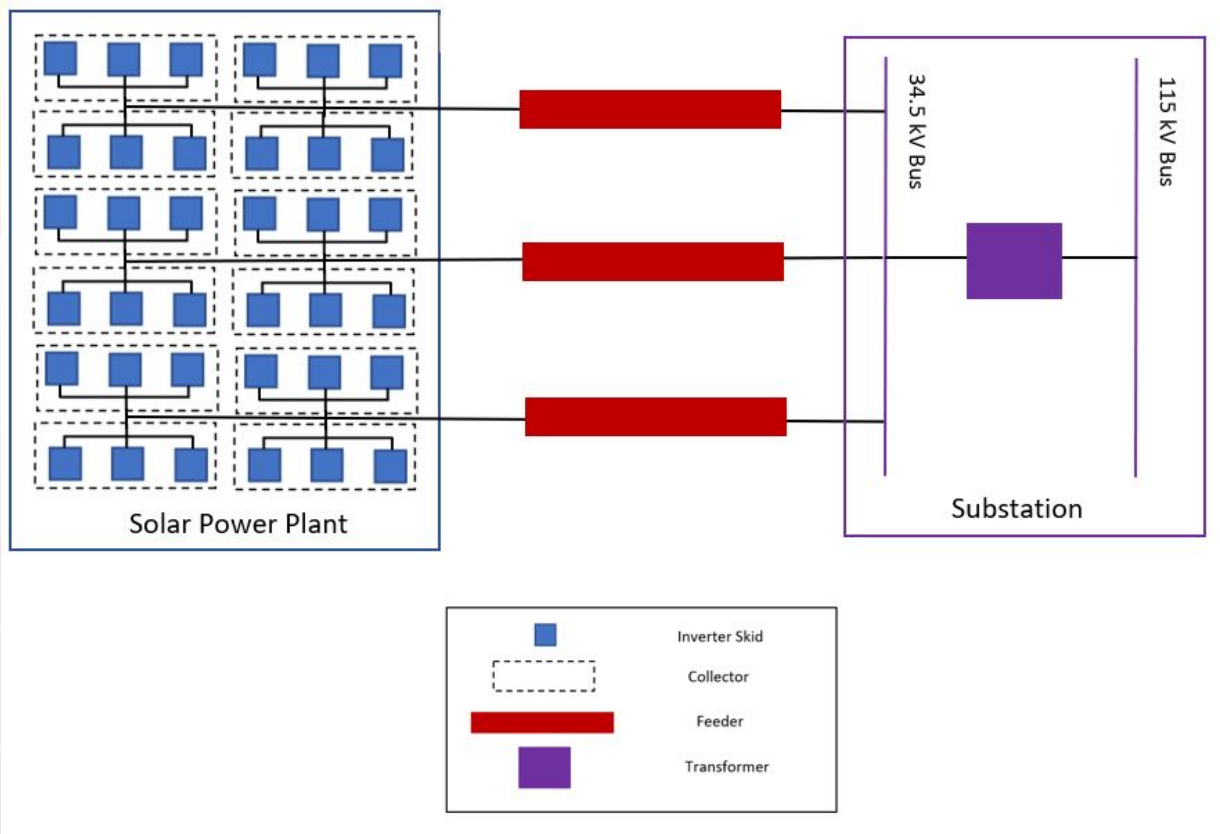
- A global engineering, construction and consulting company which specializes in infrastructure development for power, oil and gas, water, telecommunications, government, mining, and banking and finance markets.
- The largest majority employee-owned company in the U.S, and is ranked by Forbes as one of the largest privately owned companies.
- A large amount of its revenues comes from power division.

Problem Statement

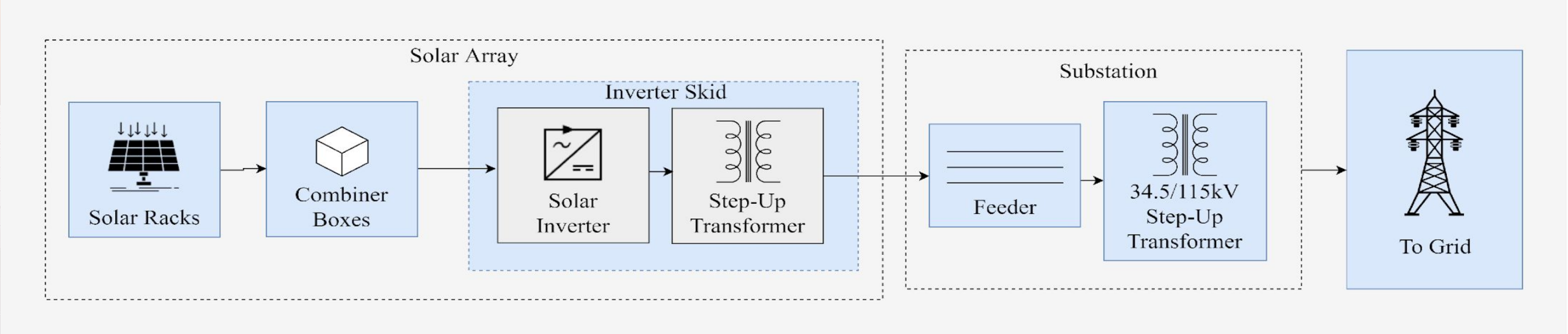
- Problem:
  - Provide clean energy for a grid shifting towards renewables to decrease its dependence on fossil fuels
- Solution:
  - Design a 60 MW solar plant that feeds a 115 kV/34.5kV substation

System Design

Conceptual Sketch



System Block Diagram



Functional Requirements

- Solar farm parameters
  - DC Voltage: 1000 V
  - Inverter: Eaton 1666kW
  - Panel: Hanwha 325W
  - ILR: 1.30
  - Fixed rack system
- Project scope document
- NEC requirements
- IEEE requirements

Non-Functional Requirements

- Location
- Cost effectiveness
- Man-hour budget

Potential Risks and Mitigation

- Component defects (high risk)

- Test components before use

Detailed Design

Design Approach

1. Scout several locations and evaluate them based on requirements
2. Perform a series of calculations to determine solar parameters
3. Create layout design of solar power plant based on parameters and ensure design meets NEC requirements
4. Create substation protection & controls schematics based on project scope document
5. Perform grounding calculations based on IEEE document

Market and Literature Survey of Similar Projects

MISO North Star Solar Project 100 MW capacity:

- Location in Saint Paul, MN
- 100 MW of solar PV capacity(440,000 solar panels)
- Approximately 800 acres of agricultural land
- Single axis tracking technology to maximize production
- Grid connection at the Chisago County substation 115kV

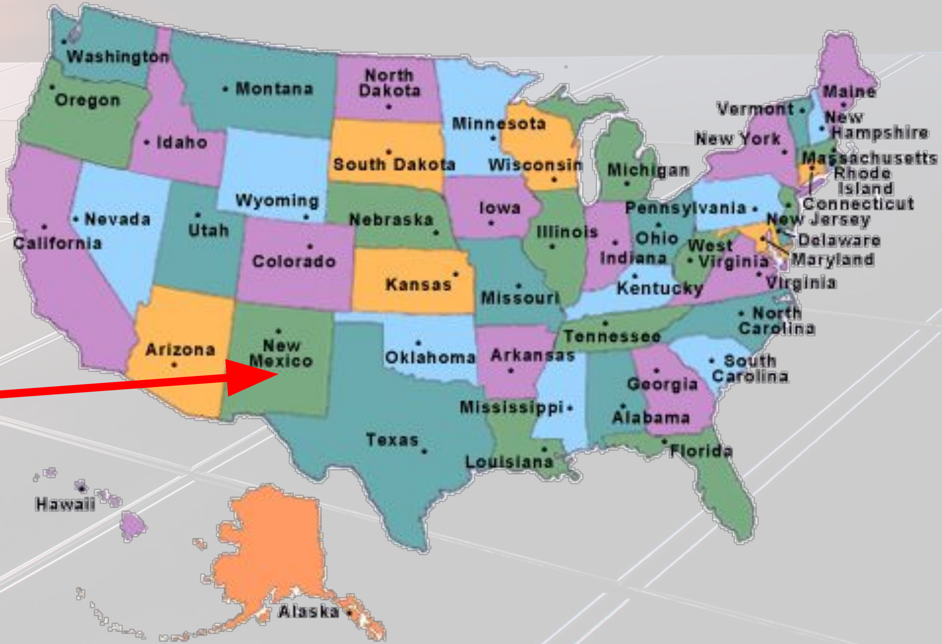
Location Decision

0 Peacock Rd
Estancia, NM 87016

LOT/LAND
$195,000
Price cut: -$15,000 (8/4)

560 acres

Central New Mexico grazing land located in the Estancia Basin near Estancia. Approximately 60 miles South of Santa Fe, 45 Miles Southeast of Albuquerque. Fully fenced with panoramic views of the Manzano Mountains. The Survey was completed on 10/9/2017.



Functional Decomposition

Component	Function	Input	Output
Solar Modules	Convert sunlight into DC power	Sunlight	DC power
Combiner Boxes	Combine the currents before sending it to the inverter	Current from string	Combined currents
Inverters	Convert DC voltage to AC voltage	DC voltage from array	AC voltage
Transformers in Inverter Skids	Step-up the voltage	Voltage from inverter	Voltage proportional to input voltage that goes to the feeders
Transformer in Substation	Step-up the voltage	Voltage from feeders	Voltage proportional to input voltage that goes to the grid
Relays	Measure the current in a line	Current in a line	Signal to circuit breaker
Circuit Breaker	Protects circuit from damage caused by excess current from an overload or short circuit	Signals from relays	Disconnect faulted lines
Communication Devices	Allows communication between substation equipment and SCADA	Signals from different substation equipment	Signals to SCADA

Resource Requirements

Solar Power Plant

- Equipment:
  - 238,032 solar panels
  - 792 combiner boxes
  - 36 inverters
  - 36 step-up transformers
- 244 acres of land
  - We found a 560-acre land for sale for $195,000
- NEC document
- Software:
  - AutoCAD
  - Microsoft Excel
  - NREL SAM

Substation

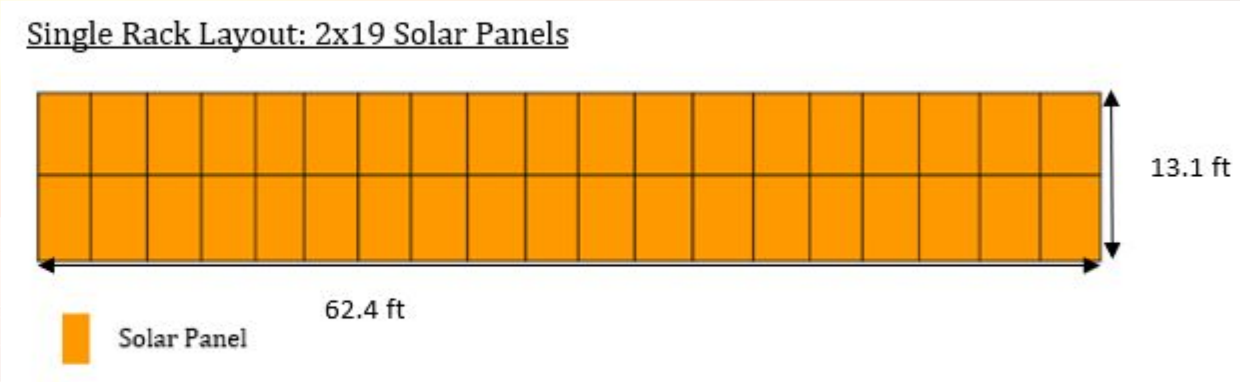
- Equipment:
  - Circuit breakers
  - Relays
  - Rigid bus
  - Steel + conductors
  - Concrete foundation
  - Communication devices
  - Transformer
- IEEE std 80-2000
- Software:
  - AutoCAD
  - Microsoft Excel

System Analysis

- Array parameter calculations
  - Determined number of components and verified the voltage and power of the system
- Voltage drop calculations
  - Carried out conductor sizing by analyzing the currents in the plant at different points
- Substation grounding grid calculations
  - Determined grounding parameters to ensure step/touch voltages were less than the tolerable step/touch

Phase 1: Solar Plant Design

Single Rack Layout

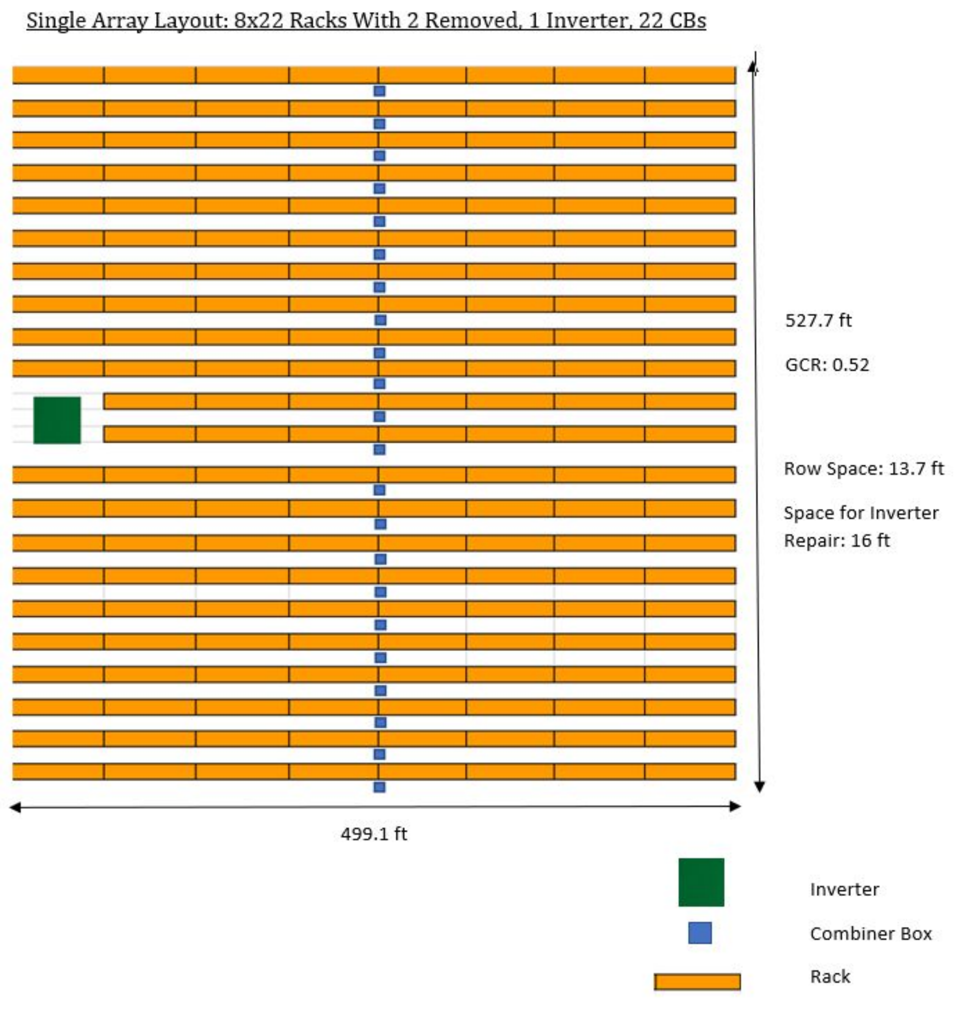


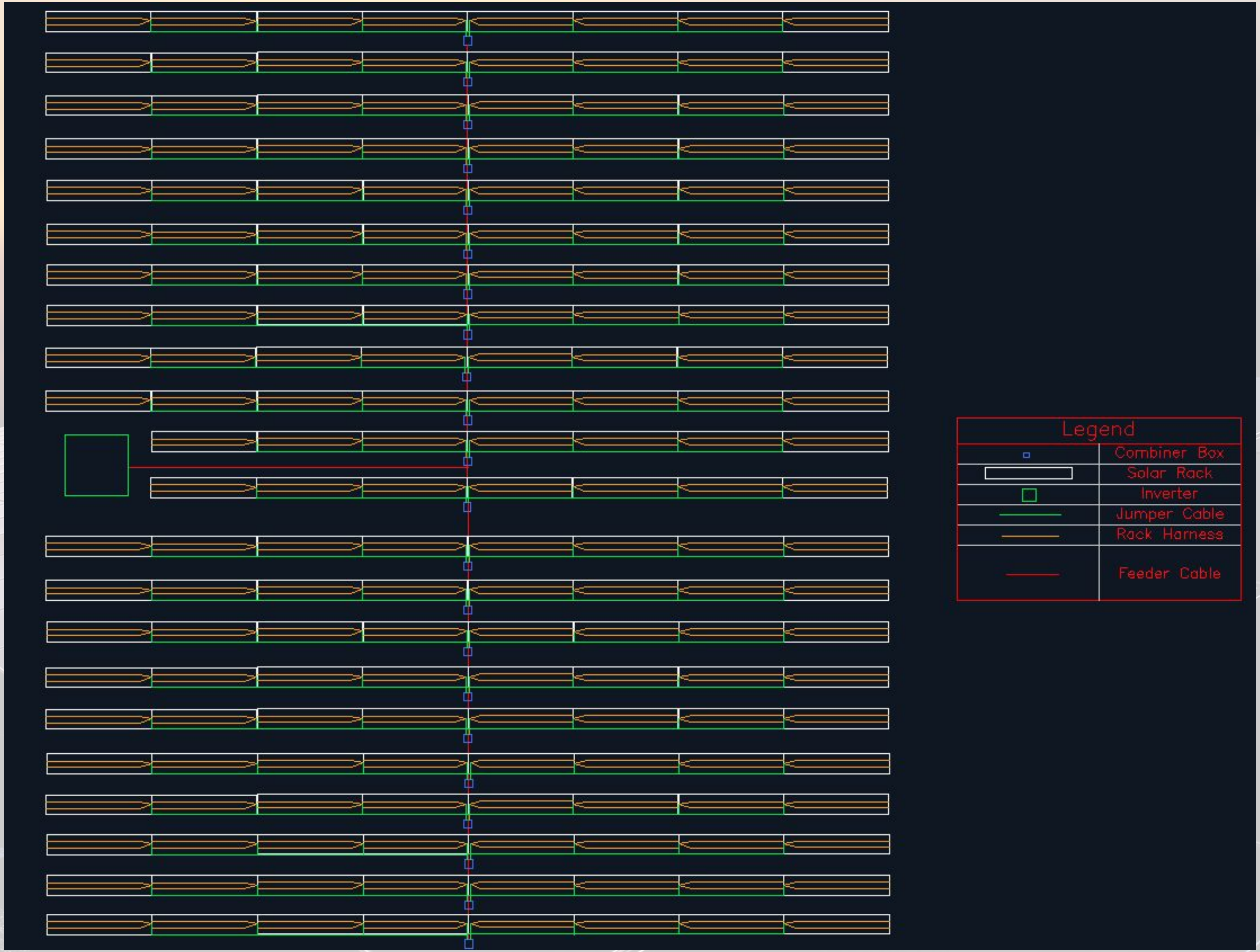
Based on:
Desired string voltage: 1000 VDC (Actual 972 V)

Voc, Isc of panels
Location min. Temp. to calculate corrected Voc

Single Array Layout

Based on:
Single rack layout
Desired ILR of 1.3 (Actual 1.29)
Tilt angle: 29.7 degrees
Sufficient row space to prevent shading losses of solar panels





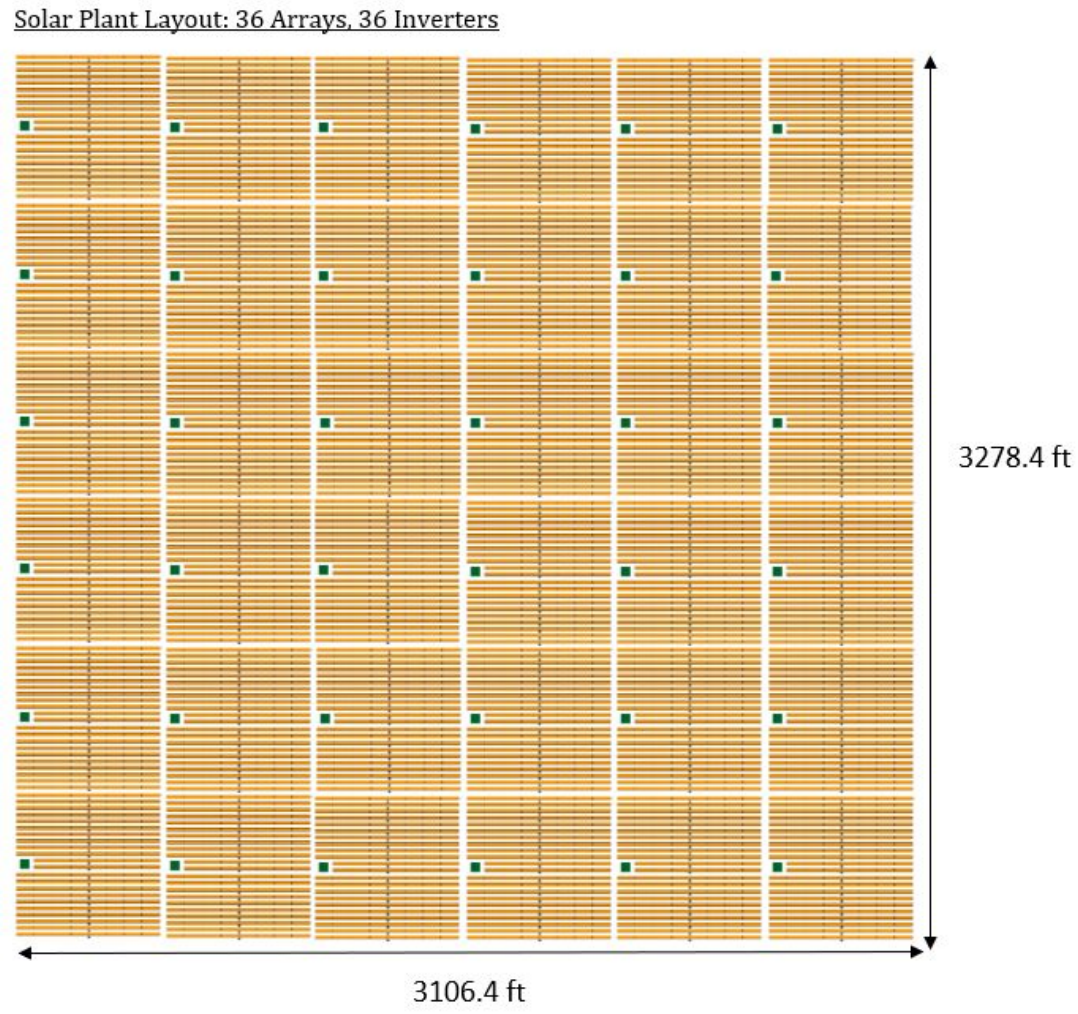
Rack harness: solar panels in a rack

Jumper cables: racks in a row to the combiner boxes

Feeder cables: combiner boxes to the inverter

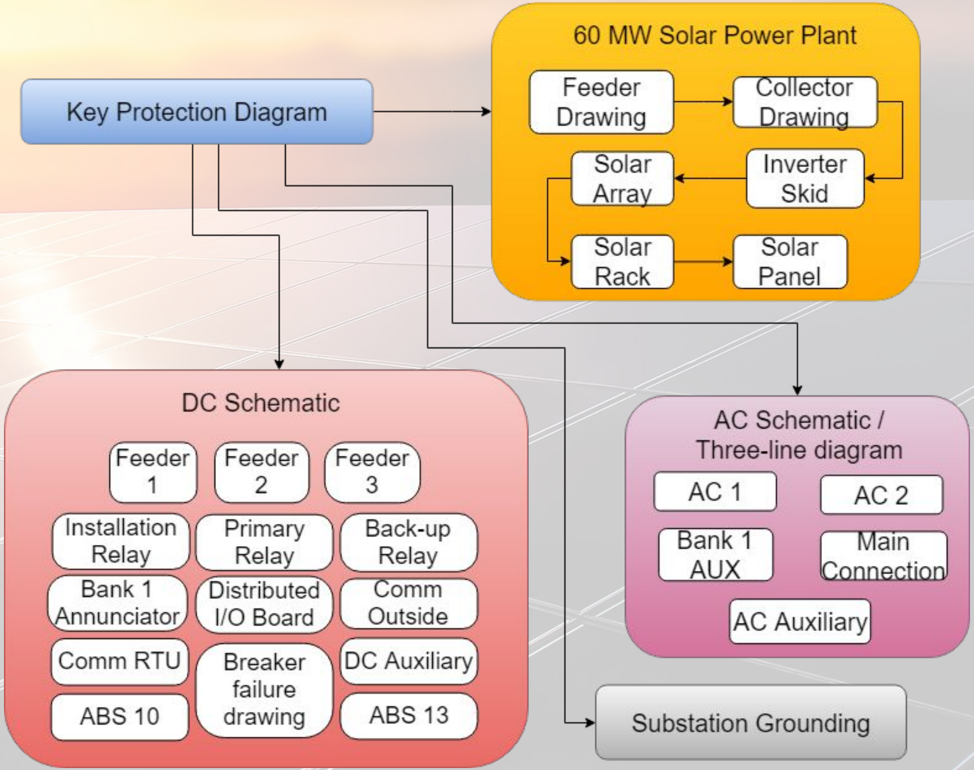
Solar Plant Layout

Consists of 36 arrays in a 6x6 arrangement
16 ft between each array for access roads

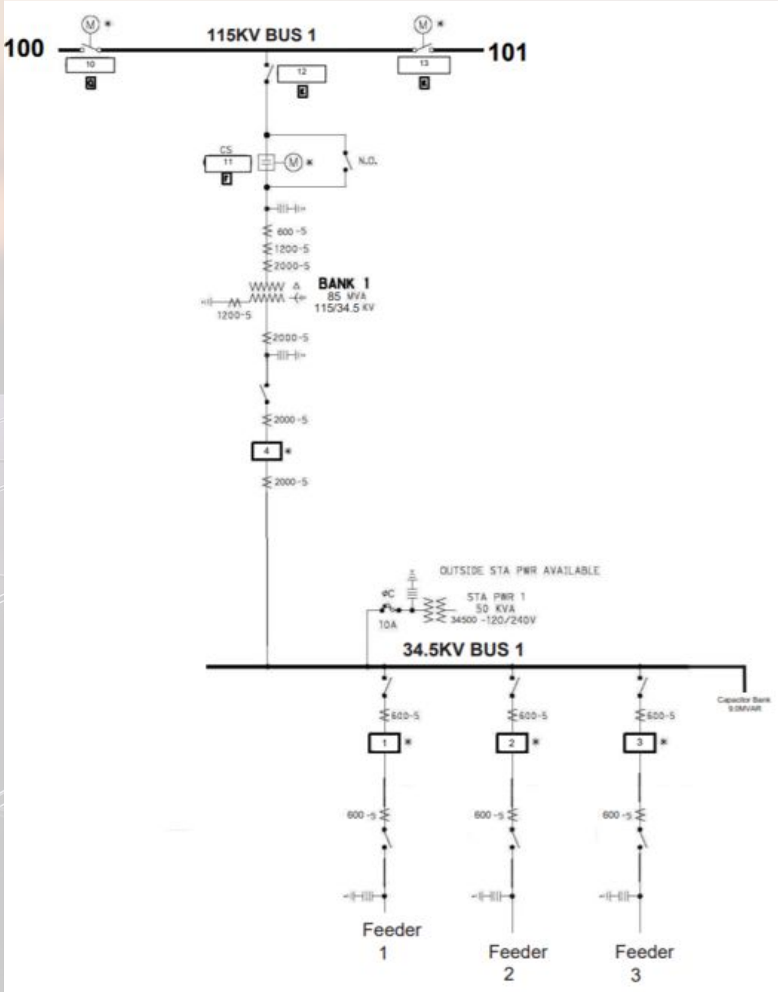


Phase 2: Substation Design

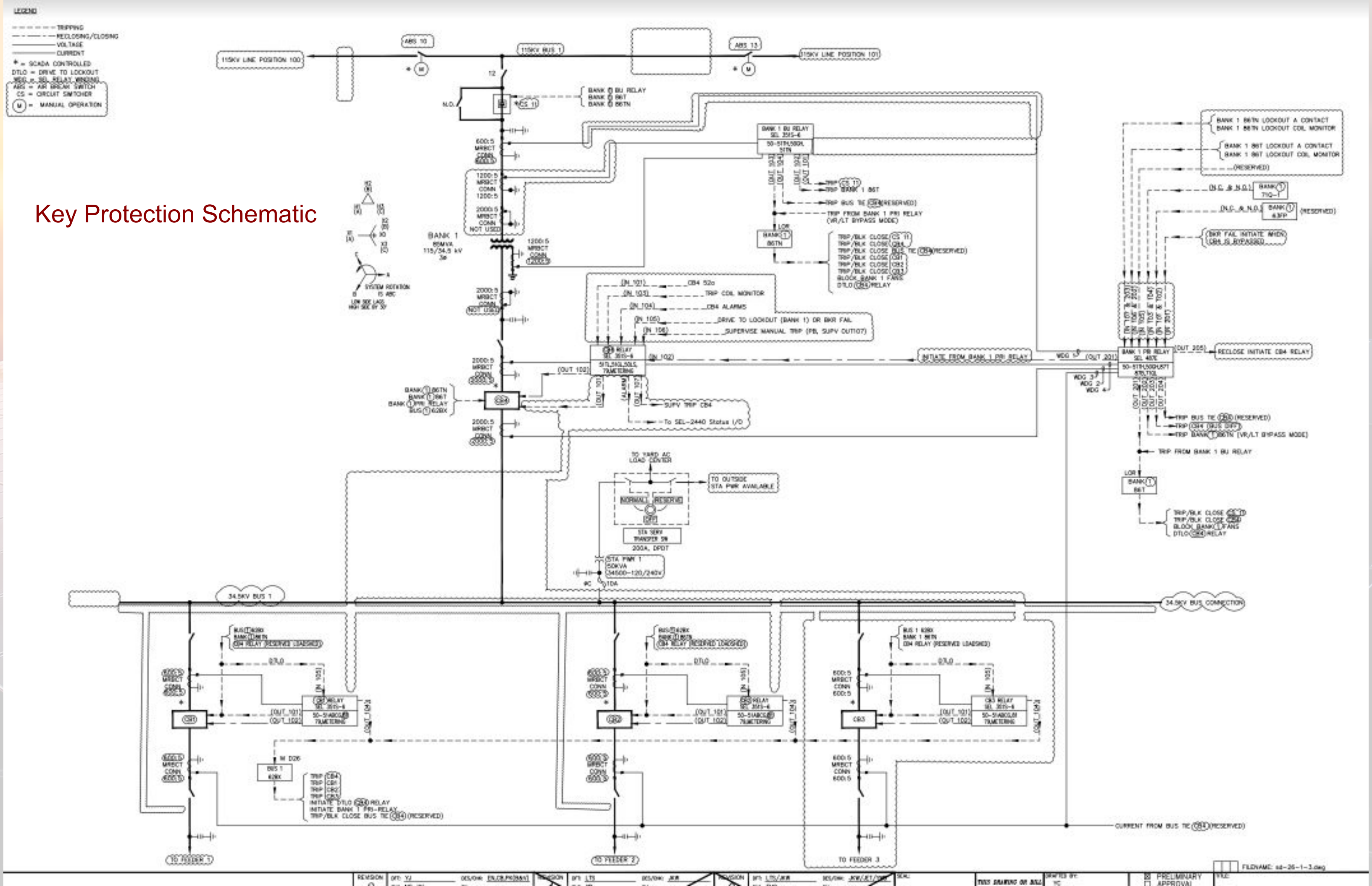
Protection & Controls Drawing Hierarchy



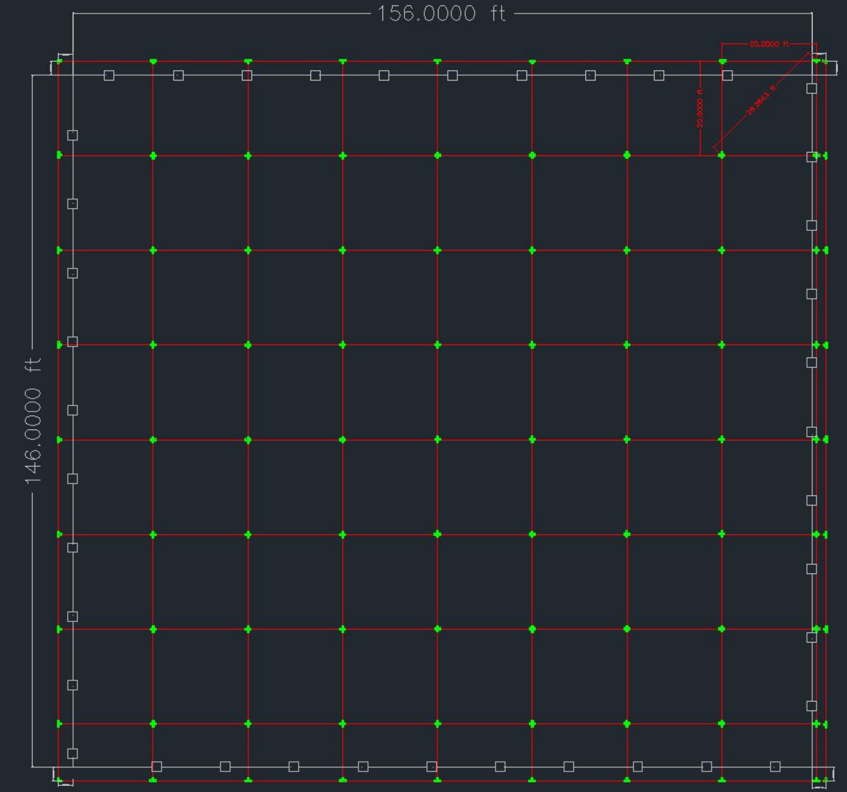
Single Line Diagram



Key Protection Schematic



Substation Grounding



1. Resistivity of soil
2. Calculate tolerable step and touch voltages
3. Make sure that the maximum step and touch voltages are less than the tolerable ones

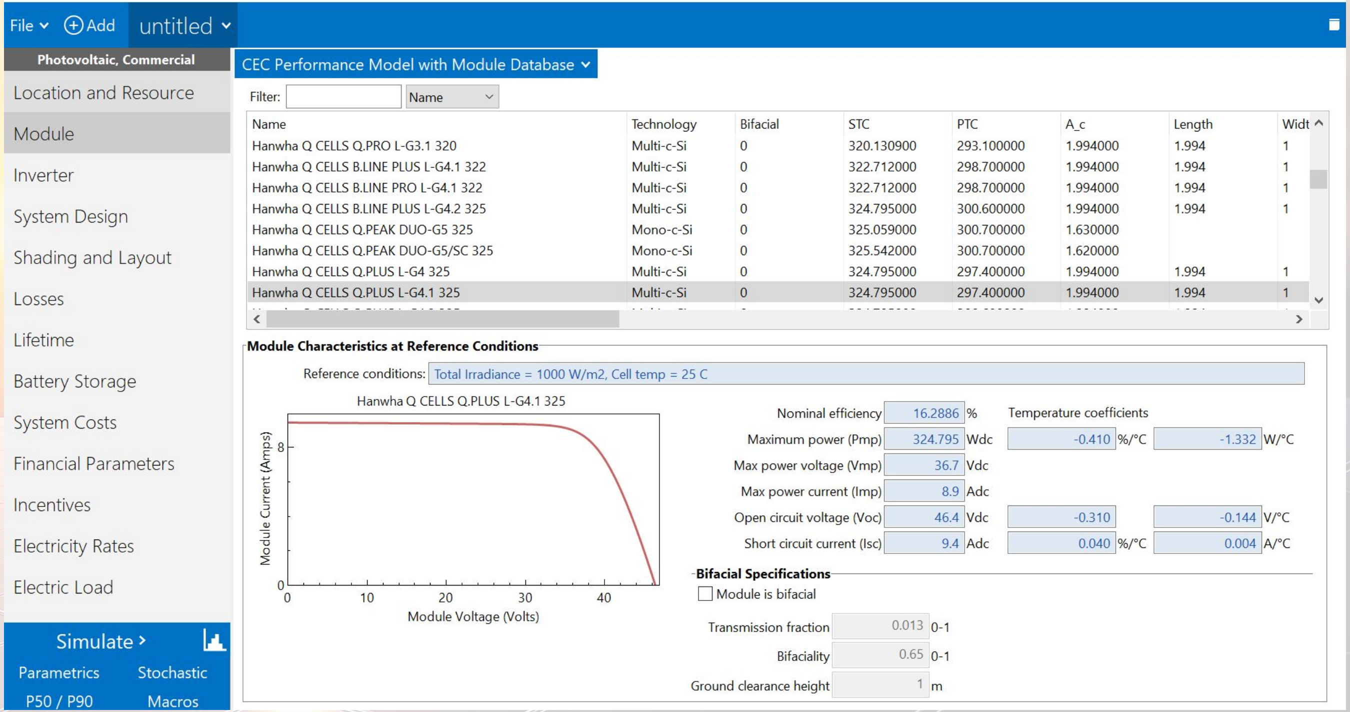
SYMBOL	DESCRIPTION
	Fence
	Exothermic Weld
---------	Ground Grid

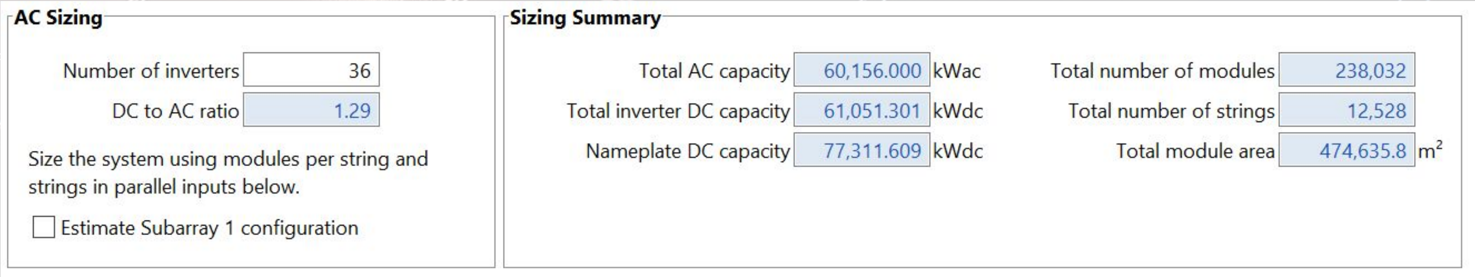
Testing

Testing and Evaluation Plan (Solar Power Plant)

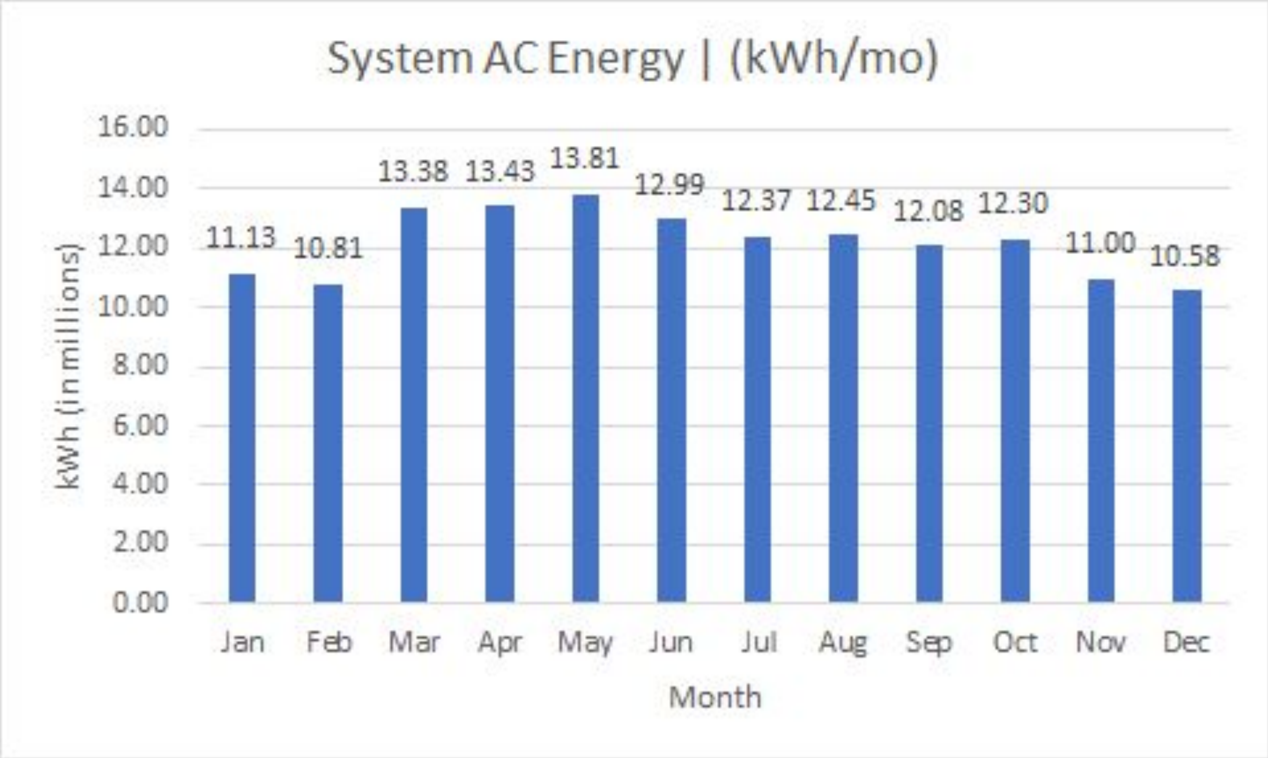
National Renewable Energy Lab System Advisor Model (NREL SAM):

- Performance model that takes in solar power plant parameters
- Simulates the system
- Simulation input parameters:
    - Location (Based on Latitude and Longitude)
    - Types of Inverters and Solar Panels we are using
    - Types of rack system (Fixed or Variable Rack and also Tilt angle and Ground Coverage Ratio)
    - Number of inverters
    - Size of panels
    - Number of solar modules in one string
- Simulation output parameters
    - The number of panels (Check if it matches with our Array Parameter Tool)
    - Number of strings (Check if it matches with our Array Parameter Tool)
    - ILR (Check if it matches with our Array Parameter Tool)


File
Add
untitled
Photovoltaic, Commercial
Location and Resource
Module
Inverter
System Design
Shading and Layout
Losses
Lifetime
Battery Storage
System Costs
Financial Parameters
Incentives
Electricity Rates
Electric Load
Simulate >
Parametrics
Stochastic
P50 / P90
Macros
CEC Performance Model with Module Database
Filter:
Name
Name | Technology | Bifacial | STC | PTC | A_c | Length | Widt
Hanwha Q CELLS Q.PRO L-G3.1 320 | Multi-c-Si | 0 | 320.130900 | 293.100000 | 1.994000 | 1.994 | 1
Hanwha Q CELLS B.LINE PLUS L-G4.1 322 | Multi-c-Si | 0 | 322.712000 | 298.700000 | 1.994000 | 1.994 | 1
Hanwha Q CELLS B.LINE PRO L-G4.1 322 | Multi-c-Si | 0 | 322.712000 | 298.700000 | 1.994000 | 1.994 | 1
Hanwha Q CELLS B.LINE PLUS L-G4.2 325 | Multi-c-Si | 0 | 324.795000 | 300.600000 | 1.994000 | 1.994 | 1
Hanwha Q CELLS Q.PEAK DUO-G5 325 | Mono-c-Si | 0 | 325.059000 | 300.700000 | 1.630000
Hanwha Q CELLS Q.PEAK DUO-G5/SC 325 | Mono-c-Si | 0 | 325.542000 | 300.700000 | 1.620000
Hanwha Q CELLS Q.PLUS L-G4 325 | Multi-c-Si | 0 | 324.795000 | 297.400000 | 1.994000 | 1.994 | 1
Hanwha Q CELLS Q.PLUS L-G4.1 325 | Multi-c-Si | 0 | 324.795000 | 297.400000 | 1.994000 | 1.994 | 1
Module Characteristics at Reference Conditions
Reference conditions: Total Irradiance = 1000 W/m2, Cell temp = 25 C
Hanwha Q CELLS Q.PLUS L-G4.1 325
Module Current (Amps)
Module Voltage (Volts)
0
8
0
10
20
30
40
Nominal efficiency 16.2886 %
Temperature coefficients
Maximum power (Pmp) 324.795 Wdc -0.410 %/°C -1.332 W/°C
Max power voltage (Vmp) 36.7 Vdc
Max power current (Imp) 8.9 Adc
Open circuit voltage (Voc) 46.4 Vdc -0.310 -0.144 V/°C
Short circuit current (Isc) 9.4 Adc 0.040 %/°C 0.004 A/°C
Bifacial Specifications
Module is bifacial
Transmission fraction 0.013 0-1
Bifaciality 0.65 0-1
Ground clearance height 1 m


AC Sizing
Number of inverters 36
DC to AC ratio 1.29
Size the system using modules per string and strings in parallel inputs below.
Estimate Subarray 1 configuration
Sizing Summary
Total AC capacity 60,156.000 kWac
Total inverter DC capacity 61,051.301 kWdc
Nameplate DC capacity 77,311.609 kWdc
Total number of modules 238,032
Total number of strings 12,528
Total module area 474,635.8 m2

Test Results & Evaluations



Testing and Evaluation Plan (Substation Design)

Compliance with NEC and IEEE codes:

- Checking design against the codes specified
- Calculating the conductor sizes and the voltage drop according the code.

Testing and Evaluation Plan (Solar Plant)

- Compliance with the following NEC codes:

NEC Code	Description	How to Check	Design Steps
Article 300.50 and Table 300.50	Discusses acceptable depth to bury conductors	Using this information during to plan wiring	Design a plant layout that applies this information
Article 310.10	Discusses the uses of conductors under different conditions	Ensure that we select the right conductors for our conditions	Choose wires that satisfy our conditions and implement them into the design
Article 310.15 and table 310.15	Defines ampacities for different conductors	Using this information in the voltage drop calculations	Applying values from calculations into conductor sizing
Section 310.120	Explains necessary markings for different conductors	Using this information to choose the right type of conductors	Choose wires with the right markings

Testing and Evaluation Plan (Substation)

- Compliance with IEEE 80-2000 Equations and assumptions:
  - Assuming that the rod length is 20ft

Deliverables

Man Hour Budget: Fall 2018

FALL 2018																		
Weeks	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	
Meetings (Client and Advisor)																		
Documentation																		
Solar Plant Size & Cost Determination																		
Solar Plant Layout Drawings																		
Feeder & Collector Design																		
Conductor Sizing and Voltage Drop																		
Key Protection Schematic																		
AC 1 and 2 Schematics																		
Review Deliverables																		
																		Sum
Hours Estimation	0	3	15	30	60	60	60	60	60	60	35	35	24	0	15	15	2	534
Hours Actual	0	3	14	46	78	90	58	94	64	88	84	39	15	0	14	6	6	699
% of Budget	100	100	93	153	130	150	97	157	107	147	240	111	63	0	93	40	300	131

Key	
Overrun	
Projected	
Break	
Billable Hours	

Man Hour Budget: Spring 2019

SPRING 2019																	
Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Substation Protection & Controls Schematics																	
Layout Schematic																	
Design Review																	
Substation Grounding																	
Project Review																	
Project Report																	
Presentation																	
																	Sum
Hours Estimation	30	30	30	30	30	30	25	25	25	0	25	15	15	15	10	0	335
Hours Actual	30	29	30	30	30	31	30	30	30	0	32	30	30	30	15	0	407
% of Budget	100	97	100	100	100	103	100	100	100	100	128	200	200	200	150	100	121

Cost of Project

Project Cost		
Components	Count	Cost ($ million)
Panels	238032	48.558528
Combiner Boxes	792	1.01420352
Inverters and Step-Up Transformers	36	1.956717
Land (Acres)	243.1172708	0.195
Substation	1	22
	Total Cost	73.72444852

Challenges Faced and Solutions

- Lack of solar parameter knowledge
  - Voltage Drop Calculations
  - MPP
- Protection and Controls design (AutoCAD)

- Client and advisor feedback
- Learned how to use AutoCAD

Project Success

- Submitted all deliverables on time with satisfaction from client
- Learned a lot about solar power plant and substation design
- If implemented, project would decrease the grid’s dependence on fossil fuels

Future Work

- Adoption of project

Conclusion & Lesson Learned

- Design process and documentation
- Importance of NEC and IEEE codes

Thank You For Listening!

Any Questions?

Work Cited

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