

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

**Team sdmay19-26**

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**Advisor: Dr. Ajarapu  
Client: Black & Veatch**

**<http://sdmay19-26.sd.ece.iastate.edu/>**

# 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.



An aerial photograph of a large-scale solar farm. The solar panels are arranged in neat, parallel rows across a grassy field. The surrounding area includes green fields, a line of trees, and a road. The text "Project Plan" is overlaid in the center in a bold, red font.

# Project Plan



# Problem Statement

- **General Problem:**
  - An increasing need for a growth in the use of renewable energy to reduce enhanced greenhouse effect
  - Prevent high power loss for long distance transmission
  - The Renewable Energy Standards (RES) allow companies to push more toward renewable energy
- **Solution:**
  - Design a 60 MW solar plant and a 115kV/34.5kV substation

# Operating Environment

- Substation and plant must be able to withstand any extreme weather conditions they will be subjected to in Estancia, New Mexico, and must be able to do so for a long time.
  - The design is equipped with all of the necessary protection devices in order to withstand any abnormal voltages that are expected.



# Possible Risks

- Defect on components
- Electric shock
  - Electric shock upon substation installation
  - Our design does not include substation grounding



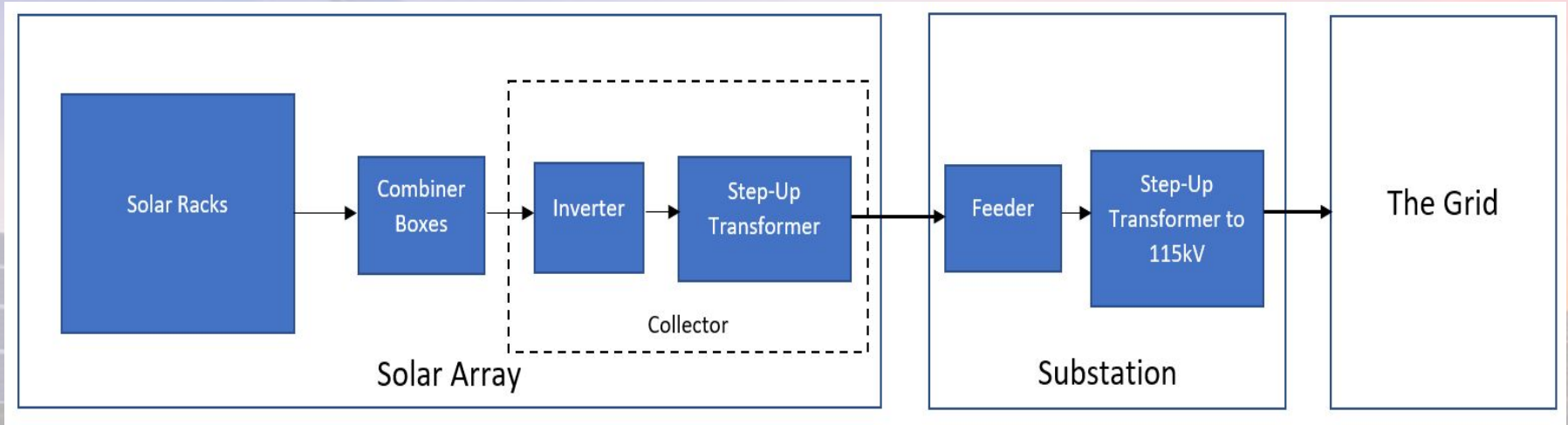
# Market and Literature Survey of Similar Products

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

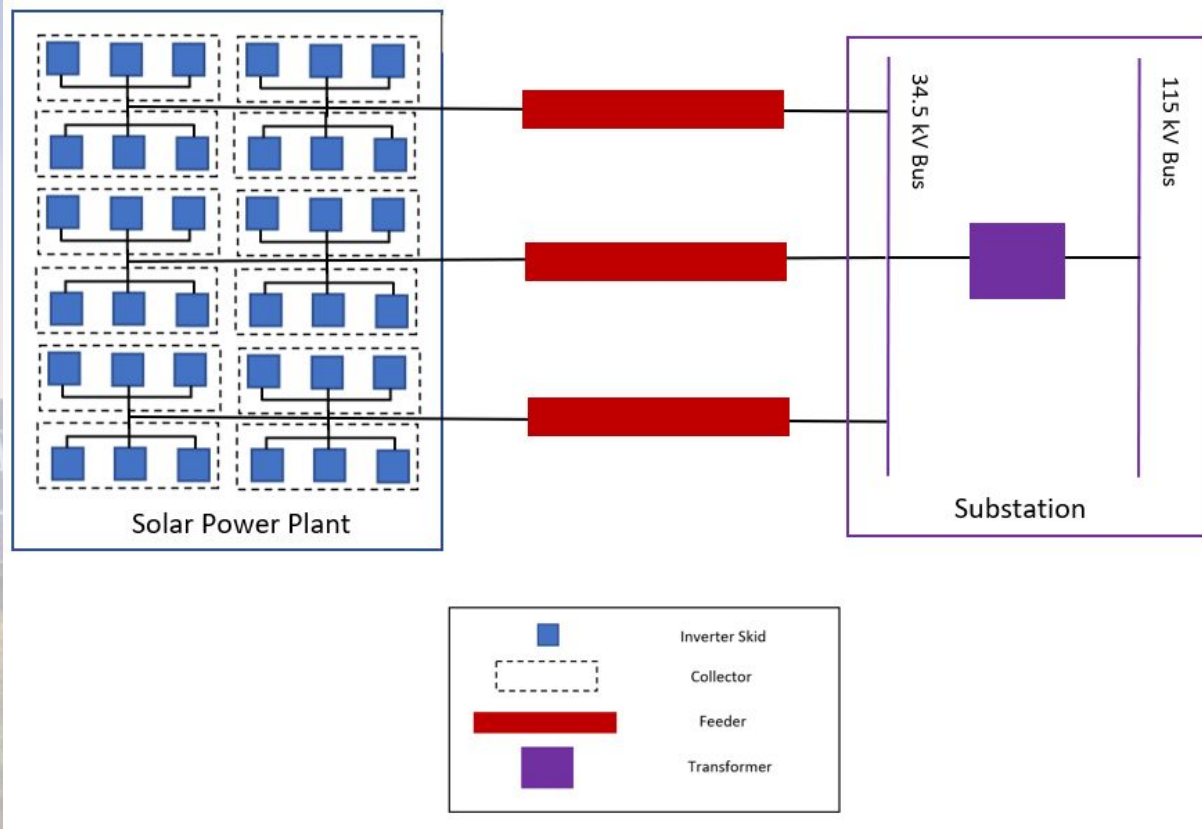


# System Block Diagram





# Conceptual Sketch



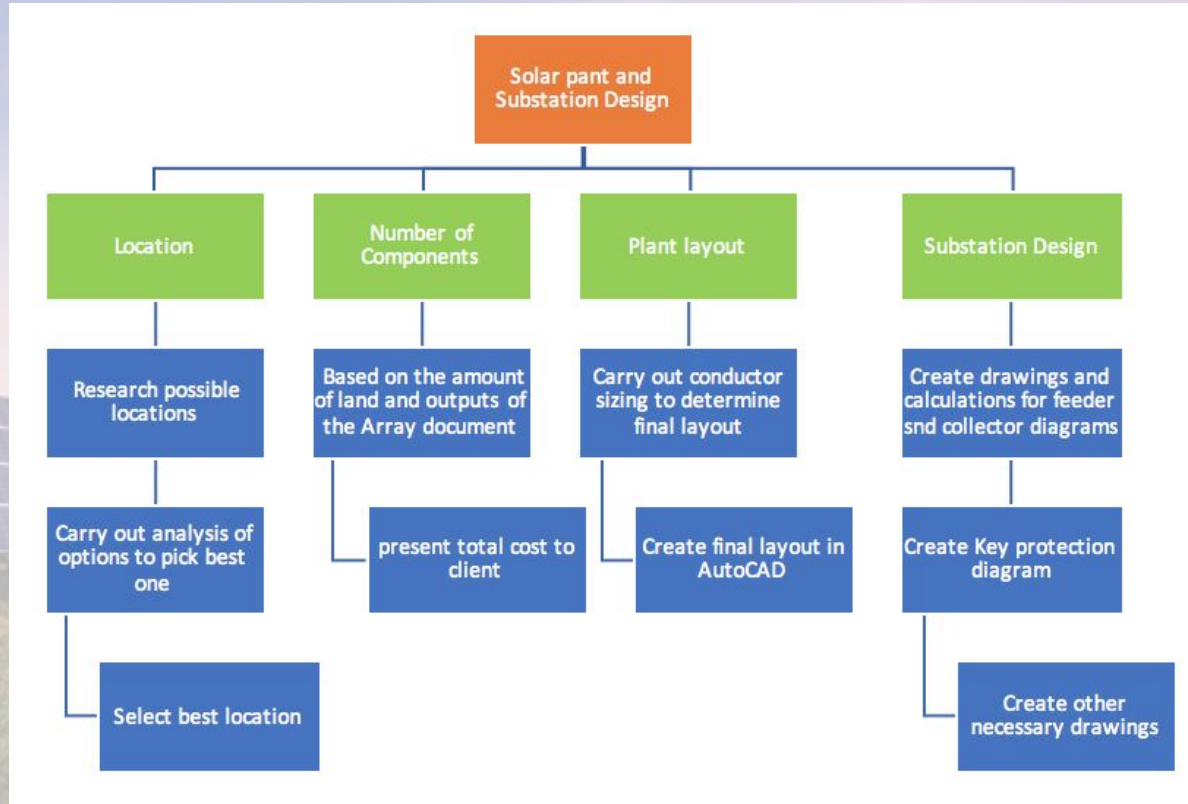
# Requirements (Functional/Non-Functional)

- Location of solar plant and substation
- Meet specifications set by the client
  - DC Voltage: 1000 V
  - Inverter: Eaton 1666kW
  - Panel: Hanwha 325W
  - ILR: 1.30
  - Fixed rack system
- Solar power plant array design
- Voltage drop calculations
- Substation diagrams
  - Relays and controls
  - 3 phase drawings
  - Communications

# Deliverables

- Man Hour Budget
- Solar plant design
  - Location
  - Number of components and total cost
  - Plant layout
  - Wiring and conductor sizing
- Substation Design
  - Feeder and collector diagrams
  - Key protection Diagram
  - AC drawings
  - Relay diagrams
  - Communication diagrams

# Project Plan: Workflow Diagram



# Resource Requirements

## Solar Power Plant

- Equipment
  - 238,032 solar panels
  - 792 combiner boxes
  - 36 inverters
  - Conductors/Cables
- 244 acres of land
  - We found a 560-acre land for sale for \$195,000

## Substation

- Equipment
  - 12 collectors
  - 3 feeders
  - Surge arrestors
  - Transformers
  - Conductors/cable

# Project Schedule For 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	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
Team roles	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
Scope and Goal Setting w/client	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
Research project/justification of components	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
Solar plant size and cost determination	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
Solar panel layout drawings	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
feeder + collector research and design	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
Solar plant layout review	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
Key protection and single line Arcadia drawings	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
AC 1 and 2 drawing reserch and reviewing	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
Review of Deliverables up to date	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
Finalize Deliverables	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█

## Key

Overrun	█
Projected	█
Break	█

An aerial photograph of a large-scale solar farm. The solar panels are arranged in neat, parallel rows across a grassy field. The surrounding landscape includes green fields, a forested area, and a body of water in the distance. The text "System Design" is overlaid in the center of the image.

# System Design

# System Requirement

- 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



# Functional Decomposition

Part	Input	Function	Output
<b>Solar Modules</b>	Sunlight	Convert sunlight into DC power	DC power
<b>Combiner Boxes</b>	Current from strings	Combine the currents before sending it to inverter	Combined currents
<b>Inverters</b>	DC Voltage from array	Convert DC voltage to AC voltage	AC Voltage
<b>Transformer</b>	Voltage from inverter	Step up voltage	Voltage proportional to input voltage that goes to feeder
<b>Relays</b>	Current in line	Measure the current in a line	Current in line
<b>Current Transformer</b>	Currents from a line	Measure alternating current	Current proportional to input current
<b>Surge Arrest</b>	Voltage in line	Protect equipment from overvoltage transients	Voltage in the line

# System Analysis

A large solar farm with rows of solar panels in a field under a sunset sky. The panels are tilted and supported by metal structures. The sky is a mix of blue, orange, and yellow, indicating the sun is low on the horizon. The foreground shows a grassy field.

- **Array parameter tool**
  - Determine number of components and verify the voltage and power of the system
- **Voltage Drop Calculations**
  - Carried out conductor sizing by analyzing the currents in the plant at different points.
- **Correspondence with seasoned engineers (Client)**

An aerial photograph of a large-scale solar farm. The solar panels are arranged in neat, parallel rows that stretch across a large, flat area of land. The surrounding landscape includes green fields, some wooded areas, and a few small buildings or structures. The overall scene is bright and clear, suggesting a sunny day. The text "Detailed Design" is overlaid in the center of the image in a bold, red font.

# Detailed Design

# Overview of Designs

Drawing List		
Drawing Number/Name	Description	State
sd-26-1-1 single array	Wiring diagram of a single array	Completed
sd-26-1-1 power plant	Wiring diagram of the entire solar plant	Completed
sd-26-1-2 collector	Collector diagram	Completed
sd-26-1-2 feeder	Feeder diagram	Completed
sd-26-2-2 key <u>prot</u>	Substation key protection diagram	Completed
sd-26-2-2 ac1	Three-line diagram	In Progress
sd-26-2-2 ac2	Three-line diagram	In Progress
sd-26-2-2 it rel	Installation relay diagram	Not Started
sd-26-2-2 <u>pri</u> rel	Primary relay diagram	Not Started
sd-26-2-2 ethernet port	Ethernet port diagram	Not Started
sd-26-2-2 <u>bu</u> relay	<u>Back-up</u> protection diagram	Not Started

# Location Decision



**0 Peacock Rd**  
**Estancia, NM 87016**

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.

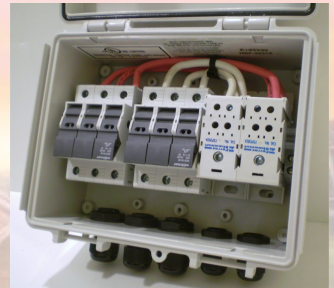
● LOT/LAND  
**\$195,000**  
Price cut: -\$15,000 (8/4)



# Solar Power Plant

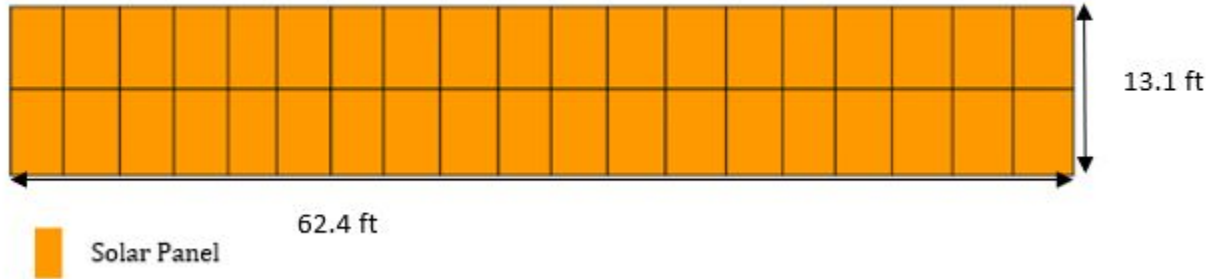
- Solar modules
- Combiner boxes
- Inverters

The solar plant generates, collects energy, and sends it to the substation.



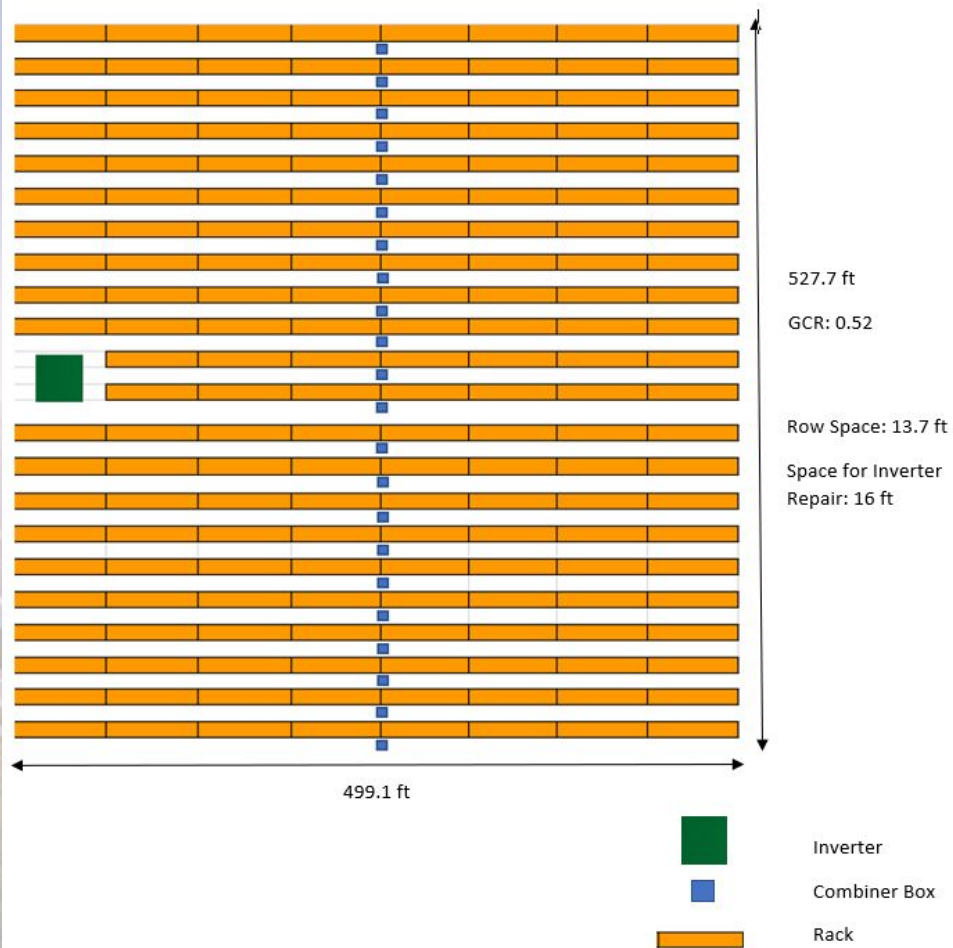
# Single Rack Layout

Single Rack Layout: 2x19 Solar Panels



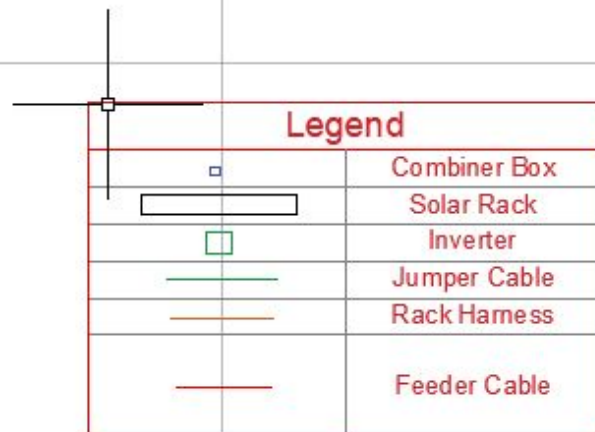
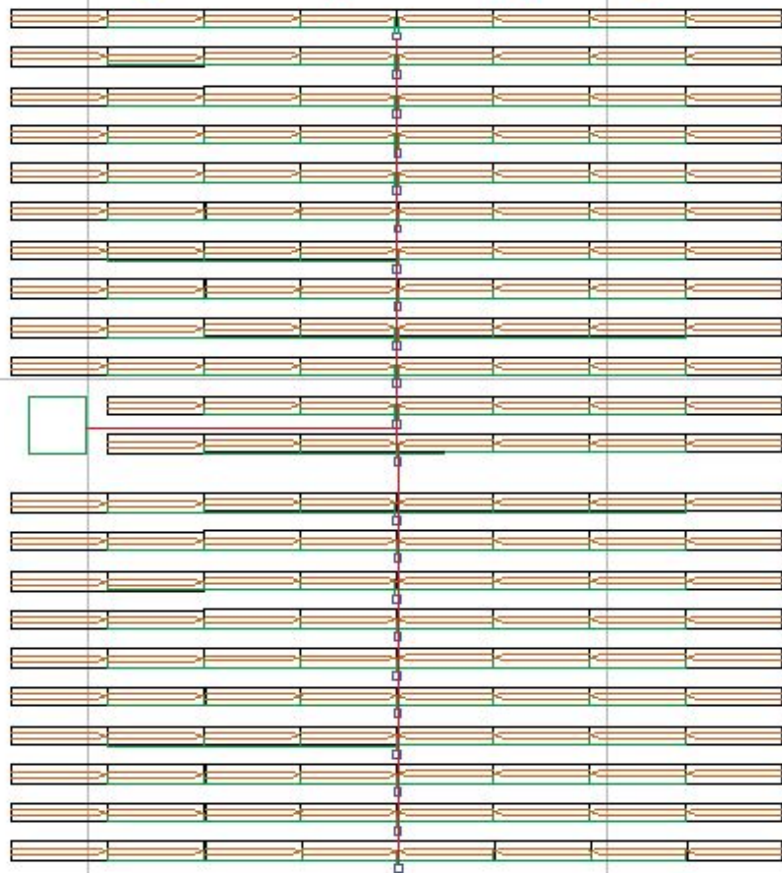
# Single Array Layout

Single Array Layout: 8x22 Racks With 2 Removed, 1 Inverter, 22 CBs



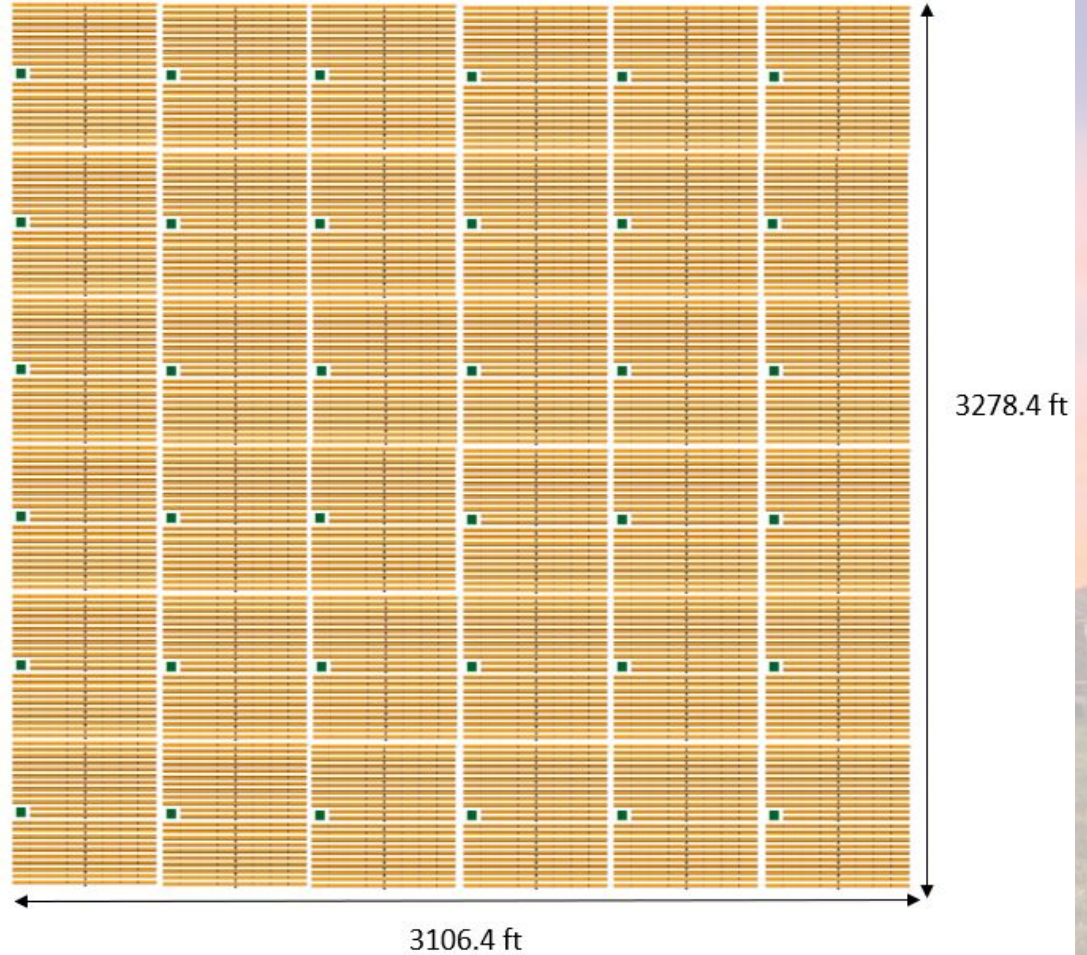


# Single Array Wiring Diagram



# Solar Plant Layout

Solar Plant Layout: 36 Arrays, 36 Inverters



## Solar Power Plant Wiring Diagram



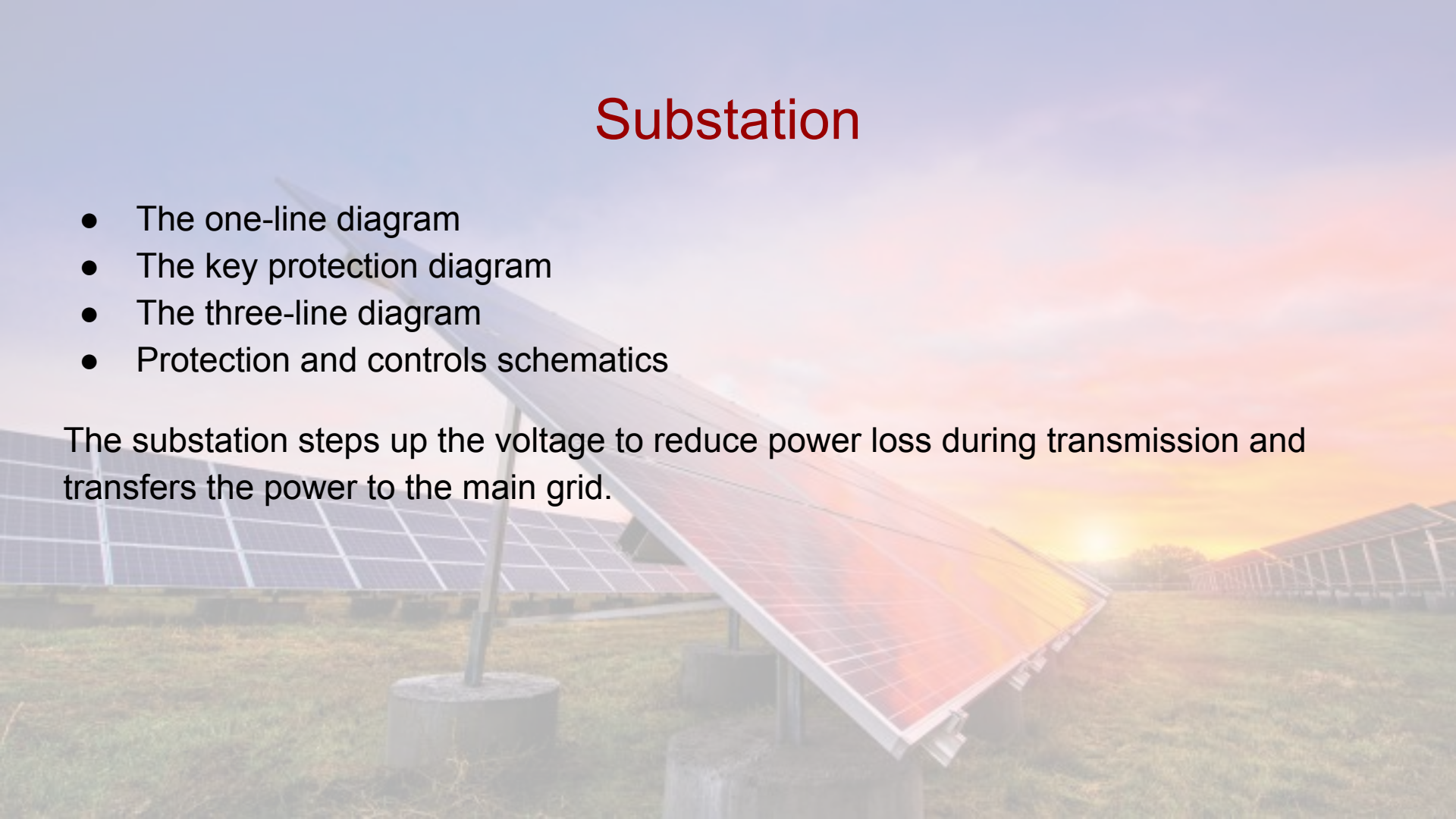
### Legend

	Combiner Box
	Solar Rack
	Inverter
	Jumper Cable
	Rack Harness
	Feeder Cable

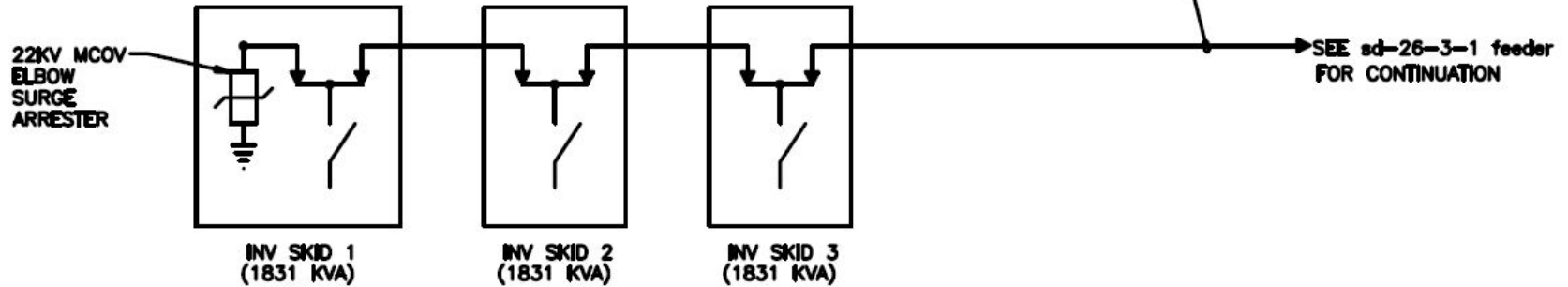
# Substation

- The one-line diagram
- The key protection diagram
- The three-line diagram
- Protection and controls schematics

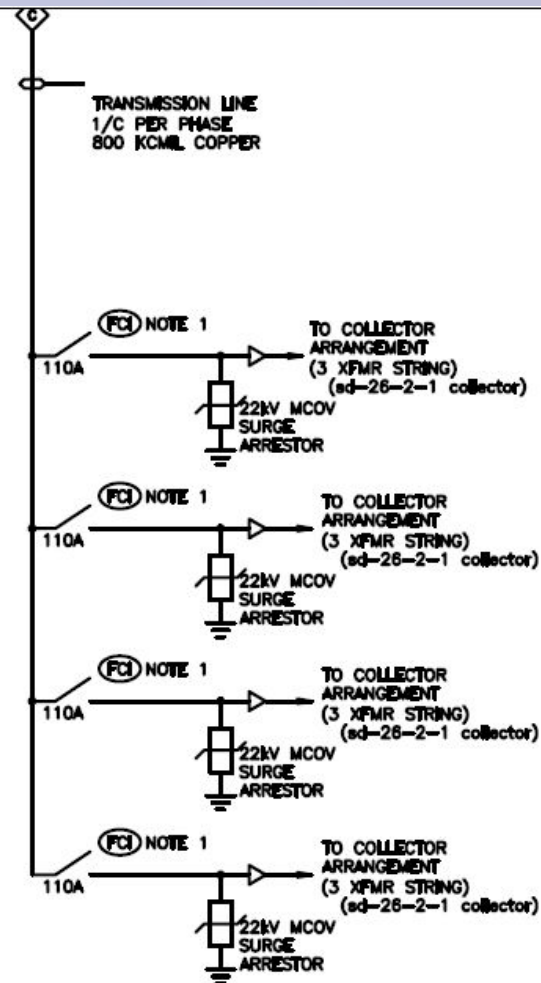
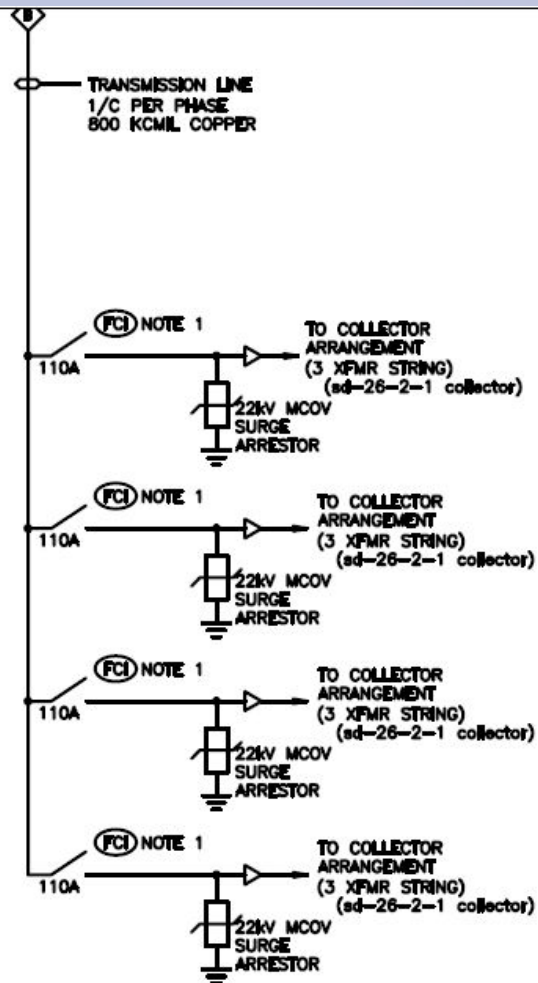
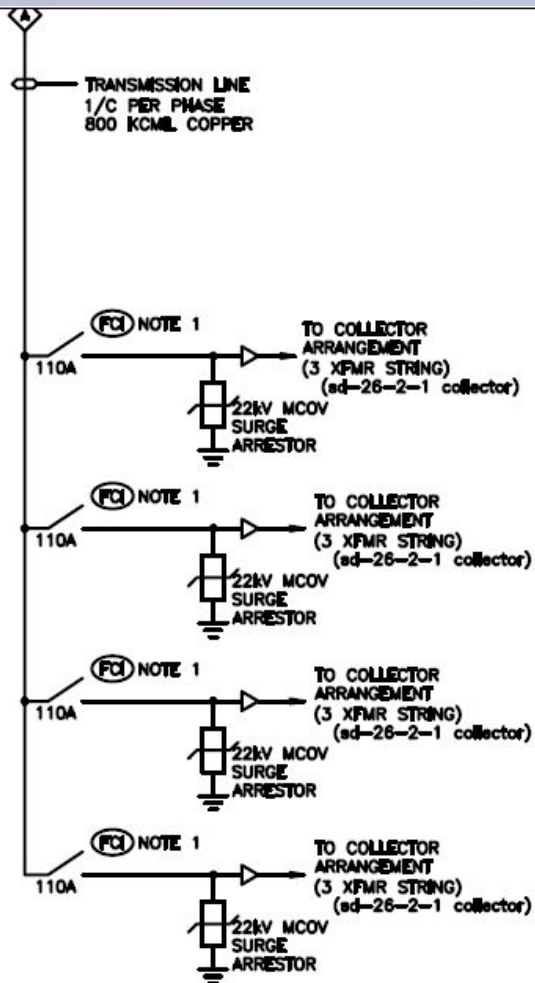
The substation steps up the voltage to reduce power loss during transmission and transfers the power to the main grid.



UG CABLE  
1AWG, COPPER  
FULL CONCENTRIC NEUTRAL  
DIRECT BURIAL



COLLECTOR ARRANGEMENT  
3 XFMR (TYP)

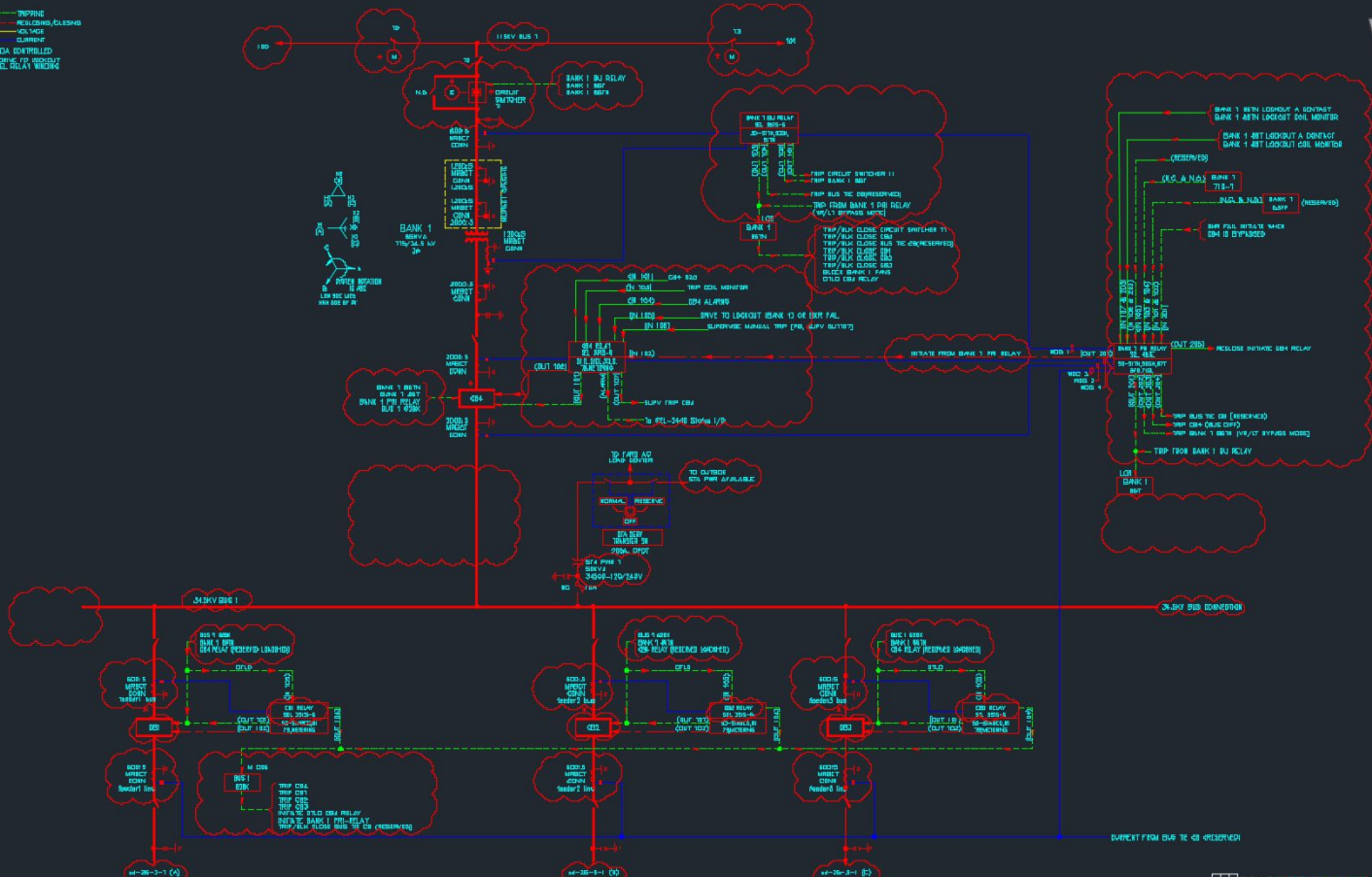


W

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**LEGEND**

- TRIPPING
- RECLOSE/LOCKOUT
- NOVAGE
- CLIPPING
- NOVA CONTROLLED
- NOVA - COME TO REST
- NOVA - RELAY TRIP



NO	REV	DESCRIPTION	DATE	BY	CHKD
1	01	ISSUED	01/01/2010	...	...
2	02	...	...	...	...
3	03	...	...	...	...
4	04	...	...	...	...
5	05	...	...	...	...
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49	49	...	...	...	...
50	50	...	...	...	...

PROJECT: OWEITH SUBSTATION  
 115/34.5KV AC SINGLE LINE DIAGRAM  
 60 MW SUBSTATION  
 ESTANCIA, NW  
 DATE: 01/01/2010  
 DRAWN BY: ...  
 CHECKED BY: ...  
 SCALE: 1:1  
 SHEET NO: 2  
 TOTAL SHEETS: 26-4-1  
 PROJECT NO: ...

# Testing Evaluation Plan

## Array parameter tool:

- Spreadsheet given by the client to determine the specification of the project.
- Determine the number of (solar panels, combiner boxes, inverters)
- We also use it to determine the ILR, the size of the plant, and the cost of the project.

## Compliance with NEC codes:

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

## Correspondence with Client :

- Due to the nature of the project we used the client as a verification tool to monitor our progress and accomplishment.



# Conclusion

Current project status with respect to milestones

- Completed all the deliverables for this semester:
  - Substation one-line drawing and solar plant array layout/drawing
  - Engineering man-hour budget, project plan, design document, and team website. <http://sdmay19-26.sd.ece.iastate.edu/>

# Plans For Next Semester

Spring 2019																
Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Project Optimization	█	█	█	█	█					█						
AC 1 drawings				█	█	█										
AC 2 drawings					█	█	█									
Relay drawings								█	█		█					
communication drawings											█	█				
Review deliverables													█	█		
Feeder drawings															█	
Review deliverables																█

Key	
Overrun	█
Projected	█
Break	█

A large, modern building with a glass facade and a green lawn in front of it. The building has multiple stories and a prominent glass entrance area. The sky is overcast.

**Thank You For Listening!**

**Any Questions?**