BUILDING A WORLD OF DIFFERENCE

115 KV/34.5KV SOLAR PLANT/SUBSTATION

27 April, 2016

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ARIF IBRAHIM:	WEBMASTER
MAKOKO MUKUMBILWA:	KEY CONCEPT HOLDER
SPONSOR/CLIENT:	BLACK & VEATCH – ADAM LITERSKI, RAHUL RAMANAN
ADVISOR:	DR. VENKATARAMANA AJJARAPU

BLACK & VEATCH
Building a world of difference.

AGENDA

- Project Overview (Scope)
- Deliverables
- Specification(Parameters)
- Solar Power Plant Design
- Substation Design
- Simulations

PROJECT OVERVIEW

- **Plant Location**
  - Iowa
  - Choose best location
- **60 MW Solar Power Plant**
  - Plant/component sizing
  - Plant layout
  - Production Simulation
- **Attached 115 kV/34.5 kV Substation**
  - Substation one-line drawings
  - Substation three-line drawings

DELIVERABLES

- Solar power plant layout and conductor sizing
- Plant and substation component connections
- Substation one-line/three-line drawings
- Drawing list
- Production simulation data
- Engineering man hour budget and schedule
- Project presentation to Black & Veatch

SOLAR PLANT REQUIRED SPECIFICATIONS

- Location: Iowa
- Fixed Rack 325 W Hanwha Q Cells solar modules
- 1670 kW Eaton Xpert inverter
- 1500 VDC string voltage
- ≈1.30 Inverter Load Ratio (ILR)

SUBSTATION REQUIRED SPECIFICATIONS

- Substation specification document
- Arcadia single line diagram
- ANSI standard device numbers

325 W HANWHA Q CELLS SOLAR MODULE

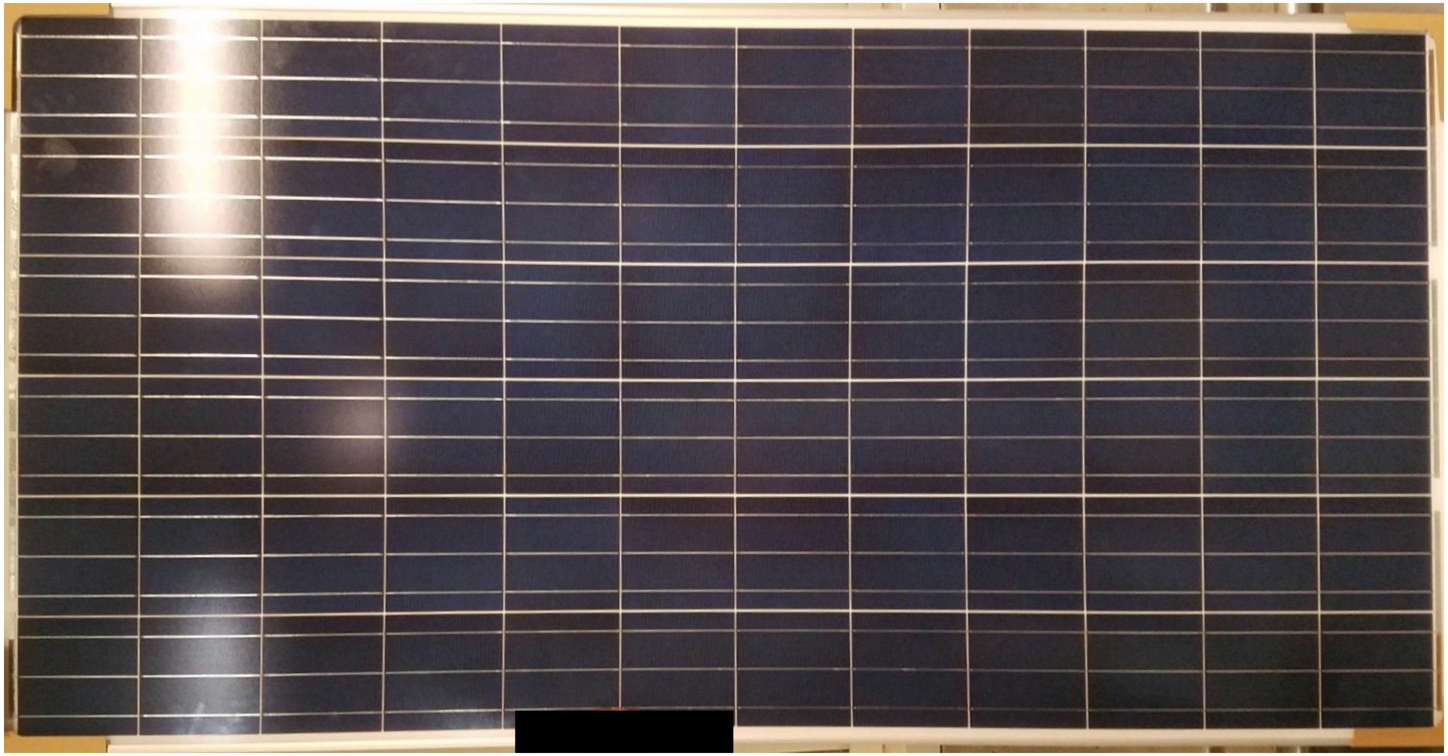
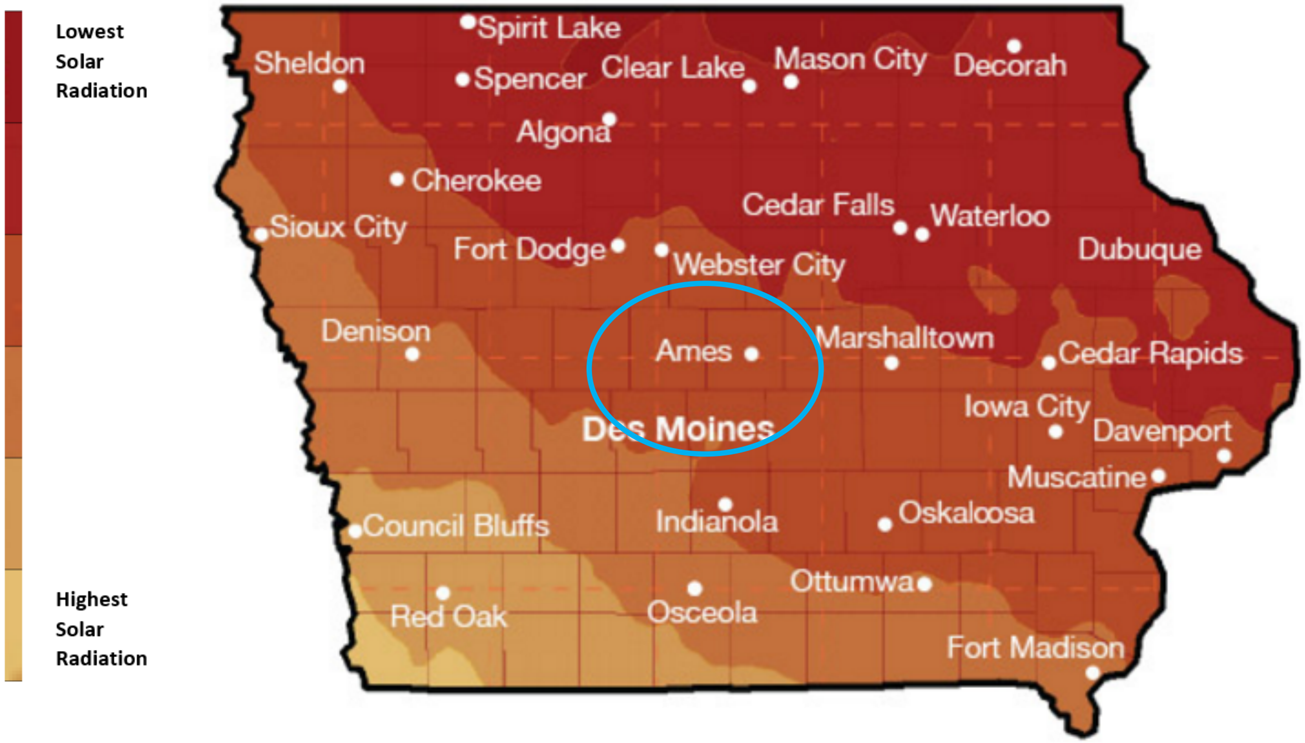


Photo taken at B&V engineering office.

SOLAR POWER PLANT LOCATION

- Using the Iowa energy center solar calculator tool
  - Area most suitable: Southwest Iowa*
  - But we are using Ames/Boone area due lack of temperature data in SW Iowa



SOLAR POWER PLANT AREA – CALCULATION

$$Number\ of\ Panels\ Needed = \frac{60\ MW}{325\ W}(1.30) = 240000\ panels$$
$$Panel\ Area = 21.45\ ft^2$$
$$Total\ Area\ of\ Panels = 240000 * (21.45\ ft^2) = 5147990\ ft^2$$

Therefore,

$$Total\ Area\ Needed = 5147990\ ft^2 = 0.185\ mi^2 = 120\ acres$$

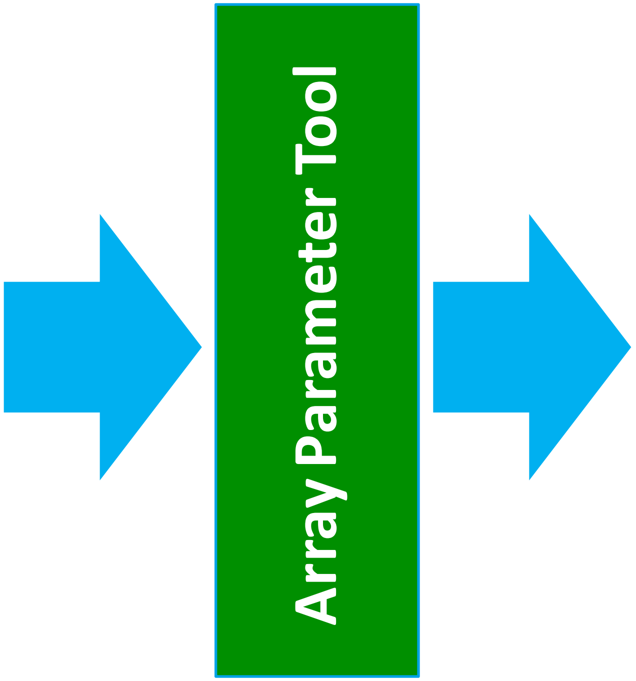
To split the solar panels into arrays, we divided the required output by the inverter power rating.

$$Number\ of\ Arrays = \frac{60\ MW}{1670\ kW} = 36\ arrays$$

Including the row spacing, inverter skid, and access road; the total area becomes about 240 acres for the entire solar plant.

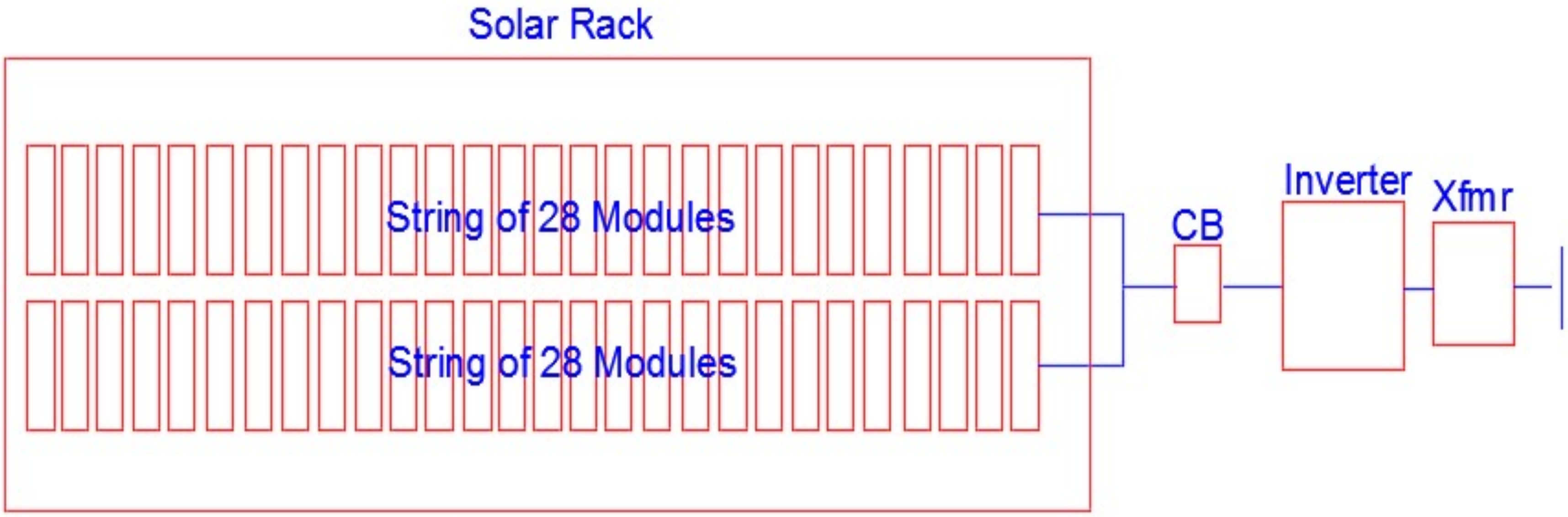
ARRAY PARAMETER TOOL

- Absolute Min Temp
- Module Dimensions
- Desired Spacing
- Desired Tilt/Azimuth
- String size
- Module voc & Isc
- Temp Coefficient
- Inverter AC Capacity



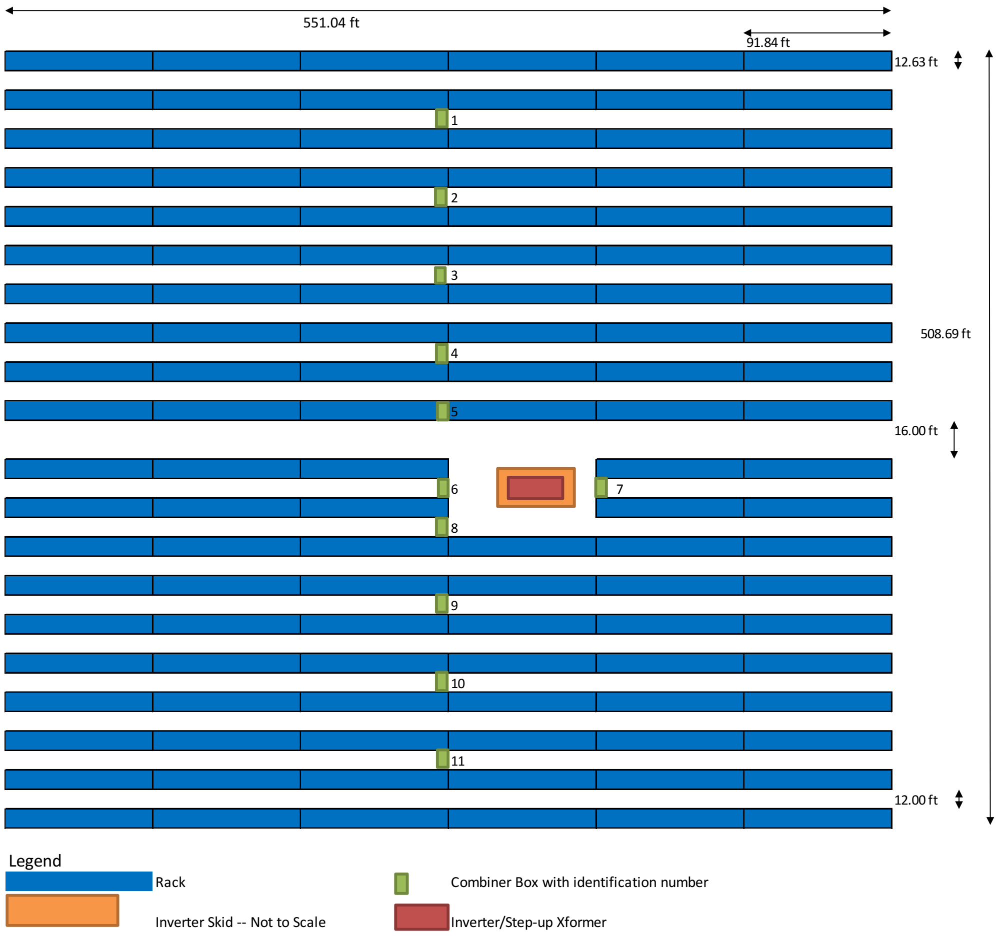
- Corrected String Voltage
- Combiner Box Current
- Total DC Capacity
- Total AC Capacity
- Inverter Load Ratio
- Tilt Adjusted Dimensions
- Ground Coverage Ratio

SINGLE RACK DETAIL

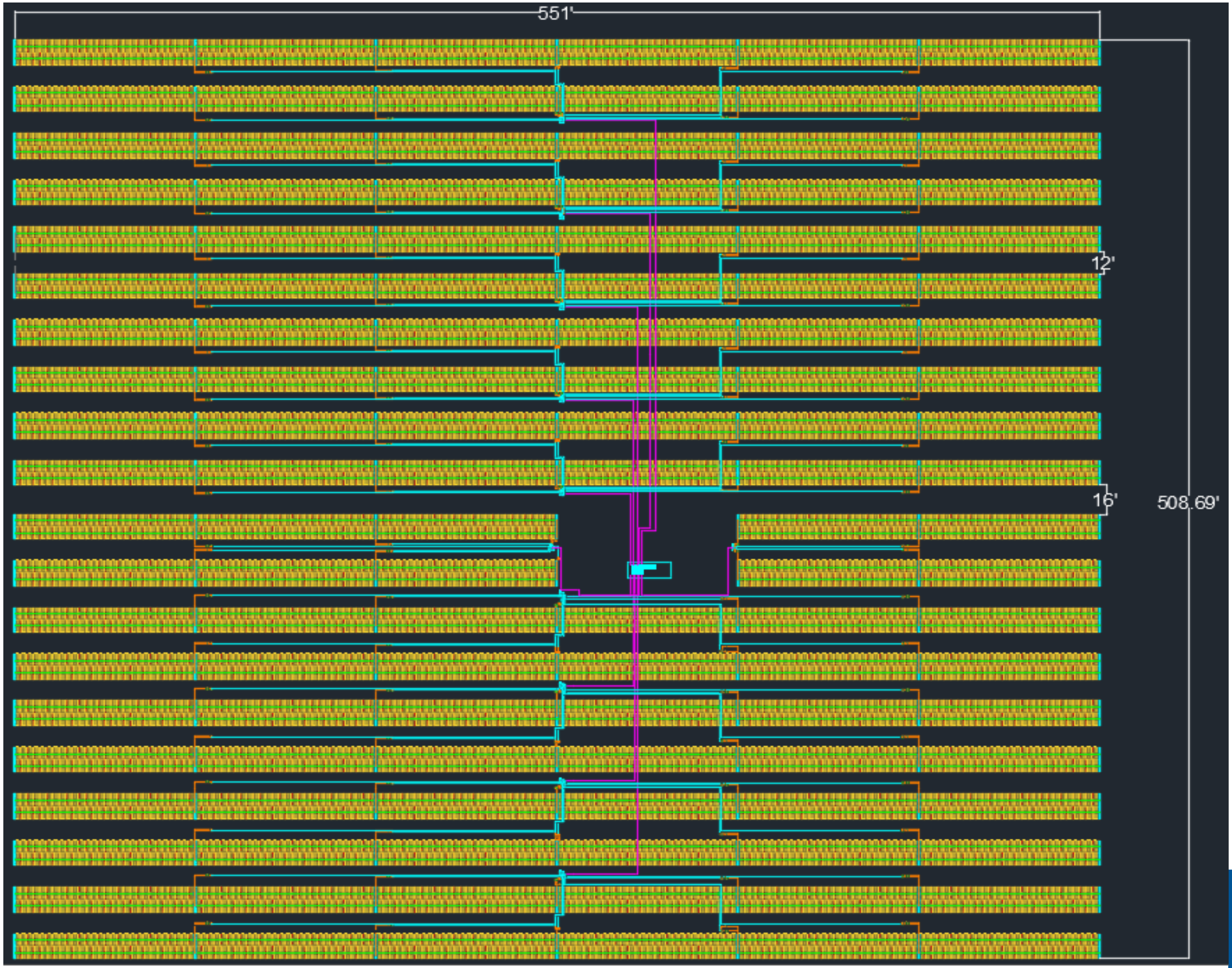


SOLAR POWER PLANT DESIGN – ONE ARRAY

- **36 total arrays**
- **Components – per array**
  - 118 racks per inverter
  - 11 combiners per inverter
  - 12 racks per combiner*
  - 2 strings per rack
  - 28 modules per string
  - 6608 modules per array
- **Spacing – per array**
  - 12 ft between rows
  - 16 ft inverter access road in the middle



DETAILED SOLAR ARRAY – AUTOCAD

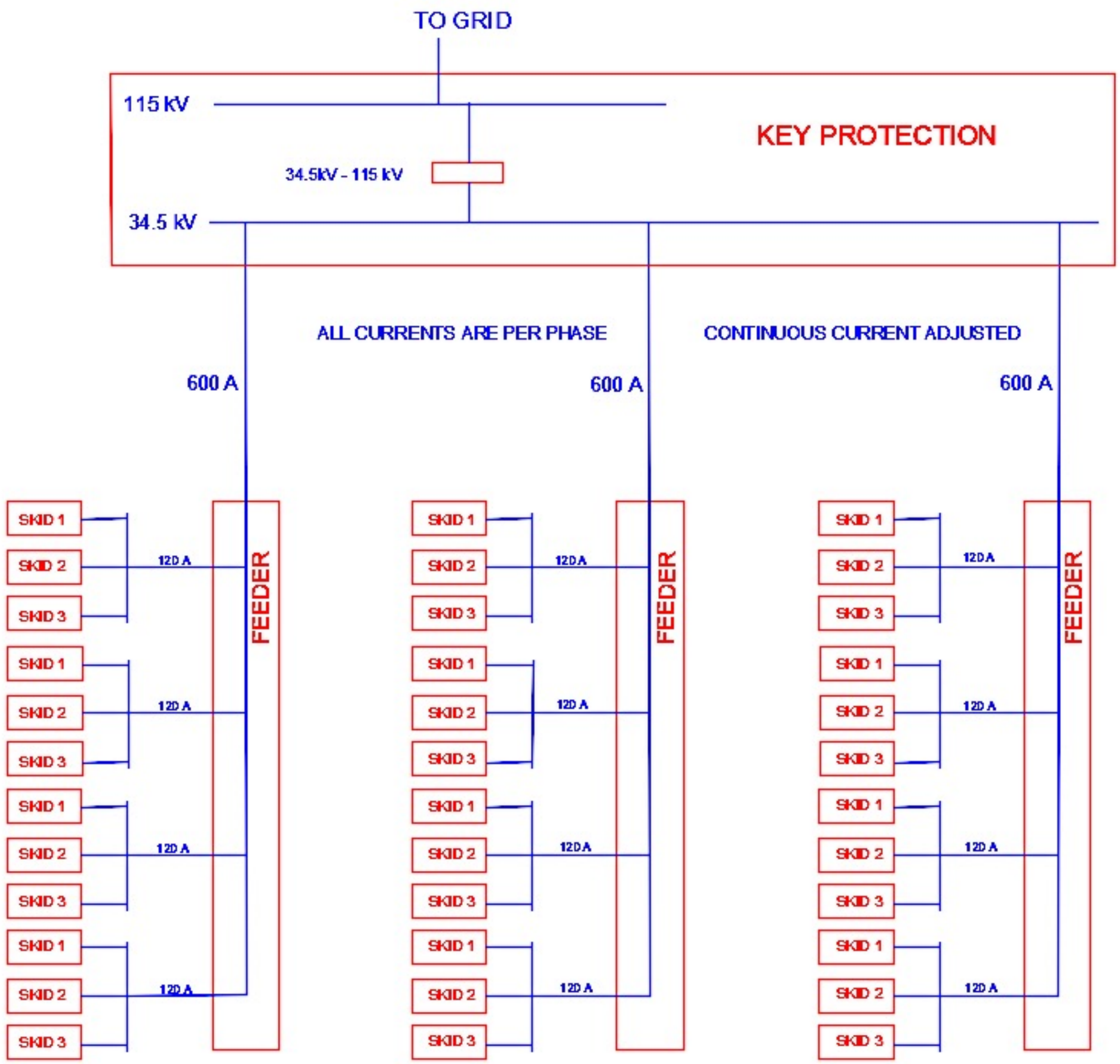


SOLAR ARRAY CONDUCTOR SIZING

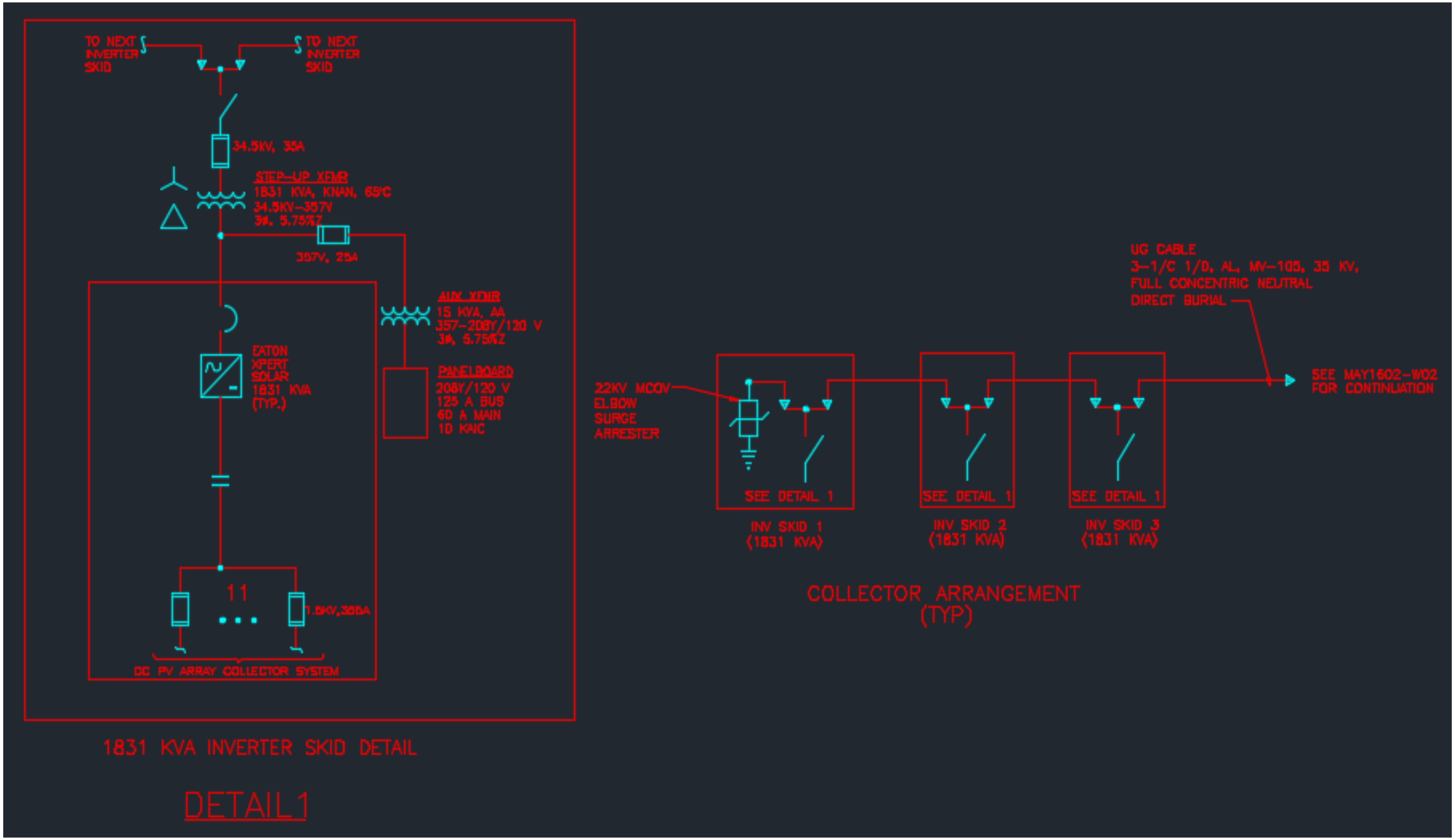
- **Irradiance correction factor of 1.25 – NEC690(A)(1)**
- **Continuous current correction of 1.25 – NEC 690(B)(1)**
- **Used NEC 310 guidelines to size conductors for solar power plant**
- **Referenced NEC 310 Table 300.50 for minimum burial depth requirements**
- **Conductor selection – NEC Table 310.15(B)(16) and Table 310.15(B)(17) guidelines.**

Conductors	Max Isc (A)	Type	Material	Temp (degC)	AWG	Cable Rating (A)	Minimum Depth	Fuse
String Conductor	14.75	Free Air	Copper	75	12	35	NA	15
Rack to CB - Jumper	29.5	Free Air	Copper	75	10	50	NA	30
CB to Inverter - DC feeder	354	Buried	Aluminum	75	700	375	30 inch	355
Xformer to Collector	116	Buried	Aluminum	75	1\0	120	36 inch	(*)

SUBSTATION SYSTEM BLOCK DIAGRAM

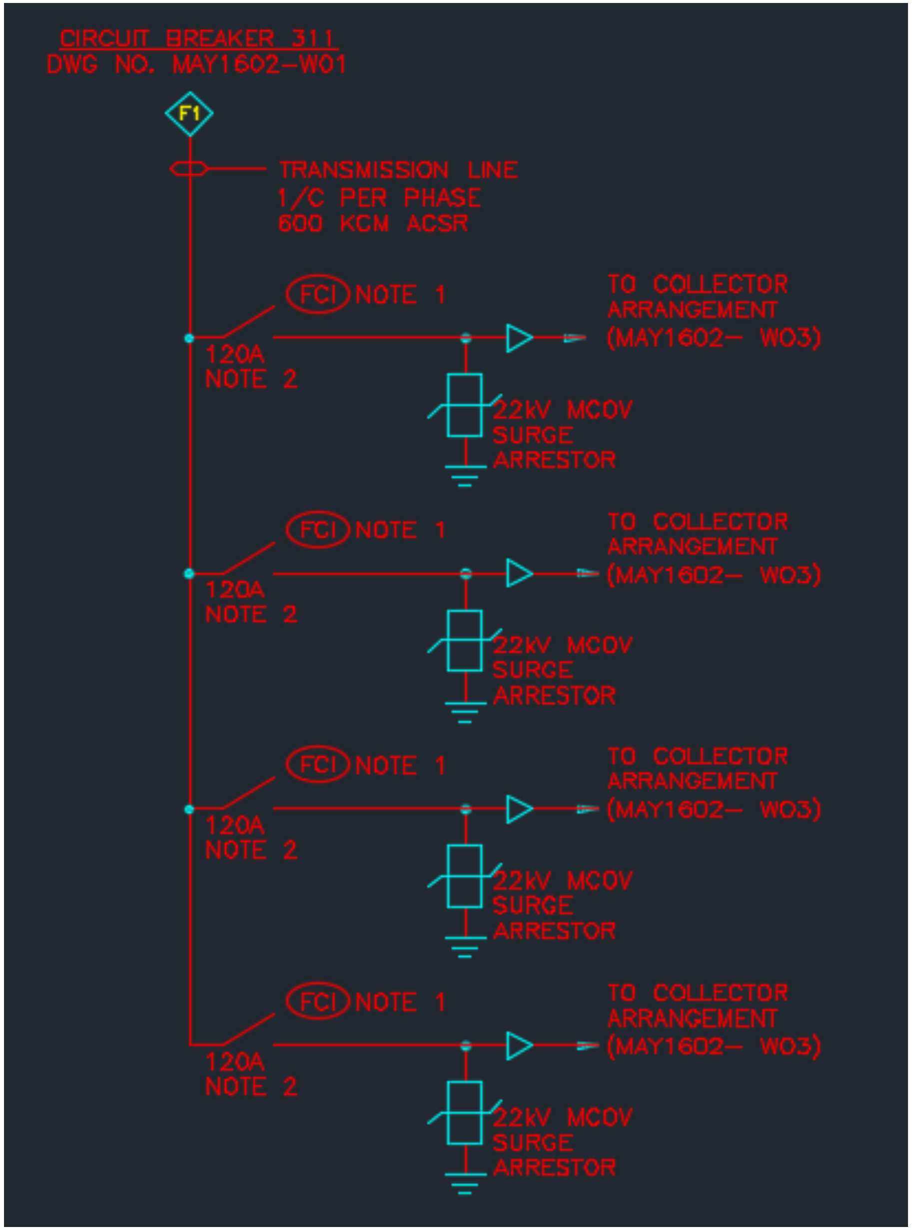


COLLECTOR



TO NEXT INVERTER SKID
TO NEXT INVERTER SKID
34.5KV, 35A
STEP-UP XFMR
1831 KVA, KNAN, 65°C
34.5KV-357V
3Ø, 5.75%Z
357V, 25A
AUX XFMR
15 KVA, AA
357-208Y/120 V
3Ø, 5.75%Z
EATON XPERT SOLAR 1831 KVA (TYP.)
PANELBOARD
208Y/120 V
125 A BUS
60 A MAIN
10 KAIC
11
1.5KV,350A
DC PV ARRAY COLLECTOR SYSTEM
1831 KVA INVERTER SKID DETAIL
DETAIL 1
UG CABLE
3-1/C 1/0, AL, MV-105, 35 KV,
FULL CONCENTRIC NEUTRAL
DIRECT BURIAL
22KV MCOV ELBOW SURGE ARRESTER
SEE DETAIL 1
SEE DETAIL 1
SEE DETAIL 1
INV SKID 1 (1831 KVA)
INV SKID 2 (1831 KVA)
INV SKID 3 (1831 KVA)
SEE MAY1602-W02 FOR CONTINUATION
COLLECTOR ARRANGEMENT (TYP)

FEEDER



CIRCUIT BREAKER 311
DWG NO. MAY1602-W01
F1
TRANSMISSION LINE
1/C PER PHASE
600 KCM ACSR
FCI NOTE 1
TO COLLECTOR
ARRANGEMENT
(MAY1602- W03)
120A
NOTE 2
22kV MCOV
SURGE
ARRESTOR
FCI NOTE 1
TO COLLECTOR
ARRANGEMENT
(MAY1602- W03)
120A
NOTE 2
22kV MCOV
SURGE
ARRESTOR
FCI NOTE 1
TO COLLECTOR
ARRANGEMENT
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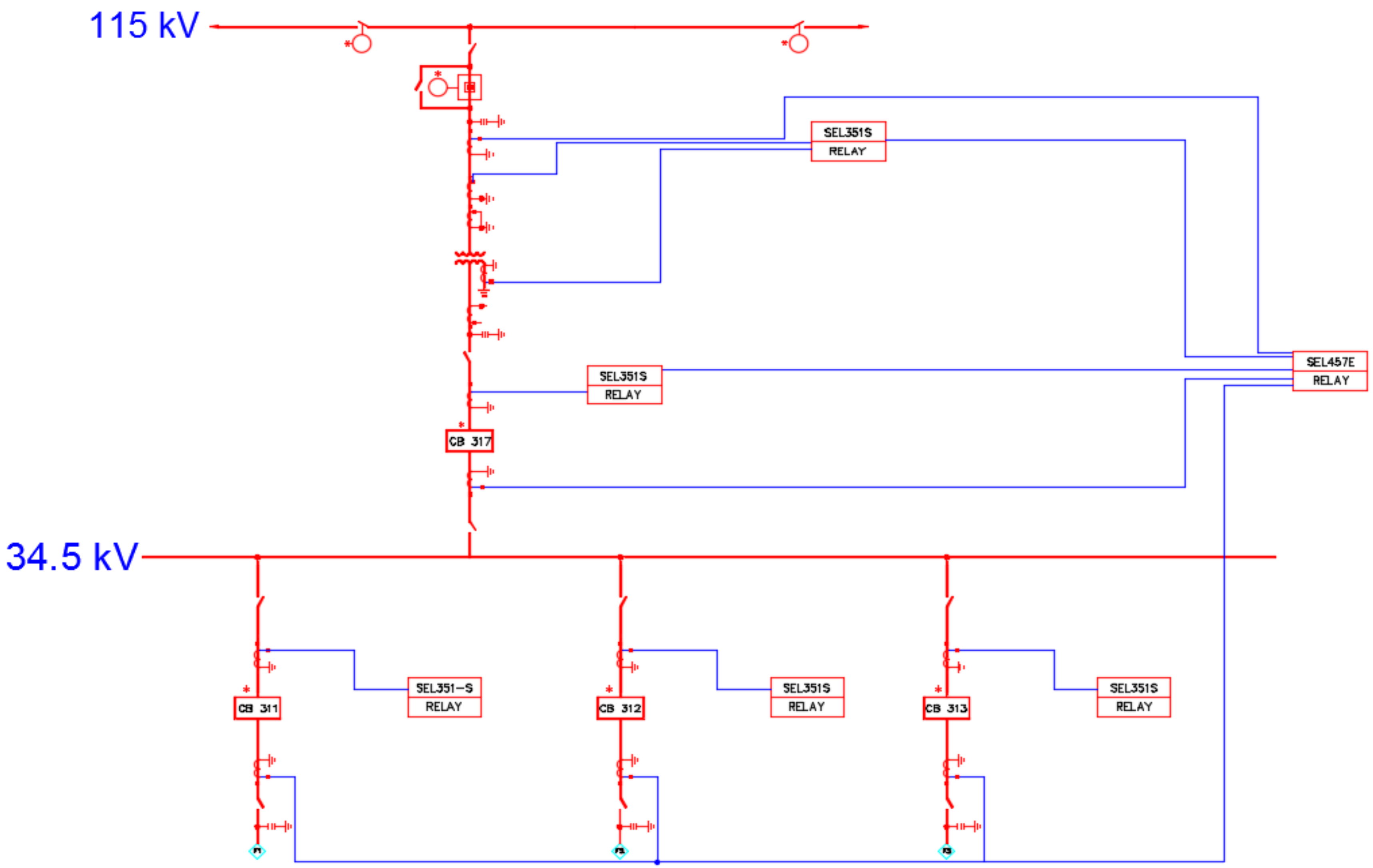
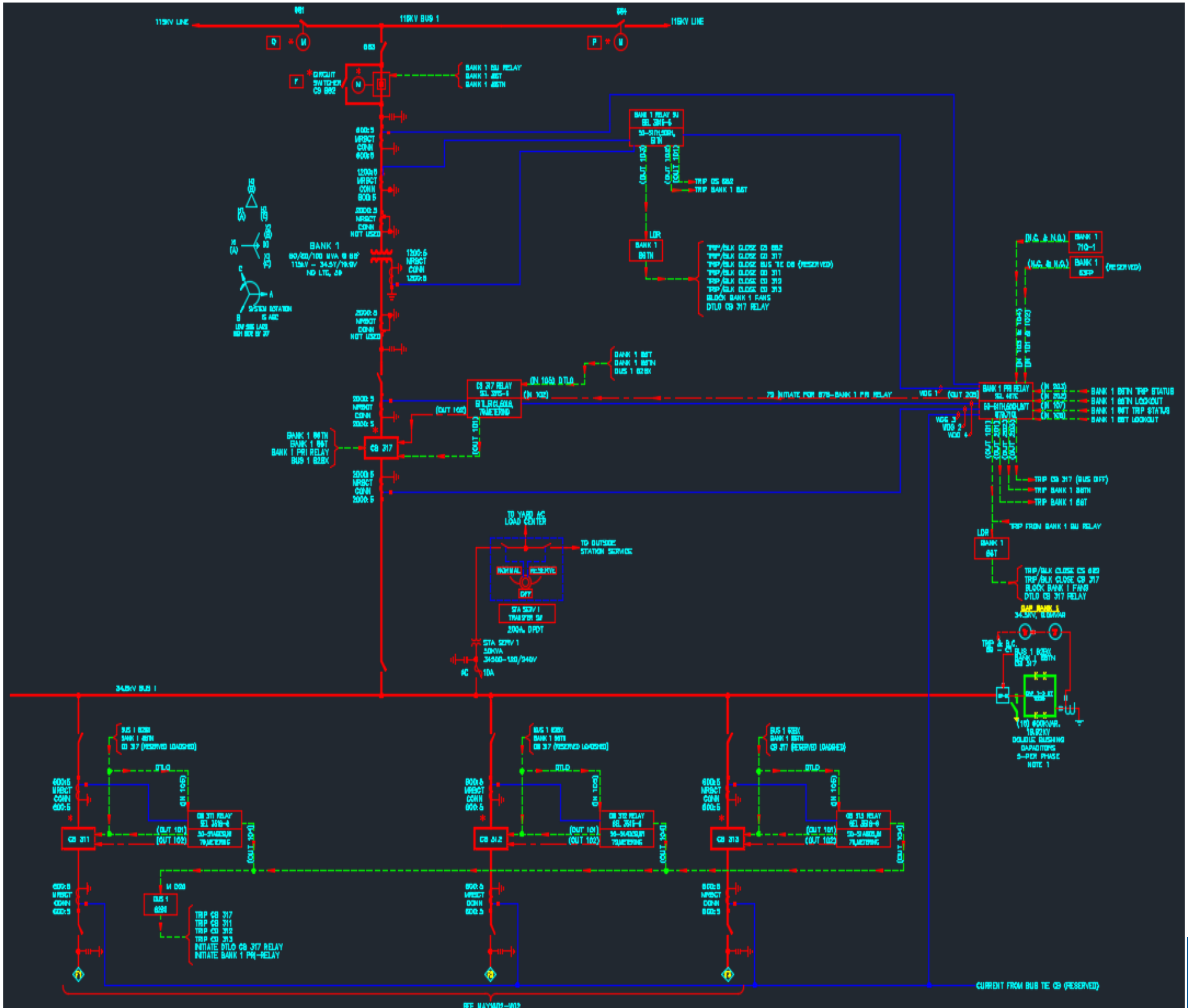
120A
NOTE 2
22kV MCOV
SURGE
ARRESTOR
FCI NOTE 1
TO COLLECTOR
ARRANGEMENT
(MAY1602- W03)
120A
NOTE 2
22kV MCOV
SURGE
ARRESTOR

KEY PROTECTION



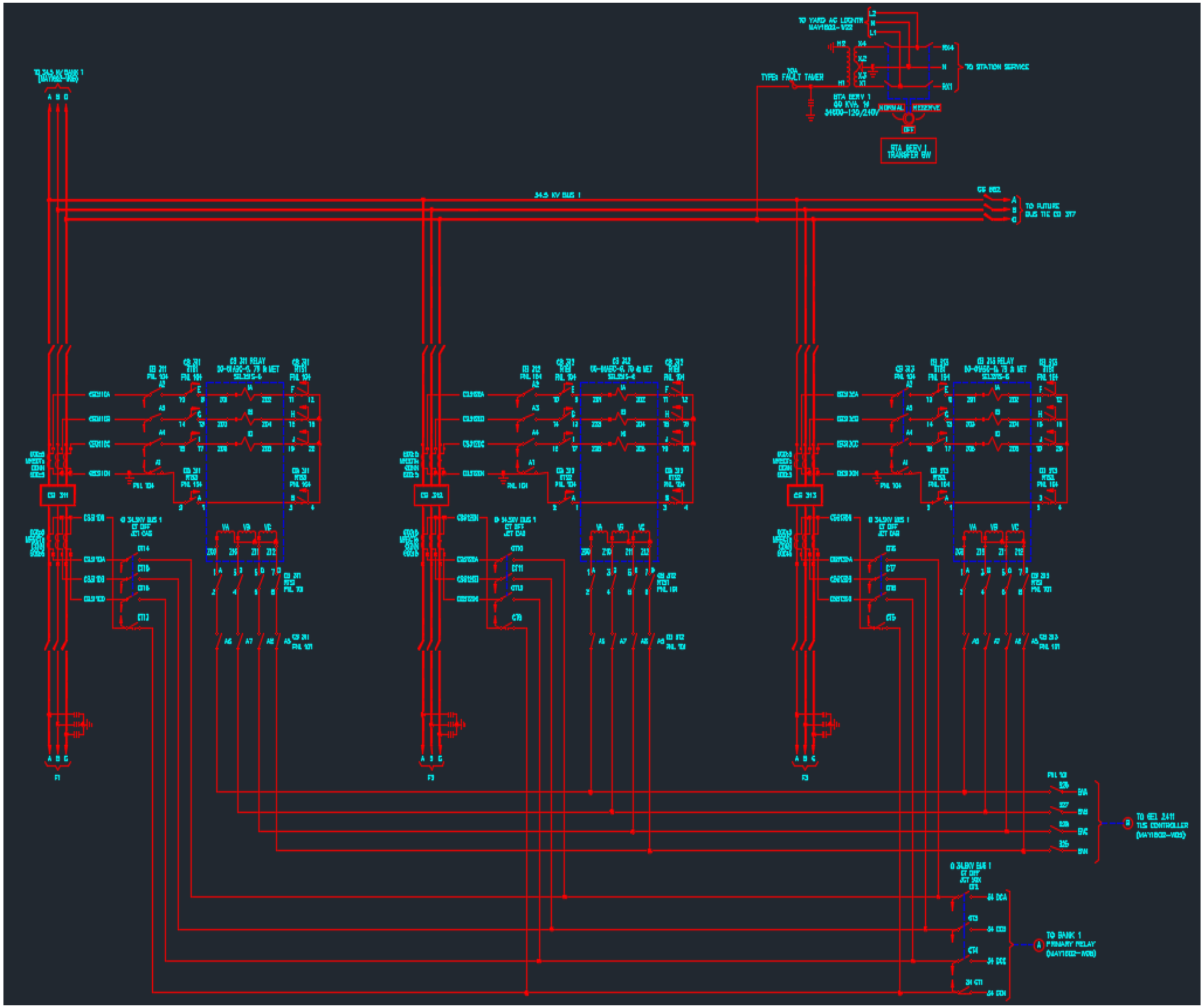
KEY PROTECTION



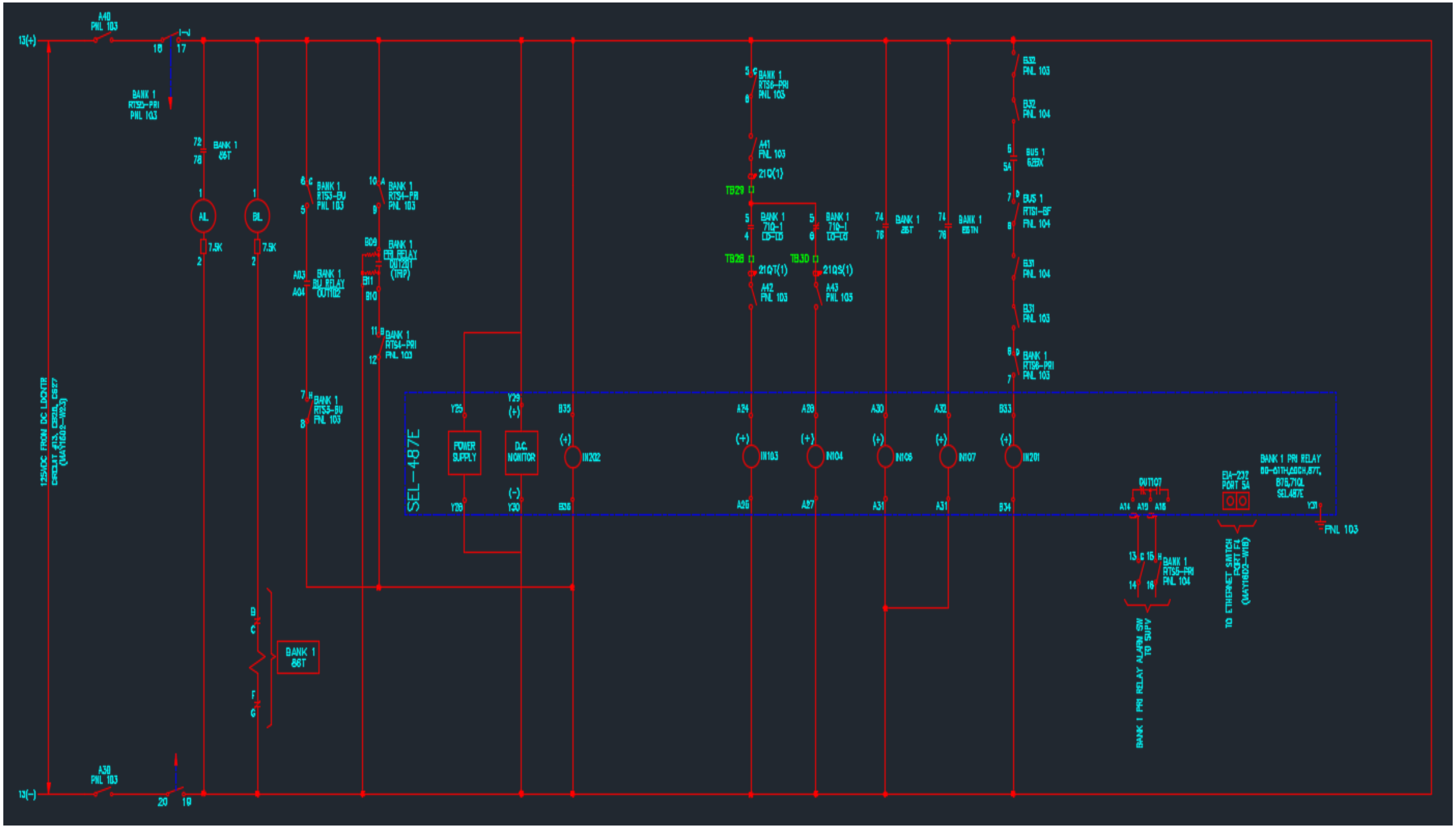
SUBSTATION 3 LINE DRAWINGS

- 3 Phase AC Schematics
- DC Schematics: Air-Breaker Bypass Switches (ABS), SEL-451 (Primary Relay), SEL-351 (Feeder & Backup Relay)
- Communication (RTU, Router, RLH Card and Ethernet Switches)
- AC and DC Load Centers
- Panel Elevations

AC THREE LINE DRAWING

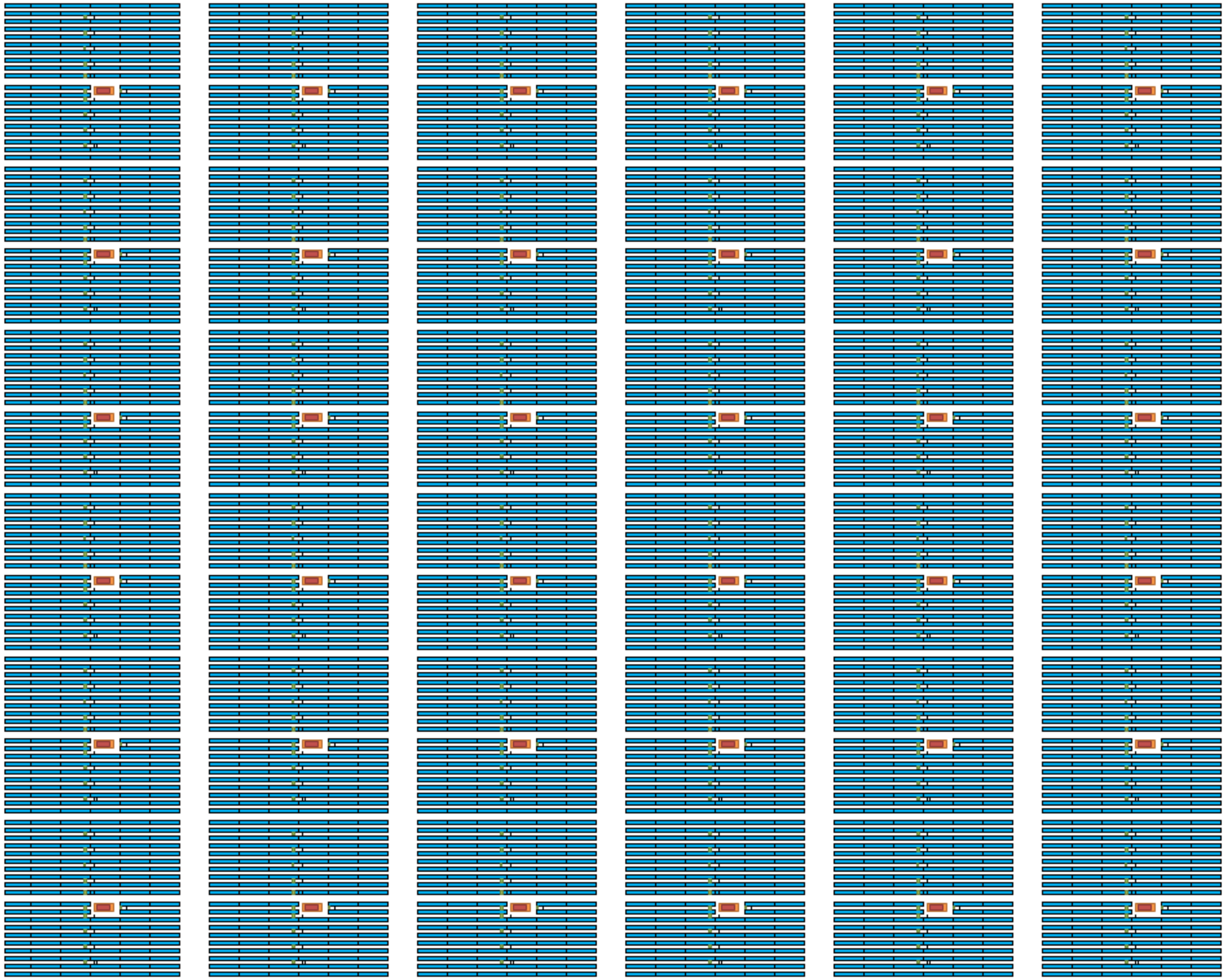


PRIMARY RELAY DC DRAWING

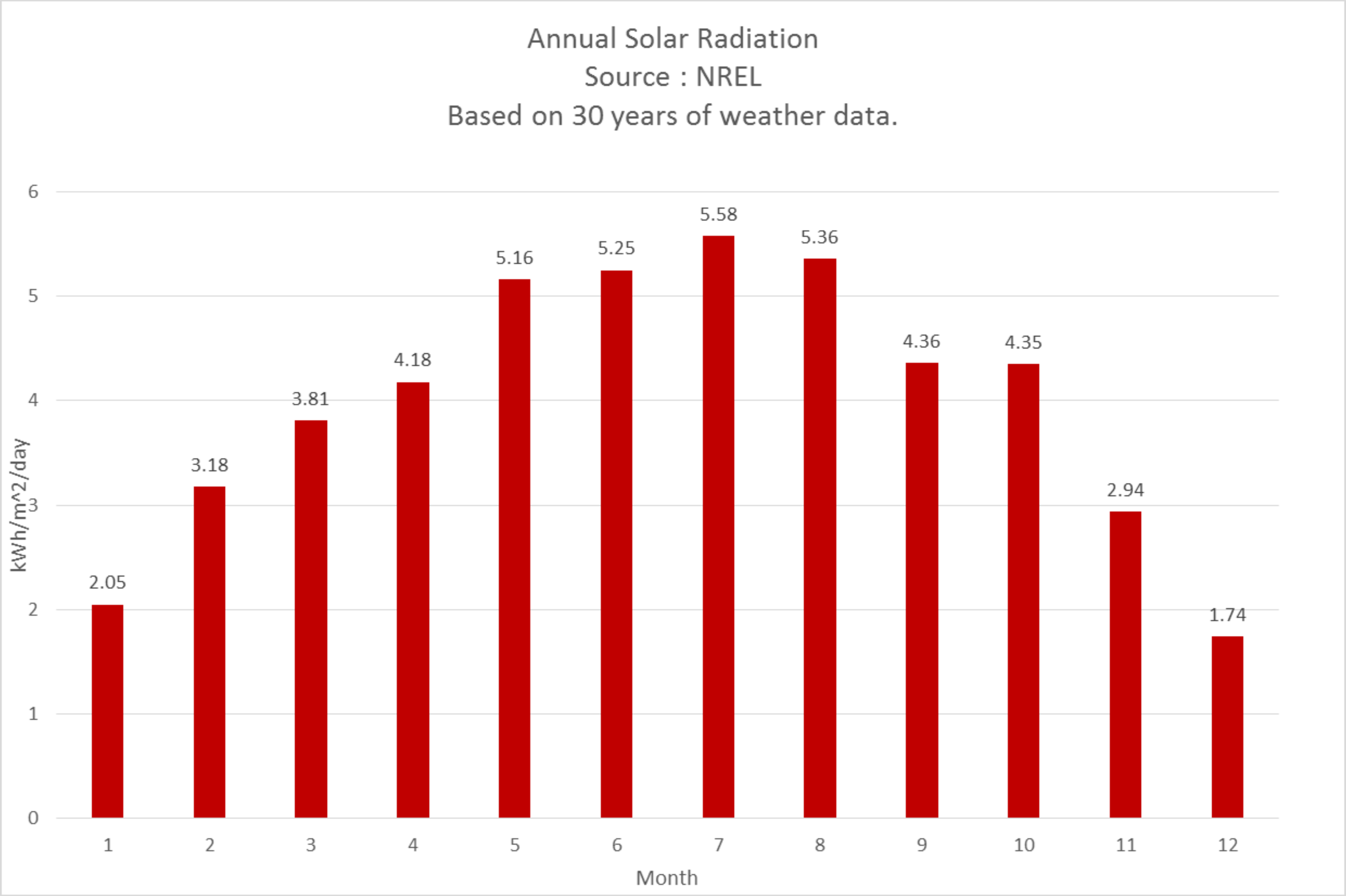


SOLAR POWER PLANT LAYOUT

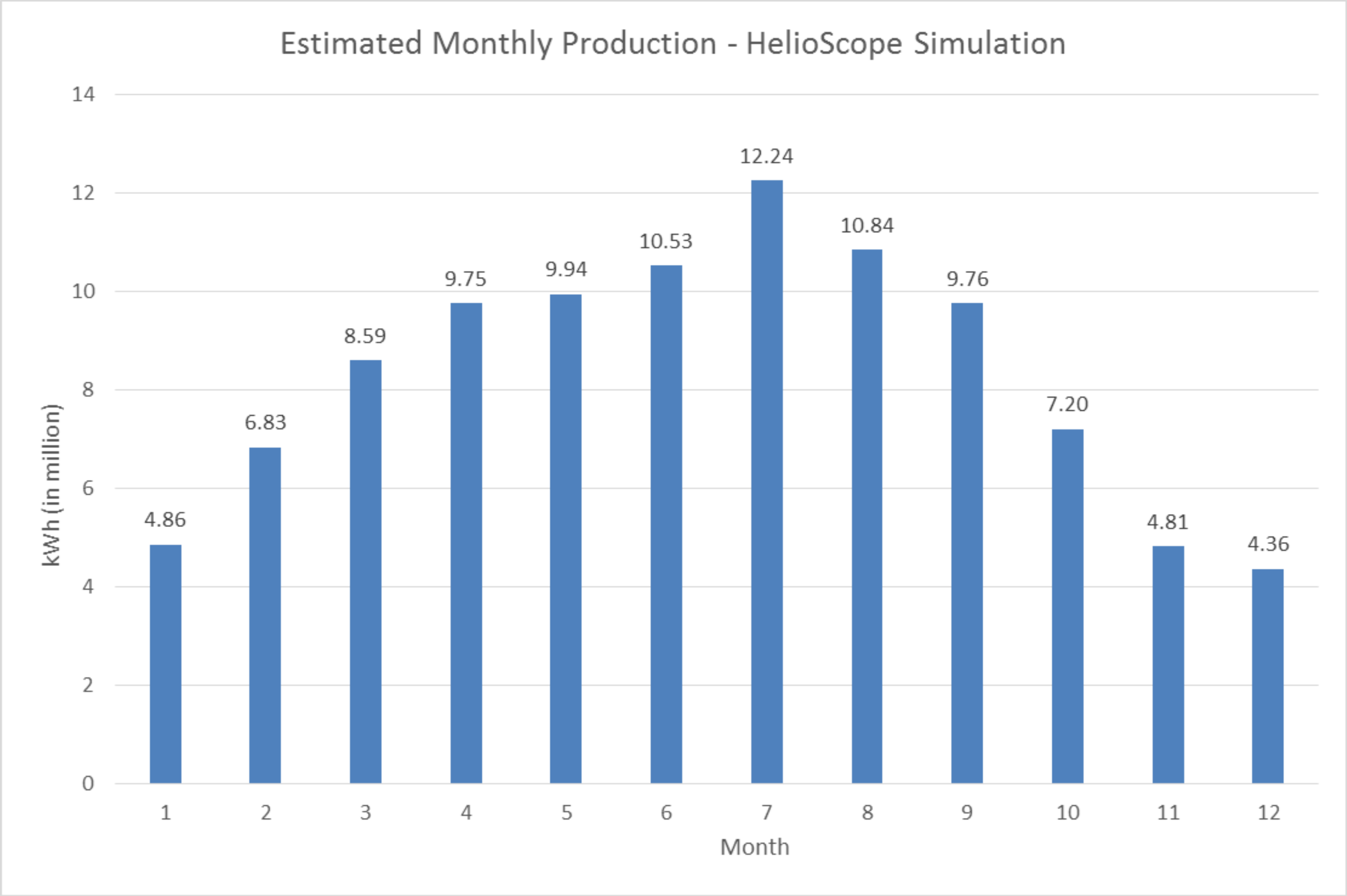
237,888 panels – 36 arrays – 60 MWac – 240 acres



ANNUAL SOLAR RADIATION



EXPECTED PRODUCTION

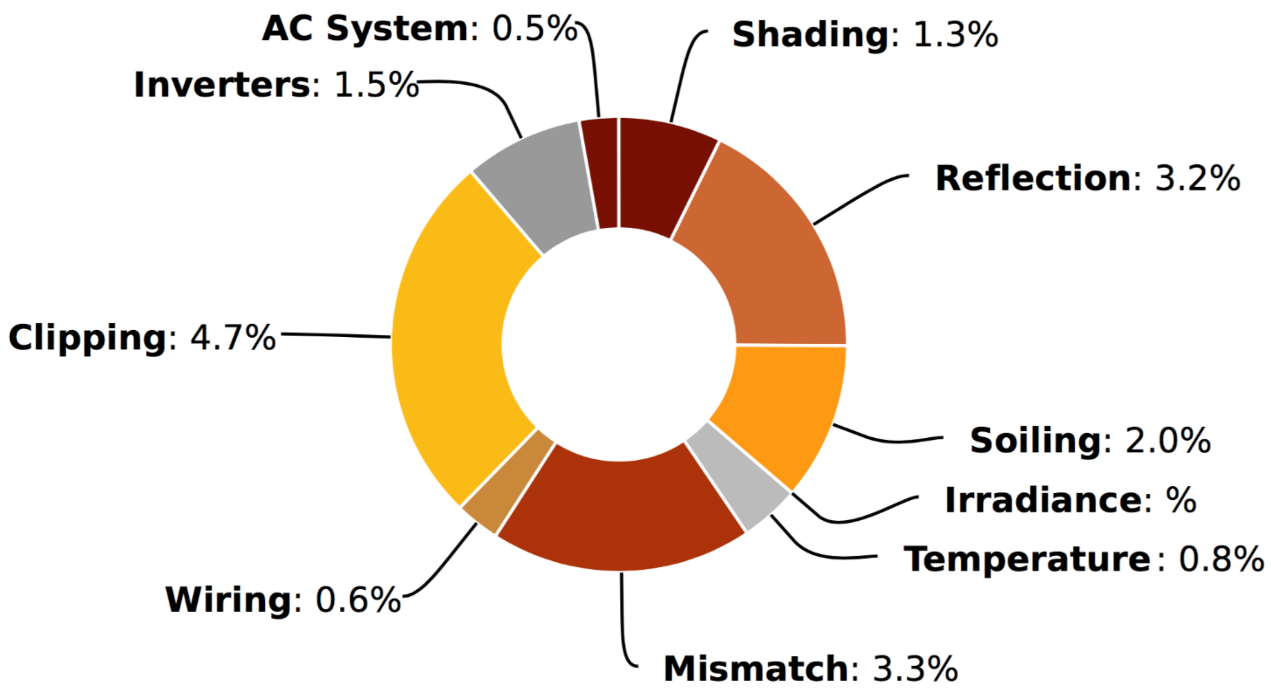


HelioScope Simulation: 99.73 million kWh/year

Comparison: Olmedilla PV Park (60MW): 87.5 million kWh/year

ESTIMATED SYSTEM LOSSES

Solar power losses
17.9% of 77.3 MWp



Helioscope Simulation

PV PLANT COST

- **Projected cost: PVWatts Estimate**
  - Solar power plant – $ 255,134,880
  - $ 4.25 Million/MW
  - Substation – $ 20,000,000
  - Grand total – $ 275,134,880

- **FOR COMPARISON: Topaz PV Plant**
  - $ 2.5 Billion
  - 550 MW
  - $ 4.53 Million/MW

MAN HOUR BUDGET

115 kV / 34.5 kV Solar Power Plant / Substation

Start Week **Aug 31, 2015**

Break | Projected | Overrun | Billable Hours

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Start Date	Aug 31	Sep 7	Sep 14	Sep 21	Sep 28	Oct 5	Oct 12	Oct 19	Oct 26	Nov 2	Nov 9	Nov 16	Nov 23	Nov 30	Dec 7	Dec 14	Tasks/Assignements
FALL 2015																	Meetings-client & advisors
																	Assign tasks/ begin research
																	Team roles/advisors meetings
																	Discuss project scope with client
																	Solar plant size determination
																	Project Plan V1
																	Design document V1
																	Solar array parameters
																	Solar array layout
																	Solar plant conductors
																	Substation one-line drawings
																	Substation three-line drawings
																	Project Plan V2
																	Design Document V2
																	Presentation slides and rehearsal
																	Faculty presentation
																	Finalize deliverables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	SUM
Hours Budget	5.0	10.0	10.0	10.0	20.0	20.0	20.0	30.0	30.0	15.0	15.0	30.0	0.0	40.0	10.0	2.0	267.0
Hours Actual	4.0	10.0	8.5	16.5	25.0	16.5	44.0	37.0	24.0	16.0	18.0	31.5	0.0	59.0	29.5	1.0	340.5
% of Budget	80	100	85	165	125	83	220	123	80	107	120	105	0	148	3	1	127.5

Start Week **Jan 11, 2016**

Break | Projected | Overrun | Billable Hours

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Start Date	Jan 11	Jan 18	Jan 25	Feb 1	Feb 8	Feb 15	Feb 22	Feb 29	Mar 7	Mar 14	Mar 21	Mar 28	Apr 4	Apr 11	Apr 18	Apr 25	Tasks/Assignements
SPRING 2016																	Meetings-client & advisors
																	Fall 2015 review
																	3-line ac drawings
																	3-line 89 drawings
																	3-line bank drawings
																	3-line bu drawing
																	3-line comm drawings
																	3-line dc drawings/ethernet
																	3-line feeder drawings
																	Design document V3
																	Optimization
																	Presentation preperation
																	BV presentation
																	IRP presentation

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	SUM
Hours Budget	8.0	8.0	8.0	8.0	8.0	10.0	10.0	8.0	15.0	0.0	10.0	20.0	20.0	10.0	20.0	2.0	165.0
Hours Actual	7.5	18.5	19.5	17.5	4.5	9.0	16.5	23.0	41.5	0.0	8.5	24.0	34.0	19.0	25.0	2.0	270.0
% of Budget	94	231	244	219	56	90	165	288	277	0	85	120	170	190	125	100	163.6

BLACK & VEATCH VISIT

Overland Park, Kansas

INITIAL CHALLENGES AND DIFFICULTIES

- Industry terminology
- Lack of experience with AutoCAD
- Team communications associated with tracking large number of drawing and parameter revisions.
- Familiarity with NEC code regulations
- Lack of solar panel parameter knowledge. Such as string voltage limitations, MPP, temperature affects of on panel voltage.
- Lack of face-to-face meetings with client/mentor.

WHAT WE LEARNED – QUICK SUMMARY

- Design process book keeping and man hour budget.
- Solar power generation parameters.
- How to maximize utilization of inverters by increasing DC capacity above inverter ratings.
- Design modularity into solar arrays to allow flexibility of placement.
- Experience with substation relay circuitry & communication circuitry.
- Importance of NEC Code compliance.
- Minimizing cost – use aluminum for large conductors, minimize space.
- Simulation of expected kWh production.

QUESTIONS?