BUILDING A WORLD OF DIFFERENCE

115 KV/34.5KV SOLAR PLANT/SUBSTATION

CHASE BENTON – TEAM LEADER
SENKO DIZDAREVIC – COMMUNICATION LEADER
ARIF IBRAHIM – WEBMASTER
MAKOKO MUKUMBILWA – KEY CONCEPT HOLDER

SPONSOR: 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

BACKGROUND

- **Chase Benton**
  - From San Diego, California
  - Focus in power systems, graduating in May of 2016
- **Senko Dizdarevic**
  - From Johnston, Iowa
  - Focus in power systems, graduating in August of 2016
- **Arif Ibrahim**
  - From Glen Allen, Virginia
  - Focus in power/control systems, graduating in May of 2016
- **Makoko Mukumbilwa**
  - From Iowa City, Iowa
  - Focus in power/control systems, graduating in May of 2016

PROJECT OVERVIEW

- **Plant Location**
  - Iowa
  - Iowa energy center – solar calculator tools
- **60 MW Solar Power Plant**
  - Plant/component sizing
  - Plant layout
  - HelioScope Simulation & PVWatts Calculator
- **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 connection
- Substation one-line drawings/three-line drawings
- Drawing list
- Production simulation data
- Engineering man hour budget and schedule

SOLAR PLANT REQUIRED INPUT PARAMETERS

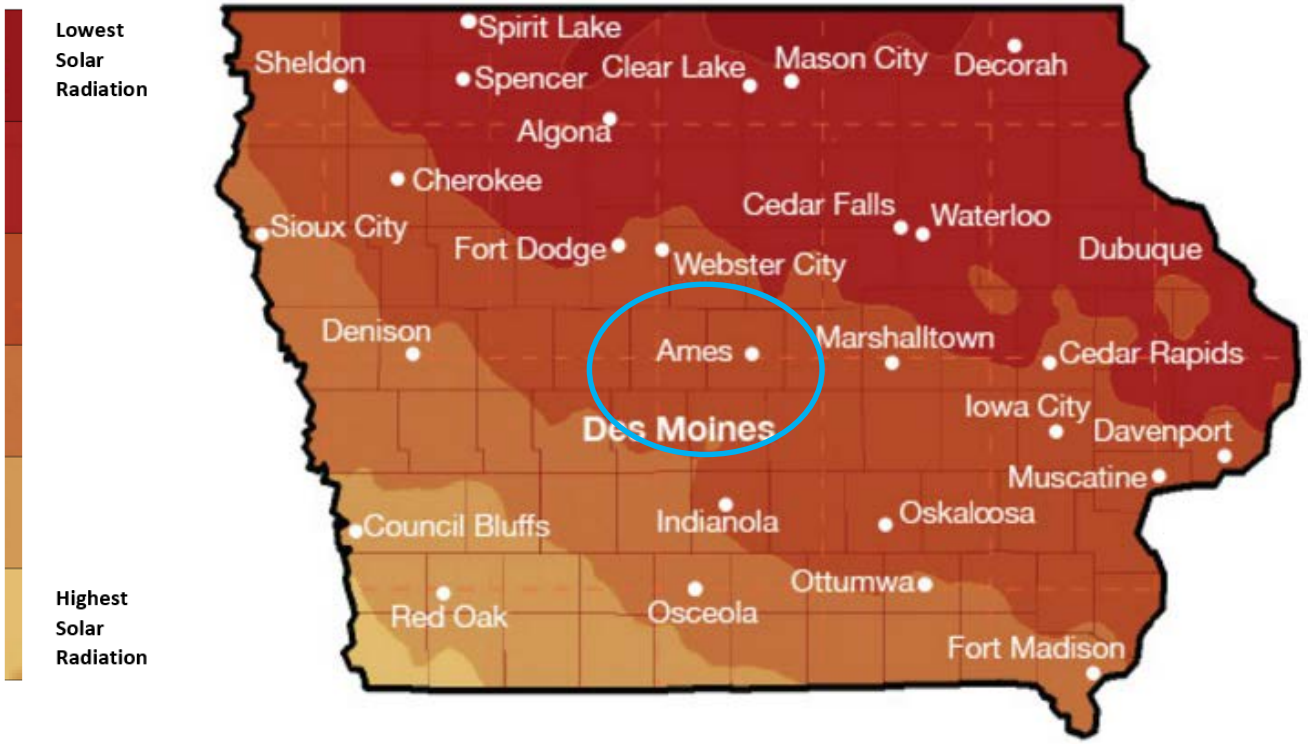
- Location: Iowa
- Fixed Rack 325 W Hanwha Q Cells solar modules
- 1670 kW Eaton Xpert inverter
- 1500 VDC string voltage
- ≈1.30 Inverter Load Ratio (ILR)

SUBSTATION REQUIRED INPUT PARAMETERS

- Substation specification document
- Arcadia single line diagram

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



ARRAY PARAMETER TOOL

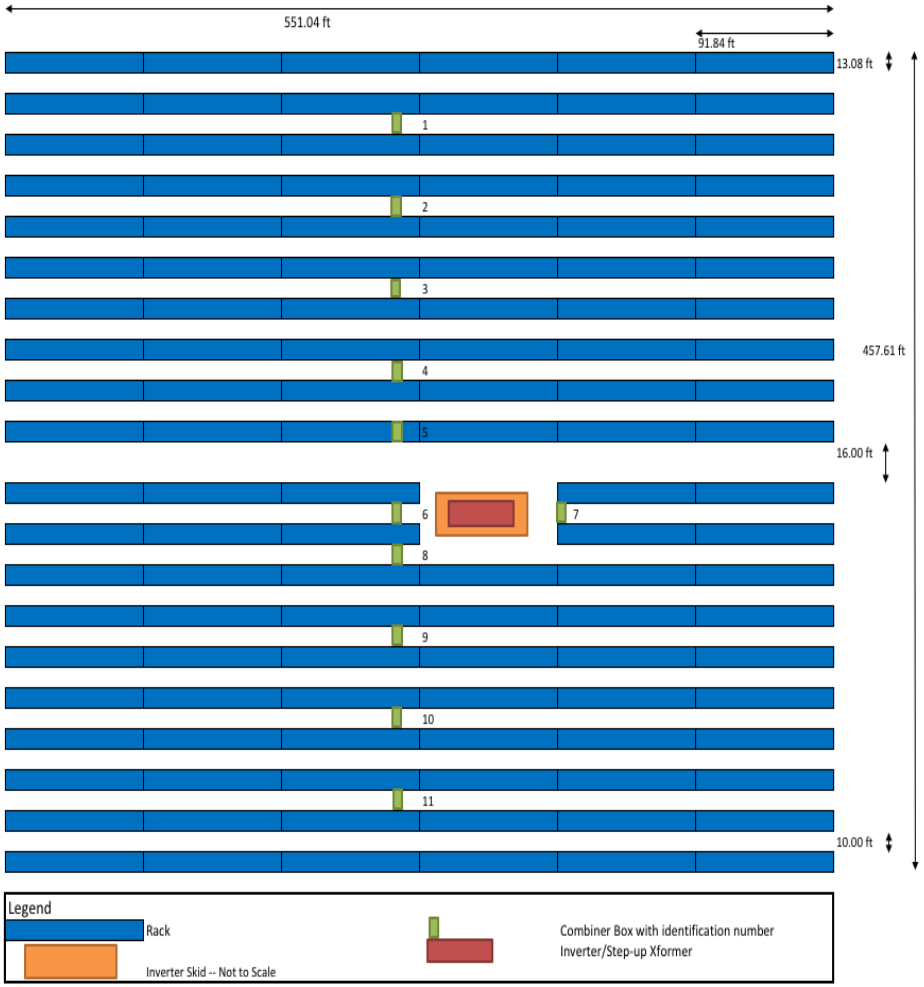
String Size			Electrical Rack Size			CB capacity		
Min Temp	-26	C	Module width	3.28	ft	Module/string Isc (series)	9.44	A
			module height	6.54	ft	Isc continous current multiplier	1.25	see (a)
Voc	46.43	V				Nom Isc	11.8	A
Ref temp	25	C	Rack width	28	modules	Isc irradiance correction	1.25	see (b)
			Rack height	2	modules	Max Isc string	14.75	A
Temp Coeff of Voc	-0.0029	per deg C				Max Isc rack, at CB	29.5	A
Temp delta	-51		Rack width	91.84	ft	Allowed current CB	400	A
temp correction	1.15		Rack height	13.08	ft	Max current per CB	354	A
Voc corrected	53.297					Strings per CB	27.118644	
			Frame width	1.38	in	Number of CB per array	11	
String voltage/CB in	1500	V				Actual strings per CB	24	****
String size	28.14417							
string size (series)	28	modules						
String voltage calcul	1492.3	V						

ARRAY PARAMETER TOOL

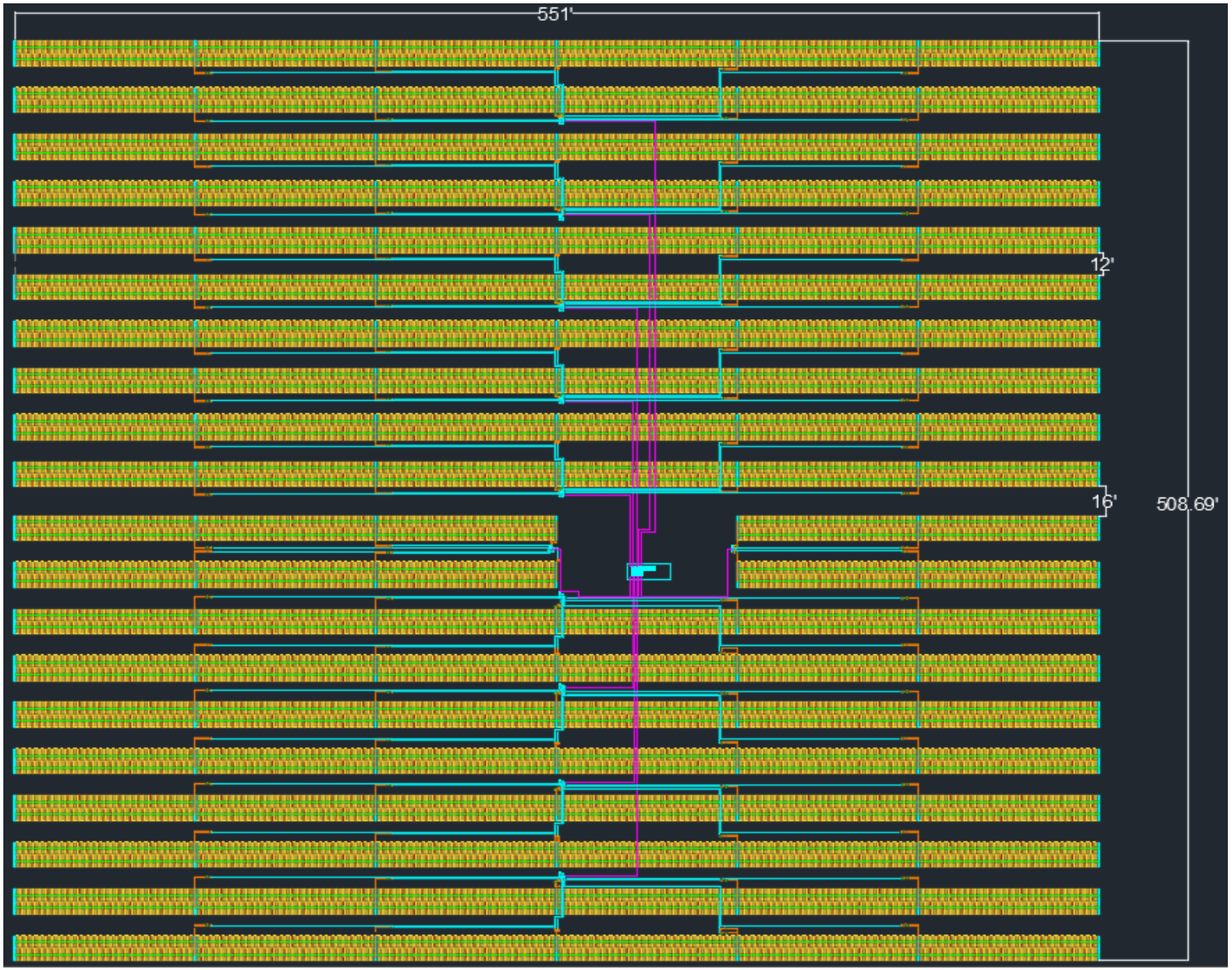
Array Design			Array Size				Plant Totals		
Racks per row	6		Tilt	15	Degrees		Array Blocks	36	
			Azimuth	180	Degrees	see (d)			
Rows per block	20		Rack height proj	12.63431	ft		Number of CBs	396	
Racks removed	2		Row spac	12	ft		Inverters	36	
Total Racks	118		Pitch	24.63431	ft		Modules/Panels	237888	
Total modules in Array	6608		Array height	492.6862	ft		Total Strings	236	
							Total Racks	472	
Module DC capacity	325	W	Array width	551.04	ft		AC Plant Output	59.976	MW AC
							DC Array Output	77.314	MW DC
DC capacity	2147.6	kW	Access road width	16	ft				
			Array Size with access road & spacing:				PV Plant Height	3132	ft ***
Inverter capacity	1666	kW	Array height	508.6862	ft **		PV Plant Width	3386	ft ***
Inverter S capcity	1831	kVA	Array width	551.04	ft				
ILR ->Inv in/Inv out	1.289076		Array Area	280306.4	ft^2		Solar Plant Area	10605348.8	ft^2 ***
				26041.32	m^2			0.380	mi^2
CB's per Array	11		Inverter skid	22 x 8.5	ft			243.5	acres
			Inverter skid area	187	ft^2			985269.1	m^2
Power per CB	195.2364	kW	Area of components	141936.5	ft^2				
Power per Rack	18.2	kW	Ground Coverage Ratio (GCR)	0.506362	see(c)				

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 racks
  - 16 ft inverter access road in the middle



DETAILED SOLAR ARRAY

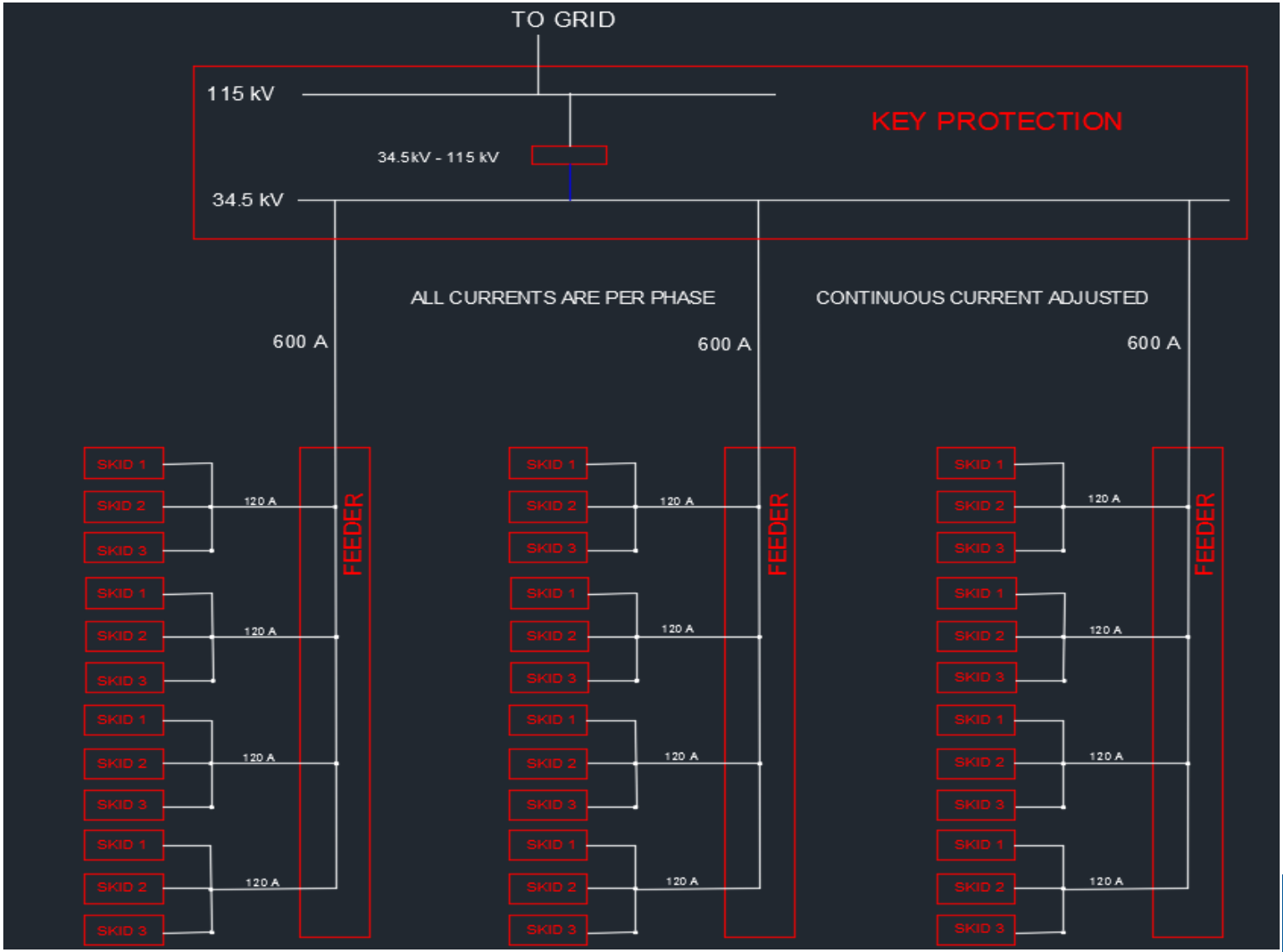


SOLAR ARRAY CONDUCTOR SIZING

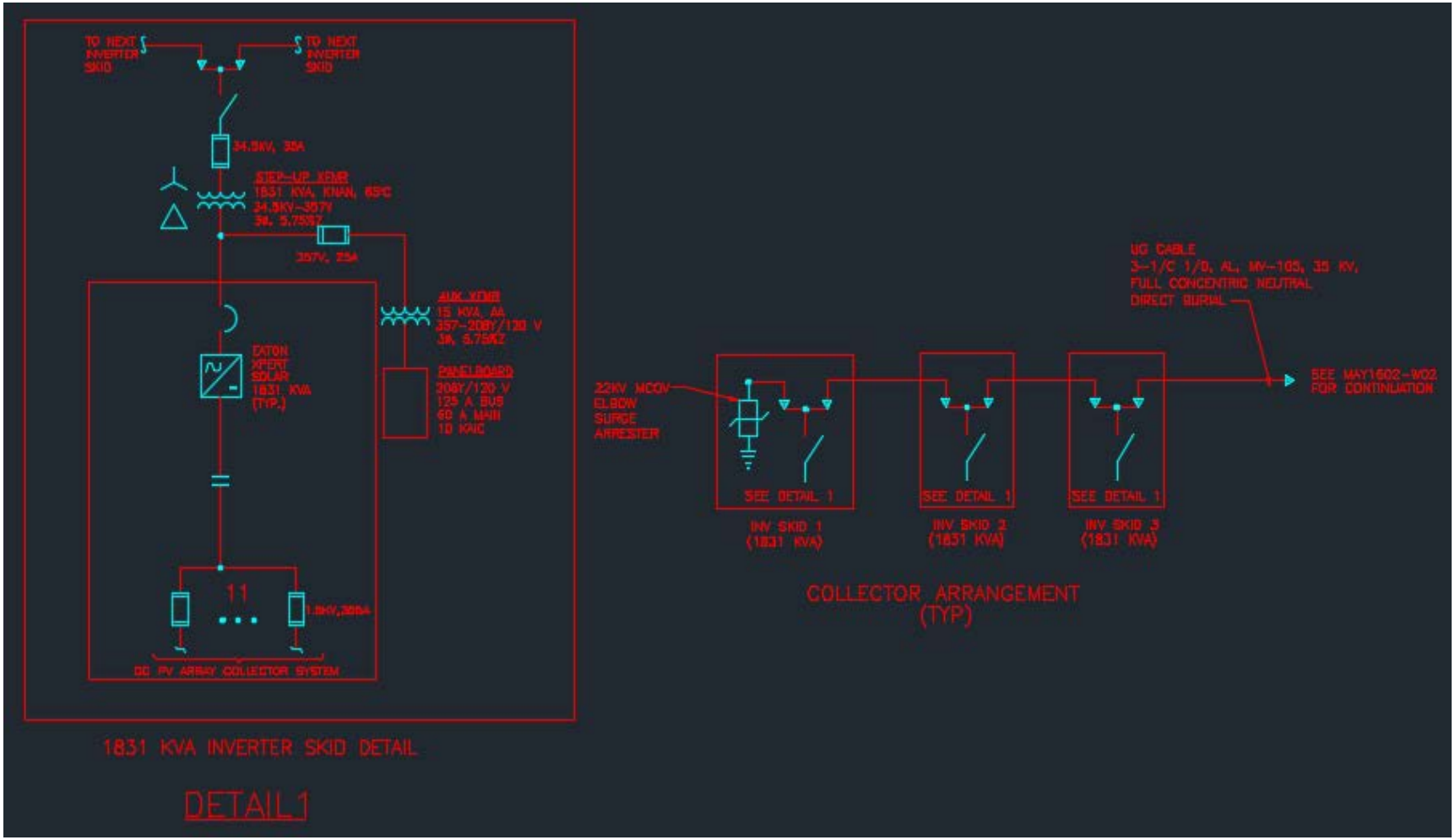
- Irradiance correction factor of 1.25 applied
- Referenced NEC 690(B) continuous current of 1.25
- Used NEC 310 guidelines to size conductors for solar power plant
- Referenced NEC 310 Table 300.50 for minimum burial depth requirements
- Referenced Table 310.15(B)(16) and Table 310.15(B)(17)

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	(*)

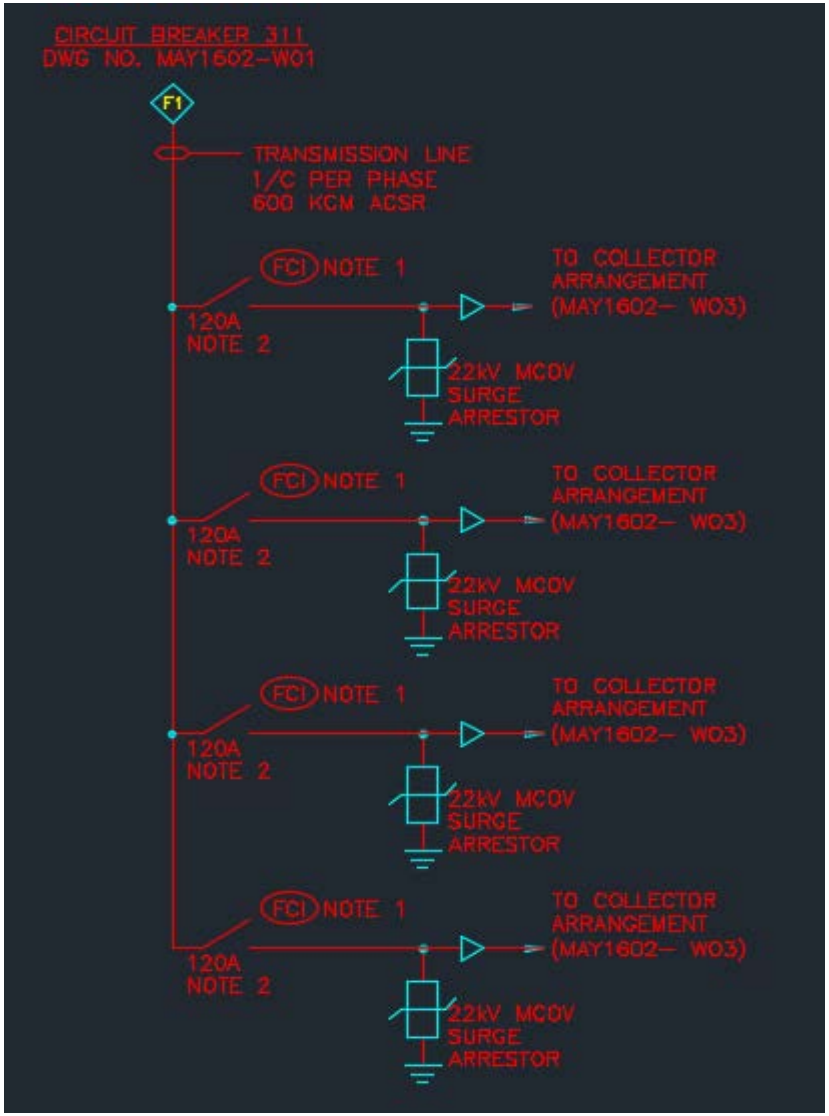
SUBSTATION SYSTEM BLOCK DIAGRAM



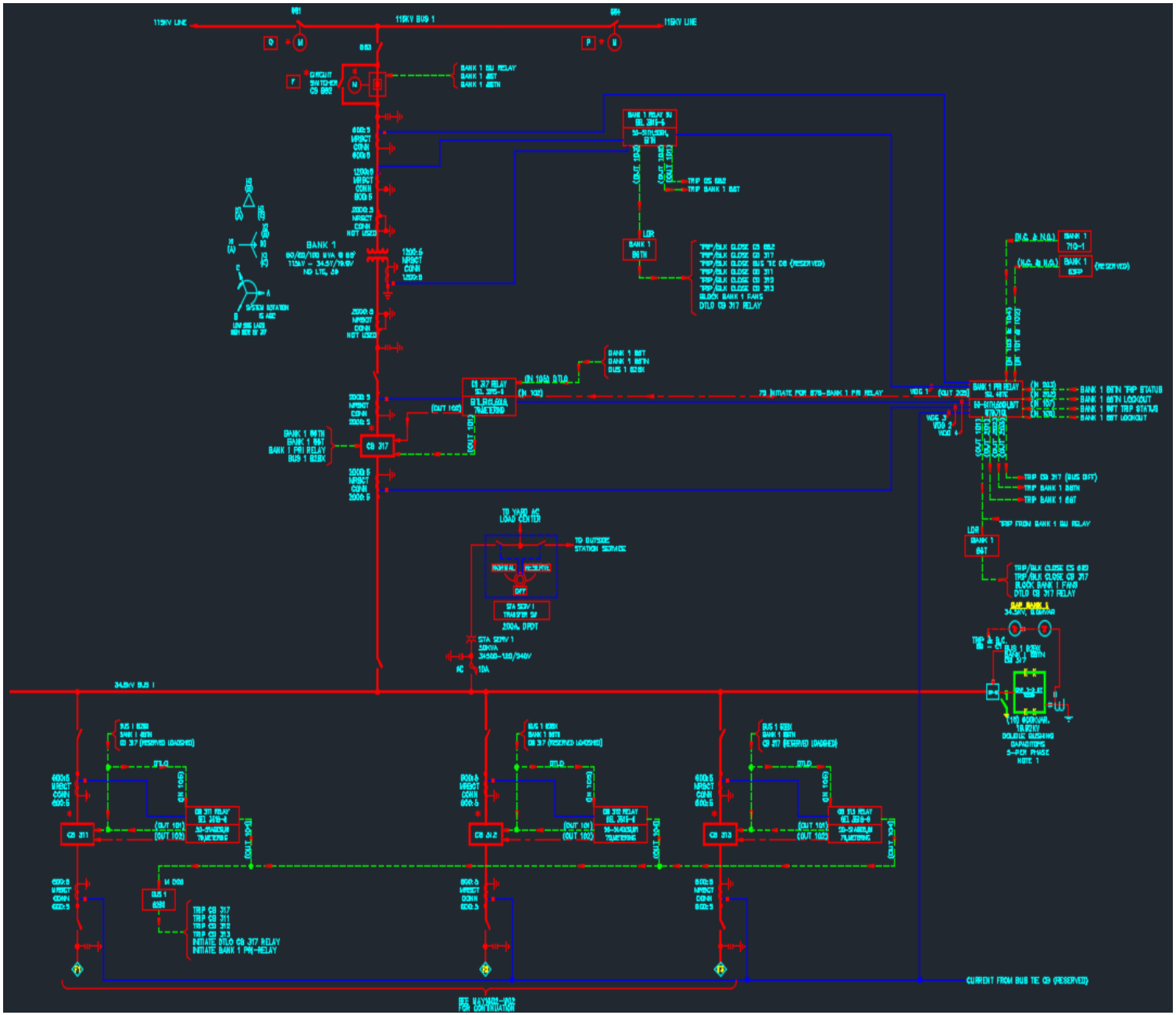
COLLECTOR


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
PANELBOARD
208Y/120 V
125 A BUS
60 A MAIN
10 KAIC
DATON XPERT SOLAR
1831 KVA
(TYP.)
1.8KV,3Ø64
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
120A
NOTE 2
TO COLLECTOR
ARRANGEMENT
(MAY1602- W03)
22kV MCOV
SURGE
ARRESTOR
FCI
NOTE 1
120A
NOTE 2
TO COLLECTOR
ARRANGEMENT
(MAY1602- W03)
22kV MCOV
SURGE
ARRESTOR
FCI
NOTE 1
120A
NOTE 2
TO COLLECTOR
ARRANGEMENT
(MAY1602- W03)
22kV MCOV
SURGE
ARRESTOR
FCI
NOTE 1
120A
NOTE 2
TO COLLECTOR
ARRANGEMENT
(MAY1602- W03)
22kV MCOV
SURGE
ARRESTOR

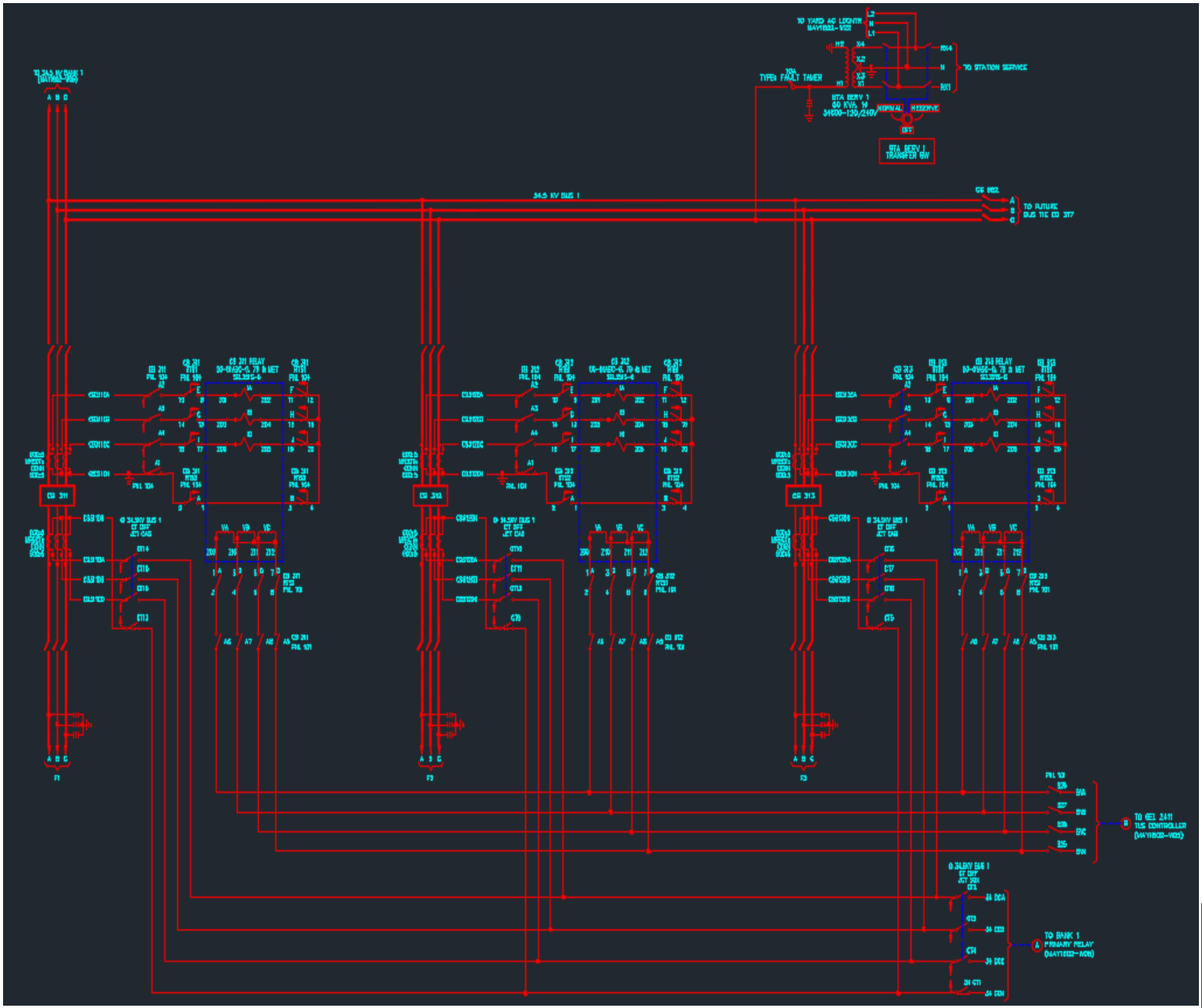
KEY PROTECTION



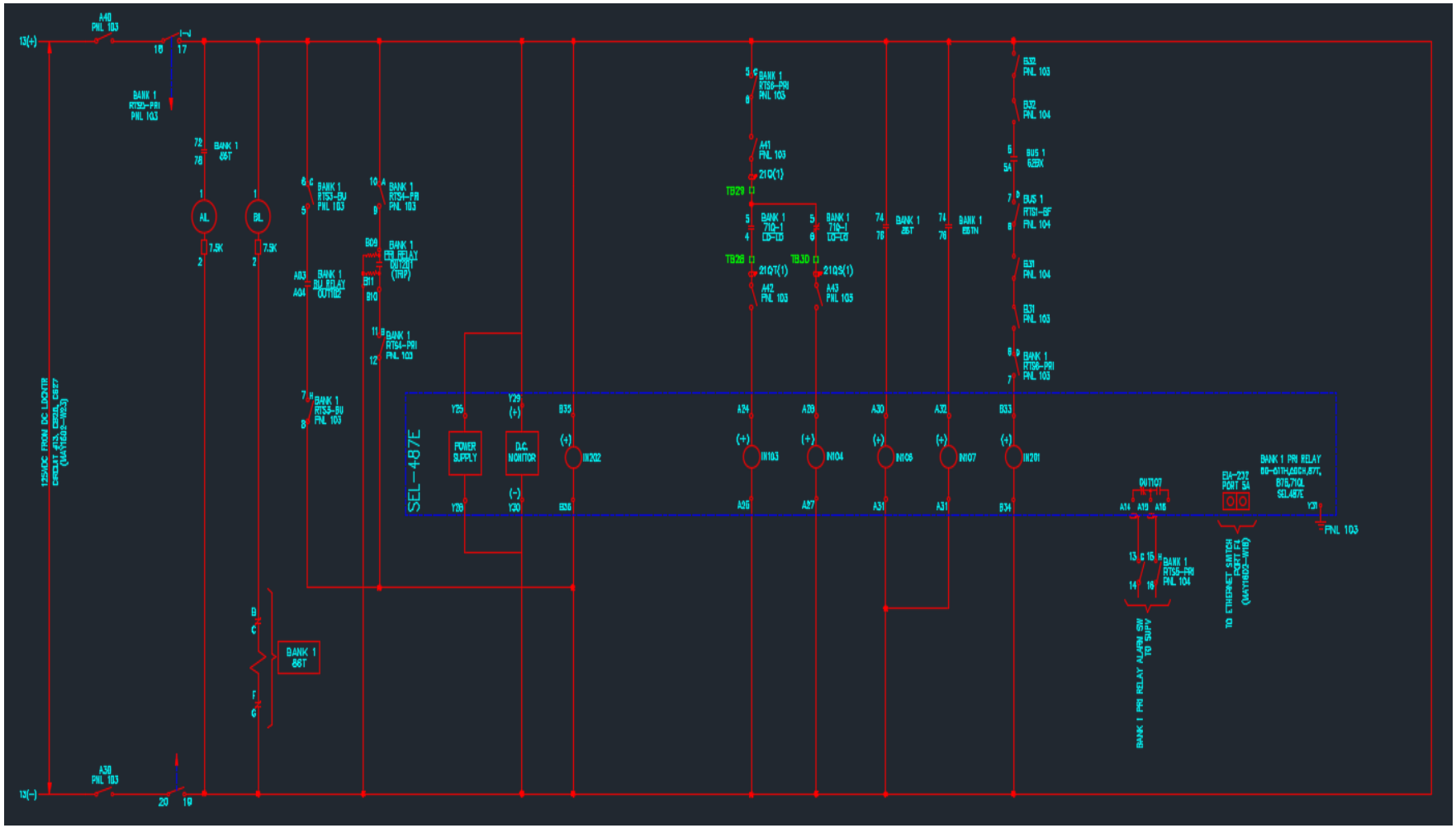
SUBSTATION 3 LINE DRAWINGS

- 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

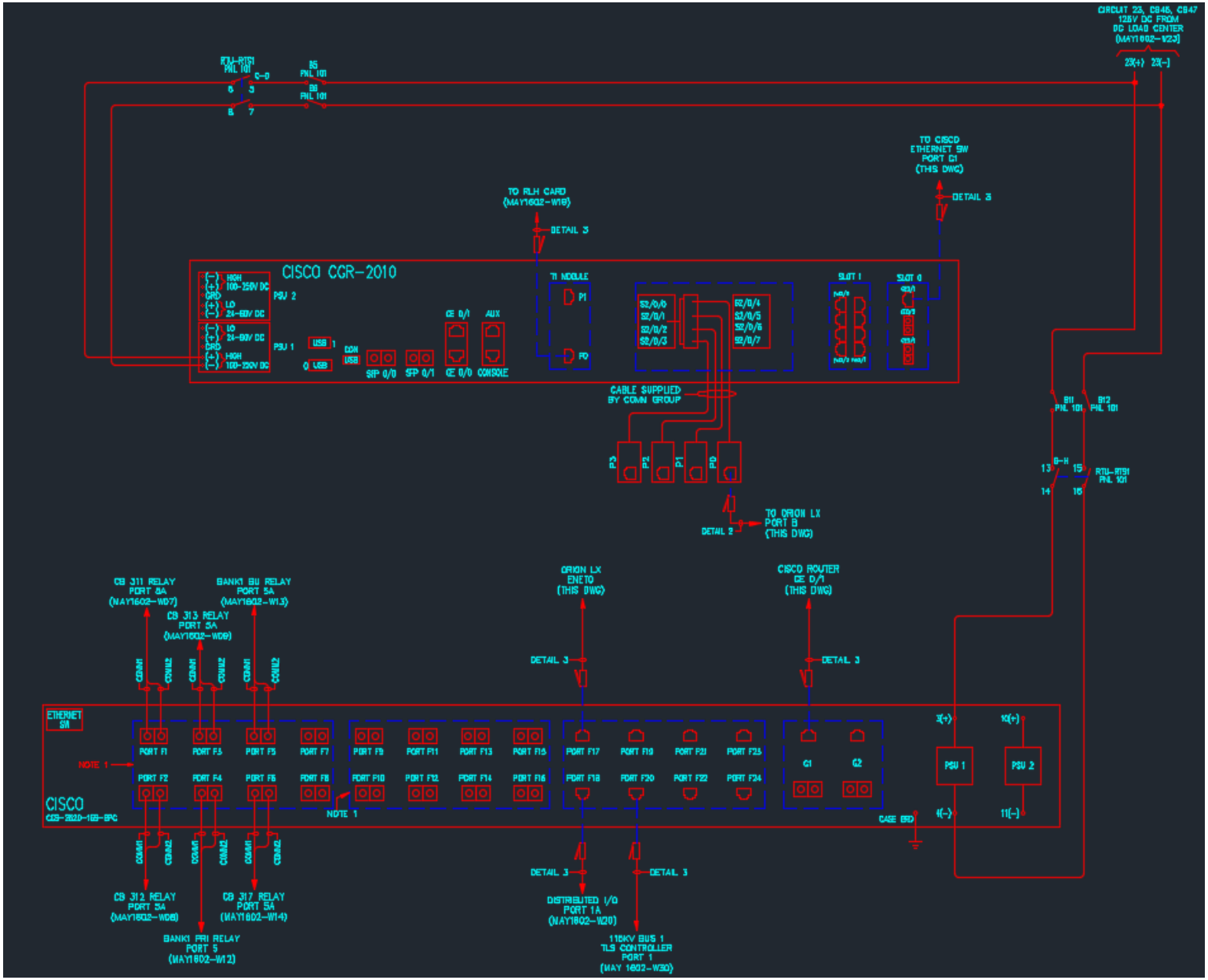
AC THREE LINE DRAWING



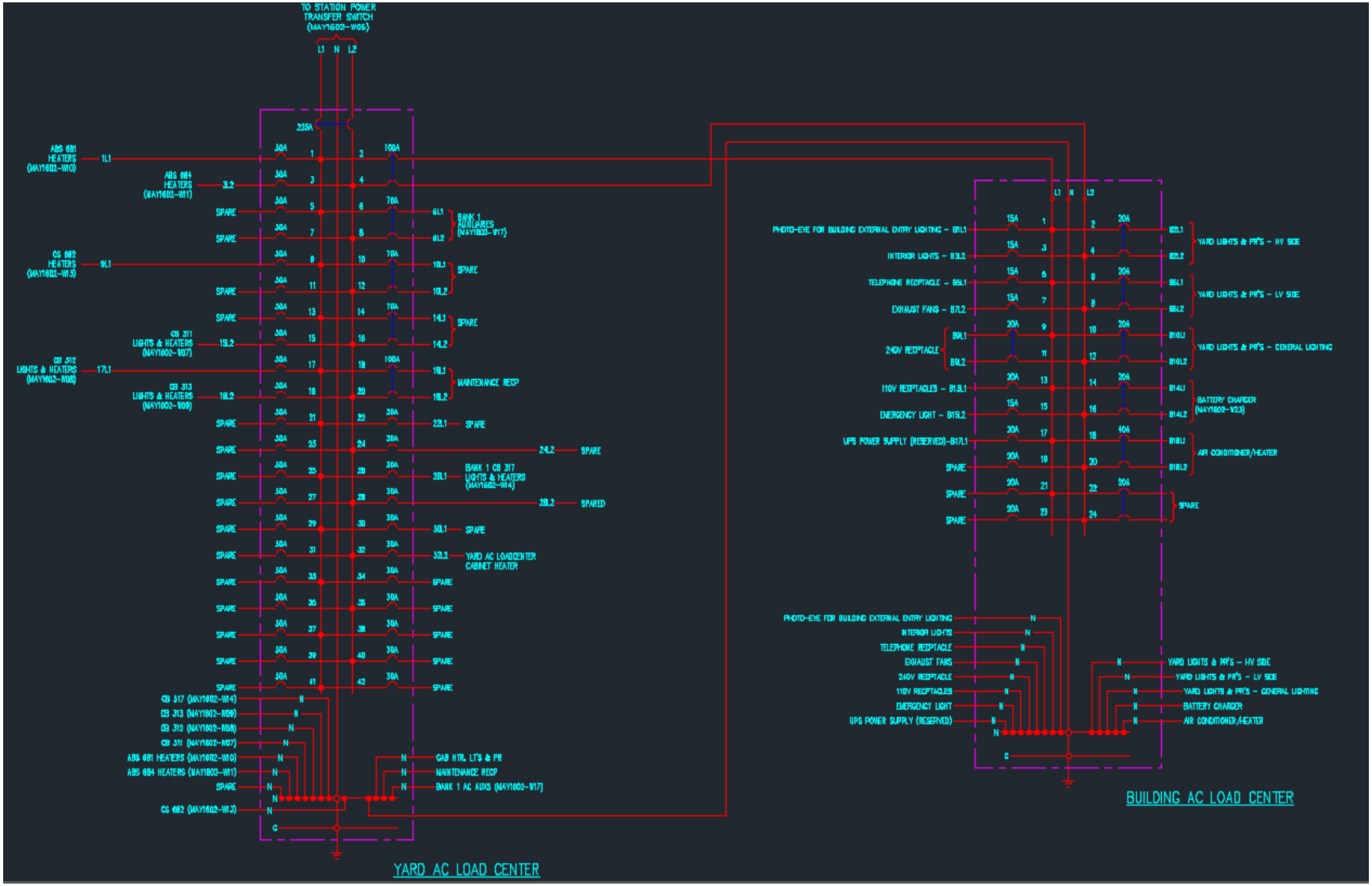
PRIMARY RELAY DC DRAWINGS



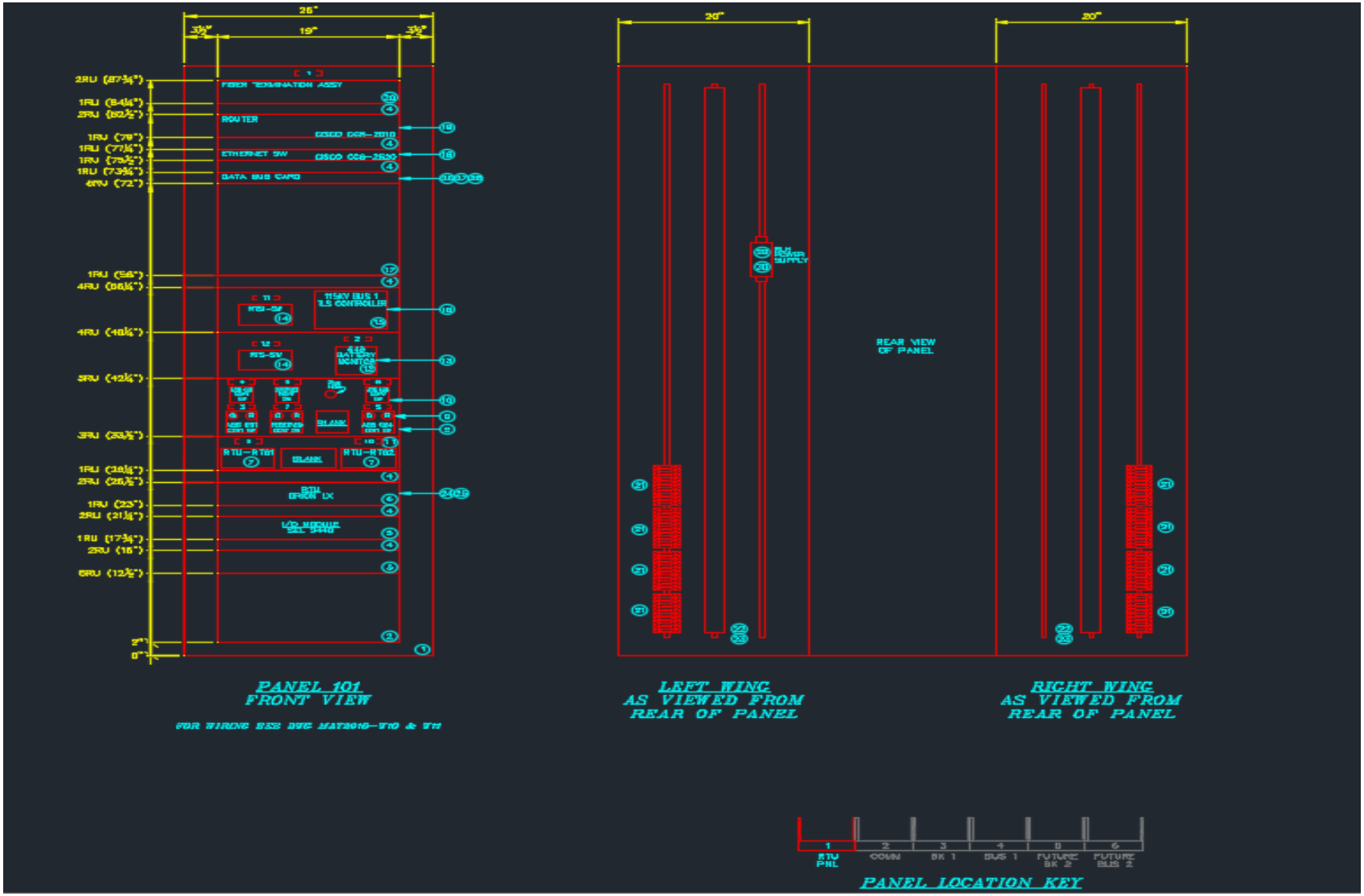
COMMUNICATION



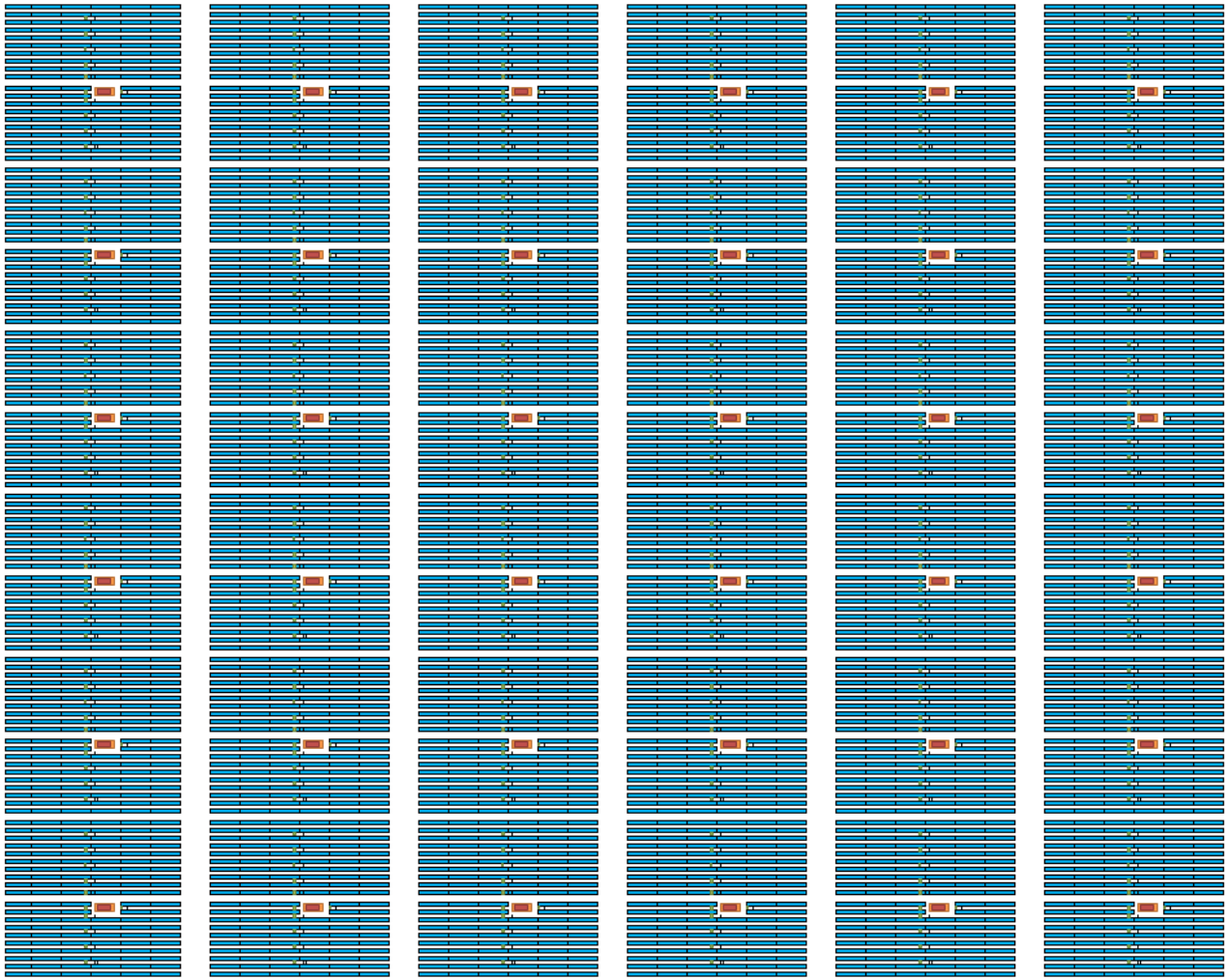
AC LOAD CENTER



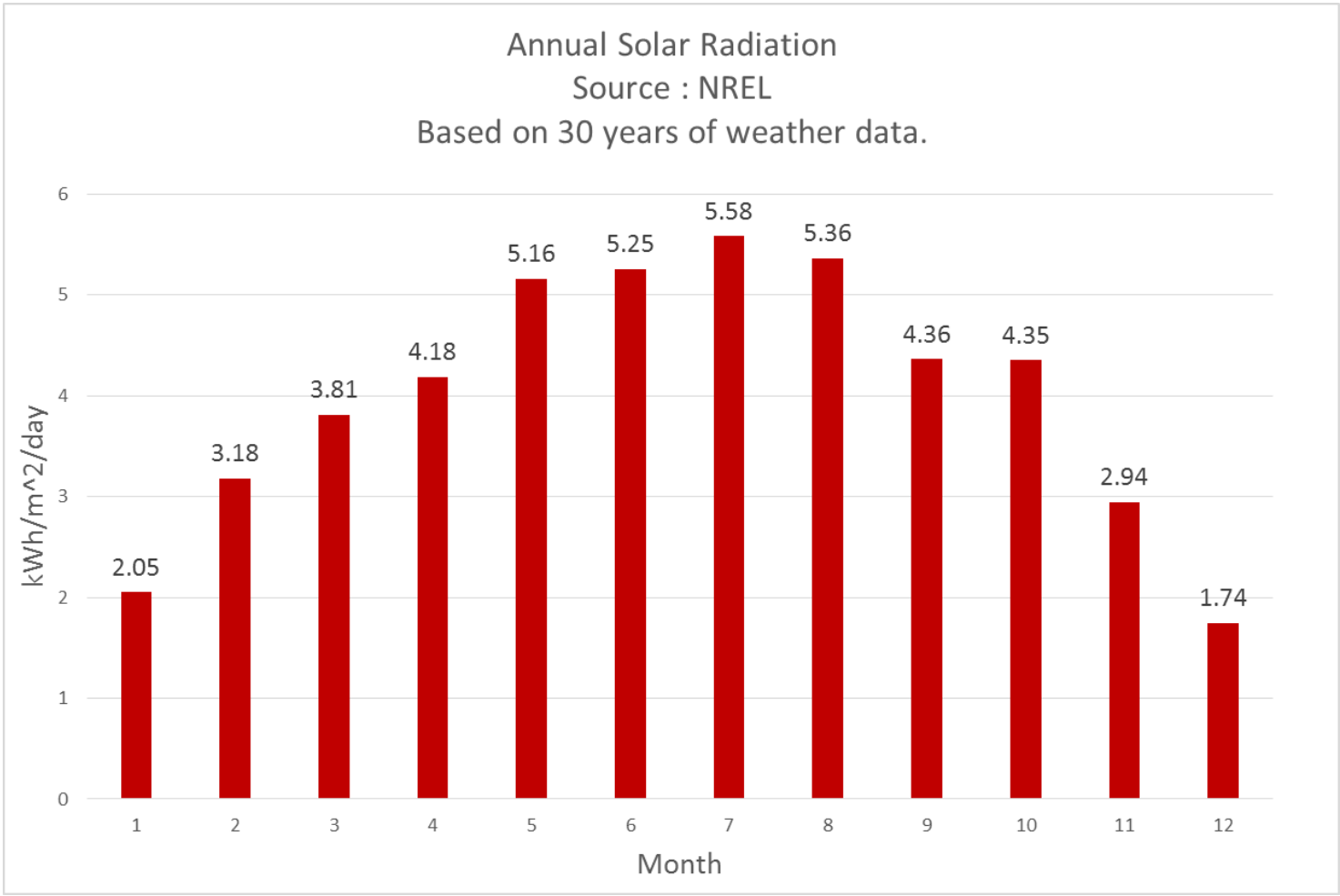
PANEL ELEVATION



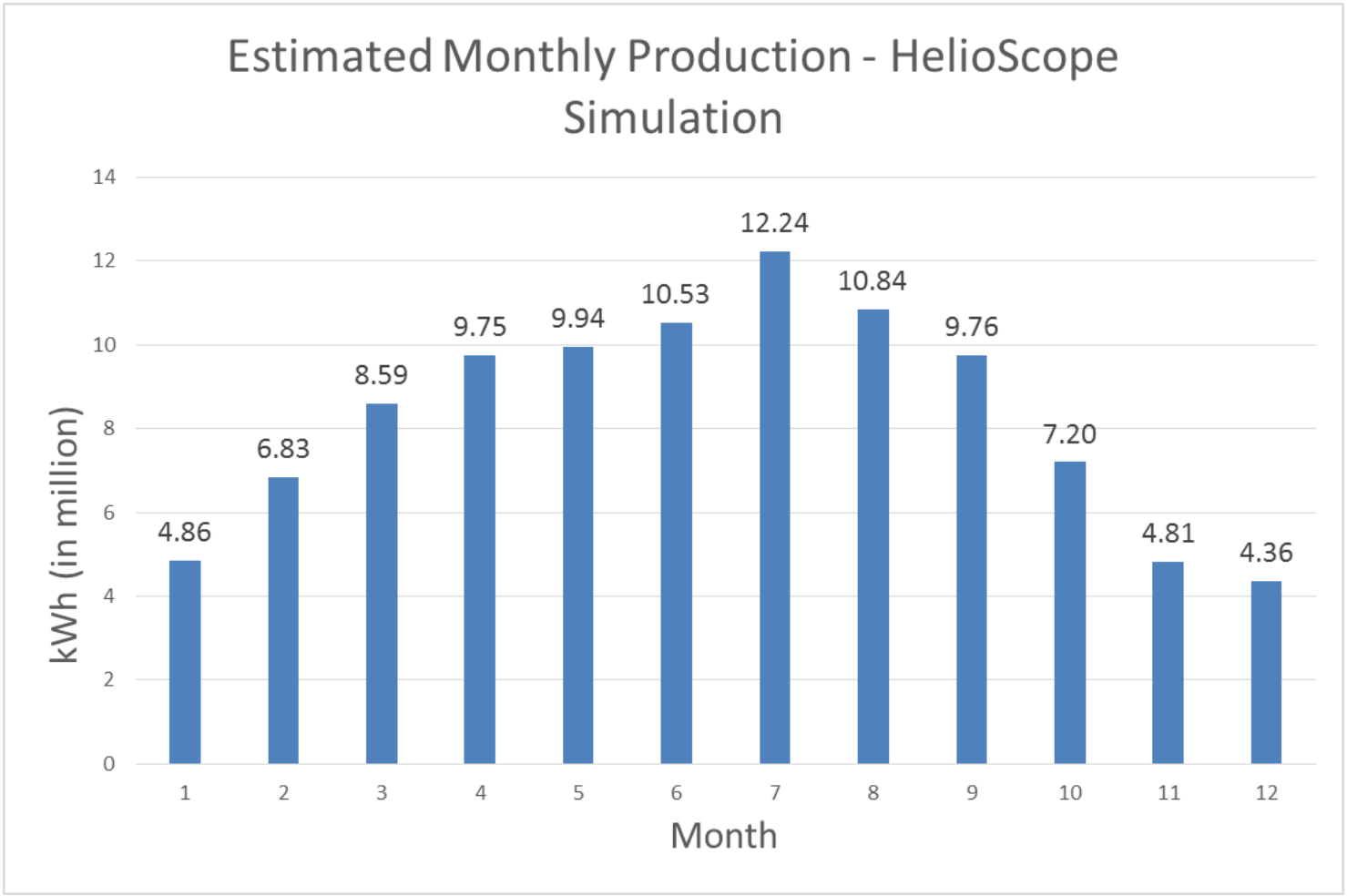
SOLAR POWER PLANT LAYOUT: 36 ARRAYS 60 MW



ANNUAL SOLAR RADIATION



EXPECTED PRODUCTION

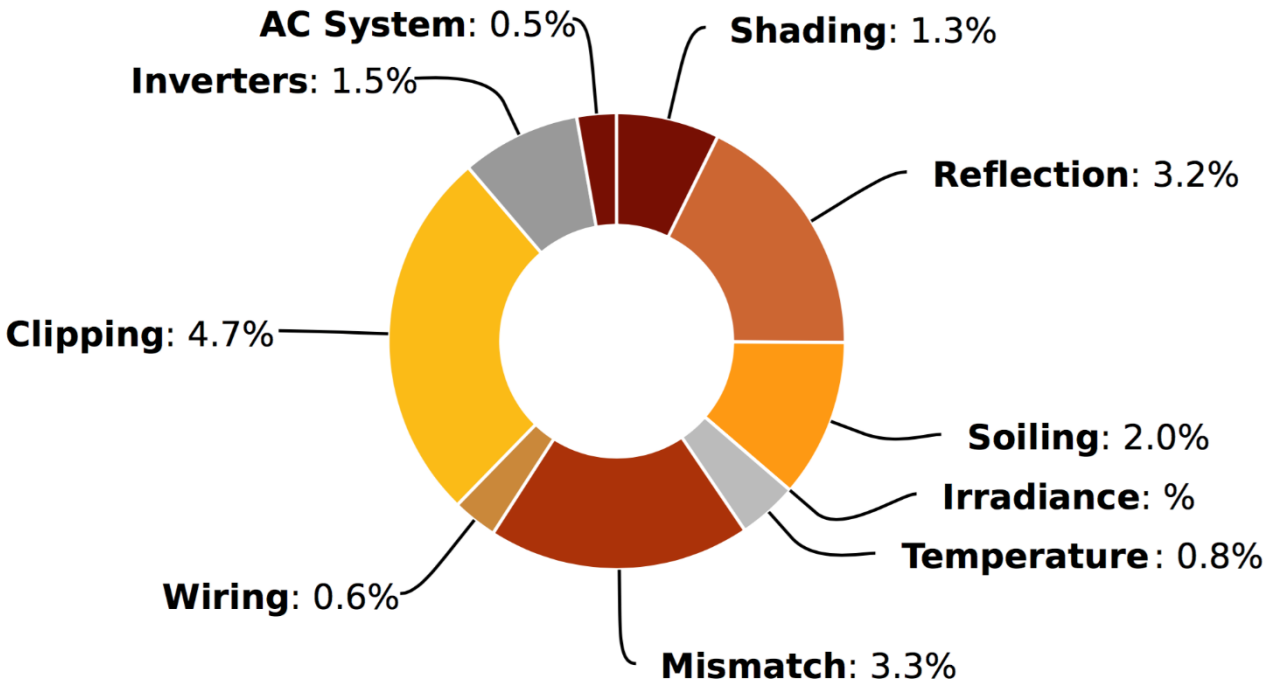


HelioScope Simulation: 99.73 million kWh/year

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

ESTIMATED SYSTEM LOSSES

DC power losses
Total 17.9%



Helioscope Simulation

MAN HOUR BUDGET

115 kV / 34.5 kV Solar Power Plant / Substation — BLACK & VEATCH

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
																		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	PROJECTED SCHEDULE																	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
																		Faculty presentation
																		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	TBD	TBD	TBD
	% of Budget	0.9	2.3	2.4	2.2	0.6	0.9	1.7	2.9	2.8	0.0	0.9	1.2	1.7	1.9	#####	#####	#VALUE!

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, documentation, and man hour budget.
- Solar power generation parameters.
- How to maximize utilization of inverters by increasing DC capacity past inverter ratings.
- How to 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 instead of copper.
- Simulation of expected kWh production.

QUESTIONS?