BUILDING A WORLD OF DIFFERENCE

12/8/2015

115 KV/34.5KV SOLAR PLANT/SUBSTATION

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BLACK & VEATCH
Building a world of difference.

AGENDA

- About BV
- Project Overview (Scope)
- Deliverables
- Project input parameters
- Solar Power Plant Design
- Substation Design
- Next Semester …

BLACK AND VEATCH

- Founded in 1915
- Headquarters in Overland, Kansas
- Global engineering, consulting, construction and operations company
- Involved in energy, water, telecommunications, management consulting and environmental markets

PROJECT OVERVIEW

- **Plant Location**
  - Iowa
  - Iowa energy center – solar calculator tools
- **60 MW Solar Power Plant**
  - Plant/component sizing
  - Plant layout
- **Attached 115 kV/34.5 kV Substation**
  - Substation one-line drawings
    - Collector, feeder connections
    - Key Protection

DELIVERABLES

- Engineering man hour budget and schedule
- Solar power plant layout and conductor sizing
- Substation one-line drawings
- Plant and substation component connection

SOLAR PLANT REQUIRED INPUT PARAMETERS

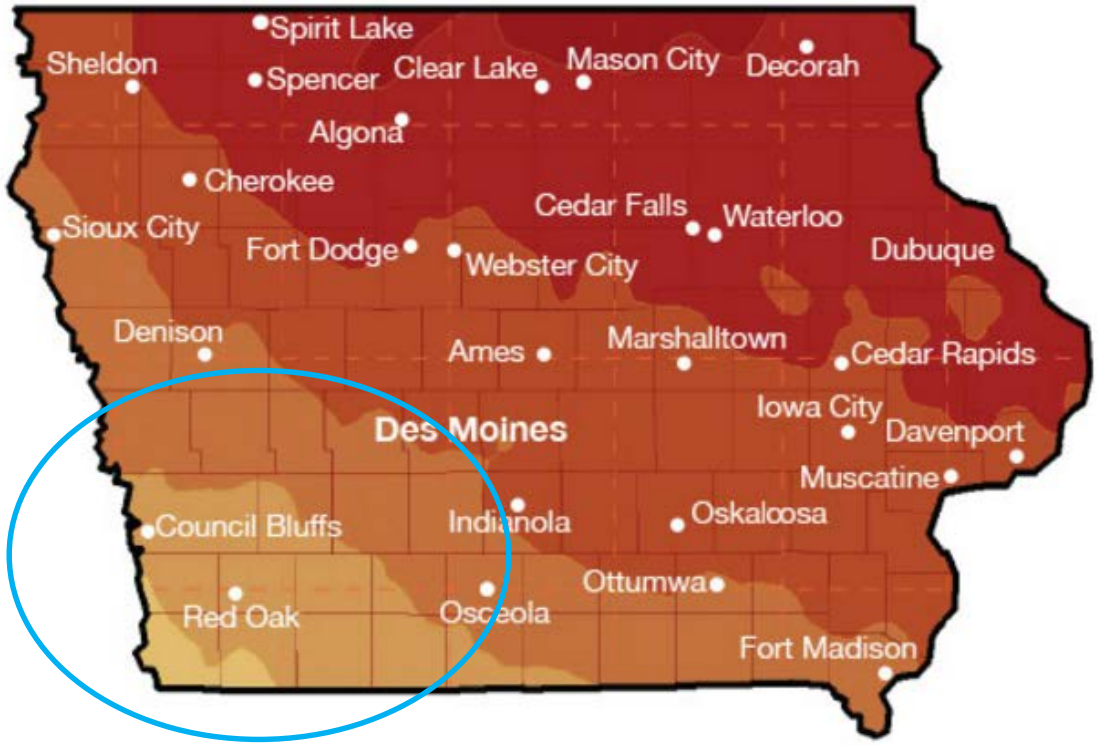
- Location: Iowa
- Fixed 325 W Hanwha Q Cells solar modules
- 1670 kW Eaton Xpert inverter
- 1500 VDC string voltage
- 1.30 Inverter Load Ratio (ILR)

SUBSTATION REQUIRED INPUT PARAMETERS

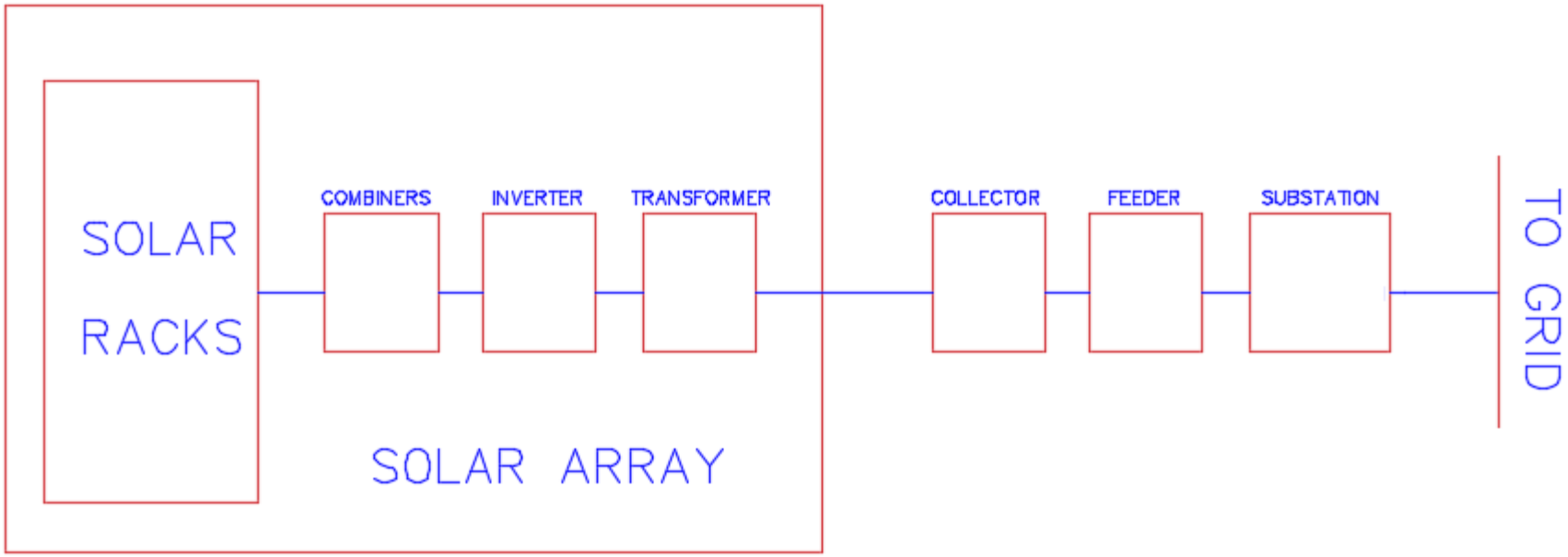
- Substation specification document
- Arcadia single line diagram

SOLAR POWER PLANT LOCATION

- Using the Iowa energy center solar calculator tool
  - Area most suitable: Southwest Iowa*



OVERALL SYSTEM BLOCK DIAGRAM



SOLAR POWER PLANT AREA

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

Therefore,

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

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

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

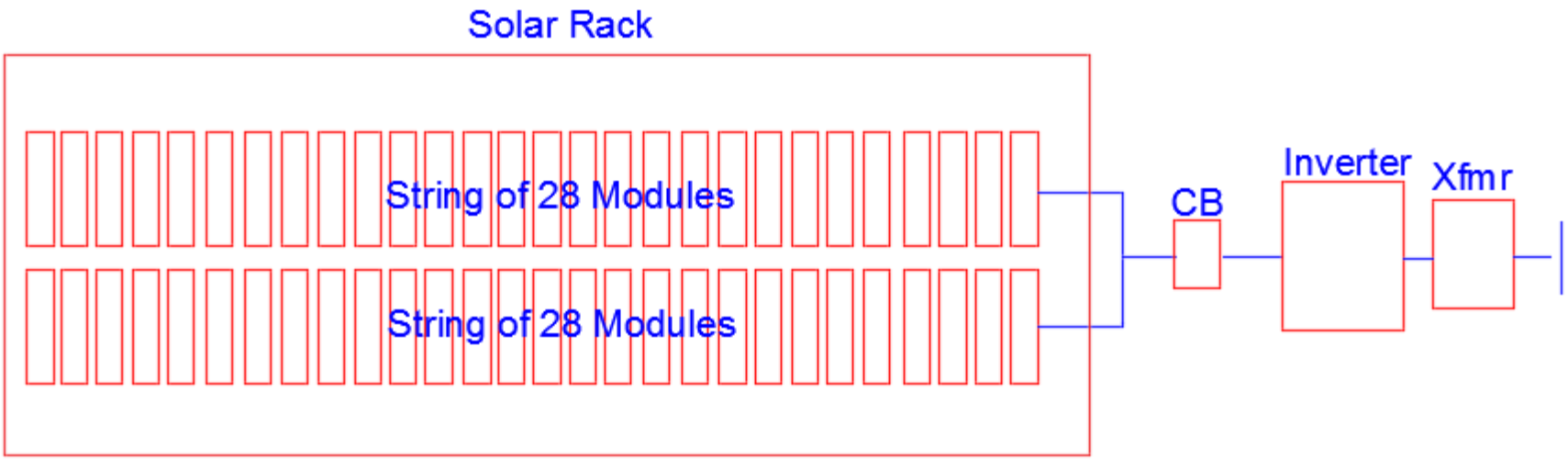
Including the row spacing, inverter skid, and access road; the total area becomes 210 acres for the entire solar plant.

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	
Voc	46.43	V				Nom Isc	11.8	A
Ref temp	25	C	Rack width	28	modules	Isc multiplier-irradiance correcti	1.25	
			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	
						Number of CB per array	11	
String voltage/CB in	1500	V						
String size	28.14417							
string size (series)	28	modules						
String voltage calcul	1492.3	V						

Array Design			Array Size				Plant Totals		
Racks per row	6		Tilt	30	Degrees		Array Blocks	36	
			Azimuth	180	Degrees	see (d)			
Rows per block	20		Rack height proj	11.32761	ft		Number of CBs	396	
Racks removed	2		Row spac	10	ft		Inverters	36	
Total Racks	118		Pitch	21.32761	ft		Modules/Panels	237888	
Total modules in Arr	6608		Array height	426.5522	ft		Strings	236	
Module DC capacity	325	W	Array width	551.04	ft		Plant Output	59.976	MW
			Access road width	16	ft				
DC capacity, Inverte	2147.6	kW	**Array Size with access road:**				Solar Plant Area	9077811	ft^2
								0.326	mi^2
Inverter capacity, In	1666	kW	Array height	457.61	ft			208.4	acres
			Array width	551.04	ft				
ILR ->Inv in/Inv out	1.289076		Array Area	252161.4	ft^2				
CB's per Array	11		Inverter skid area	187	ft^2				
Power per CB	195.2364	kW	Area of components	141936.5	ft^2				
Power per Rack	38.35	kW	Ground Coverage Ratio (GCR)	0.56288	see(c)				

ARRAY PARAMETER TOOL

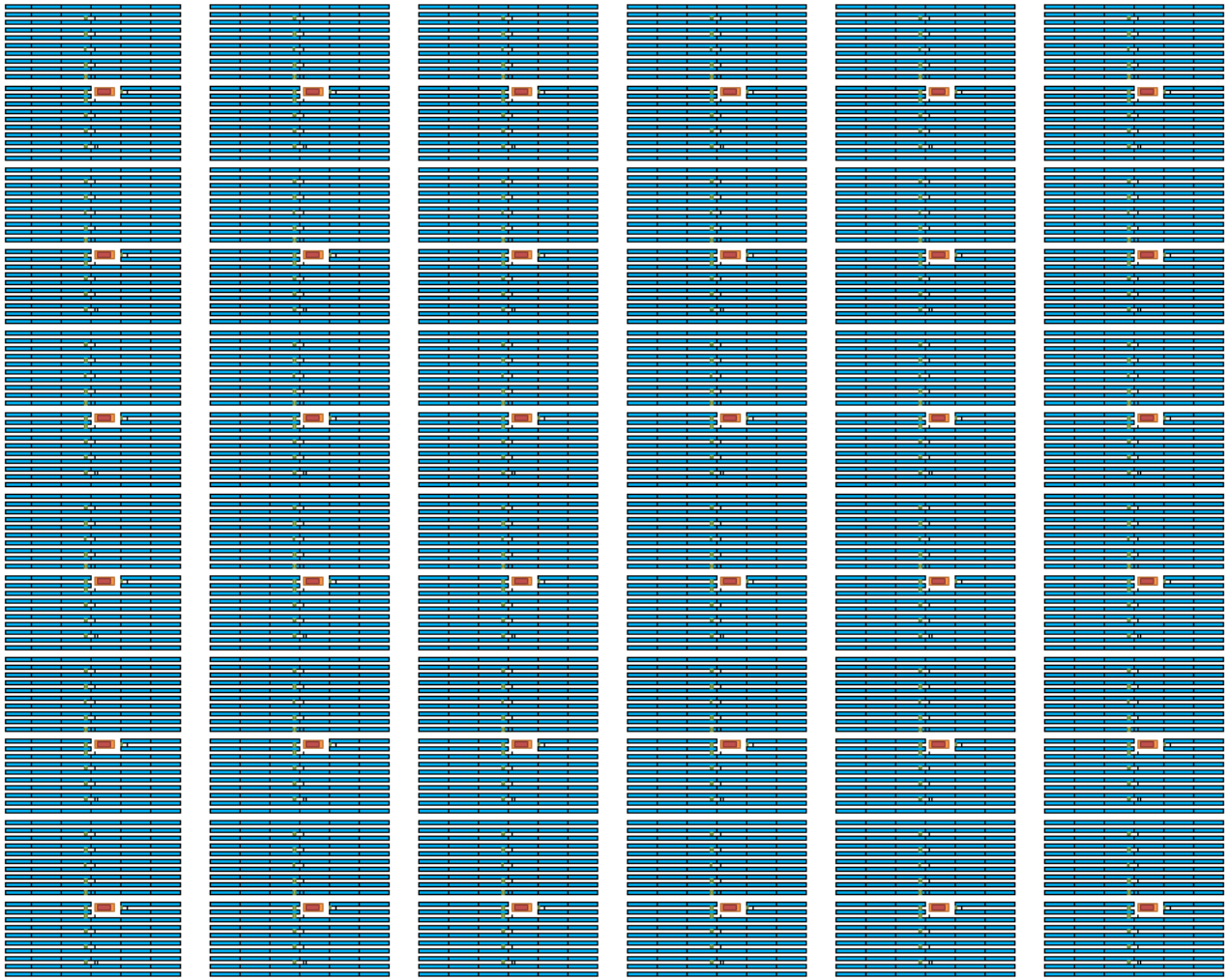
SOLAR POWER PLANT SYSTEM BLOCK DIAGRAM



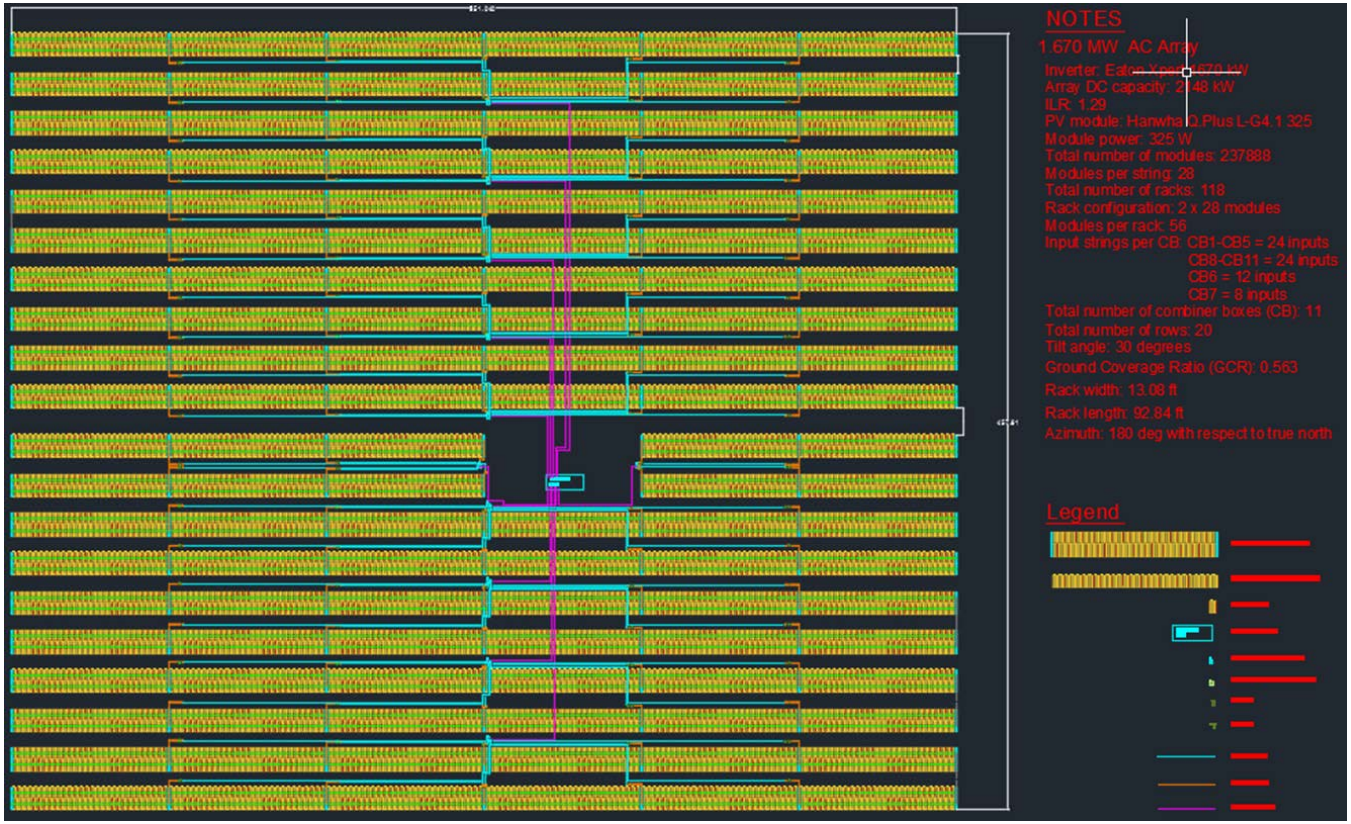
SOLAR POWER PLANT DESIGN – ARRAY

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

SOLAR POWER PLANT: FULL SIZE



DETAILED CAD DRAWING OF ONE ARRAY

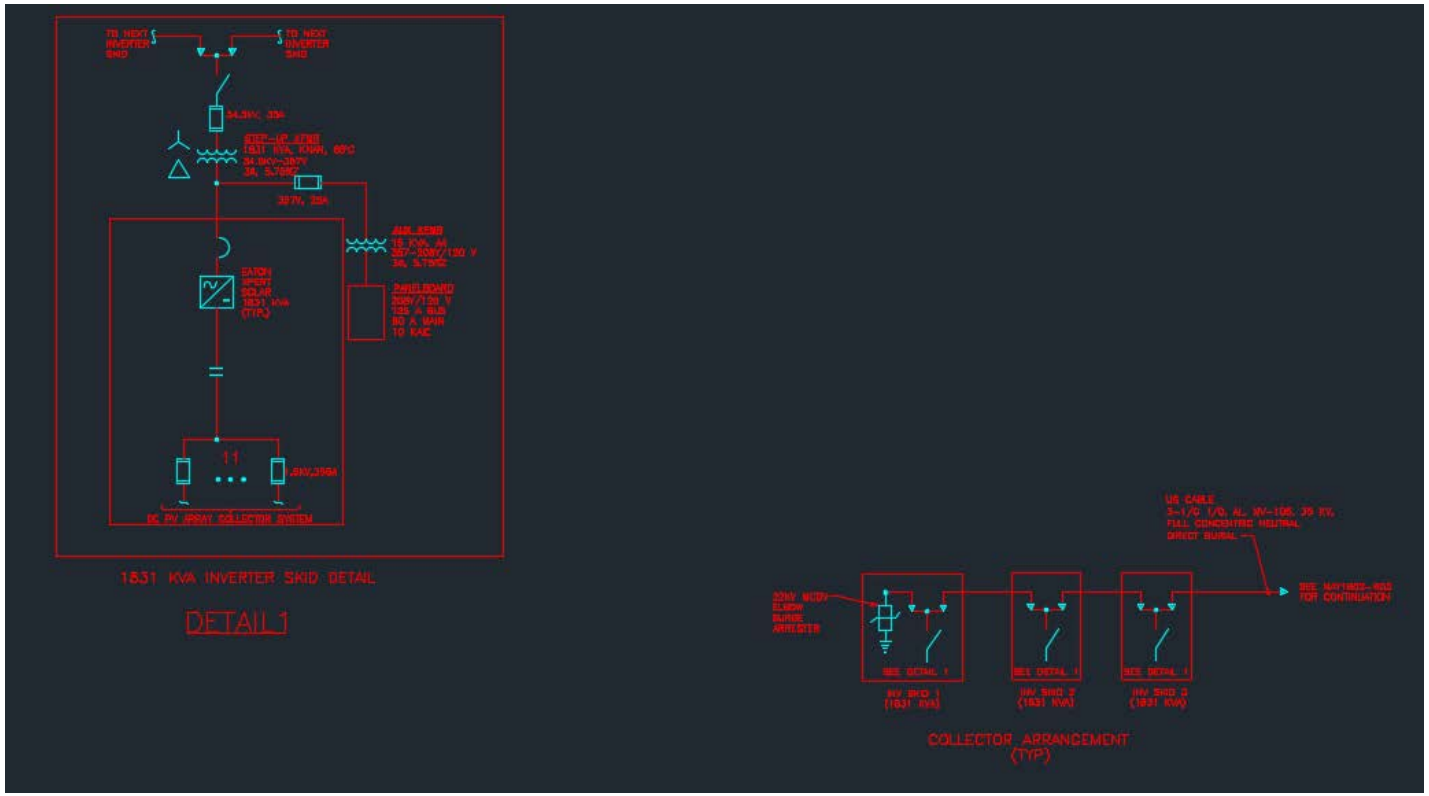


SOLAR ARRAY CONDUCTOR SIZING

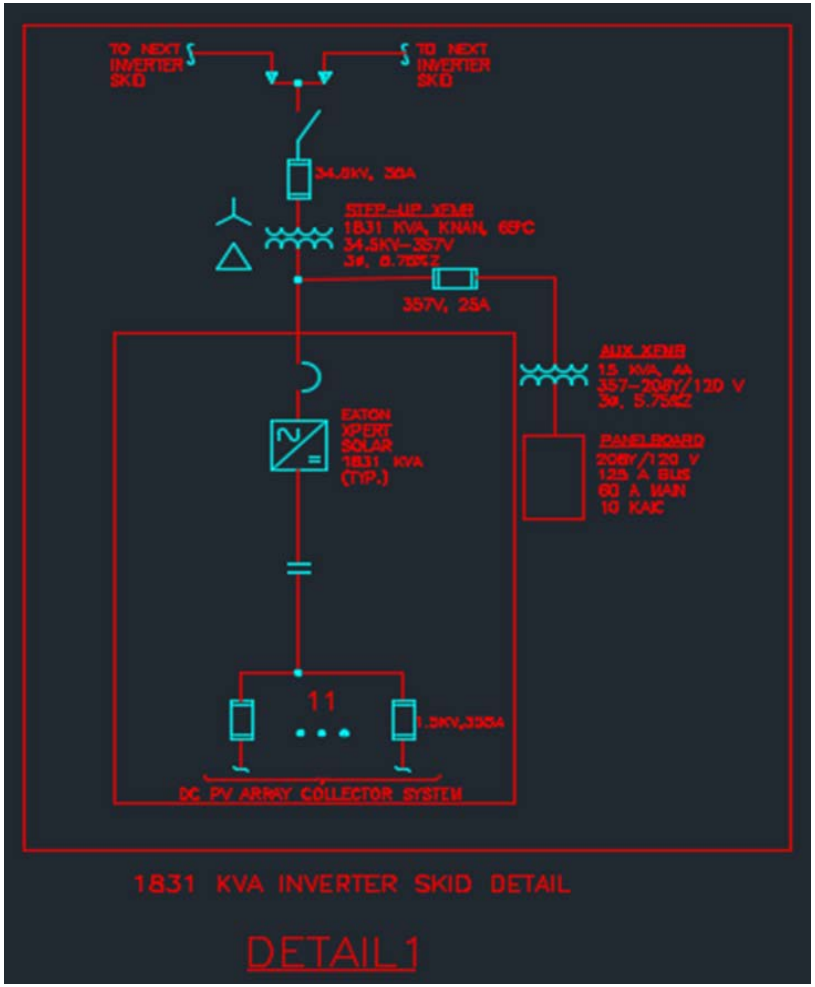
- Irradiance correction factor of 1.25 applied, according to NEC 690.8 A
- Referenced NEC 690.8 continuous current of 1.25
- Used NEC 310 guidelines to size conductors for solar power plant
- 1500 VDC conductors must buried at least 30 inches, according to NEC 310 Table 300.5
- 34.5 kV conductors must be buried at least 36 inches, according to NEC 310 Table 300.5

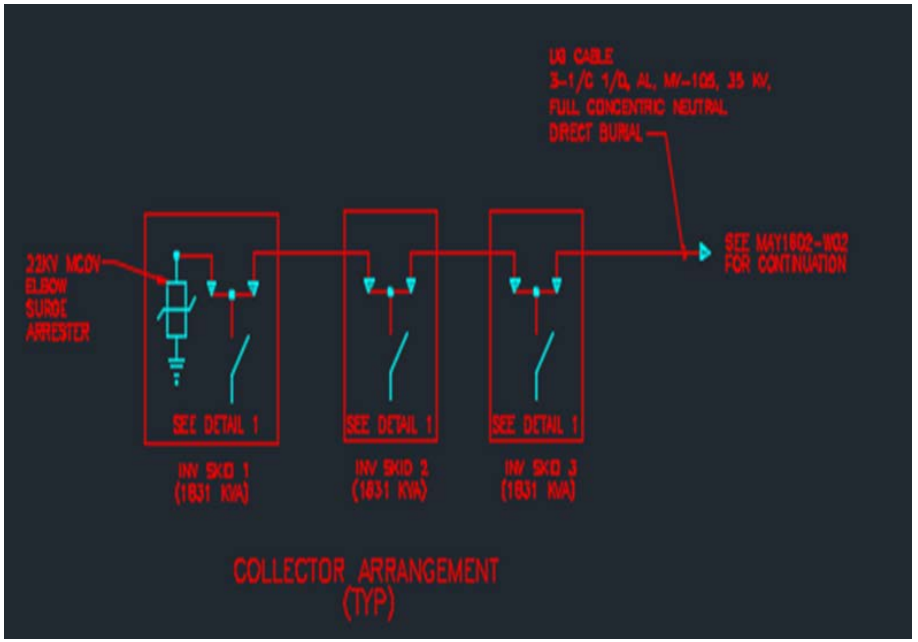
Conductors	Max Isc (A)	Type	Material	Temp (degC)	AWG	Cable Rating (A)	Minimum Depth	Fuse
String Conductor	14.75	Free Air	Copper	75	12	35	NA	15
Rack to CB - Jumper	29.5	Free Air	Copper	75	10	50	NA	30
CB to Inverter - DC feeder	354	Buried	Aluminum	75	700	375	30 inch	355
Xformer to Collector	116	Buried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

SUBSTATION — COLLECTOR

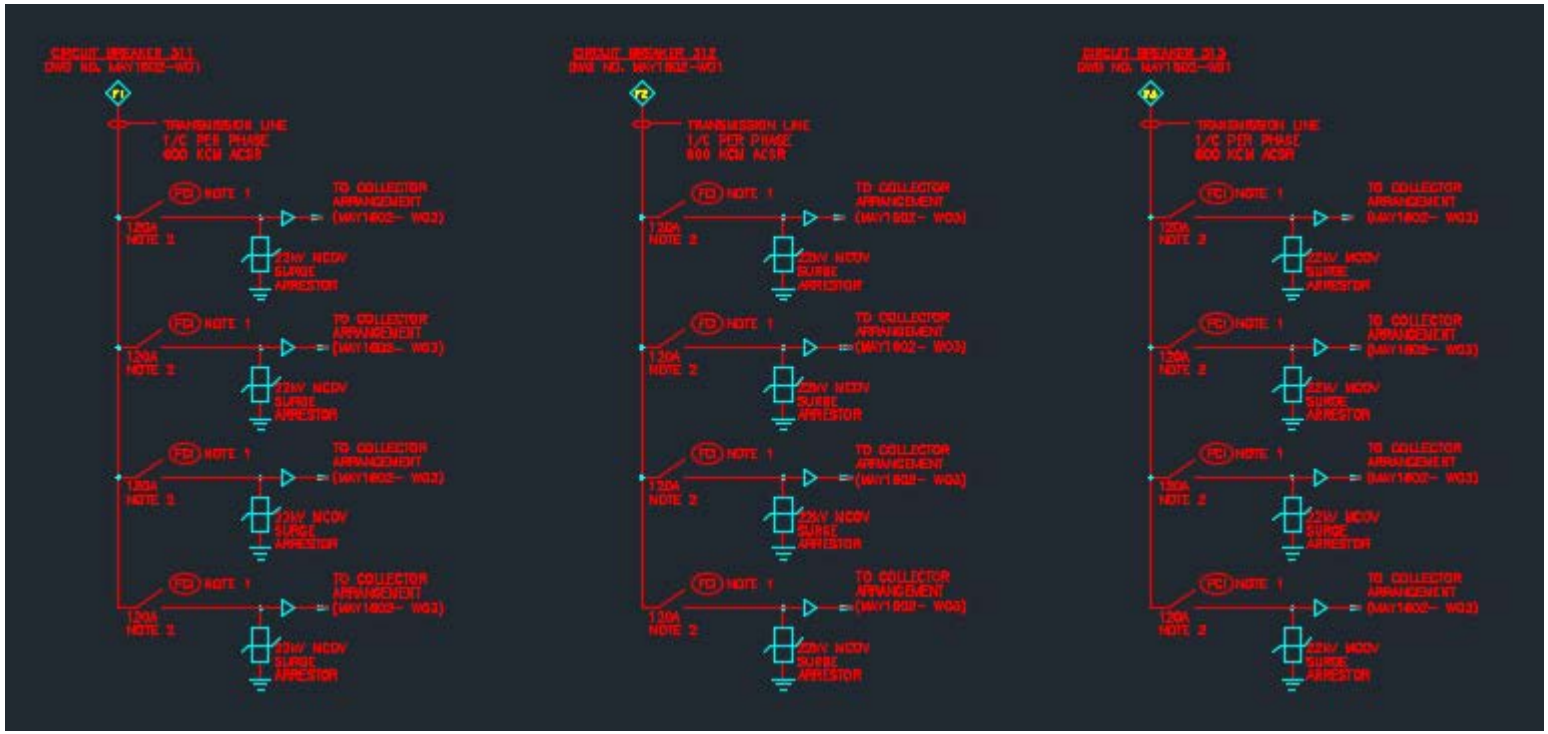


SUBSTATION — COLLECTOR

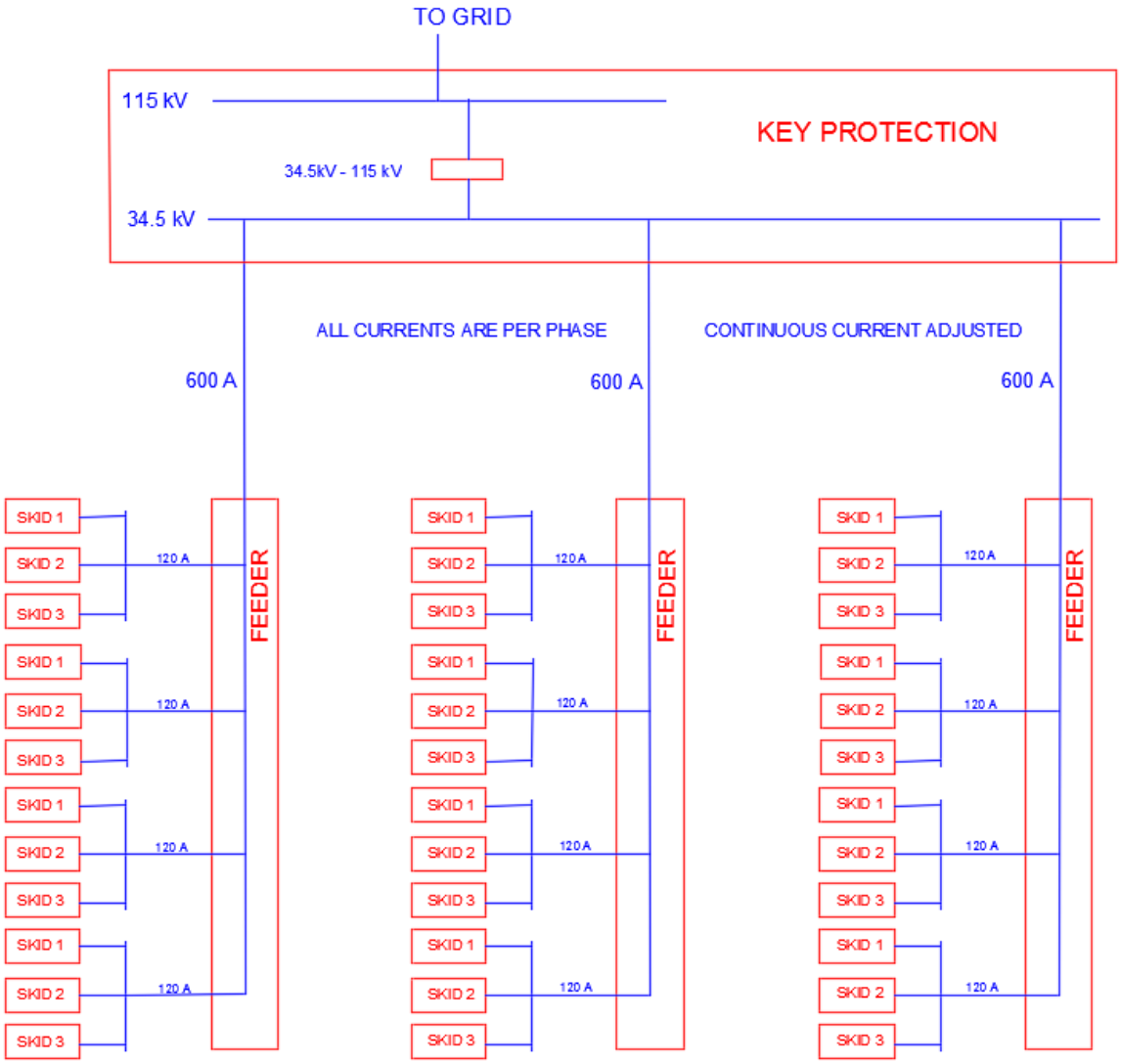




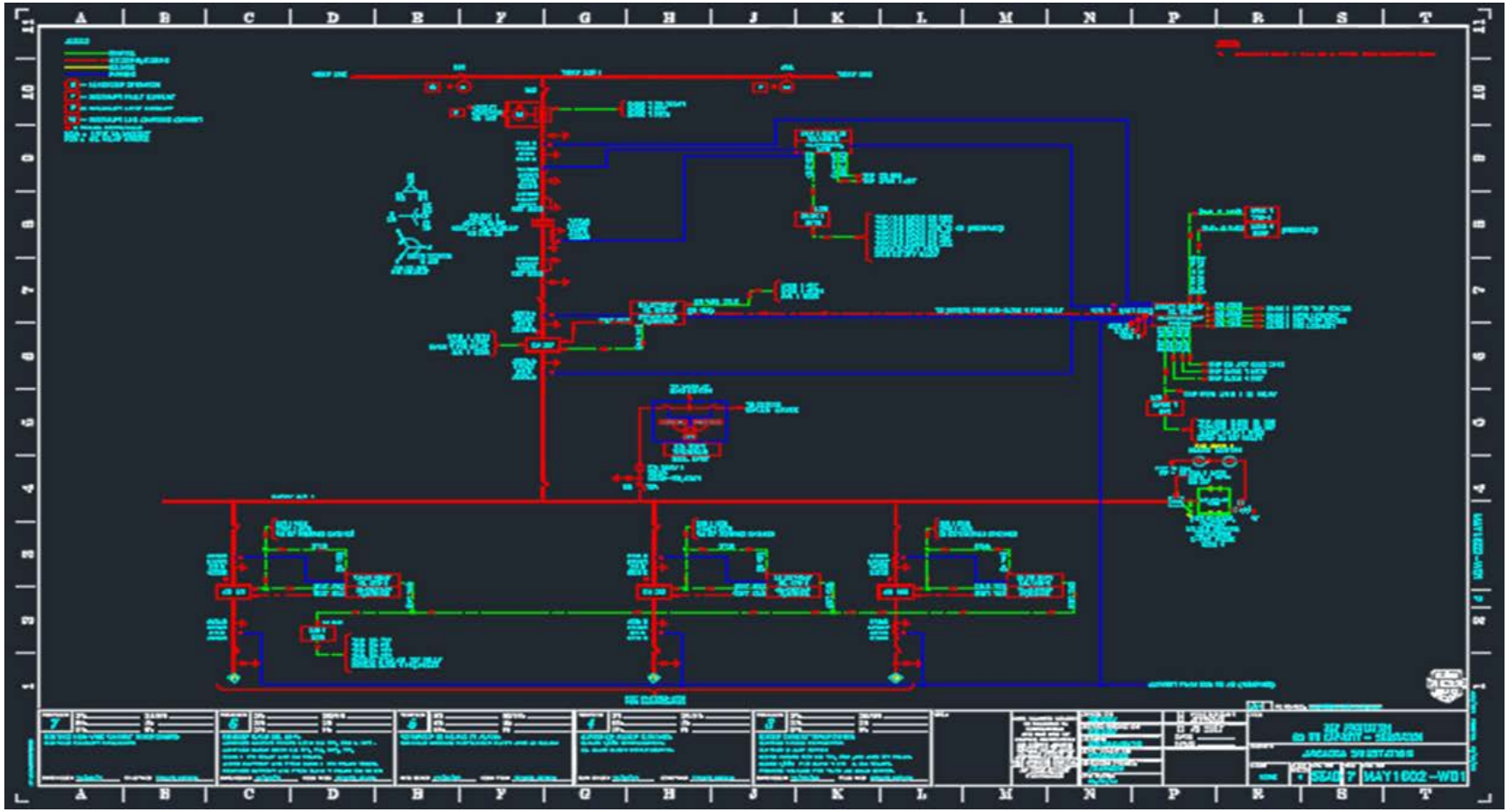
SUBSTATION – FEEDER



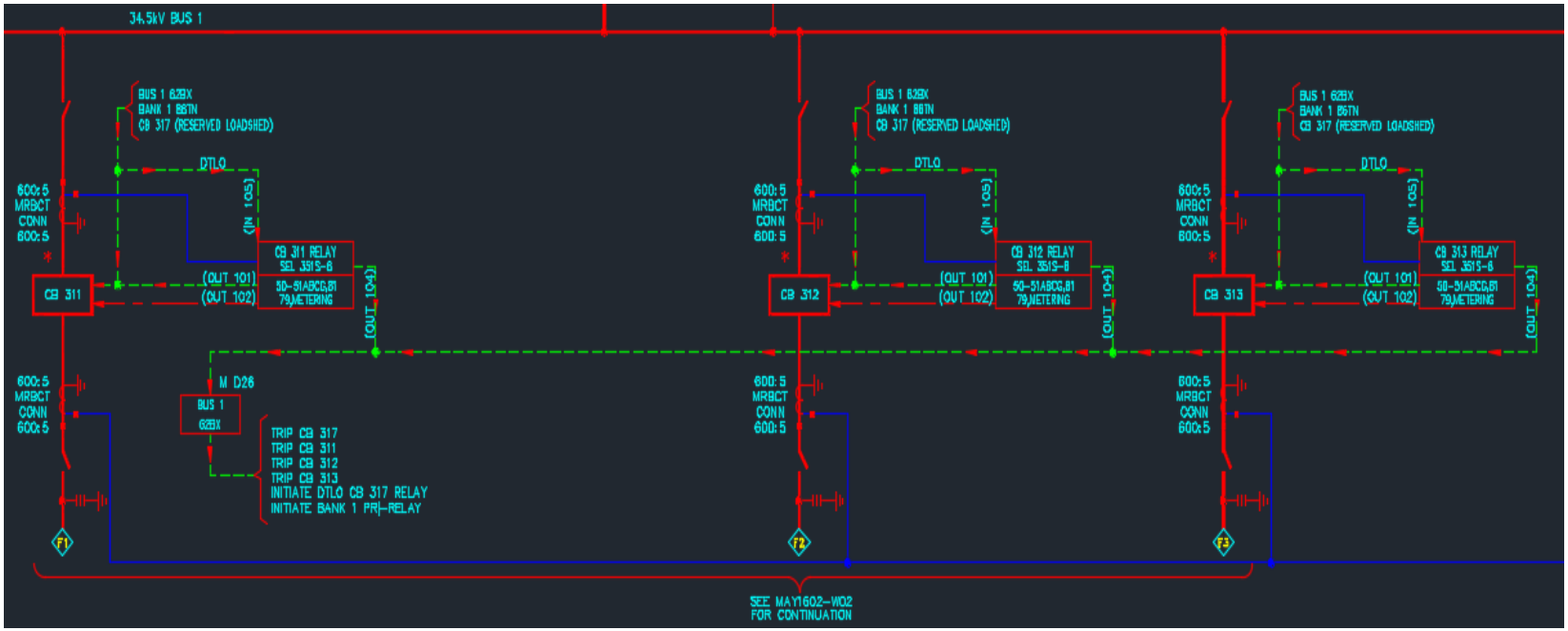
SUBSTATION SYSTEM BLOCK DIAGRAM



SUBSTATION – KEY PROTECTION



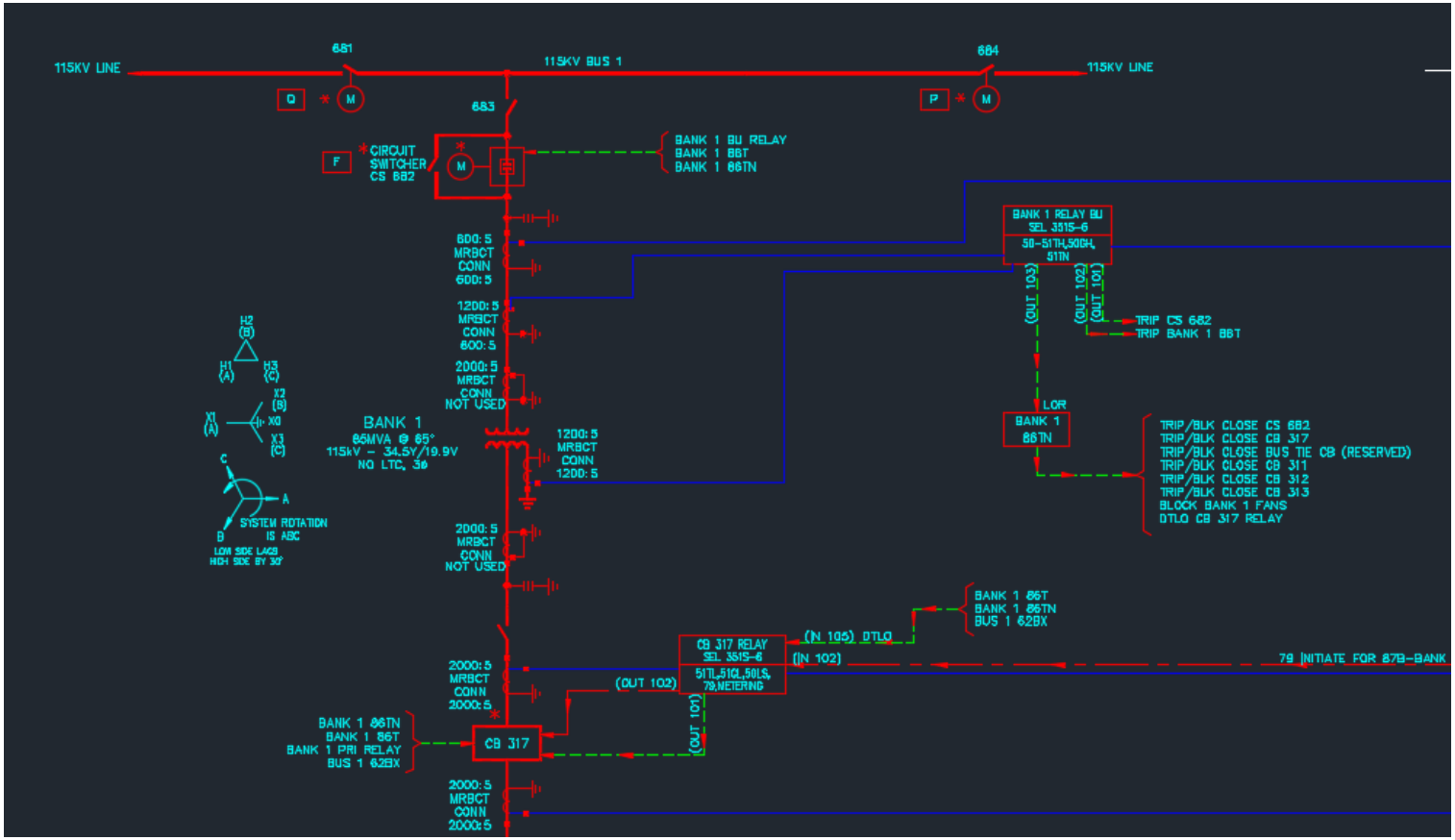
SUBSTATION – FEEDERS
(SOLAR ARRAY CONNECTIONS)



SUBSTATION – PROTECTION RELAY/ CAPACITOR BANK

- Cap Bank is connected to the 34.5kV Bus bar
- SEL 487E Relay is connected to the CT's below each of the circuit breakers

SUBSTATION – PROTECTION RELAY/BANK 1



MAN HOUR BUDGET

115 kV / 34.5 kV Solar Power Plant / Substation

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Start Week Aug 31, 2015 — Break | Projected | Overrun | Billable Hours

FALL 2015

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
																	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	10.0	1.0	321.0
% of Budget	80	100	85	165	125	83	220	123	80	107	120	105	0	148	1	1	120.2

Start Week Jan 11, 2016 — Break | Projected | Overrun | Billable Hours

SPRING 2015 — PROJECTED SCHEDULE

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
																	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																	
% of Budget	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00

QUESTIONS?