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

Senior Design Team 18 - May 2024

Siti Mohd Radzi, Baylor Clark, Eduardo Jimenez-Tzompaxtle, Chicheng Tang, Eli Schaffer, Liam Gossman

Agenda

- Safety Moment
- Calculation Documents
- AutoCAD Update
- ETAP
- Feedback

Safety Moment - Hazardous materials & chemicals

Types of Chemicals

- **Toxic:** cause death or sickness
- **Corrosive:** burns or irritation on the skin and eyes
- **Flammable:** easy to catch on fire
- **Reactive:** explosion in specific scenarios
- **Radioactive:** Cancer causing sometimes or burns to skin

Risks Working with Chemicals

- **Contact:** with eyes or skin
- **Ingestion:** with beverages or food
- **Breathing:** inhaling toxic gases
- **Injection:** accidental gash with contaminated item

Be aware of surrounding chemicals and the safety guidelines. If needed, use protective equipment. Have access to emergency showers and eyewash kits.

Calculations

AC Load Calculation :

Total worst case load:
41.652 kW or
45.817 (10% worst case scenario added)

Assumptions

1. 180VA load per Outlet assumed as worst case
2. The worst case scenario will be as follows:
    a) Time of day: Day (no lights on).
    b) Temperature: 90 deg F (all Transformer fans on).
    c) Battery: Deep discharge (charger on full).
3. Worst case tripping conditions shall be as follows:
    a) 115/34.5 kV Transformer fault
        - (1) 115 kV Breaker will trip
        - (4) 34.5 kV Breakerwill trip

' - Ratings estimated.

Calculations

The continuous 120/240VAC single phase loads are as follows:

AC Panel - Control Building

	Quantity	Load/Unit(W)	Amps (ea)	Voltage(V)	Total(W)	Amps Total
Breaker Recepticle and Lights	5	210	1.75	120	1,050	8.75
Transformer Fans	1	24,000	100.00	240	24,000	100.00
Transformer Sump Pump	1	2,000	8.33	240	2,000	8.33
Control House Lighting	20	36	0.30	120	720	6.00
Yard Lights (Assuming lights are off)	0	55	0.46	120	0	0.00
HVAC System	1	10,000	41.67	240	10,000	41.67
Fire Detection Equipment	1	150	1.25	120	150	1.25
Exhaust Fan	1	132	1.10	120	132	1.10
AC Battery Charger	1		#DIV/0!		0	#DIV/0!
Power Outlet		180	1.50	120	0	0.00
			#DIV/0!		0	#DIV/0!
			#DIV/0!		0	#DIV/0!
			#DIV/0!		0	#DIV/0!
Worst Case Tripping:						
High Side Breaker Trip	1	720	3.00	240	720	3.00
Low Side Breaker Trip	4	720	3.00	240	2,880	12.00
Total Worse Case AC Panel Load					41,652	#DIV/0!

Total Worst Case Load (+10 %)	**45,817**	**#DIV/0!**

Sizing Recommendations:
Station Service - XXkVA
MTS, Safety Switch - XXA

recommend XXXA Station Service Equipment
1. Breaker tripping load is temporary
2. 10% worst case scenario is added to the final value

https://docs.google.com/spreadsheets/d/1hwF8cv3VBiy1_Yih5wwwBzs9P8UB_BBc/edit?usp=sharing&ouid=101132689819119398819&rtpof=true&s

Calculations

DC Load & Battery Sizing :

1. Fill out the DC Load Profile below. Read the assumptions and notes below the table.
2. Determine and record the current load amounts for 3 periods:
   a. Period 1: T=0min   Fault occurs, relays detect. Breakers Trip due to relay operation.
   b. Period 2: T=1min   Breakers are open, everything else is simply running.
   c. Period 3: T=240min   Fault is cleared, relays operate to close Breakers
3. Create an account for the Enersys Battery Sizing Program https://bsp.enersys.com/bsp/index.do and enter your parameters to obtain a full battery system and PDF of the sizing report. This should give you a breakdown of the Amp-hours for the time periods determined.

Some notes on the table above and how to use it:

- Continuous load will be the above parameters NOT INCLUDING the trip coils from the breakers.
  - Keep in mind, there will be more than one of each type of relay, use your zones of protection to keep in mind how many of each there are.
    - 34.5kV Feeder position (array) –Primary SEL-411L, Backup SEL-451
    - Transformer Position – Primary SEL-487E, Backup SEL-451
    - 115kV Line Position – Primary SEL-411L, Backup SEL-311L
- There will be 3 periods of operation:
  - Period 1: T=0min   Fault occurs, relays detect. Breakers Trip due to relay operation.
  - Period 2: T=1min   Breakers are open, everything else is simply running.
  - Period 3: T=240min   Fault is cleared, relays operate to activate the Breaker close-coils, bringing the Breakers back into the closed position for normal operation.
- Last item listed are LED Lamps. These will be placed around the substation yard to illuminate important equipment and cabinets. Assume we have 8 of these.
- Assume a 60 Cell system
- Use device cut-sheets to find SEL parameters (you will need to create an account, should be quick to create!) for the relay current-draw.

DC Load Profile

	Components	Load Current (A)	Nominal Voltage (V) DC	Inception and Active Shutout Time (Min.)	Power Requirement (remember to account for # of relays required)	Number of Components
	34.5kV Breaker:	Tripping Current: 3.3A Closing Current: 2.6A	70 – 140 90 - 140	0 -1	231 - 343W 234 - 364W	4
	115kV Breaker:	Tripping Current: 3.3A Closing Current: 2.6A	70 – 140 90 - 140	239- 240	462 - 924W 324 – 504W	1
	SEL-411L (Line)	0.28 A	125	1 - 240	35 W / 90 VA	1
	SEL-311L (Line)	0.2 A	125	1 - 240	25 W	1
	SEL-487E (XFMR)	0.28 A	125	1 - 240	35 W / 90 VA	1
	GE Multilin T35 (XFMR)		125	1 - 240	Unknown	1
	SEL-751 (Bus/Feeder)	0.2 A	125	1 - 240	25 W / 55 VA	2
	ABB REU615 (Bus/Feeder)	0.144 A	125	1 - 240	18 W	2
	SEL-451 (Breaker)	0.28 A	125	1 - 240	35 W / 90 VA	4
	Battery Monitoring Equipment	0.024A	50 -180	1 - 240	3VA	1
	DC Ammeter	0.048A	125	1 - 240	6VA	1
	DC Voltmeter	0.048A	120	1 - 240	6VA	1
	SACO Annunciator (L8)	0.12 A	125	1 - 240	15 W	Unknown
	Edwards Bell	0.012A	125	1 - 240	1.5VA	1
	Power Line Indicating Lamps (LEDs)	0.017A	125	1 - 240	2.125 W	8

60 cell system	Continuous Load	Discontinuous Load Current

	T = 0	T = 1 min	T = 240 min

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Grounding Calculations

Requirements:

1. Find the uniform soil resistivity (ρ_a) in ohm-m using the given soil resistivity measurements.
2. Find the minimum conductor size (in kcmil) for a copper, soft-drawn grounding conductor. (Although the minimum value may be significantly smaller, 4/0 AWG is typically the smallest size conductor used in a substation grounding grid)
3. Find the tolerable Step (E_{STEP}) and Touch (E_{TOUCH}) voltages with a surface layer derating factor $C_s = 0.8$. (Note that equations are 31-33 are labeled incorrectly as step equations. They are touch equations)
4. Design a square grid for the given substation area and find the maximum step (E_s) and maximum mesh/touch (E_m) voltages. Refine the ground grid design as needed so that the maximum step/touch voltages are less than the tolerable step/touch voltages that were found in problem 3. If needed, use ground rods with a length of 20'.
5. Provide a drawing of the ground grid in the proposed substation area showing grid spacing distances. Industry standard typically has the ground grid extend 3 feet outside the fence line.
6. Provide a short report that includes references, any assumptions made, and final results (please include equations and calculations, even if hand-written).

Given parameters for grounding

Parameters	Value	Unit	Symbols
Maximum grid current	32	kA	Ig
Fault duration for conductor sizing	1	s	tc
Shock duration	0.5	s	ts
Surface layer thickness	0.15	m	hs
Surface layer resistivity	3000	ohm-m	ps
Body weight	50	kg	w
Ambient temperature	40	C	Ta
Grounding conductor depth	0.15	m	h
Grid reference depth	1	m	h0
Dimension of fence (x)	160,48.768	ft, m	
Dimension of fence (y)	100, 30.48	ft,m	
Grid dimension	16 x 10		

Parameters to calculate/find

Parameters	Value	Unit	Symbols	Value	Unit
Number of parallel conductors	12.47723374		n		
Spacing between n parallel conductors	10	ft	D	3.048	m
grid conductor diameter	0.0383333	ft	d	0.01168398984	m
Total length of conductor in the horizontal grid	3200	m	Lc	975.36	m
Perimeter length of grid	520	m	Lp	158.496	m
Area of the grid	16000	m^2	A	4876.8	m
Max length in the x direction	160	ft	Lx	48.768	m
Max length in the y direction	100	ft	Ly	30.48	m
Max distance between any two points on the grid	188.6796226	m	Dm	57.50954898	m
Total length of rod	12800	m	LR	3901.44	m
Length of each rod	20	m	Lr	6.096	m
Number conductors	12.30769231		na	3.751384615	m
Number conductors	1.013775241		nb	0.3089986935	m
Number conductors	1		nc	0.3048	m
Number conductors	1		nd	0.3048	m
Number of grounding rods	640		r	195.072	m

Outer dimension of substation fence

160' by 100' (ft) or
48.768 by 30.48 (m)

Grid Dimension

16X10
With spacings between conductor = 10ft or 3.048 m

Tolerable Touch & Step Voltage based on the parameters

Etouch = 377.312V
Estep = 1263.1755

Maximum Touch & Step Voltage, based on the substation dimension and parameters

Etouch (max) = 277.759V
Estep(max) = 1075.6457

1	Calculation for the uniform soil resistivity (pa) in ohm-m				
	Probe Spacing (ft)	Apparent Resistivity (ohm-m)			
	1	120			
	2	85	pa	56.28571429	ohm-m
	3	65			
	6	48			
	10	32			
	20	24			
	30	20			
	7	394			

2 Calculation for Minimum Conductor Sizing

Description	Material conductivity (%)	α_r factor at 20 °C (1/°C)	K_o at 0 °C (0 °C)	Fusing[a] temperature T_m (°C)	ρ_r 20 °C (µΩ·cm)	TCAP thermal capacity [J/(cm^3·°C)]
Copper, annealed soft-drawn	100.0	0.003 93	234	1083	1.72	3.42

ar	K0	Tm	pr	TCAP
0.00393	234	1083	1.72	3.42

3 Calculation for Tolerable Step Voltage

$$E_{step50} = (1000 + 6C_s \cdot \rho_s)\frac{0.116}{\sqrt{t_s}}$$

E(step50)	1263.175554	V

4 Calculation for Tolerable Touch Voltage

$$E_{touch50} = (1000 + 1.5C_s \times \rho_s)\frac{0.116}{\sqrt{t_s}}$$

E(touch50)	377.3121784	V

5 Calculation for Maximum Step Voltage

$$E_s = \frac{\rho \cdot K_s \cdot K_i \cdot I_G}{L_S}$$

Es	1075.645723	V

6 Calculation for Maximum Touch Voltage

$$E_m = \frac{\rho \cdot K_m \cdot K_i \cdot I_G}{L_M}$$

Em	277.7595728	V

Conductor sizing	158.35	kcmil
	80.235945	mm
	3/0	size
	size	***4/0***

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Calculations

High voltage buses in substations - interconnect the various pieces of equipment to
form the desired bus configuration.

- provide controlled paths for current to flow between the connected equipment
- The basic task of the substation bus designer is
  - select the bus conductor, components, and arrangement to meet criteria and being cost effective.

Variable	Description	Value	Unit
ΔT	Temperature difference between ambient and conductor surface	50	°C
T2, Tc	Conductor Temperature	90	°C
ε	Emissivity	0.2	new al
		0.5	Weathered al
Ta	Ambient Temperature	40	°C
ε'	Solar absorption	0.5	
E	Modulus of elasticity for aluminum	68.9x109	N/m2
FG	Gravitational Force	33.7	N/m
σ (allowable)	Allowable stress of material accounting for welds	120	MPa
wc	Specific weight of aluminum	26500	N/m3
wi	Ice weight	8820	N/m3
ri	Equivalent uniform radial ice thickness	0.00635	m
C	Constant, for metric units	0.613	
V	Extreme wind velocity	40	m/s
		144	km/h
Cf	Force coefficient for rigid tubular bus	1	
Gf	Gust response factor	0.85	
I	Importance factor	1.15	
ISC	Short-circuit current	15	kA
Γ	Constant based on type of fault and conductor location	0.866	
Kf	Mounting structure flexibility factor	1	
Df	Half cycle decrement factor	0.927	
η	Allowable deflection as a fraction of span length	0.0067 (1/150)	
C'	Conductivity, % IACS. For 6101-T6 alloy per Table 2	55	

Bus calculation:

1. Ampacity
2. Bus Force
3. Maximum Allowable Span

Variable	Description	Value	Unit	Remarks
D	Diameter	0.0889	m	
t	Wall thickness	0.0054864	m	
Hc	Altitude of sun latitude	80	degree	from H.5
Zc	Azimuth of sun	180	degree	from H.5
Zl	Azimuth of conductor line	0	degree	from H.5
ε'	Solar absorption	0.5		from H.6
Qs	Solar heat gain	1032.6	W/m	
A'	Projected area of conductor by unit legth	0.0889	m	A'=D
K	Heat multiplying factor	1.027432		From C.4
	Elevation	274.32	m	Assumption
F	Skin effect coefficient	1		
D	Conductor outside diameter (flexible)	0.0286	m	
C'	Conductivity (flexible)	61		
Ac	Cross-sectional area	0.00	m	
A'	Projected area of conductor by unit legth (flexible)	0.0286		
Tc	Conductor Temperature (flexible)	75	°C	
Ta	Ambient temperature(flexible)	25	°C	

Parameters based on the IEEE 605, and conductor material/type/size

https://docs.google.com/spreadsheets/d/1B0NZYBSkD5nU1I6lLadosi6QVMOQBY21F-alNrFIGwY/edit?usp=sharing

Calculations

Bus calculation:

1. Ampacity

$$R = \frac{1.724\times10^{-6}}{C' A_c}\left(1 + \frac{0.00403C'}{61}(T_2 - 20)\right)$$

$$A_c = \frac{\pi}{4}\times\left[(D)^2 - (D - 2\times t)^2\right] =$$

$$q_c = 3.561\ D^{-0.4}\ A\ \Delta T$$

$$A = \pi D l =$$

$$q_r = 5.6697\times10^{-8}\,\varepsilon\,A\left[(T_c + 273)^4 - (T_a + 273)^4\right]$$

$$\theta = \cos^{-1}\left[\cos H_c \cos(Z_c - Z_1)\right]$$

$$q_s = \varepsilon'\,Q_s\,A'\,K\,\sin(\theta)$$

$$I = \sqrt{\frac{q_c + q_r - q_s}{RF}} =$$

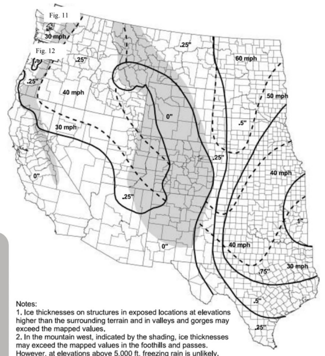
1	Rigid bus calculation		
Variable	Description	Value	Unit
R	DC resistance	0.000027	ohm/m
Ac	cross-sectional area	0.001438	m2
A	surface area by unit length	0.2792875869	m2/m
qc	Forced convection heat loss	130.9281126	W/m
qr	radiation loss from a surface	61.47963125	W/m
θ	effective angle of incidence of sun (theta)	1.692969374	rad
θ	effective angle of incidence of sun (angle)	97	degree
qs	heat gained from incident solar radiation	46.80666342	W/m
I	Allowable current (I)	2322.204256	A
2	Flexible bus (conductor) calculation		
Variable	Description	Value	Unit
R	DC resistance	0.000075	ohm/m
A	surface area by unit length	0.08984954989	m2/m
qc	Forced convection heat loss	66.29968585	W/m
qr	radiation loss from a surface	19.7677	W/m
qs	heat gained from incident solar radiation	15.05816168	W/m
I	Allowable current (I)	973.0311689	A
I	Rating of two conductor	1946.062338	A
		should be greater than the maximum load current	

https://docs.google.com/spreadsheets/d/1B0NZYBSkD5nU1I6lLadosi6QVMOQBY21F-alNrFIGwY/edit?usp=sharing

Calculations

Bus calculation:

1. Bus force



Notes:
1. Ice thicknesses on structures in exposed locations at elevations higher than the surrounding terrain and in valleys and gorges may exceed the mapped values.
2. In the mountain west, indicated by the shading, ice thicknesses may exceed the mapped values in the foothills and passes. However, at elevations above 5,000 ft, freezing rain is unlikely.
3. In the Appalachian Mountains, indicated by the shading, ice thicknesses may vary significantly over short distances.

Figure 8—Extreme radial glaze ice thickness (in) Western United States (except the Pacific Northwest), 50-year return period with concurrent 3 s wind speeds[14]

Bus calculation (IEEE 80) - Bus Force

Symbols	Variables	Value	Unit	Remarks	
wc	Conductor weight	26500		H.6.1	
Do	Conductor outside diameter	0.0889	m		
Di	Conductor inside diameter	0.0762	m		
tc	Conductor wall thickness	0.0054864	m		
w1	Ice weight	8820			
r1	Uniform radial thickness of ice	0.00635			
C	Constant	0..613			
V	Extreme wind speed without ice	44.7		racking	
Cf	Force coefficient	1			
Kz	Height and exposure factor	1.09		substation height = 50 ft	
Gf	Gust repsonse factor	0.85			
I	Importance factor of structure	1.15			
I`	Constant based on fault and location	0.866			
Isc	Symmetrical RMS fault current	688.0369379		I/2*sqrt(2)	
D	Conductor spacing center-to-center	2.44			
Df	Hald-cycle decrement factor				
Kf	Mounting structure flexibility factor	1		30ft bus	
Kf	Mounting structure flexibility factor	0.95		40ft bus	figure 20 IEEE

Symbols	Equations	Value	
Fc	Conductor unit length	38.00997229	
Fi	Ice unit weight	16.75938	
Fwi	WInd load with ice	132.5907578	H.21
Fw	Wind load without ice by unit length	116.0169421	H.20
Fsc	Short circuit force	0.2444432507	H.22
Qs	Snow load	11-20 psi	
Fsc-corr	Short circuit force corrected	0	

https://docs.google.com/spreadsheets/d/1B0NZYBSkD5nU1I6lLadosi6QVMOQBY21F-alNrFIGwY/edit?usp=sharing

Calculations

Bus calculation:
3. Maximum allowable span

Bus calculation (IEEE 80) - Maximum allowable span

Symbols	Variables	Value	Unit	Remarks
Fc	Conductor unit weight	38.00997229		
Fd	Damping material unit length			
Fi	Ice unit weight	16.75938		
dmax	Vertical deflection limit			
Do	Conductor outside diameter	0.0889		
Di	Conductor inside diameter	0.0762		
E	Young's modulus of conductor	70000000000	Aluminium	
n	Fraction of allowable span limit	0.00666666667		
Fv	Total vertical force	54.85910402		
Fh	Total horizontal force	132.8352011		
Fw	Wind force	116.0169421		
Fwi	WInd force with ice	132.5907578		

Symbols	Equations	Value		
Fg	Total gravitational force	54.85910402	H.23	
J	Bending moment of inertia	0.000001411076	H.23	
Lv	Allowable span	0		
Lv (using n)	Allowable span	9.732474516		

Equations for fiber stress

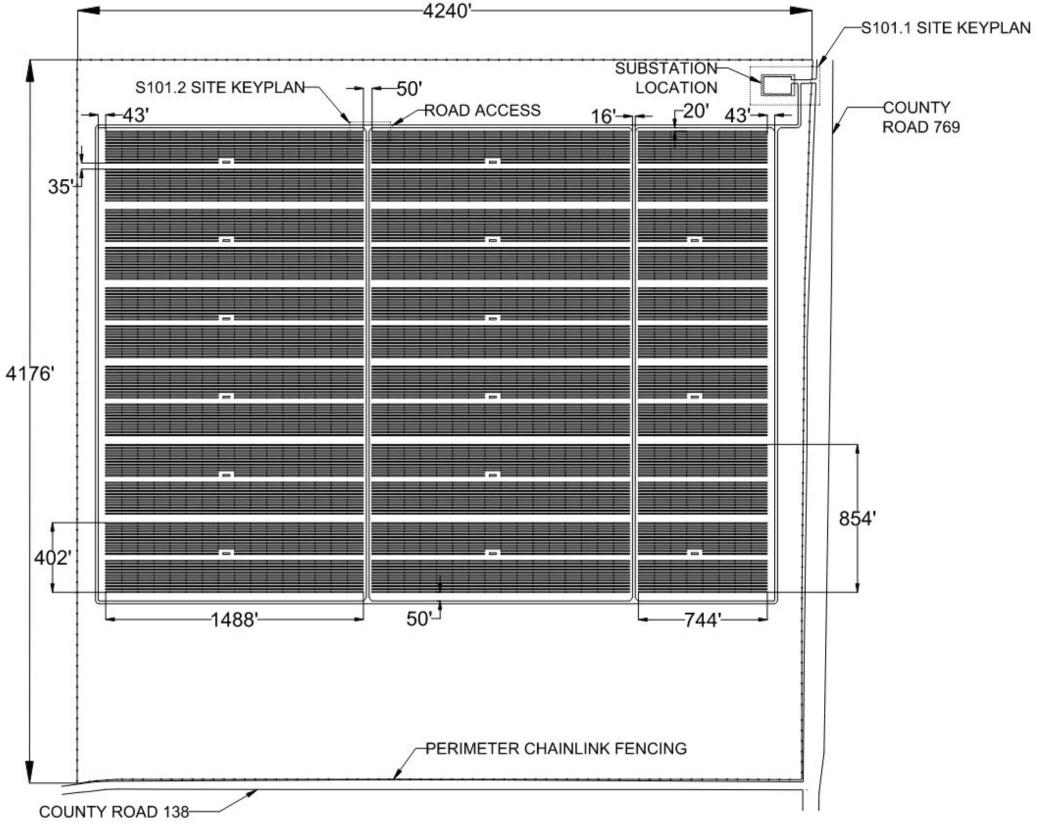
Symbols	Equations	Value		
Ft1	Total force on conductor	143.7174726		
Ft2	Total force on ice and short circuit	143.7174726		
Ls	Allowable length with two pinned ends	14.56195825	Fiber stress	H.7.2
Ls	Allowable length fixed-fixed ends	17.83468368		

https://docs.google.com/spreadsheets/d/1B0NZYBSkD5nU1I6lLadosi6QVMOQBY21F-alNrFIGwY/edit?usp=sharing

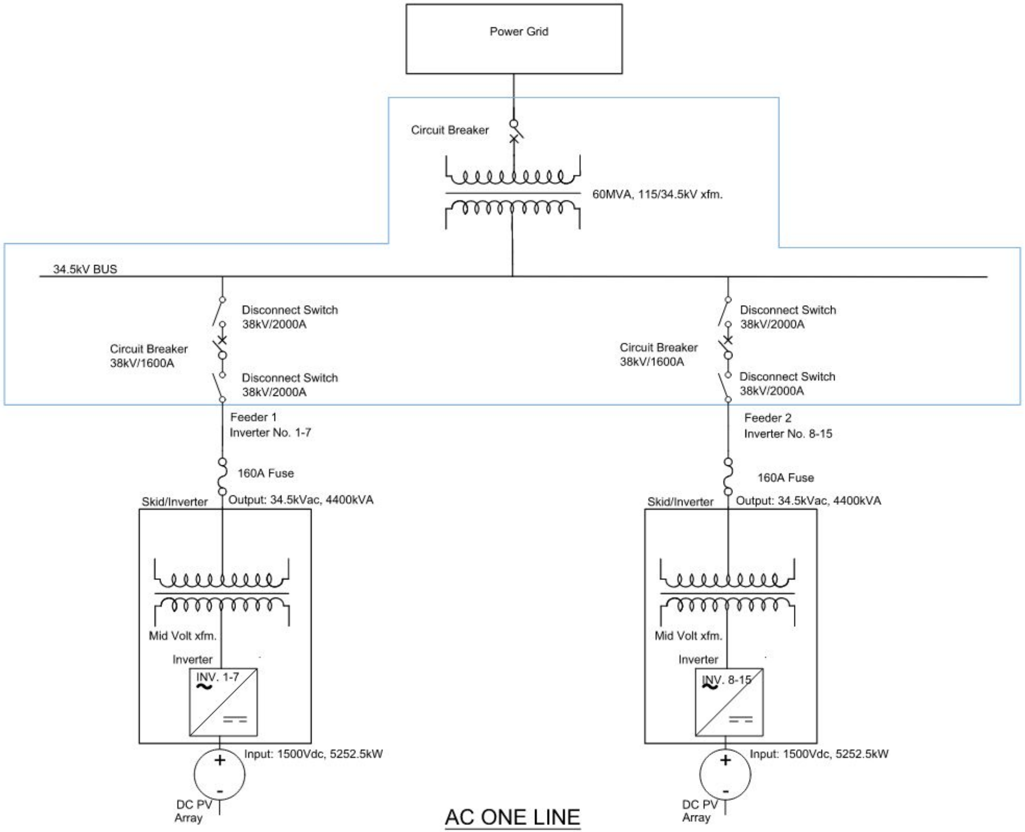
AutoCAD - Updates

SHEET LIST TABLE			
SHEET NUMBER	**SHEET TITLE**	**SHEET NUMBER**	**SHEET TITLE**
E100	PROJECT TITLE	SS100	SUB DESIGN SYMBOLS
S100	SITE PLAN	SS101	SUB ONE-LINE
S101	SITE KEYPLAN	SS102	SUB KEY PLAN
S102	SITE WIRING	SS103	SUB ONE-LINE DETAILS
PV100	SOLAR KEY PLAN	SS104	SUB GROUNDING INFO
PV101	OVERALL ARRAY LAYOUT	SS105	SUB THREE-LINE
PV102	ARRAYS 1 - 12 LAYOUT	SS106	SUB ONE-LINE PLAN VIEW
PV103	ARRAYS 13 - 15 LAYOUT	SS107	SUB SECTION VIEW
PV104	WIRING ARRAYS 1 - 12	SS108	SUB SITE ENLARGED
PV105	WIRING ARRAYS 13 - 15	SS109	FUTURE
PV106	SOLAR DESIGN DETAILS	SS110	CB1-X DATASHEET
PV107	AC ONE LINE	SS111	CB2-X DATASHEET
PV108	DC ONE LINE	SS112	DS1-X DATASHEET
PV109	STRING ONE LINE	SS113	DS2-X DATASHEET
PV110	PANEL DATASHEET	SS114	LA1-X DATASHEET
PV111	COMBINER BOX DATASHEET	SS115	T1 NAMEPLATE
PV112	SKID INVERTER DATASHEET		

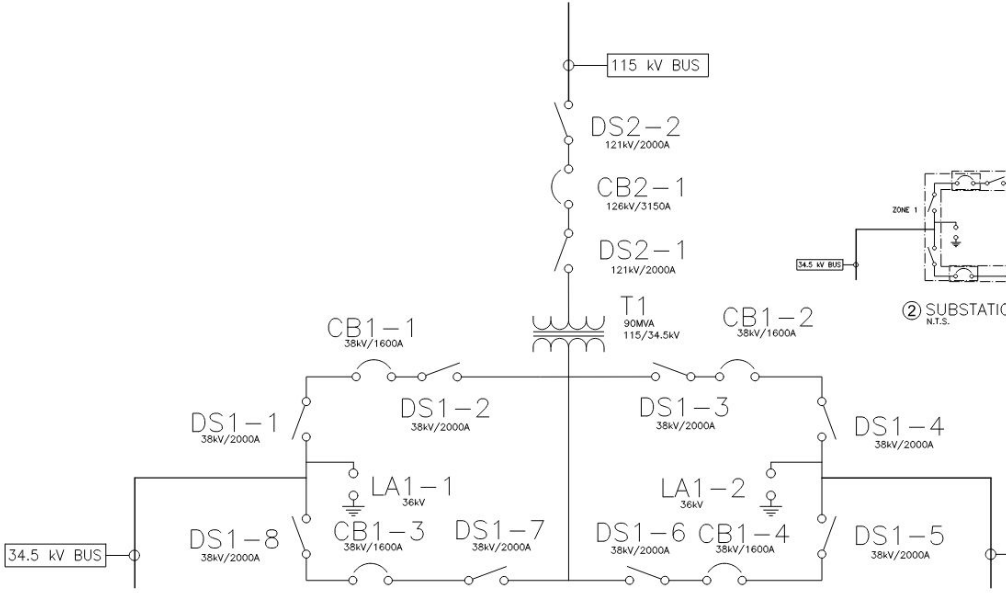
AutoCAD - Updates



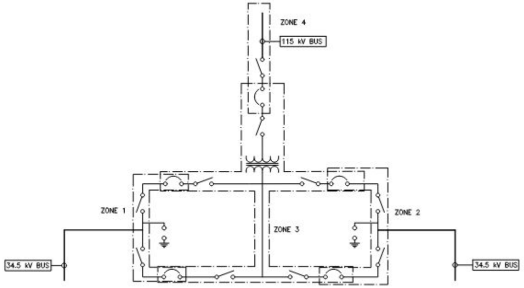
AutoCAD - Updates



AutoCAD - Updates

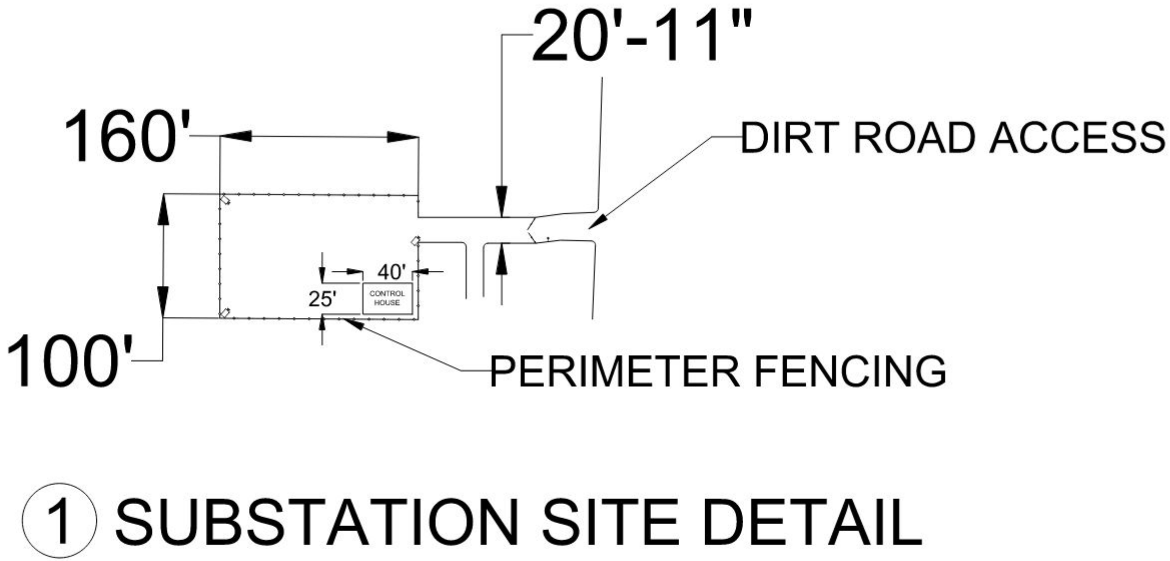


1 SUBSTATION ONE–LINE
N.T.S.

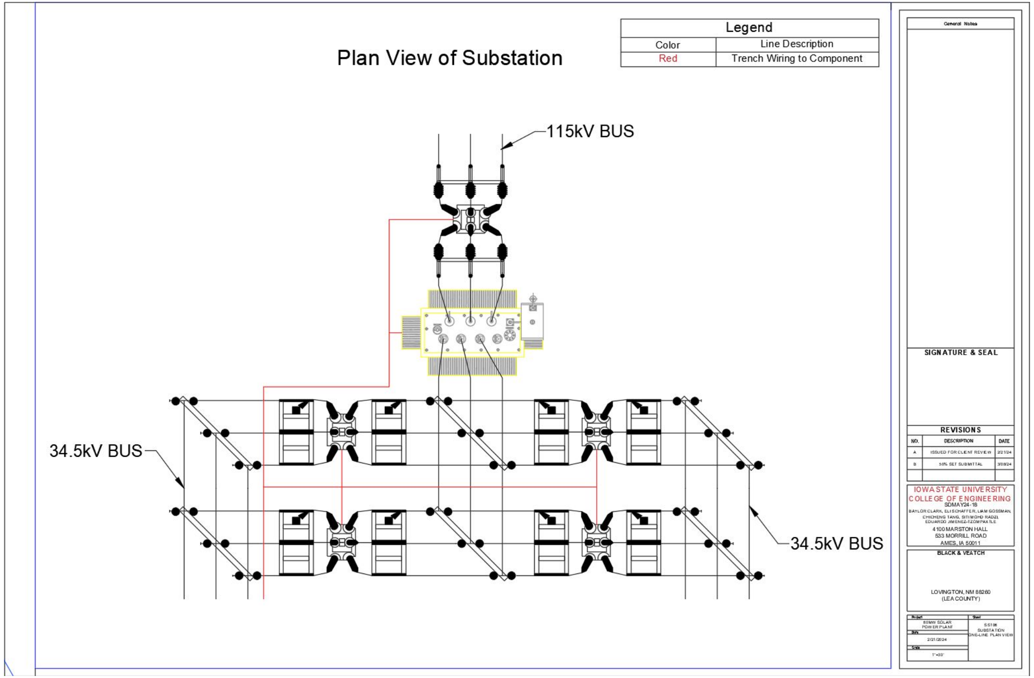


2 SUBSTATION PROTECTION ZONES
N.T.S.

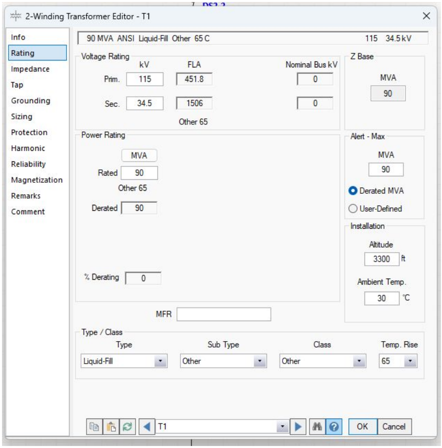
AutoCAD - Updates

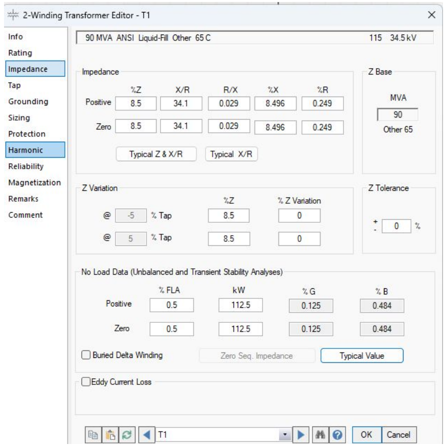


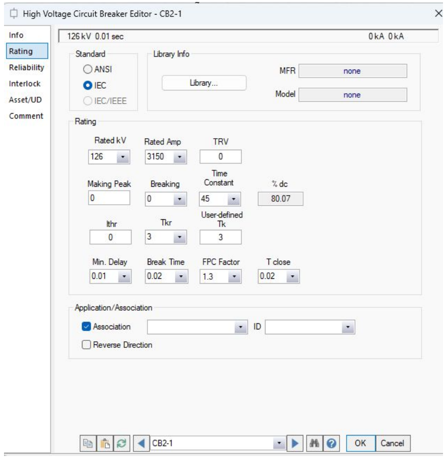
AutoCAD - Updates

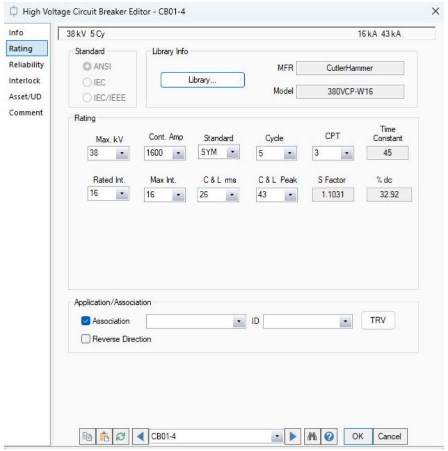


ETAP - Substation

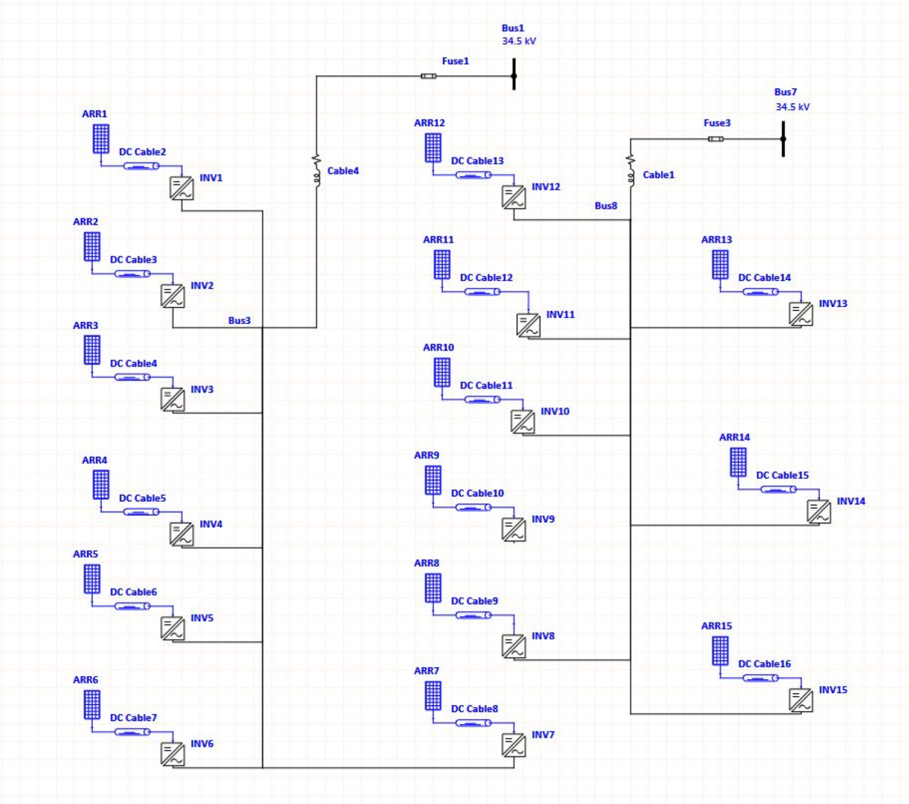




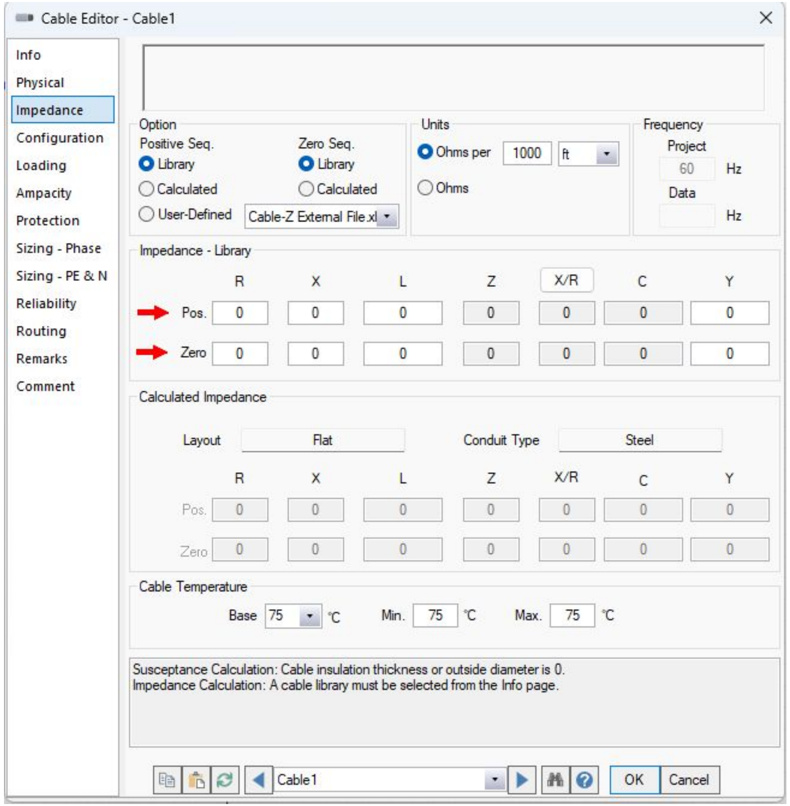


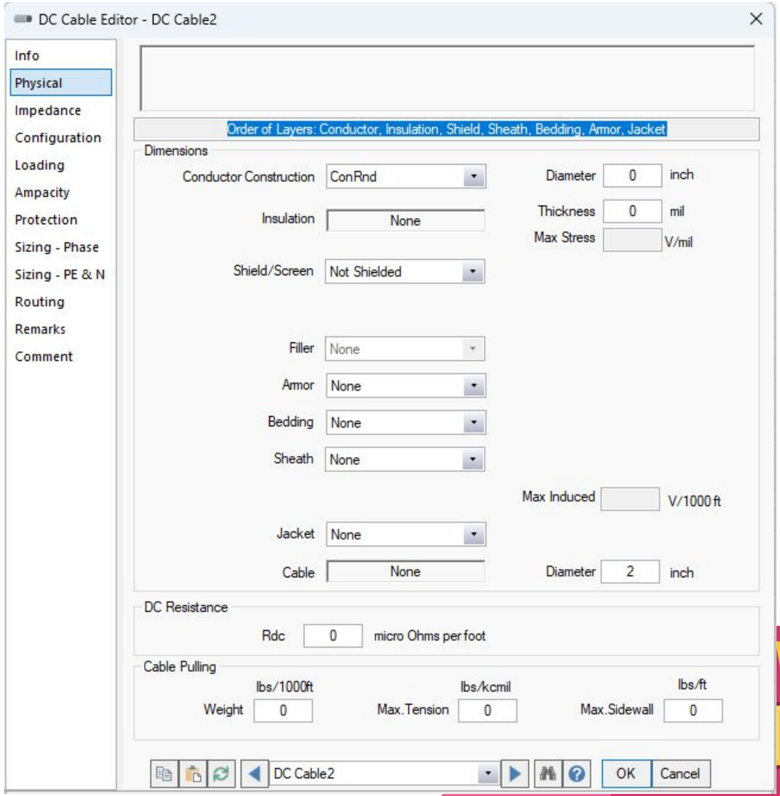


ETAP - PV Power Flow



ETAP - PV Power Flow





Questions

- Next steps
  -

Feedback and Updates

- Tasks: Updates
  - Bell:
  - Liam:
  - Eli:
  - Baylor:
  - Eduardo:
  - Chicheng: