Development of Solar Power Systems for ITS

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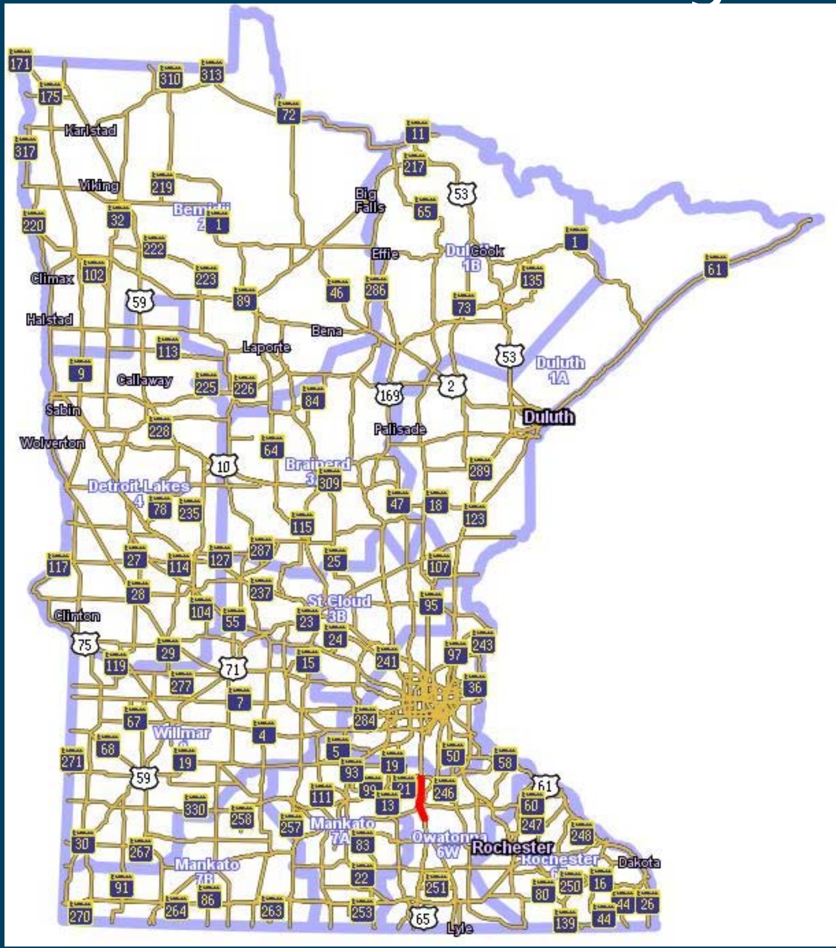
Your Destination...Our Priority

Presentation Outline

- Background
- Design Requirements
- Solar Design Process / Procedures
  - Battery Bank
  - Power Array
  - Environmental Factors
  - Other Considerations
- Challenges
- Cost Analysis
- Lessons Learned & Conclusions

Project Background

- Second phase installation of ITS devices along I-35 near Faribault MN
- Primarily rural area
- <u>7 of 19 locations with no viable SOP</u>



Use of renewable energy for ITS (in Minnesota)

- DMS system powered by solar was deployed
- Camera deployed using wind power
  - Later retrofitted to add solar panels to improve reliability – has history of maintenance problems

Design Requirements

- Minimize down time
- Minimize maintenance requirements
- Environmental factors
  - Solar Insolation
  - Temperature
- Use same devices as phase-I (prior project)
- Cost
  - Operational / Maintenance
  - Installation

Design Process

Determine Specific Design Requirements

↓

Battery Bank Design

↓

Solar Array Design

↓

Electrical System Design

↓

Shade and Site Design

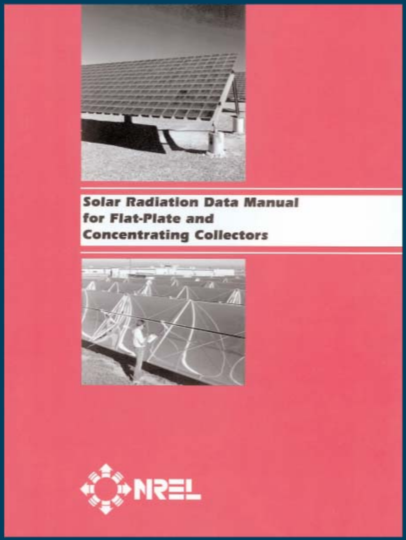
Power Demand

PTZ Camera
<u>Power Requirements</u>
Volts: 24 VDC
Watts: 51 W

Fiber Optic Switch
<u>Power Requirements</u>
Volts: 10.5-60 VDC
Watts: 24 W / 15 W

Total Power Demand (Average)
Volts: 24 VDC
Watts: 66 W
Amps: 2.75 A

Climate Data



- Temperature
- Insolation
- Sun Path

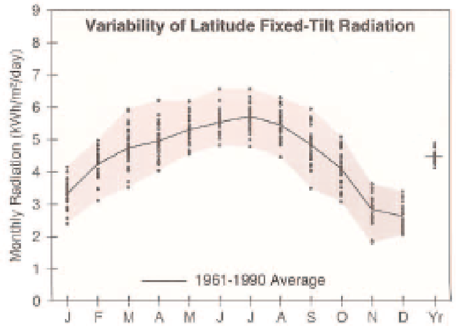
- *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors (Red Book)*
- State Climatologist
- University of Oregon Solar Radiation Monitoring Laboratory

Rochester, MN

WBAN NO. 14925

LATITUDE: 43.92° N
LONGITUDE: 92.50° W
ELEVATION: 402 meters
MEAN PRESSURE: 968 millibars

STATION TYPE: Secondary



Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt (kWh/m²/day), Uncertainty ±9%

Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	1.8	2.7	3.7	4.6	5.6	6.2	6.2	5.3	4.0	2.8	1.7	1.4	3.8
	Min/Max	1.5/2.1	2.3/3.0	3.0/4.3	3.9/5.5	4.8/6.5	5.4/7.3	5.3/7.0	4.5/6.0	3.3/4.7	2.3/3.3	1.4/2.0	1.2/1.7	3.7/4.1
Latitude -15	Average	2.9	3.9	4.6	5.1	5.7	6.0	6.2	5.7	4.8	3.8	2.6	2.3	4.5
	Min/Max	2.2/3.6	2.9/4.5	3.5/5.6	4.1/6.3	4.9/6.6	5.3/7.1	5.2/7.1	4.7/6.5	3.6/5.8	3.0/4.7	1.7/3.2	1.8/2.9	4.1/4.9
Latitude	Average	3.3	4.2	4.7	4.9	5.3	5.5	5.7	5.5	4.8	4.1	2.8	2.6	4.5
	Min/Max	2.4/4.2	3.1/5.0	3.5/5.9	4.0/6.2	4.6/6.2	4.8/6.6	4.8/6.6	4.4/6.3	3.5/5.9	3.1/5.1	1.8/3.6	2.0/3.4	4.1/4.9
Latitude +15	Average	3.6	4.4	4.7	4.6	4.7	4.8	5.0	4.9	4.6	4.1	2.9	2.8	4.3
	Min/Max	2.5/4.5	3.2/5.2	3.4/6.0	3.8/5.8	4.1/5.4	4.2/5.6	4.2/5.7	4.0/5.7	3.3/5.7	3.0/5.1	1.8/3.8	2.2/3.7	3.9/4.6
90	Average	3.5	4.1	3.9	3.2	2.8	2.7	2.9	3.2	3.4	3.4	2.7	2.7	3.2
	Min/Max	2.4/4.4	2.9/4.9	2.7/5.3	2.7/3.9	2.6/3.2	2.5/3.1	2.5/3.2	2.6/3.6	2.4/4.2	2.5/4.3	1.5/3.5	2.1/3.7	2.9/3.5

Solar Radiation for 1-Axis Tracking Flat-Plate Collectors with a North-South Axis (kWh/m²/day), Uncertainty ±9%

Axis Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	2.7	3.9	5.0	6.1	7.3	8.0	8.2	7.1	5.5	4.0	2.4	2.0	5.2
	Min/Max	1.9/3.3	2.8/4.5	3.6/6.3	4.7/7.7	5.8/8.9	6.8/9.9	6.7/9.6	5.7/8.3	3.9/6.9	2.9/4.9	1.5/3.0	1.6/2.5	4.8/5.8
Latitude -15	Average	3.5	4.8	5.7	6.5	7.5	8.0	8.3	7.5	6.1	4.7	3.0	2.7	5.7
	Min/Max	2.5/4.4	3.3/5.7	4.0/7.3	5.0/8.4	5.9/9.1	6.8/10.0	6.7/9.7	5.9/8.8	4.2/7.7	3.4/6.0	1.8/3.9	2.1/3.5	5.2/6.4
Latitude	Average	3.8	5.1	5.8	6.4	7.2	7.7	8.0	7.4	6.2	4.9	3.2	2.9	5.7
	Min/Max	2.7/4.9	3.5/6.1	4.1/7.6	4.9/8.3	5.7/8.9	6.5/9.6	6.5/9.4	5.7/8.7	4.2/7.8	3.5/6.3	1.9/4.3	2.3/3.9	5.2/6.4
Latitude +15	Average	4.0	5.2	5.8	6.1	6.8	7.2	7.5	7.0	6.0	5.0	3.3	3.1	5.6
	Min/Max	2.8/5.2	3.5/6.2	4.0/7.6	4.7/8.0	5.3/8.4	6.1/9.0	6.1/8.8	5.4/8.3	4.0/7.6	3.5/6.3	1.9/4.4	2.4/4.1	5.0/6.3

Solar Radiation for 2-Axis Tracking Flat-Plate Collectors (kWh/m²/day), Uncertainty ±9%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
2-Axis	Average	4.1	5.2	5.8	6.5	7.6	8.2	8.5	7.6	6.2	5.0	3.3	3.1	5.9
	Min/Max	2.8/5.2	3.6/6.2	4.1/7.6	5.0/8.4	6.0/9.3	7.0/10.3	6.9/9.9	5.9/8.9	4.2/7.8	3.6/6.3	1.9/4.4	2.4/4.2	5.3/6.6

Direct Beam Solar Radiation for Concentrating Collectors (kWh/m²/day), Uncertainty ±8%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
1-Axis, E-W Horiz Axis	Average	2.2	2.6	2.6	2.8	3.4	3.7	3.9	3.5	2.9	2.6	1.8	1.7	2.8
	Min/Max	1.2/3.1	1.2/3.5	1.4/3.6	1.6/4.4	2.2/4.7	2.6/5.4	2.6/5.0	2.2/4.5	1.4/4.2	1.7/3.8	0.6/2.7	1.1/2.4	2.3/3.4
1-Axis, N-S Horiz Axis	Average	1.5	2.2	2.8	3.6	4.4	4.9	5.2	4.6	3.5	2.5	1.3	1.0	3.1
	Min/Max	0.8/2.1	0.9/3.0	1.5/3.9	2.0/5.5	2.8/6.3	3.6/7.1	3.6/6.6	3.0/5.9	1.7/5.0	1.5/3.6	0.4/2.0	0.7/1.5	2.6/3.8
1-Axis, N-S Tilt=Latitude	Average	2.4	3.1	3.4	3.9	4.4	4.7	5.0	4.7	4.0	3.3	2.0	1.8	3.6
	Min/Max	1.2/3.3	1.4/4.3	1.8/4.8	2.2/6.0	2.8/6.2	3.4/6.8	3.5/6.4	3.1/6.1	2.0/5.7	2.1/4.7	0.6/3.0	1.1/2.5	2.9/4.3
2-Axis	Average	2.6	3.2	3.4	3.9	4.7	5.1	5.4	4.9	4.0	3.4	2.1	1.9	3.7
	Min/Max	1.3/3.5	1.4/4.4	1.8/4.8	2.2/6.1	3.0/6.5	3.7/7.4	3.7/6.8	3.2/6.3	2.0/5.8	2.1/4.8	0.7/3.1	1.2/2.8	3.1/4.5

Average Climatic Conditions

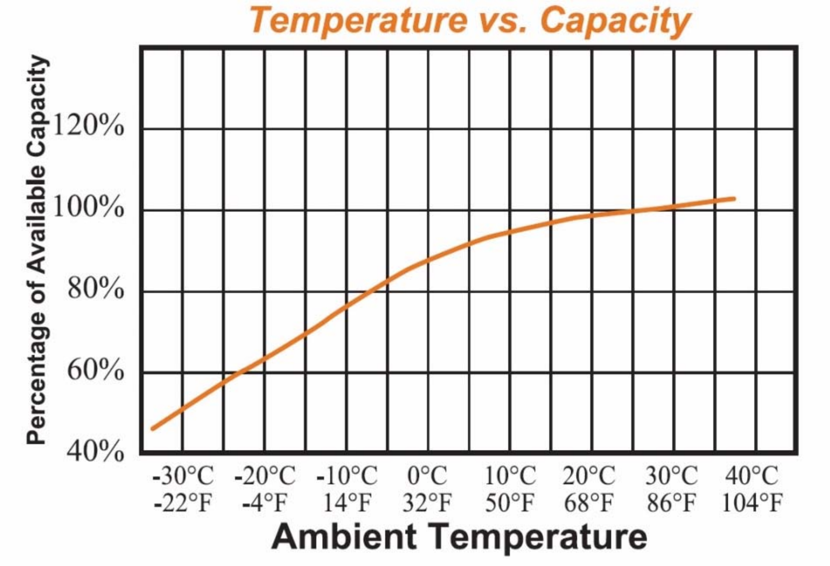
Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°C)	-11.4	-8.3	-1.2	7.2	13.8	19.2	21.6	20.1	15.1	8.8	0.3	-8.2	6.4
Daily Minimum Temp	-16.3	-13.3	-5.9	1.4	7.5	12.9	15.6	14.2	9.2	3.1	-4.2	-12.6	0.9
Daily Maximum Temp	-6.6	-3.3	3.4	12.9	20.1	25.4	27.7	26.0	21.0	14.6	4.9	-3.9	11.8
Record Minimum Temp	-35.6	-33.9	-35.0	-15.0	-6.1	1.7	5.6	2.8	-5.0	-11.7	-28.9	-36.1	-36.1
Record Maximum Temp	12.8	17.2	26.1	32.8	33.3	38.3	38.9	37.2	35.0	31.1	22.8	16.7	38.9
HDD, Base 18.3°C	922	745	606	335	157	31	9	18	103	294	540	823	4583
CDD, Base 18.3°C	0	0	0	0	16	56	111	74	6	0	0	0	262
Relative Humidity (%)	77	76	75	68	67	69	72	75	75	72	77	80	74
Wind Speed (m/s)	6.6	6.3	6.6	6.6	6.0	5.7	4.9	4.9	5.4	5.9	6.2	6.3	5.9

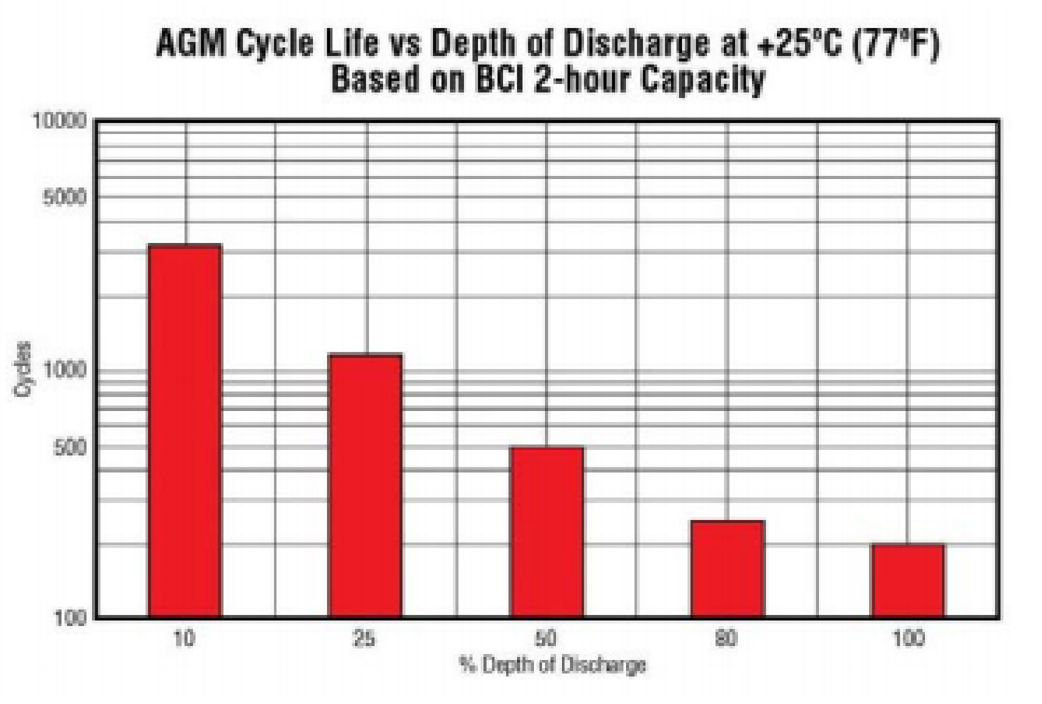
Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt ($kWh/m^2/day$), Uncertainty ±9%

Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	1.8	2.7	3.7	4.6	5.6	6.2	6.2	5.3	4.0	2.8	1.7	1.4	3.8
	Min/Max	1.5/2.1	2.3/3.0	3.0/4.3	3.9/5.5	4.8/6.5	5.4/7.3	5.3/7.0	4.5/6.0	3.3/4.7	2.3/3.3	1.4/2.0	1.2/1.7	3.7/4.1
Latitude -15	Average	2.9	3.9	4.6	5.1	5.7	6.0	6.2	5.7	4.8	3.8	2.6	2.3	4.5
	Min/Max	2.2/3.6	2.9/4.5	3.5/5.6	4.1/6.3	4.9/6.6	5.3/7.1	5.2/7.1	4.7/6.5	3.6/5.8	3.0/4.7	1.7/3.2	1.8/2.9	4.1/4.9
Latitude	Average	3.3	4.2	4.7	4.9	5.3	5.5	5.7	5.5	4.8	4.1	2.8	2.6	4.5
	Min/Max	2.4/4.2	3.1/5.0	3.5/5.9	4.0/6.2	4.6/6.2	4.8/6.6	4.8/6.6	4.4/6.3	3.5/5.9	3.1/5.1	1.8/3.6	2.0/3.4	4.1/4.9
Latitude +15	Average	3.6	4.4	4.7	4.6	4.7	4.8	5.0	4.9	4.6	4.1	2.9	2.8	4.3
	Min/Max	2.5/4.5	3.2/5.2	3.4/6.0	3.8/5.8	4.1/5.4	4.2/5.6	4.2/5.7	4.0/5.7	3.3/5.7	3.0/5.1	1.8/3.8	2.2/3.7	3.9/4.6
90	Average	3.5	4.1	3.9	3.2	2.8	2.7	2.9	3.2	3.4	3.4	2.7	2.7	3.2
	Min/Max	2.4/4.4	2.9/4.9	2.7/5.3	2.7/3.9	2.6/3.2	2.5/3.1	2.5/3.2	2.6/3.6	2.4/4.2	2.5/4.3	1.5/3.5	2.1/3.7	2.9/3.5

Design Battery Bank

- Power draw of equipment (2.75 A)
- Temperature
- Battery lifecycle





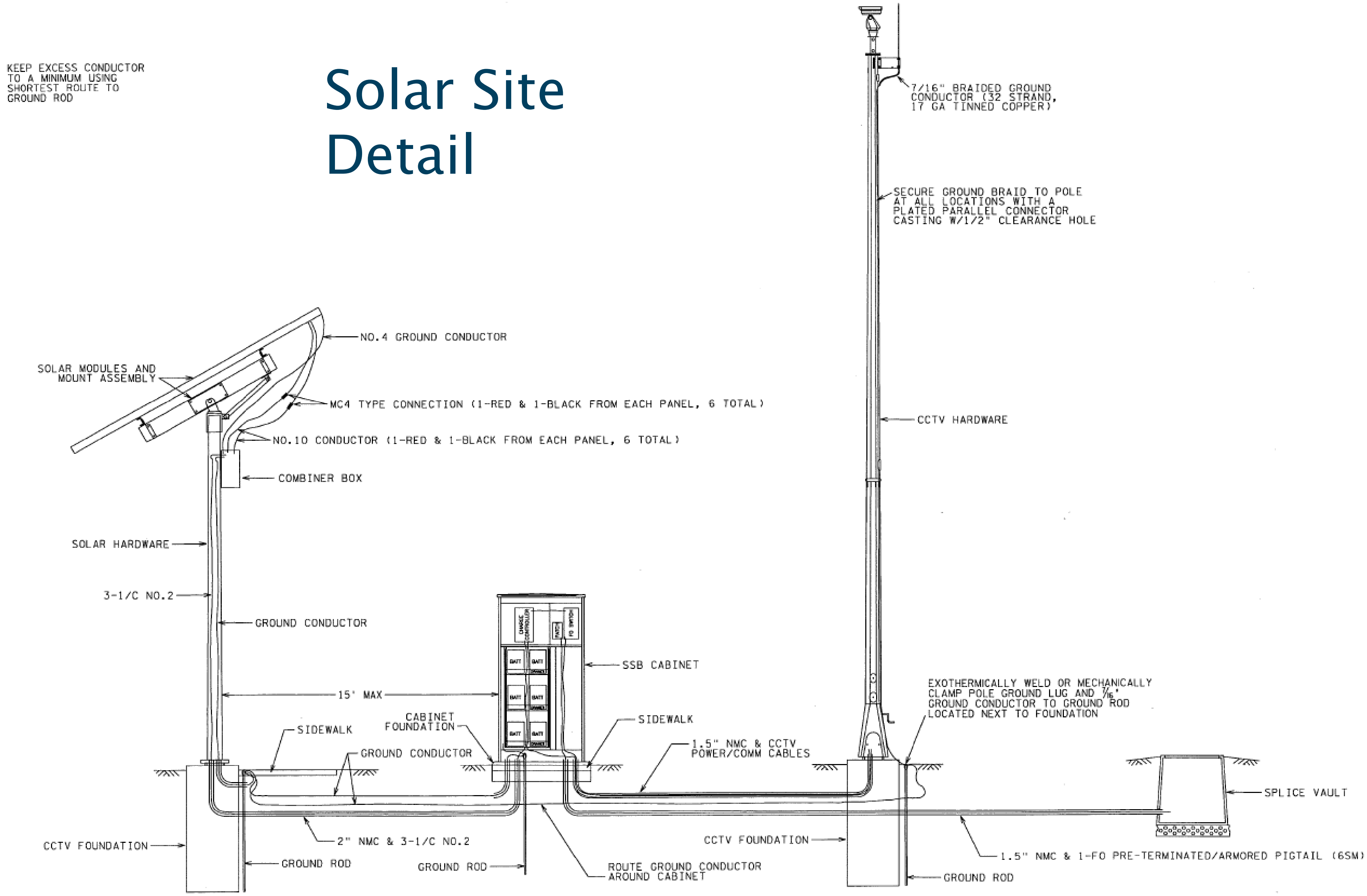
Solar Array Design

- Solar isolation
  - Power output at standard test condition (1000 w/m^2)
  - vs. measured condition (2.7 kWh / m^2 / day)
- De-rating factors
  - Soil on panels
  - Efficiency of equipment (charger)
  - Age of panels

Other Factors

- Theft / Vandals – pole height, mounting hardware (RTMC experience)
- Lightning protection (Electronic Communication)
- Structural (Structures & Foundations)
- Cabinet
- National Electric Code
- Network Connected Control and Monitoring

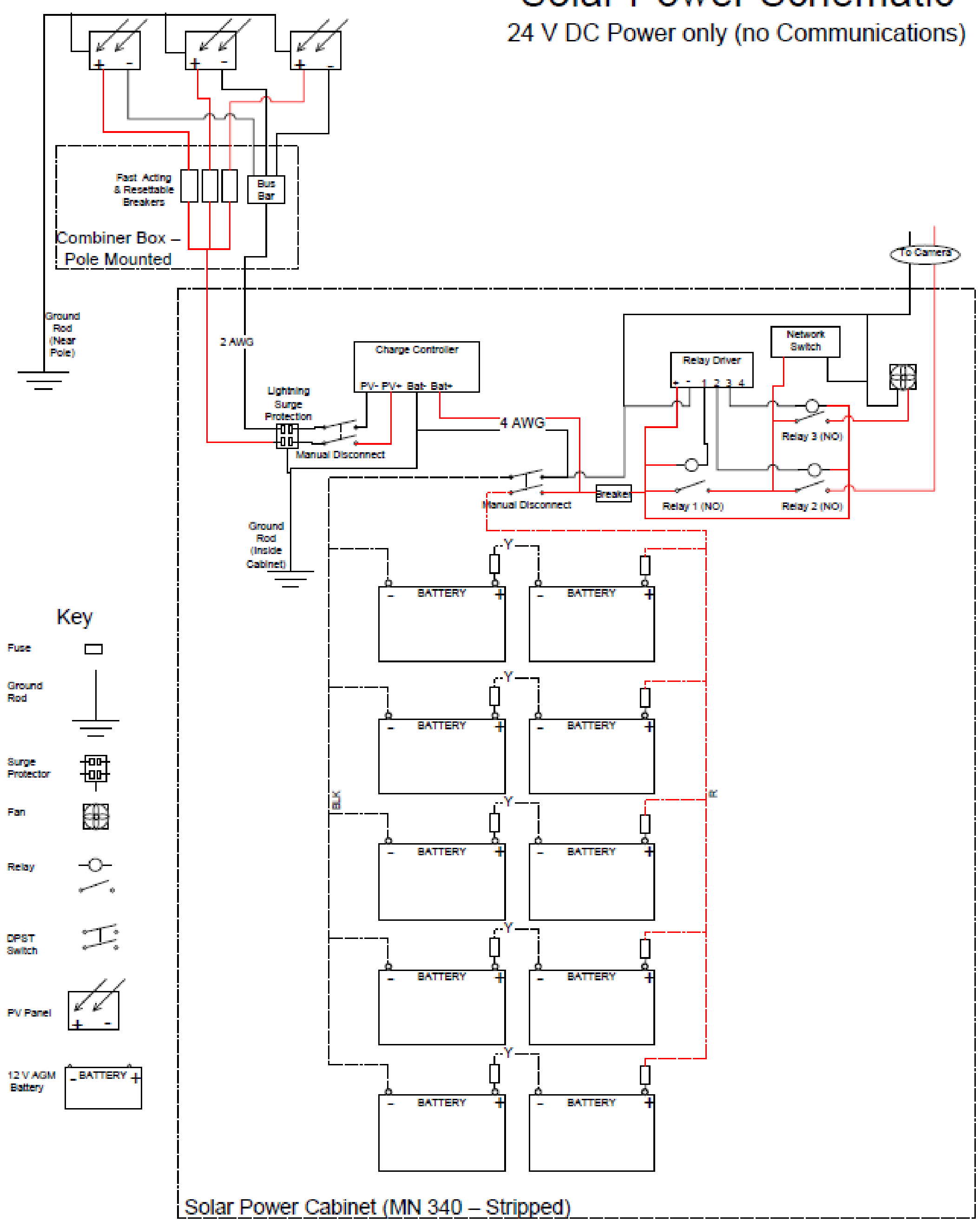
Solar Site Detail




EGAN

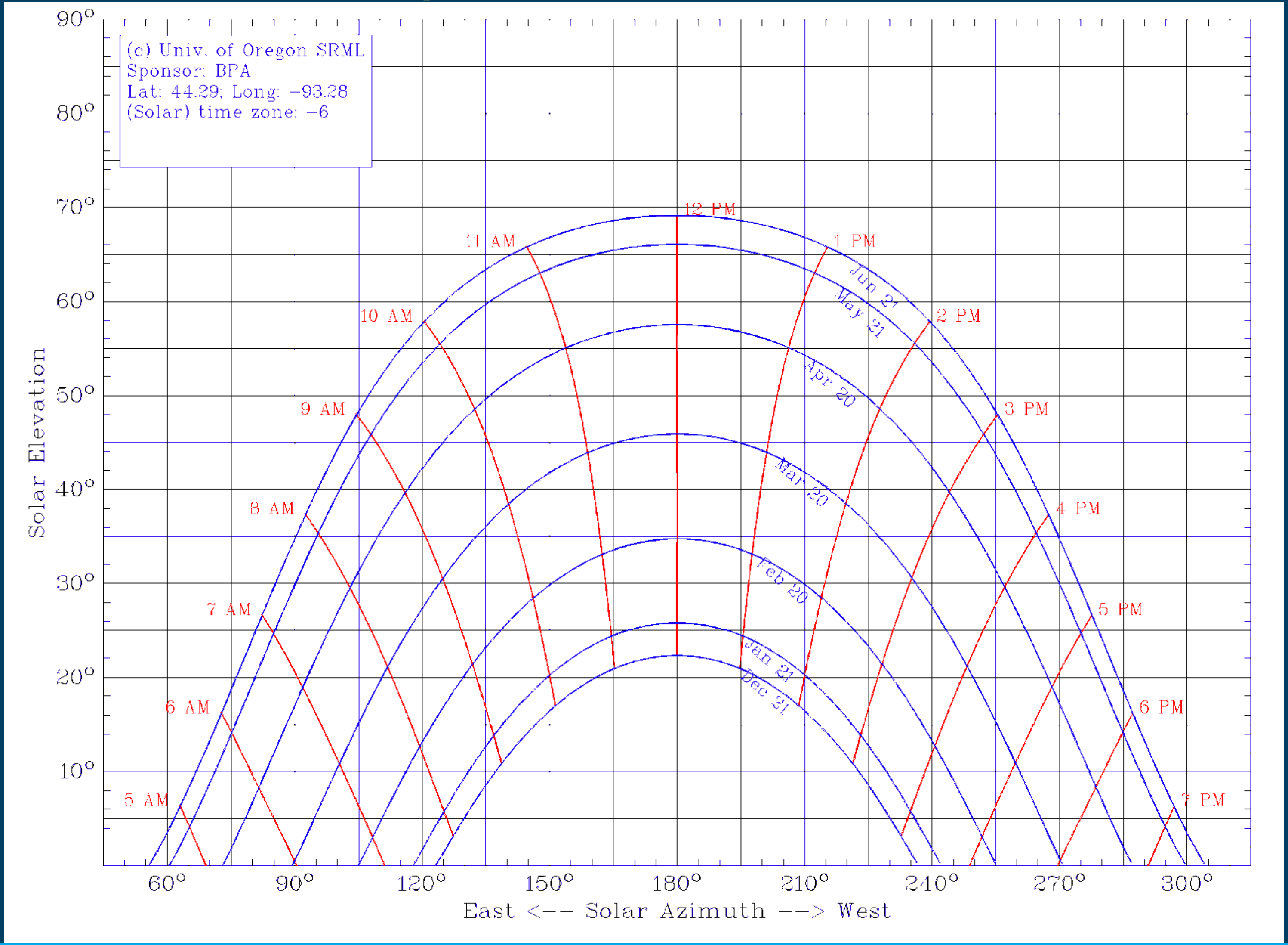
Solar Power Schematic

24 V DC Power only (no Communications)



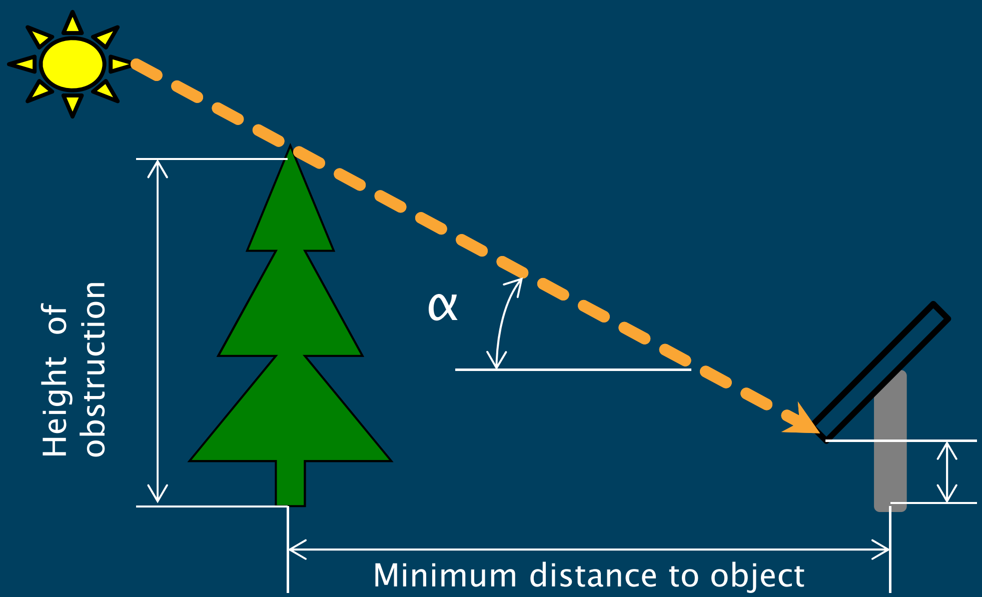
District 6 Traffic
12/5/2012

Placement / Shade

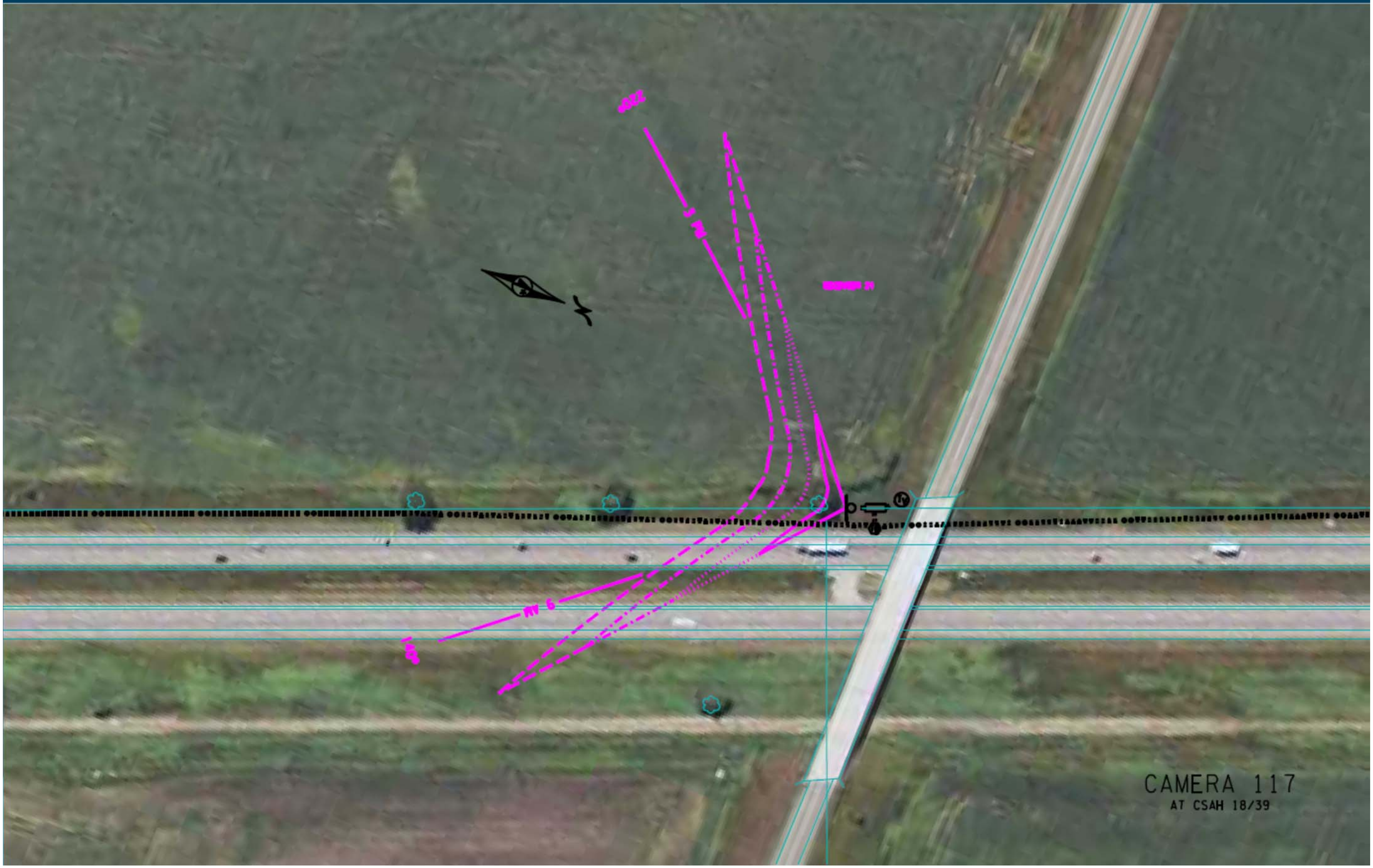


Placement / Shade

$$D = \frac{H_0 - H_S}{\sin(\alpha)}$$



Placement / Shade



Challenges

- Legal / legislative
- Extreme environmental demands
- Site accessibility / slopes

Cost Comparison (Installation)

Grid Connected Site

$28,693

- Service Cabinet
- Camera Pole
- Camera Cabinet
- Conductor
- Foundations

Solar Site

$37,735

- Cabinet
- "Solar Hardware"
- Solar Panels
- Solar Mount
- Camera Pole
- Conductor
- Foundations

Cost Comparisin (opperating)

	6 Batteries		8 Batteries		Grid Connected	
Year	Costs	Present Value	Costs	Present Value	Costs	Present Value
1	$ 1,320	$ 1,320	$ 1,760	$ 1,760	$ 440	$ 440
2		$ -		$ -	$ 440	$ 427
3		$ -		$ -	$ 440	$ 415
4	$ 1,320	$ 1,208		$ -	$ 440	$ 403
5		$ -	$ 1,760	$ 1,564	$ 440	$ 391
6		$ -		$ -	$ 440	$ 380
7	$ 1,320	$ 1,105		$ -	$ 440	$ 368
8		$ -		$ -	$ 440	$ 358
9		$ -		$ -	$ 440	$ 347
		$ 3,633		$ 3,324		$ 3,529

Lessons Learned / Conclusions

- Solar industry lead-times
- Additional safety concerns
  - both sides of switch live
  - high current potential
  - Battery safety
- Solar Power is a feasible option for SOP problems

Resources

- NREL
- PVwatts
- Solar Power in Building Design by Peter Gevorian