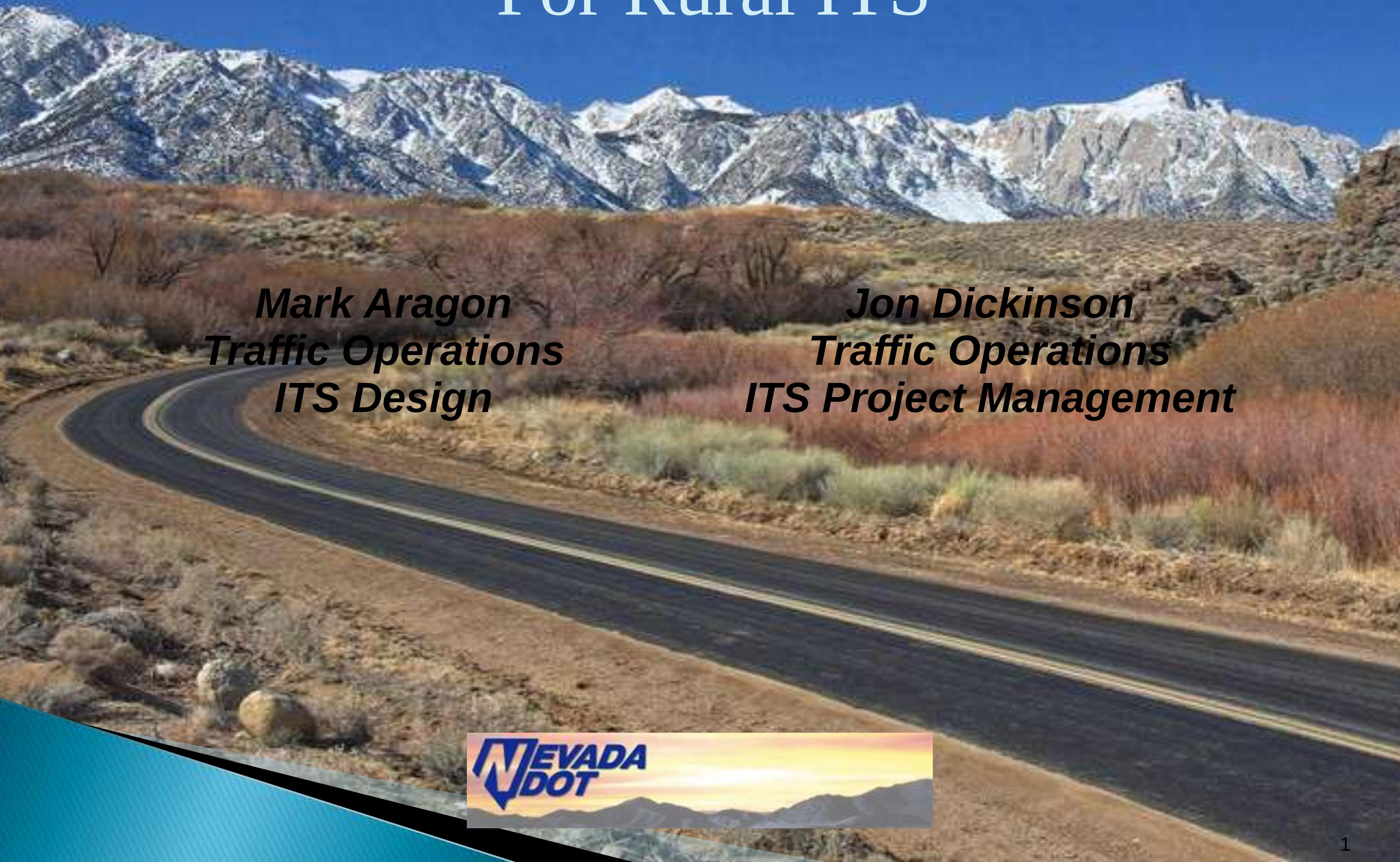


Photovoltaic Power Systems For Rural ITS

Mark Aragon
Traffic Operations
ITS Design

Jon Dickinson
Traffic Operations
ITS Project Management

Photovoltaic Systems for Rural ITS
Presentation Topics

1. Introduction and Background
2. System Overview
3. Design Methods and Calculations
4. System Lifecycle costs
5. Potential Pitfalls and Lessons Learned

Introduction and Background

- Photovoltaic systems benefit the state by allowing deployment of ITS systems at critical rural locations where commercial power sources are either unavailable or cost prohibitive.
- Existing systems are typically low power (less than 20 watts), however, increased efficiency and reduced costs are increasing the power threshold.
- Increased options and improved technology in photovoltaic (PV) system components allow for more diversity in design. This allows for a more streamline design to meet the specific needs of the application thereby increasing efficiency and reducing costs.

PV Systems Background

- The first systems were used for solar flashers with low power requirements (<10 watts).
- Systems were pre-packaged and self-contained.
- Contractor designed and selected in accordance with performance specifications and loading requirements.
- Contractor has no long term ownership or accountability in the system. This may lead to increased risk of system failure and increased maintenance costs.
- Newer systems and components have greater capability and complexity.
- This has created a need for development of component level design standards and specifications for PV systems.

Current Rural PV Systems in Nevada

Solar power is used extensively throughout the state of Nevada for deployment of Flashing Warning Signs, Road Weather Information Systems (RWIS) and Highway Advisory Radio (HAR). Nevada's arid climate and average high elevation provide an ideal environment for photovoltaic power systems.

Current NDOT PV Inventory

- Flashing Warning Signs: 32
- Road Weather Information System (RWIS): 29
- Highway Advisory Radio (HAR): 1

Solar Power Advantages

- Flexibility: Self contained systems allow ITS devices to be placed in optimal locations without the constraints of distance or right-of-way
- Autonomy: no need for 3rd party agreements (easements, line extension agreements, etc.)
- Reliability: The sun is a reliable energy source not subject to surges and blackouts
- Low maintenance: newer systems are more reliable and require less preventative maintenance.
- Green: Once installed, the system has minimal environmental impact.

Solar Power Disadvantages

- Higher initial capital cost.
- Lifecycle cost is usually greater than metered service.
- Cost per kilowatt hour exceeds commercial energy cost.
- Reliability is subject to local weather conditions.
- Periodic replacement of components (batteries, controllers, etc.).
- Theft and vandalism.

A Brief History of Photovoltaics

- 1953: First working silicon PV cell developed at Bell Labs 4% efficiency.
- 1958: First used in space satellites in 1958. Commercial applications were too costly at this time (around $300 per watt).
- 1960: Efficiency of 14% achieved.
- 1970: Cost is down to $20 per watt allowing use several terrestrial applications (mostly public works).
- 1980: Solar power plants appear with worldwide production exceeding 21.3 MW. Residential installations are becoming more common.
- 2000: Worldwide solar productions exceeds 1000 MW. Solar power systems are readily available for commercial and residential applications.

Photovoltaics in the New Millennium

•Since the year 2000, PV use has increased exponentially, while costs continue to decline.

•Global demand for PV technology is predicted to increase by 75 GW in the next 5 years.

As of 2009:

•Worldwide annual PV production has gone from 3.7 GW in 2007 to 10.7 GW in 2009, about 70% increase per year.

•Cumulative PV capacity in the United States surpassed 1 GW.

•PV cost as low as $2.50 per watt.

Types of Photovoltaic Systems

1. **<u>Grid tied system</u>:** PV provides primary power with any unused power returned to the power grid. Grid power is used when demand exceeds solar output. Battery backup is optional with this type of system.

2. **<u>Grid fall-back system</u>:** PV is primary source of power with switch over to grid power when solar power source is unavailable (no sun or backup batteries are drained).
3. **<u>Hybrid System</u>:** PV is primary source of power with an alternative power source such as a generator, windmill, or hydropower system. This would be suitable for rural ITS applications where wind generated power could supplement the lack of PV power during periods of low insolation (incident solar radiation). NDOT has been looking into such a hybrid system for future installations (Mt. Rose Summit on SR 431).

4. **<u>Stand-alone system</u>:** PV is the sole source of power with backup batteries during periods of low solar insolation. This is the system type most commonly used for rural ITS applications in Nevada.

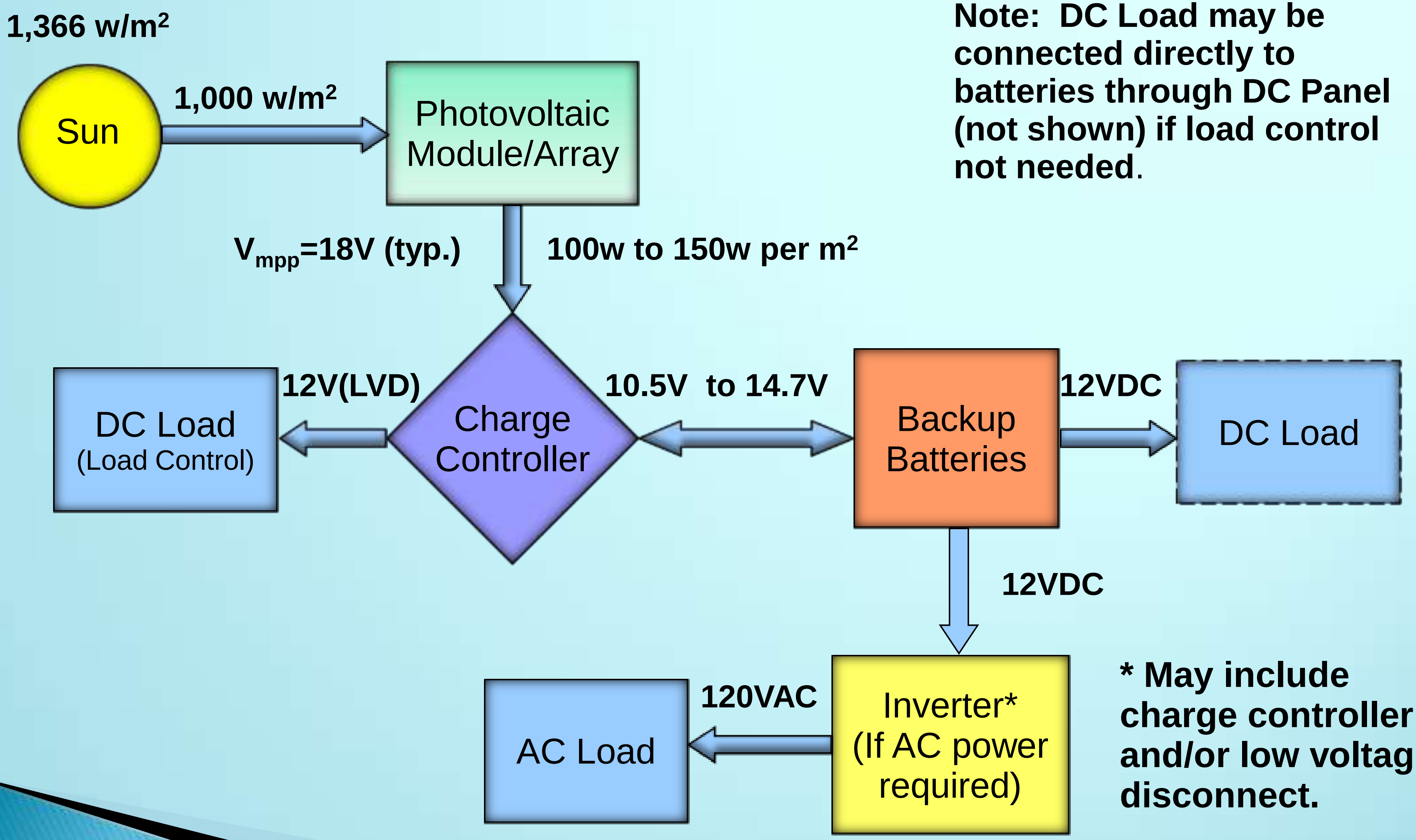
There are several more configurations possible, however, the focus of this presentation will be on the stand-alone system since it is the best suited for rural ITS, where commercial power is unavailable.

System Overview
Rural ITS Stand-Alone System Components

- Source: The Sun (solar irradiance)
- Collector: Photovoltaic Module/Array
- Regulator: Charge Controller
- Storage: Battery Backup
- Power Conditioning: Inverter (AC), DC to DC converter, etc.
- Load: DC and/or AC

Photovoltaic System Block Diagram

Typical Stand Alone Configuration



$1,366\ w/m^2$

Sun

$1,000\ w/m^2$

Photovoltaic Module/Array

V_{mpp}=18V (typ.)

100w to 150w per m^2

DC Load (Load Control)

12V(LVD)

Charge Controller

10.5V to 14.7V

Backup Batteries

12VDC

DC Load

12VDC

AC Load

120VAC

Inverter* (If AC power required)

Note: DC Load may be connected directly to batteries through DC Panel (not shown) if load control not needed.

*** May include charge controller and/or low voltage disconnect.**

Solar Energy Source Terminology

Solar irradiance: Instantaneous power from the sun in watts/m^2
Average value at top of atmosphere = 1,366 w/m^2
Average value at the surface of the earth = 1,000 w/m^2. This is under ideal conditions (surface perpendicular to the sun's rays at noon in the summer).

Solar insolation (incident solar radiation): Total energy received per unit area over time: power/area x time = Kilowatt-hours/m^2. Found from the integration of the solar irradiance over time.

Peak Sun Hours: The irradiance of the sun at any given location varies throughout the day, with the maximum at solar noon. Total solar insolation for 24 hours divided by the standard peak value of 1,000 w/m^2 gives the peak sun hours, i.e. the equivalent solar insolation produced by a steady peak sun irradiance for the given number of hours.

Solar and Weather Data

➢An important step in designing a rural PV system is to select the site and obtain the solar and weather data for that location. The following resources are available at no cost and are adequate for most stand-alone applications:

Resources for obtaining PV and solar information:

- NREL - www.nrel.gov
- Sandia - www.sandia.gov
- NASA – www.nasa.gov

The following website contains some excellent resources for calculating solar insolation: www.pveducation.org/pvcdrom

Resources for obtaining historical climate data:

- NOAA – www.noaa.gov
  www.weather.gov
- World Climate – www.worldclimate.com
- Climate Records: www.wrcc.dri.edu

- Higher accuracy can be obtained using a “pyranometer”, a passive device used to measure local solar radiation flux density (irradiation).

Sun Orientation

Elevation of sun varies 47 degrees from the Winter Solstice to the Summer Solstice

Elevation of the sun at solar noon (180 degrees azimuth)

-Winter Solstice = 90º – latitude -23.5º
- Summer Solstice = 90º –latitude +23.5º

Consider the variable length of shadows from nearby buildings, trees, and mountains during site selection.

Example: 30 ft tree at 40º North Latitude.

Summer Sun Altitude = 90º-40º+23.5º= 73.5º deg
Shadow Length = 30 ft/tan(73.5º)=8.9 ft

Winter Sun Altitude = 90º-40º-23.5º=26.5º deg
Shadow Length=30 ft/tan(26.5º)=60.2 ft

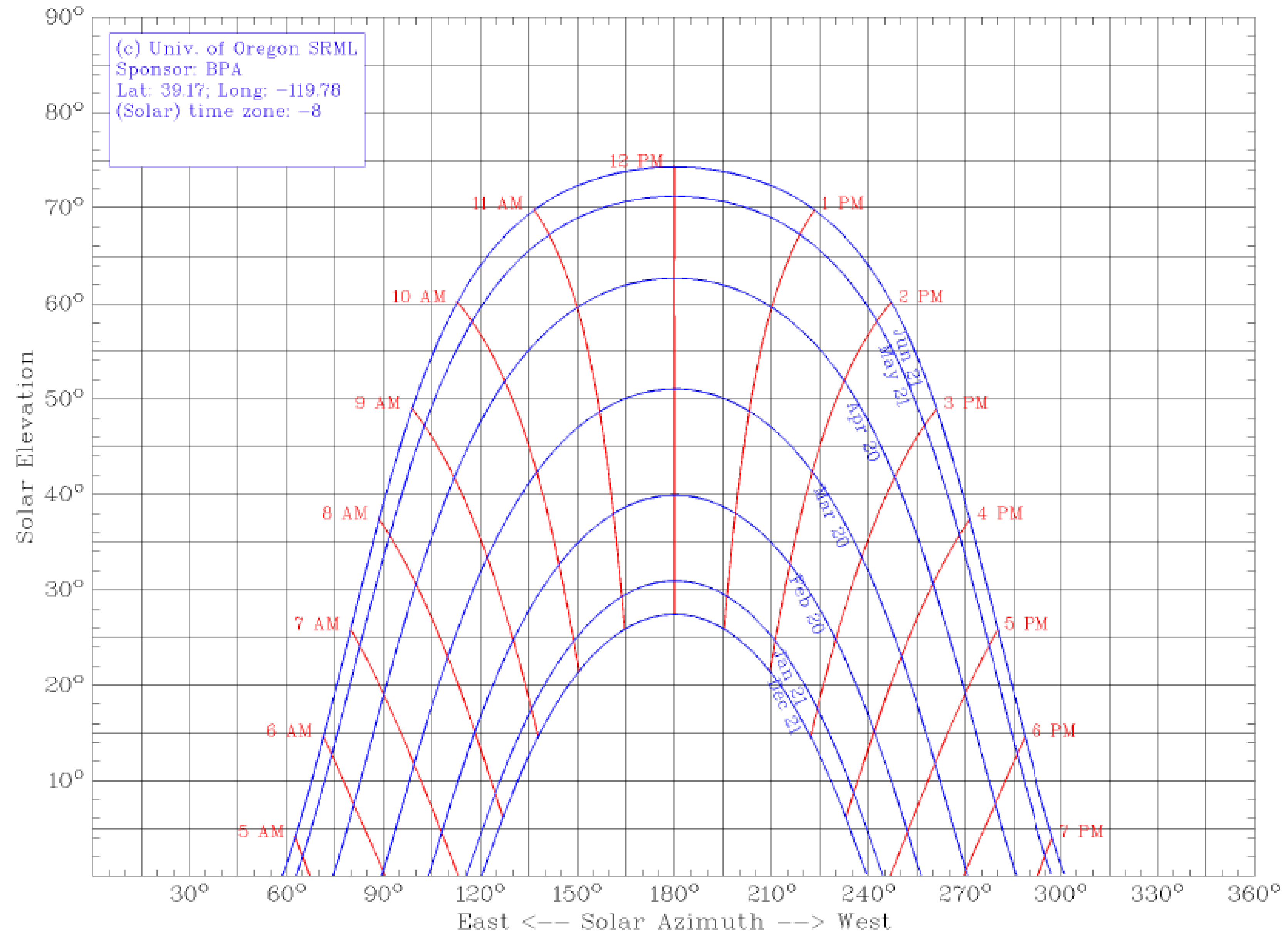
Here is a free web resource for plotting solar paths for any location:

http://solardat.uoregon.edu/SunChartProgram.html

Sun Plot with Azimuth and Elevation

University of Oregon SRML

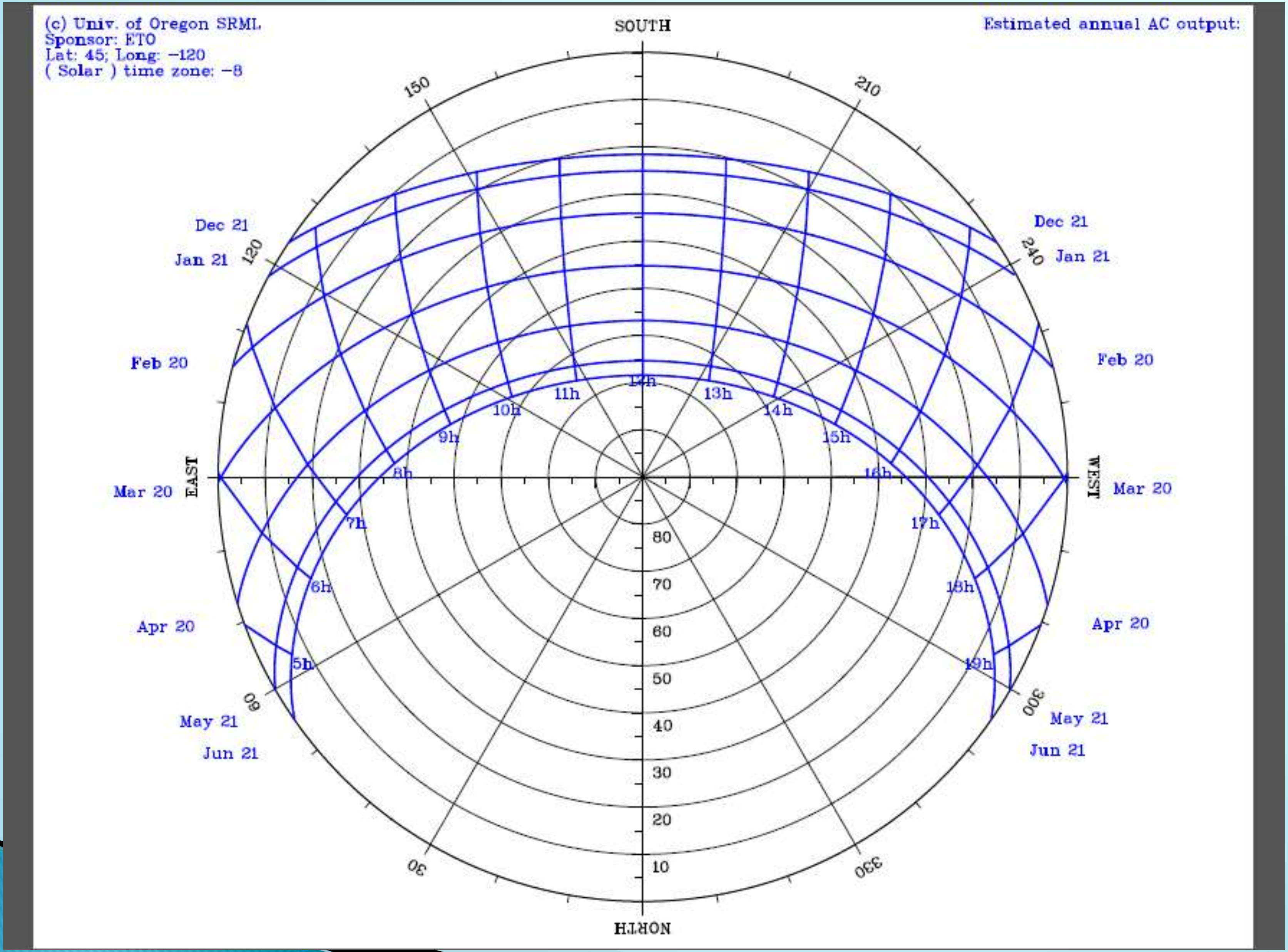
http://solardat.uoregon.edu/SunChartProgram.html



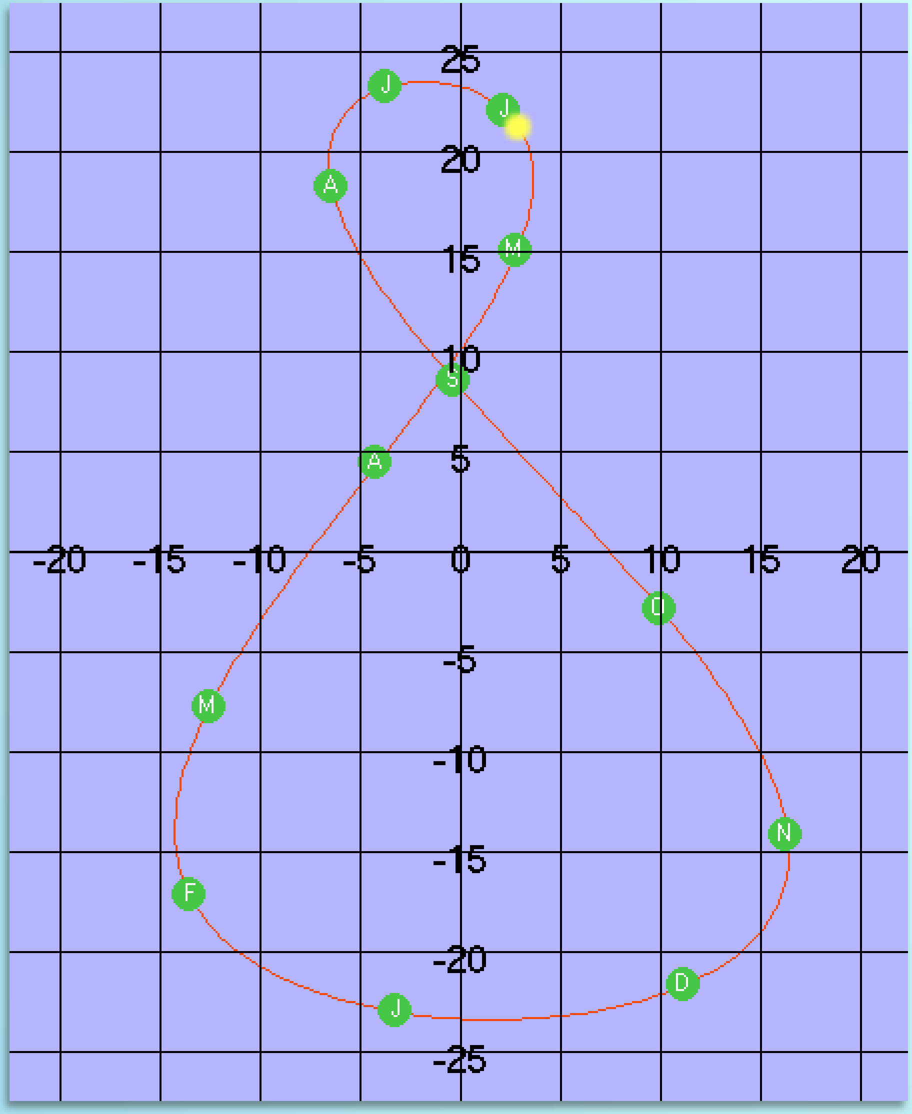
Sun Plot with Azimuth and Elevation

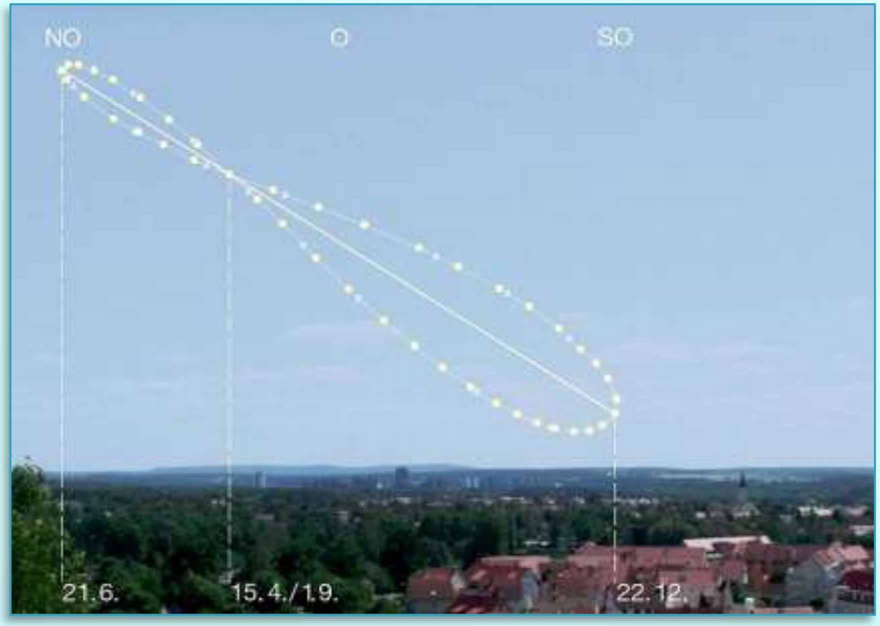
University of Oregon SRML

http://solardat.uoregon.edu/SunChartProgram.html



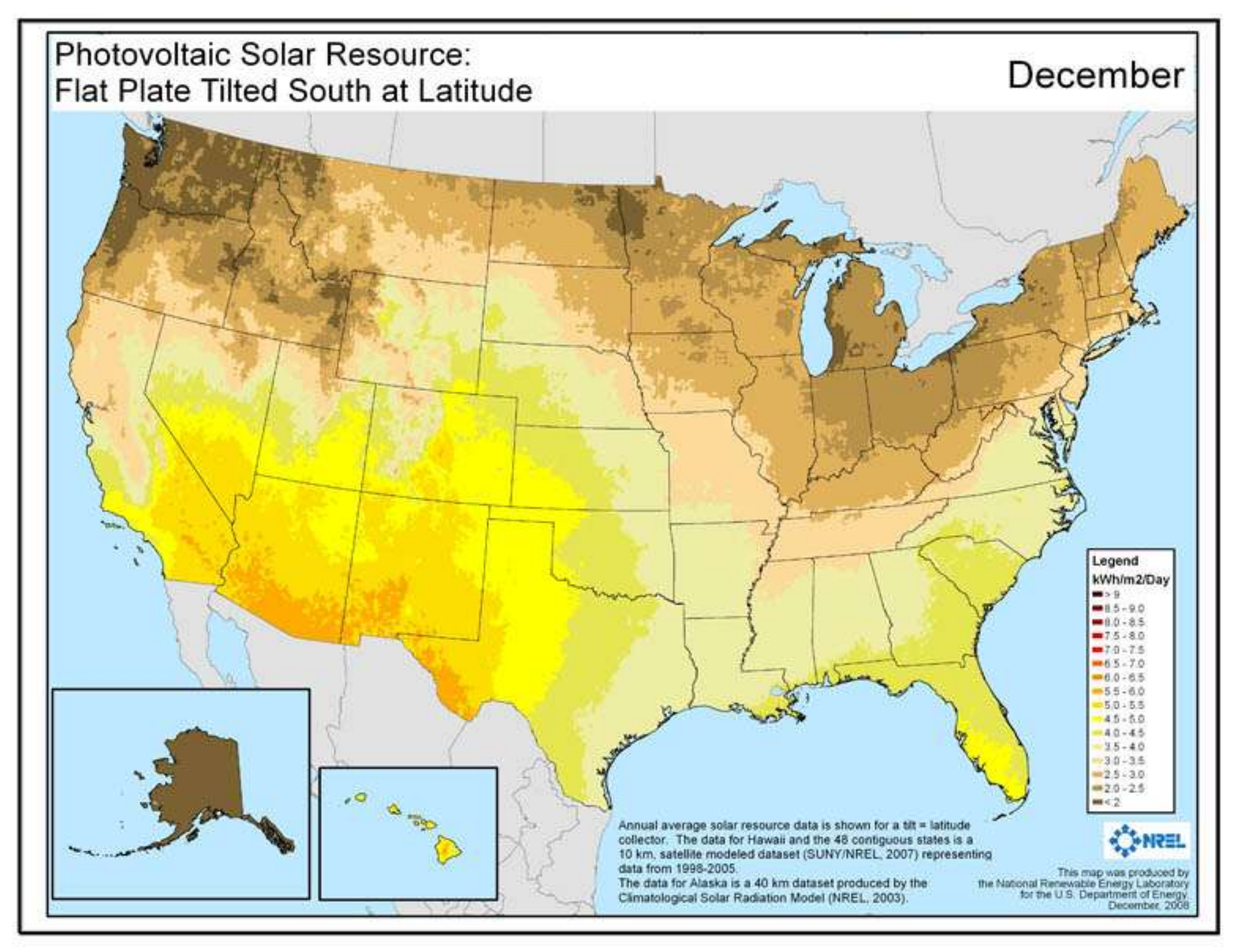
Analemma





A plot showing the sun’s position as viewed from a fixed position on the Earth at the same time each day for a complete year.

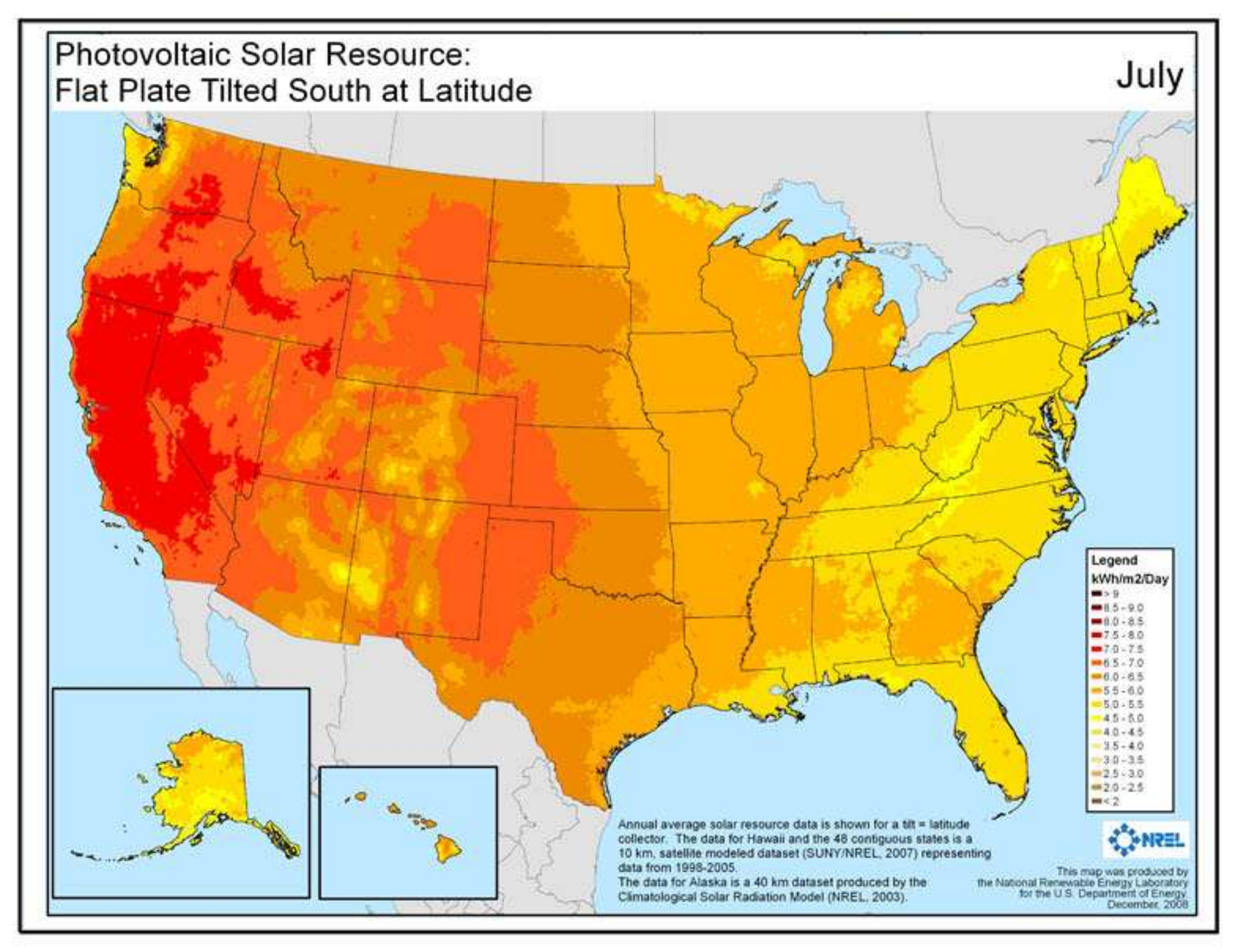
NREL Solar Insolation December Average



Annual average solar resource data is shown for a tilt = latitude collector. The data for Hawaii and the 48 contiguous states is a 10 km, satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2005.
The data for Alaska is a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).

This map was produced by
the National Renewable Energy Laboratory
for the U.S. Department of Energy.
December, 2008

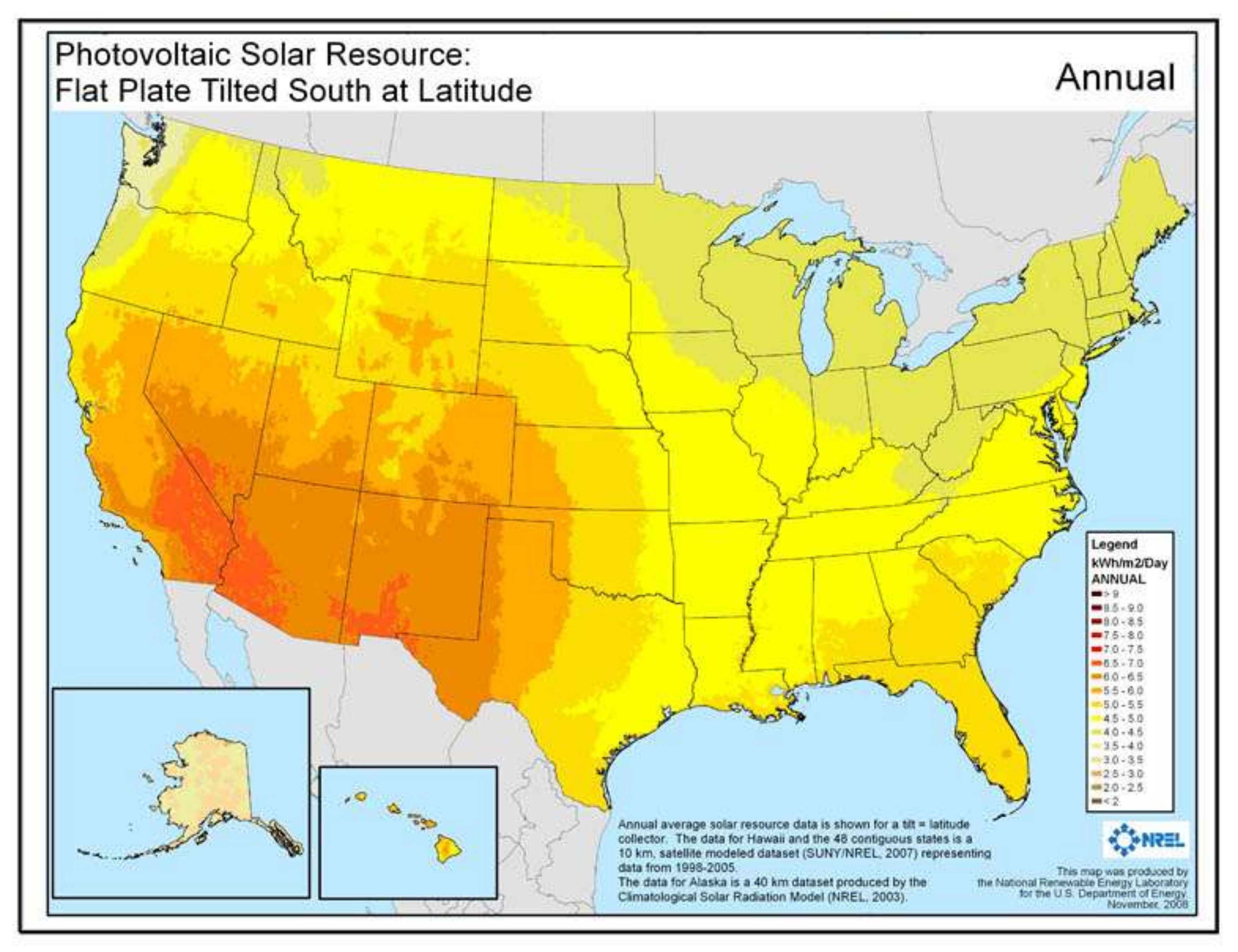
NREL Solar Insolation July Average



Annual average solar resource data is shown for a tilt = latitude collector. The data for Hawaii and the 48 contiguous states is a 10 km, satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2005.
The data for Alaska is a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).

This map was produced by
the National Renewable Energy Laboratory
for the U.S. Department of Energy.
December, 2008

NREL Solar Insolation Annual Average



Annual average solar resource data is shown for a tilt = latitude collector. The data for Hawaii and the 48 contiguous states is a 10 km, satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2005.
The data for Alaska is a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).

This map was produced by
the National Renewable Energy Laboratory
for the U.S. Department of Energy.
November, 2008

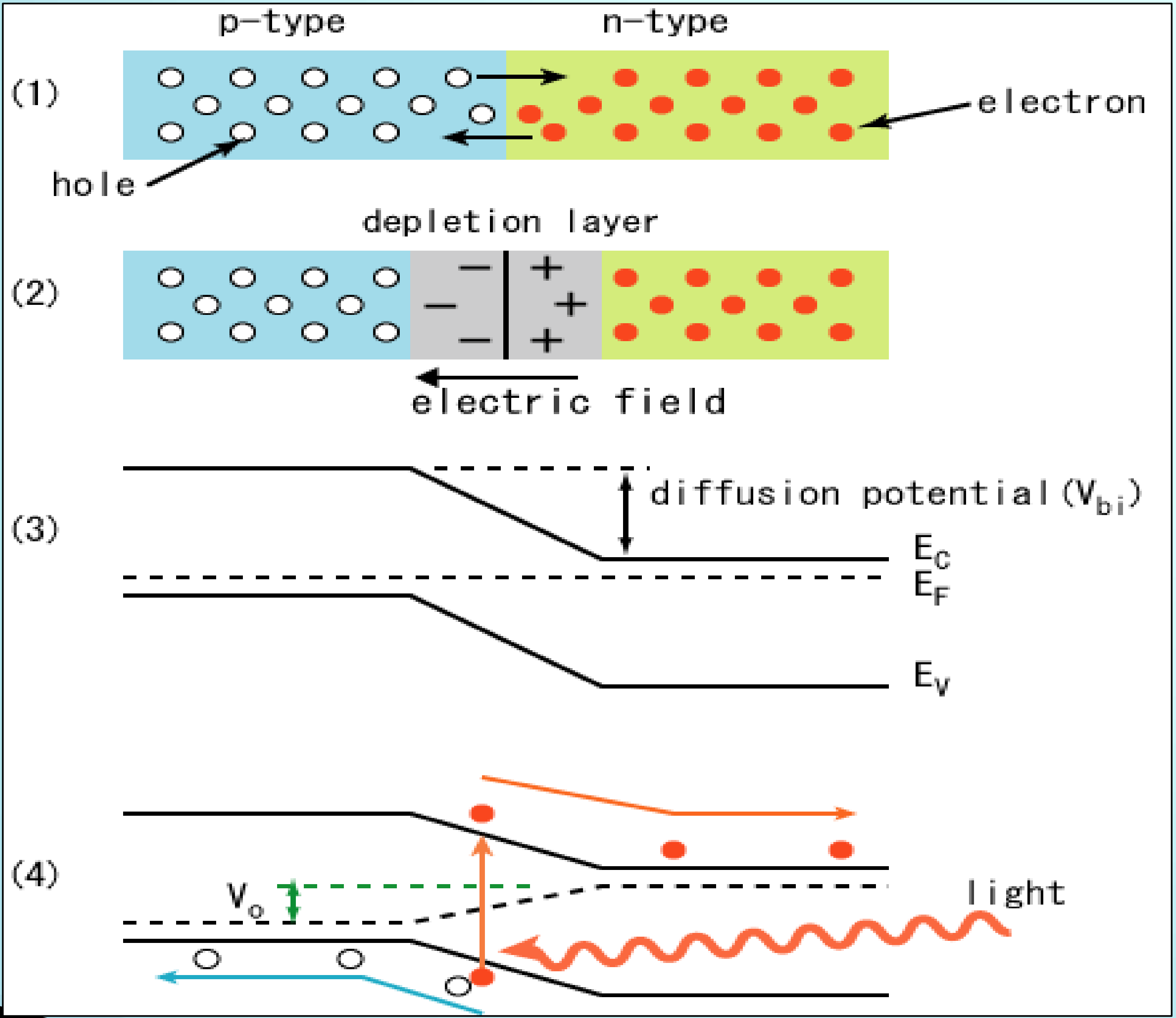
Photovoltaic (PV) Modules

Polycrystalline array with 20 modules. Modules are 72 cell (6 x 12)

Photovoltaic Cell
Description and theory of operation

- **Photovoltaic effect:** Sunlight incident on the cell surface and absorbed energizes and liberates electrons from the valence band to the conduction band. Diffusion of free charge carries develops a net separation of charges resulting in an electrical potential between the opposite sides of the semiconductor.
- The photovoltaic cell is the fundamental component of the PV module.
- Voltage is typically 0.5 V per cell and decrease about 0.5 percent per degree centigrade increase in temperature.
- A photovoltaic module normally consist of 36 or 72 cells combined to produce a desired voltage and current. Cells are place within a laminate with protective covering on both sides. Conductors are connected to provide a path for current to flow from the PV module. An array consists of two or more PV modules.

Photovoltaic Effect



Photovoltaic Cells
Three Types

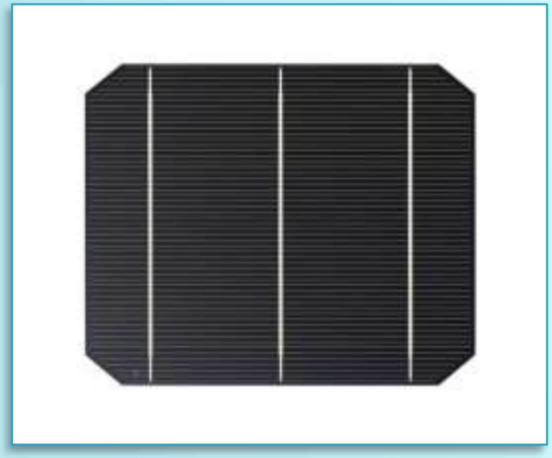
1. **Monocrystalline**

2. **Thin film**

3. **Polycrystalline**

Mono-crystalline

Single Cell



36 Cell Module

- Most efficient at 11% to 14% efficiency
- Most expensive.
- Inefficient use of space with beveled shape
- Not used for rural ITS applications since the increased efficiency comes at a much greater expense.

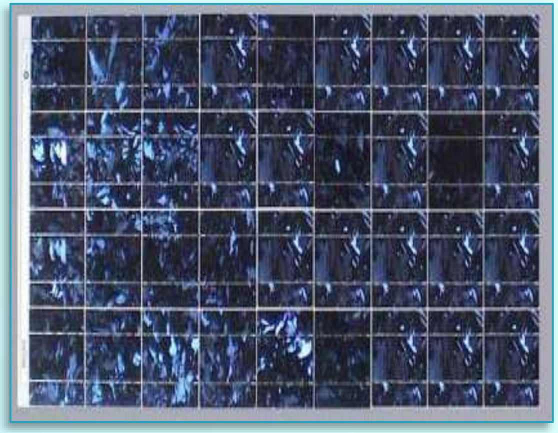
Thin Film

- Amorphous silicon or cadmium telluride
- Relatively inexpensive.
- Least efficient at 6% to 12%.
- Can be place on rigid surface or flexible substrates; low weight
- Better performance in low light conditions.
- Not used for rural ITS applications since they are less efficient and have a shorter lifespan.

Polycrystalline

Single Cell

36 Cell Module



- Less efficient (10% to 12%) than monocrystalline
- Lower cost than monocrystalline
- Square shape uses space efficiently
- The current choice for rural ITS applications; cost effective and robust. Will typically last in excess of 20 years.

PV Module Performance Specifications

STC (Standard test conditions): Used for performance specifications. PV modules specifications are based on the following conditions:

- Irradiance: 1,000 watts/m^2
- Module temperature: 25º C
- 1.5 thickness of atmosphere

MPP: Maximum power point (current x voltage is max, see graph)

P_{max}: Maximum power (maximum power point)

V_{mpp}: Voltage at maximum power point

V_{oc}: Open circuit voltage

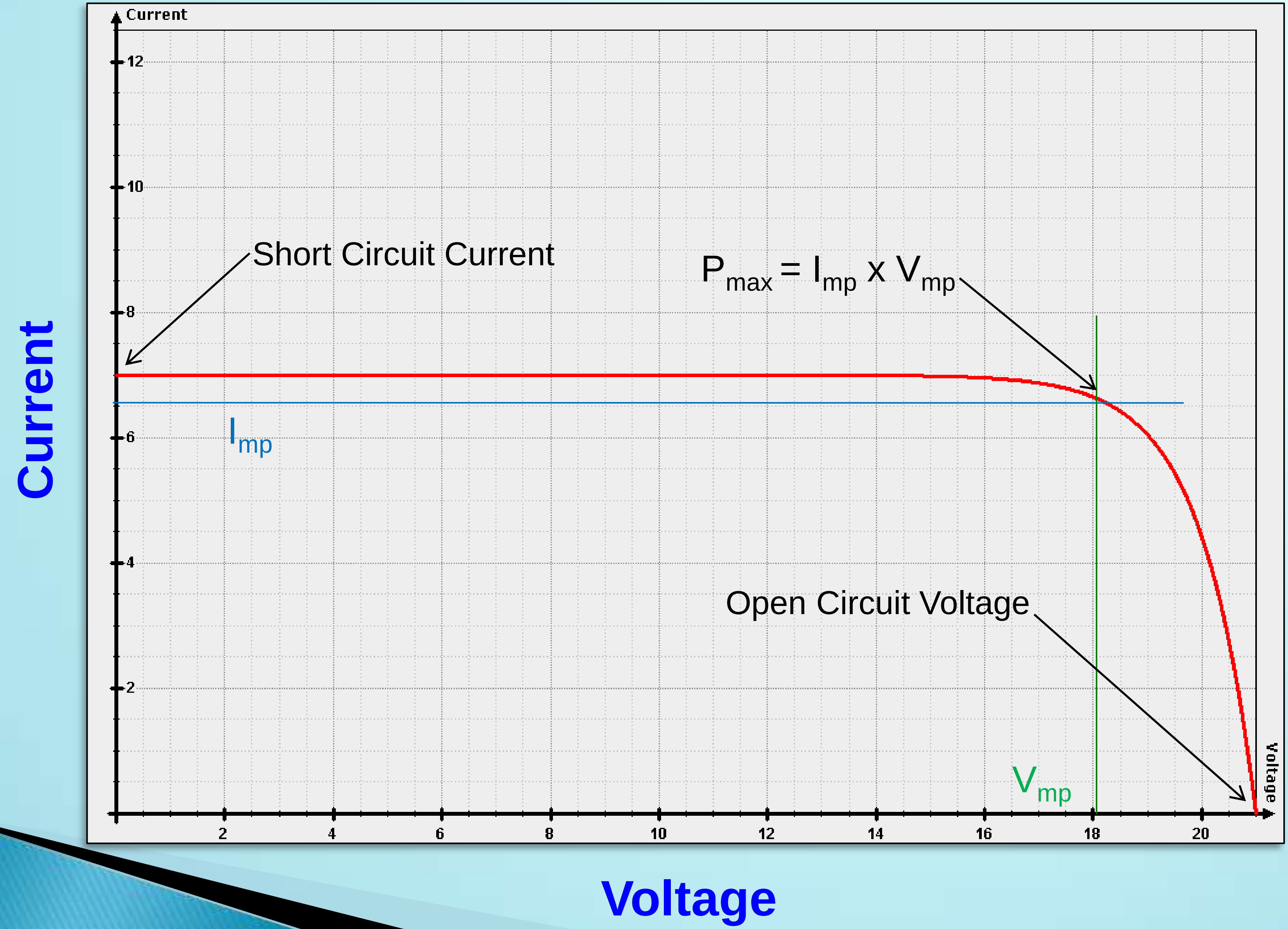
I_{mpp}: Current at maximum power point

I_{sc}: Short circuit current

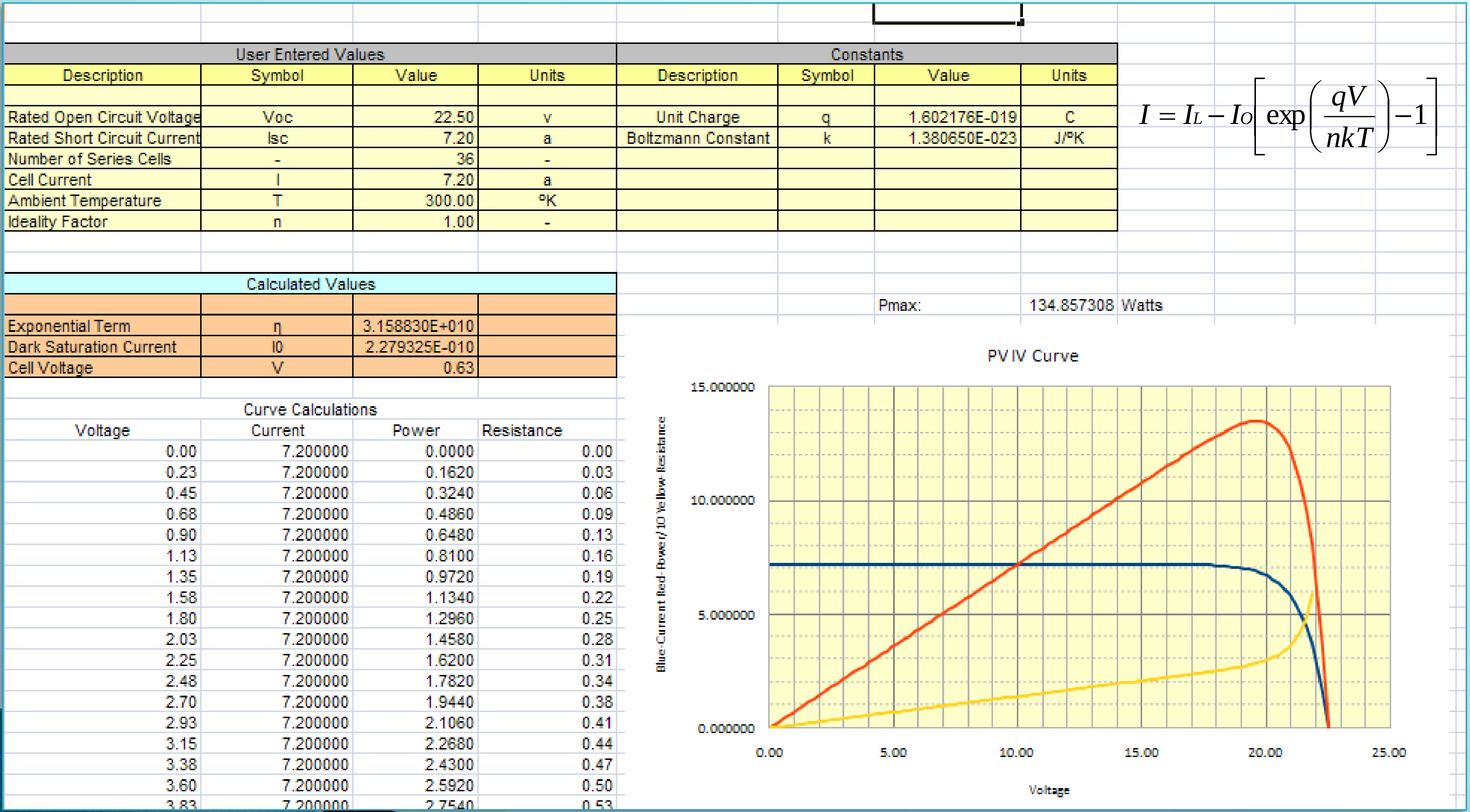
V_{oc} temperature coefficient: reduction in V_{oc} for each degree above 25º C.

I_{sc} temperature coefficient: increase in I_{sc} for each degree above 25º C.

PV current vs. voltage characteristics (typical)



Photovoltaic IV Curve in Excel



User Entered Values				Constants			
Description	Symbol	Value	Units	Description	Symbol	Value	Units
Rated Open Circuit Voltage	Voc	22.50	v	Unit Charge	q	1.602176E-019	C
Rated Short Circuit Current	Isc	7.20	a	Boltzmann Constant	k	1.380650E-023	J/°K
Number of Series Cells	-	36	-				
Cell Current	I	7.20	a				
Ambient Temperature	T	300.00	°K				
Ideality Factor	n	1.00	-				

$$I = I_L - I_O\left[\exp\left(\frac{qV}{nkT}\right) - 1\right]$$

Calculated Values			
Exponential Term	η	3.158830E+010	
Dark Saturation Current	I0	2.279325E-010	
Cell Voltage	V	0.63	

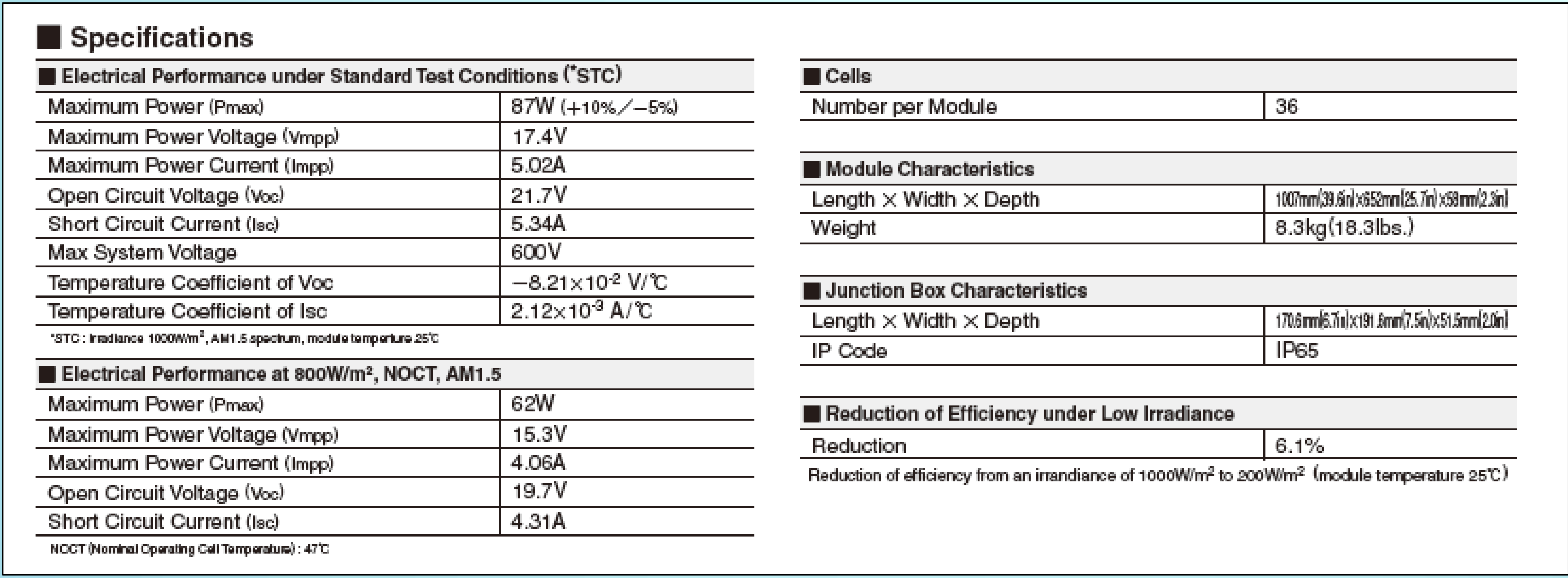
Pmax: 134.857308 Watts

Curve Calculations

Voltage	Current	Power	Resistance
0.00	7.200000	0.0000	0.00
0.23	7.200000	0.1620	0.03
0.45	7.200000	0.3240	0.06
0.68	7.200000	0.4860	0.09
0.90	7.200000	0.6480	0.13
1.13	7.200000	0.8100	0.16
1.35	7.200000	0.9720	0.19
1.58	7.200000	1.1340	0.22
1.80	7.200000	1.2960	0.25
2.03	7.200000	1.4580	0.28
2.25	7.200000	1.6200	0.31
2.48	7.200000	1.7820	0.34
2.70	7.200000	1.9440	0.38
2.93	7.200000	2.1060	0.41
3.15	7.200000	2.2680	0.44
3.38	7.200000	2.4300	0.47
3.60	7.200000	2.5920	0.50
3.83	7.200000	2.7540	0.53

PV Module Specifications

Kyocera KC85T 85W Module



■ Specifications

■ Electrical Performance under Standard Test Conditions (*STC)

Maximum Power (Pmax)	87W (+10%／−5%)
Maximum Power Voltage (Vmpp)	17.4V
Maximum Power Current (Impp)	5.02A
Open Circuit Voltage (Voc)	21.7V
Short Circuit Current (Isc)	5.34A
Max System Voltage	600V
Temperature Coefficient of Voc	-8.21×10^{-2} V/℃
Temperature Coefficient of Isc	2.12×10^{-3} A/℃

*STC : Irradiance 1000W/m², AM1.5 spectrum, module temperture 25℃

■ Electrical Performance at 800W/m², NOCT, AM1.5

Maximum Power (Pmax)	62W
Maximum Power Voltage (Vmpp)	15.3V
Maximum Power Current (Impp)	4.06A
Open Circuit Voltage (Voc)	19.7V
Short Circuit Current (Isc)	4.31A

NOCT (Nominal Operating Cell Temperature) : 47℃

■ Cells

Number per Module	36

■ Module Characteristics

Length × Width × Depth	1007mm(39.6in)×652mm(25.7in)×58mm(2.3in)
Weight	8.3kg(18.3lbs.)

■ Junction Box Characteristics

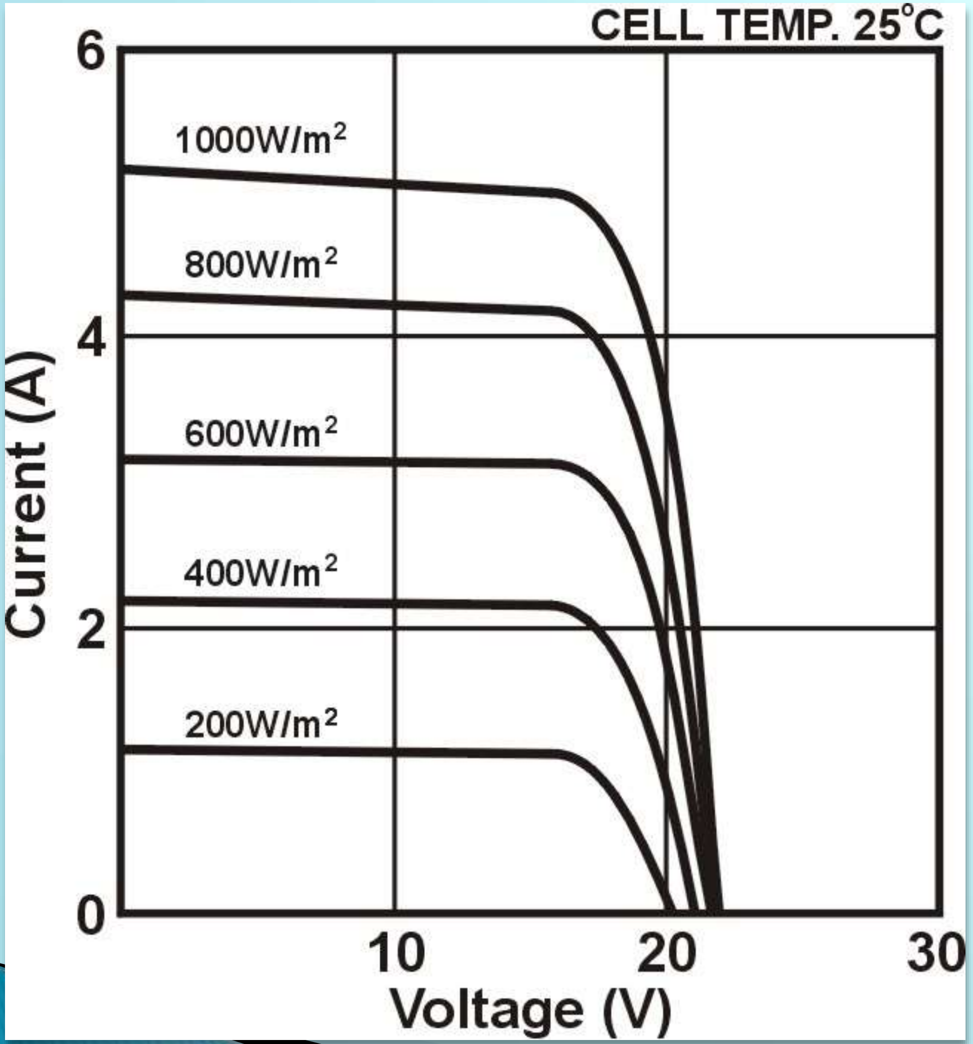
Length × Width × Depth	170.6mm(6.7in)×191.6mm(7.5in)×51.5mm(2.0in)
IP Code	IP65

■ Reduction of Efficiency under Low Irradiance

Reduction	6.1%

Reduction of efficiency from an irrandiance of 1000W/m² to 200W/m² (module temperature 25℃)

PV Current and Voltage at Various Irradiance Levels



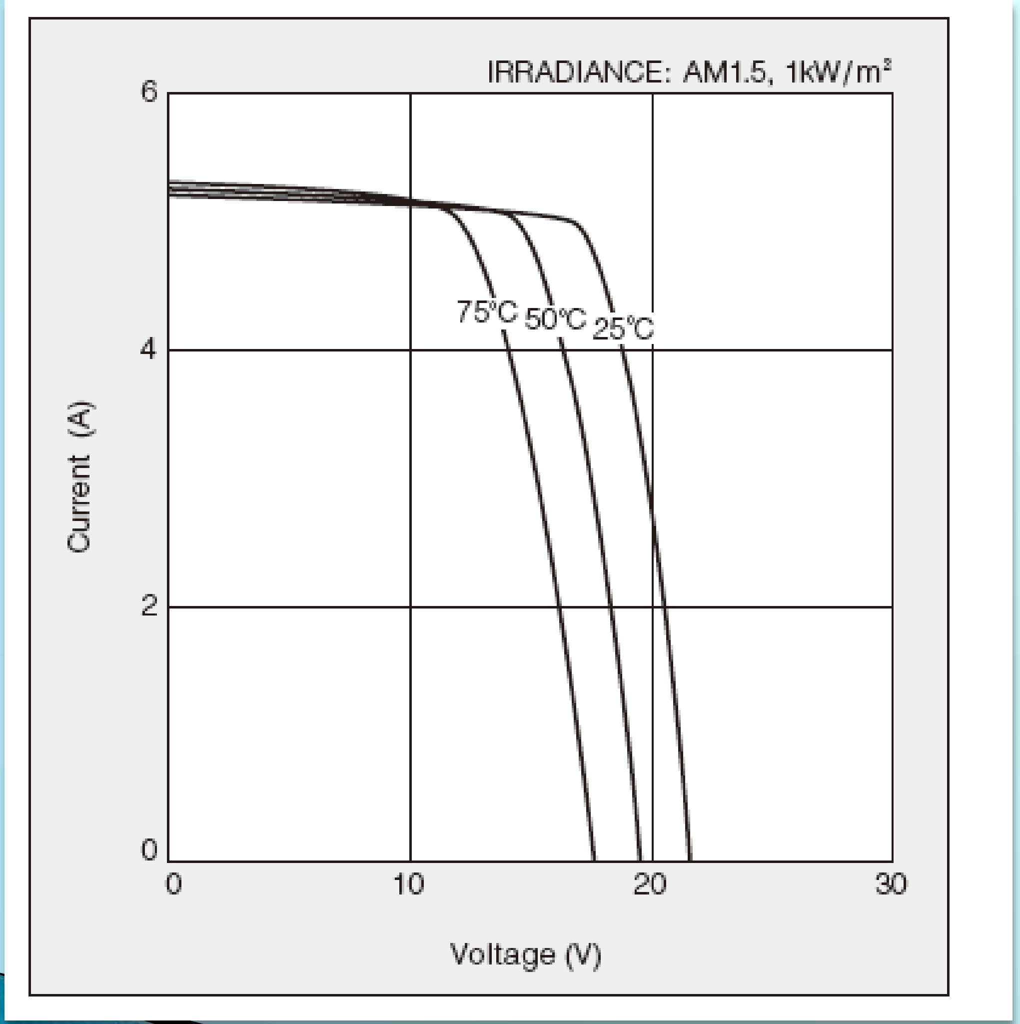
Some PV Characteristics:

•Short circuit current is proportional to solar intensity

•Open circuit voltage is relatively unaffected

•In low light conditions, the modules will have voltage but little current

PV Current and Voltage at Various PV Cell Temperatures



- As cell temperature increases, open circuit voltage decreases.

- Temperature coefficent = -8.21 x 10^{-2} V/ºC

Battery Backup

Some Battery Terms and Definitions:

Cell: Fundamental battery unit. A typical 12V battery has 6 cells of 2v each connected in series for a total of 12V.

Amp-Hour Capacity: the amount of charge in a fully charged battery. This is dependent on the discharge rate, usually stated in terms of hours using the “C” designation (C/100 = 100 hour capacity, C/20 = 20 hour capacity).

Depth of discharge (DOD): the amount (in percentage of capacity) that a battery is discharged. Can be determined by measuring the voltage or specific gravity.

State of charge (SOC): the inverse of DOD (= 100-DOD); the percentage of capacity remaining.

Cycle: One complete charge and discharge. The number of cycles available is dependent on frequency and depth of discharge.

Battery Backup Types

- Rural ITS and solar power in general require the lead-acid, deep cycle type of battery. It is constructed with thicker plates and designed for repeated deep discharge.
- Rural ITS devices require a back up battery that is robust, easily maintained, affordable, and able to withstand repeated cycles of deep discharge (50% to 80%).

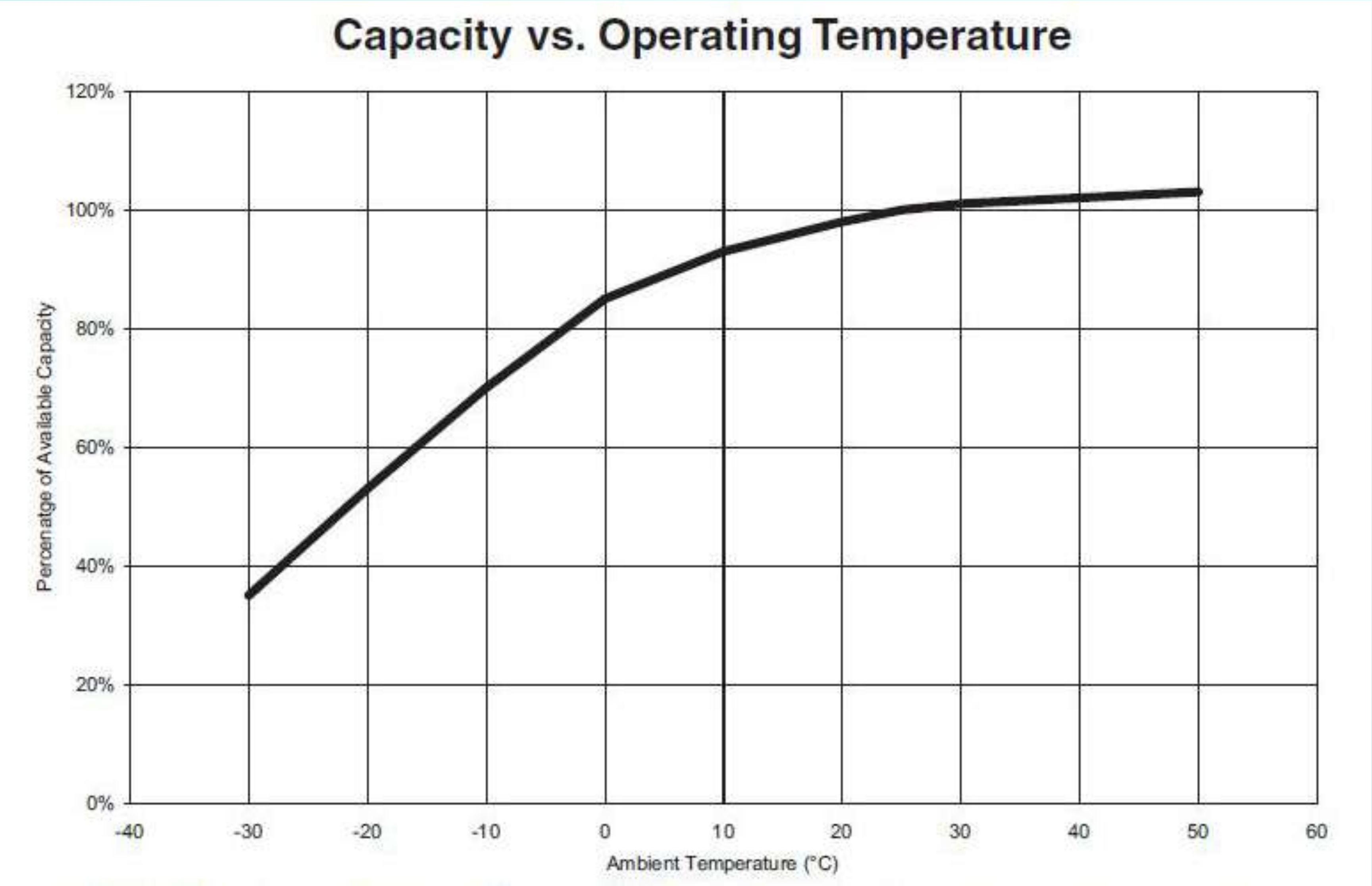
Three main type of deep cycle lead-acid batteries:

1. **Flooded (wet):** original type. Very reliable and economical. Require regular maintenance to maintain water levels. Must be stored in a well ventilated enclosure. Can be used for rural ITS as long as temperatures are not too extreme.
2. **Gelled (gel cells):** Electrolyte is “gelled” to prevent spilling. Require less maintenance but have much higher initial cost. Must be charged at a lower rate than conventional flooded batteries.
3. **AGM (Absorbed Glass Mat):** Utilize a Boron-Silicate glass mat between the plates. Better suited to low temperature environments (will not freeze). Low maintenance since there is little to no water loss. Cost is comparable to gel cells but with better performance. Much lower ventilation requirements; can be stored in ground enclosures.

Temperature Effect on Battery Capacity

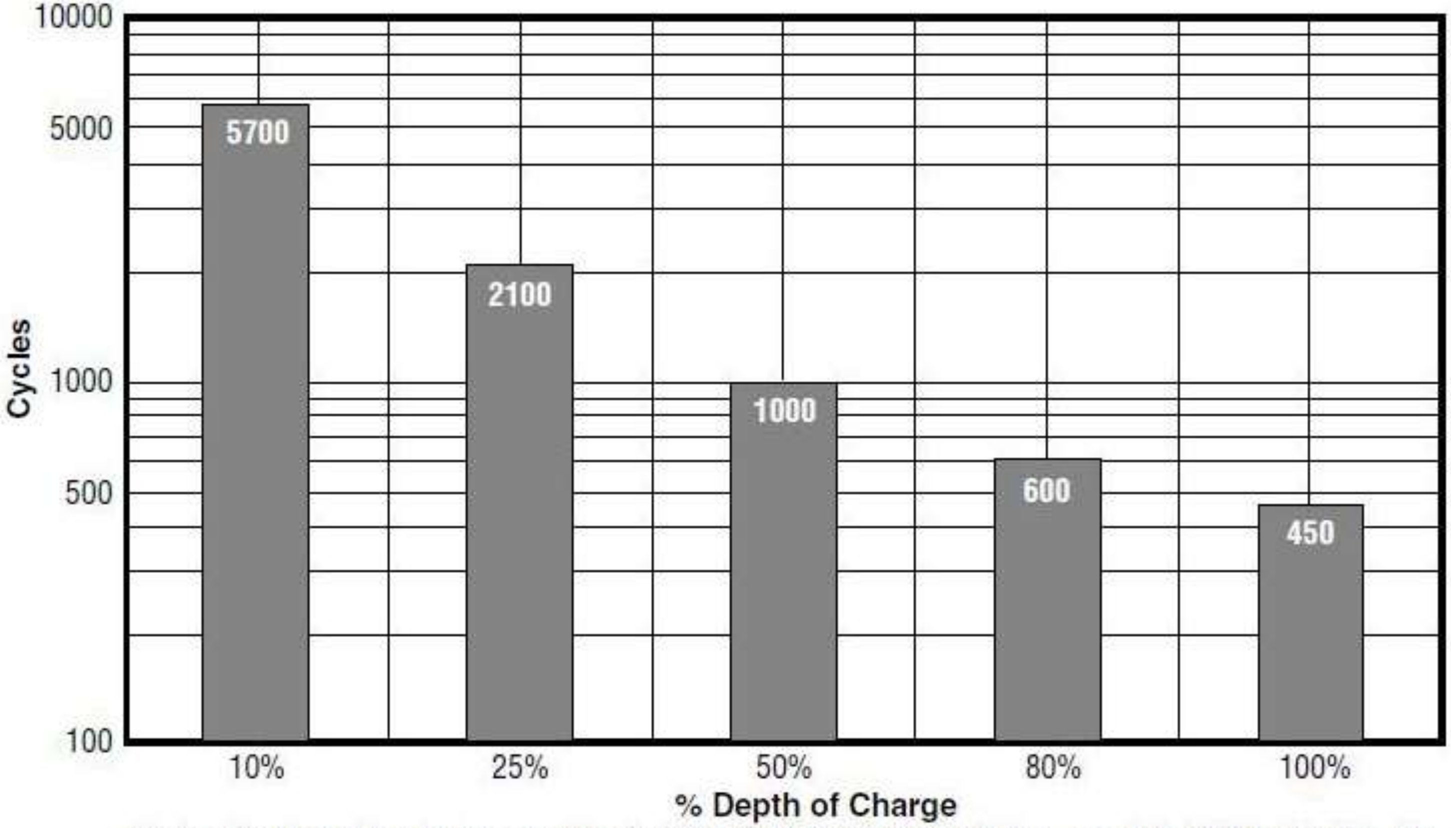
Solar Deka 8G4D Sealed Gel Cell

Use to derate battery in cold climates



Battery Cycle Life vs. Depth of Discharge

Solar Deka 8G4D Sealed Gel Cell



Gel Cycle Life vs Depth of Discharge at +25°C (77°F)*
Based on BCI 2-hour Capacity

Cycle Chart applies to types with similiar design characteristics, ex., U1, 22NF, 24, 27, 31.

The solar battery excels in cycling applications.

**Dependent upon proper charging and ambient temperatures.*

Solar Charge Controllers

The charge controller regulates the voltage and current sent to the backup batteries. Deep cycle lead-acid batteries require a 3 step charging process to correctly charge these type of batteries. A properly configured charge controller will improve the performance and extend the lifetime of the batteries. A charge controller is not always needed but highly recommended for any rural ITS installation.

Three types of charge controllers:

- **1-2 Stage (float)**: Very simple and reliable. Operation is to either short (no volts) or disconnect (no current) the PV modules upon reaching a “float” voltage level. Not used for newer systems, but found in older installations.

- **3-stage**: Typically microprocessor controlled charging process in 3 stages:

1) Bulk: Constant current applied to restore 80% of rated capacity.

2) Absorption: Voltage held constant with gradually reducing current to restore remaining 20% rated charge.

3) Float: Voltage lowered to “float” level (13.5v) and held constant to keep the battery at full charge without overcharging. Some 3-stage controllers use PWM (pulse width modulation) during the float stage (more efficient, voltage applied in short burst when needed).

Graph of 3 Stage Charging for Deep Cycle Batteries

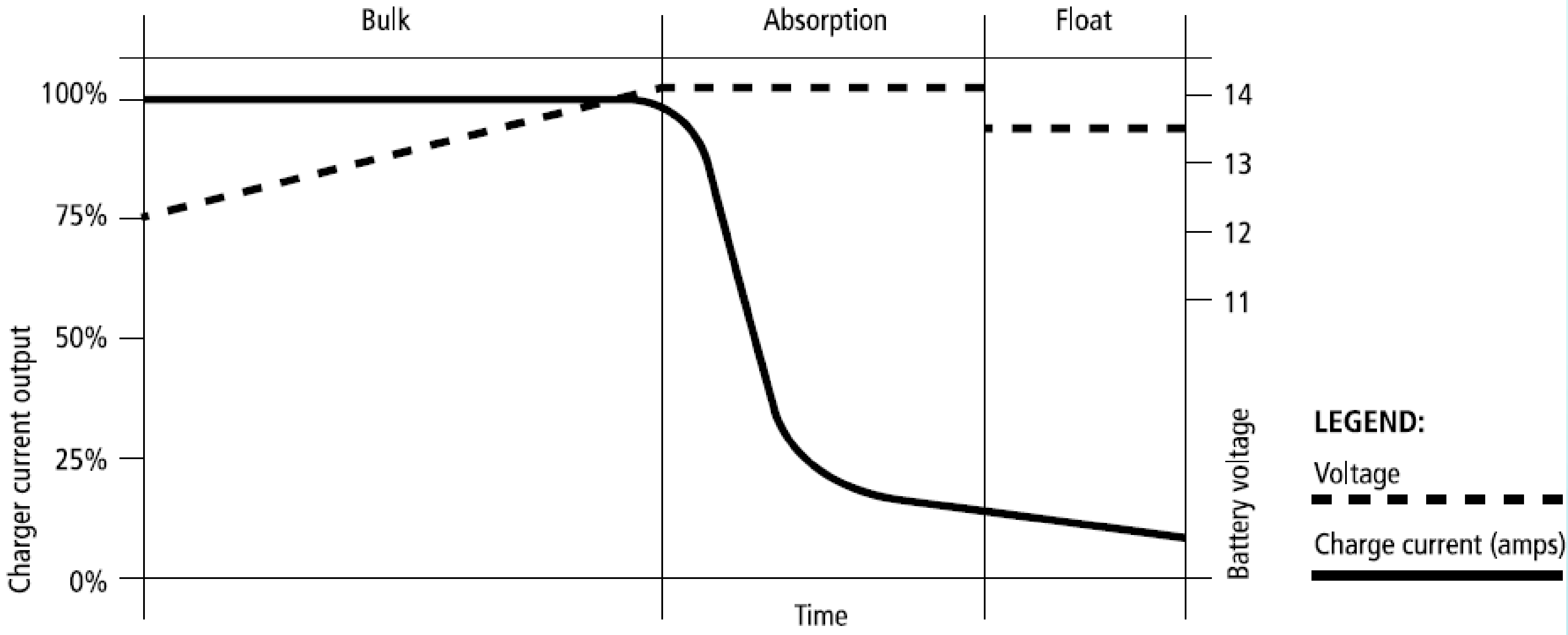


Figure 1: Three-Stage Charging Algorithm

Solar Charge Controllers

- **Maximum Power Point Tracking (MPPT):** Charges the battery just like a three stage charger except it contains circuitry to track the maximum power point PV module thereby making the most effective use of the PV rated power output. Downside is the cost, so may only be justified for locations with low PV output or colder climates.

How MPPT works:

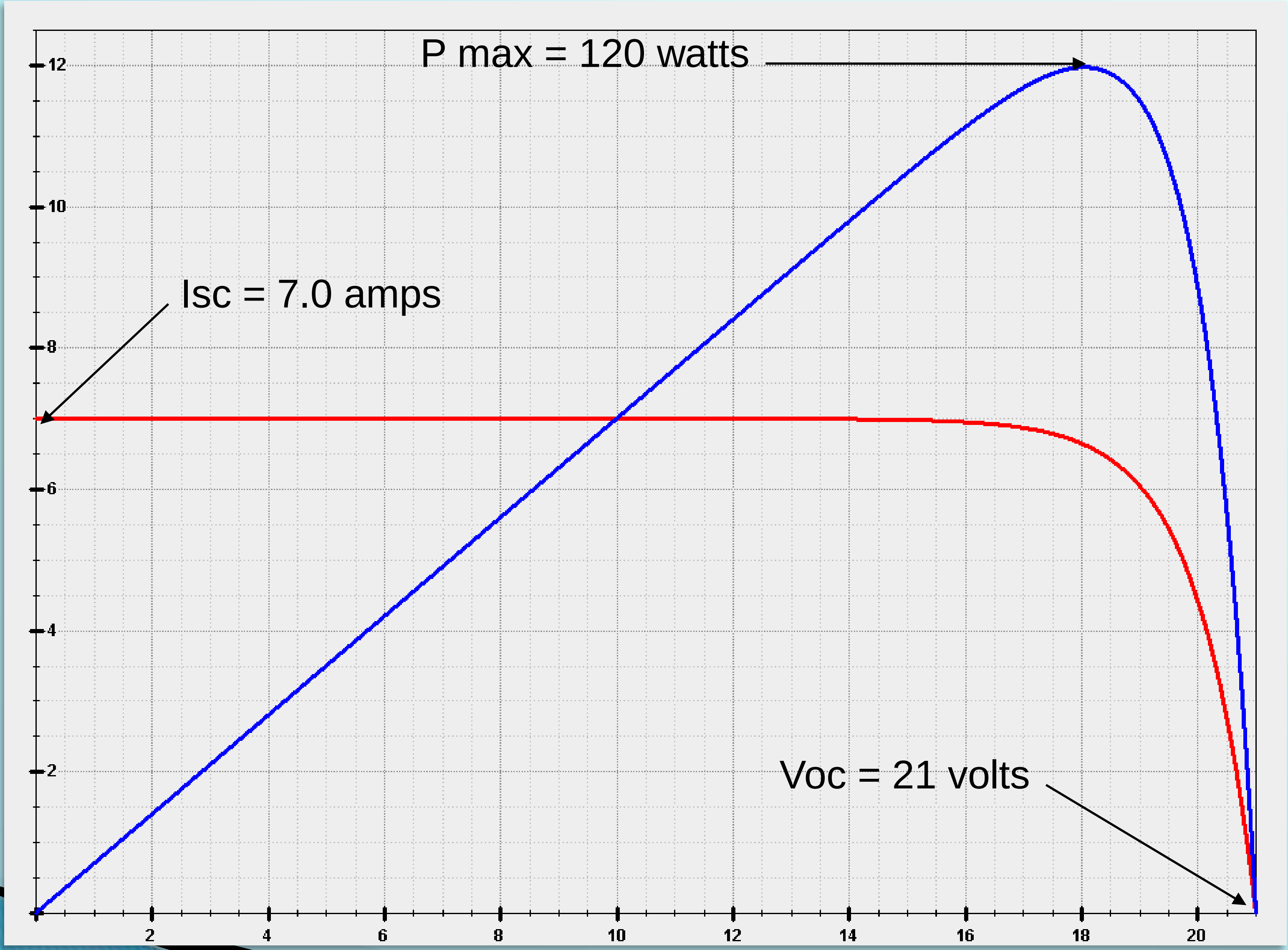
- The MPPT controller operates by adjusting the loading to the PV module so that it is operating at the maximum power point. The controller (using a high frequency DC-DC converter) converts the voltage down to the battery level, while increasing the current to maintain the maximum power level.

- Referring to the power curve (next slide), a typical charger will operate at 12v (to charge the battery). With a current of around 7 amps, the power is 84 watts, well below the 120 watt power rating of the PV module.

- The controller will pull current from the module at the optimal operating point of 18v, with a power output just below the rated maximum (90% to 95% efficiency) The controller adjusts to changes in the maximum power point due to temperature and insolation changes.

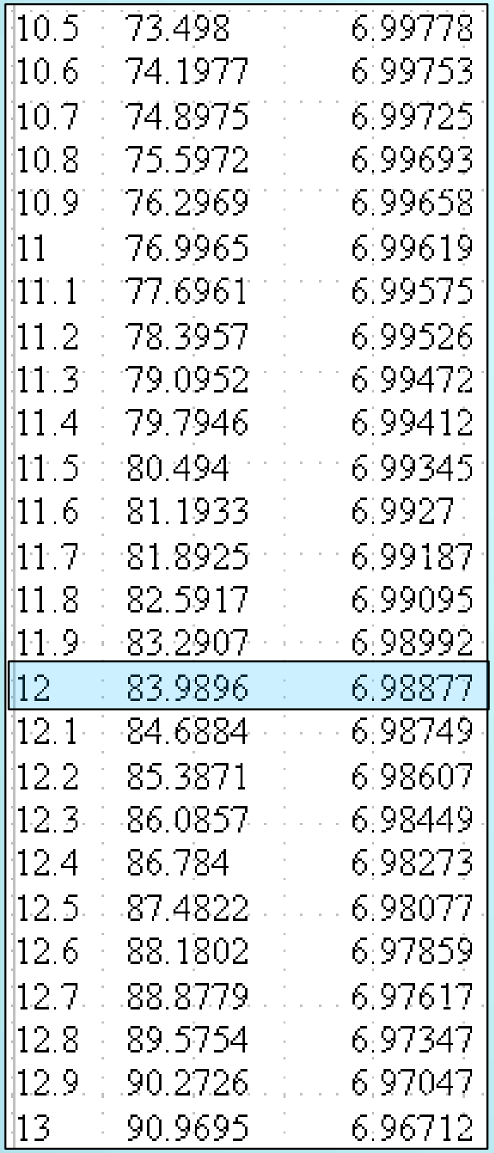
PV Current-Voltage with Power Curve

Current is constant from v=0 to 16

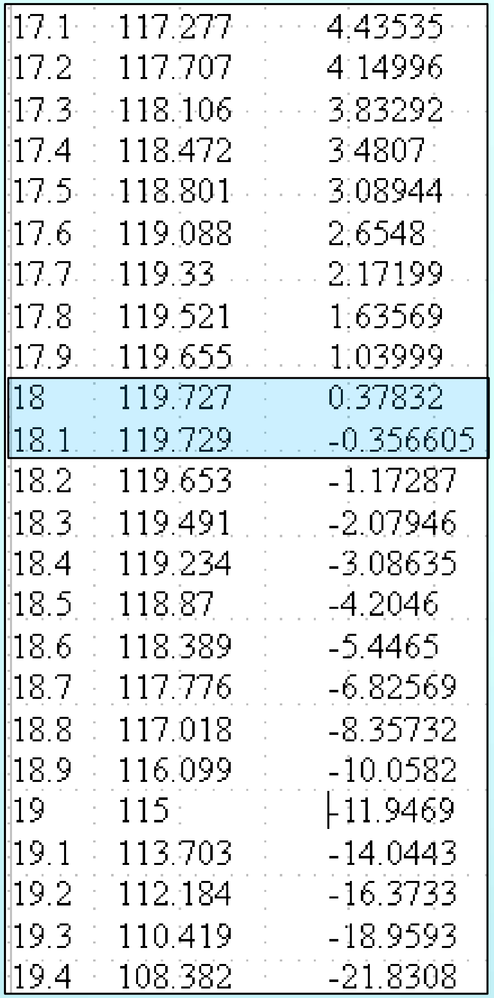


Power Curve Function Value Table

Power at 12 volt point



v	w	dw
10.5	73.498	6.99778
10.6	74.1977	6.99753
10.7	74.8975	6.99725
10.8	75.5972	6.99693
10.9	76.2969	6.99658
11	76.9965	6.99619
11.1	77.6961	6.99575
11.2	78.3957	6.99526
11.3	79.0952	6.99472
11.4	79.7946	6.99412
11.5	80.494	6.99345
11.6	81.1933	6.9927
11.7	81.8925	6.99187
11.8	82.5917	6.99095
11.9	83.2907	6.98992
12	83.9896	6.98877
12.1	84.6884	6.98749
12.2	85.3871	6.98607
12.3	86.0857	6.98449
12.4	86.784	6.98273
12.5	87.4822	6.98077
12.6	88.1802	6.97859
12.7	88.8779	6.97617
12.8	89.5754	6.97347
12.9	90.2726	6.97047
13	90.9695	6.96712



v	w	dw
17.1	117.277	4.43535
17.2	117.707	4.14996
17.3	118.106	3.83292
17.4	118.472	3.4807
17.5	118.801	3.08944
17.6	119.088	2.6548
17.7	119.33	2.17199
17.8	119.521	1.63569
17.9	119.655	1.03999
18	119.727	0.37832
18.1	119.729	-0.356605
18.2	119.653	-1.17287
18.3	119.491	-2.07946
18.4	119.234	-3.08635
18.5	118.87	-4.2046
18.6	118.389	-5.4465
18.7	117.776	-6.82569
18.8	117.018	-8.35732
18.9	116.099	-10.0582
19	115	-11.9469
19.1	113.703	-14.0443
19.2	112.184	-16.3733
19.3	110.419	-18.9593
19.4	108.382	-21.8308

Maximum Power Point, dw/dv = 0

Design Method and Calculations

Design Standards:

- National Electrical Code (NEC Section 690)
- Sandia National Laboratories (SNL)
- Electrotechnical Commission (IEC)
- Institute of Electrical and Electronic Engineers (IEEE)
- United Laboratories (UL)

Calculate the system parameters:

1) Load requirements
2) Design current
3) Battery size and quantity
4) Array size

Example Location for Design Calcs

Description: Design a stand-alone PV system with battery backup for a Road Weather Information System utilizing the EDACS 800 MHz communication system.

PV System Location: Goldfield Summit, NV. N 37.68, W 117.23, Elev. 6040

NREL Solar Data Location: Tonopah, NV. N 38.04, W 117.07, Elev 5920

Climate data: www.wrcc.dri.edu/

January Average High/Low: 41/20. Record High/Low: 65/-7

July Average High/Low: 89/61. Record High/Low: 105/43

Average number of days below 32 (January): 29

Average number of days above 90 (July): 16

Load Requirements:

RWIS ROSA Controller and sensors: 72 watts, 24 VDC, active 24 hours, 7 days.

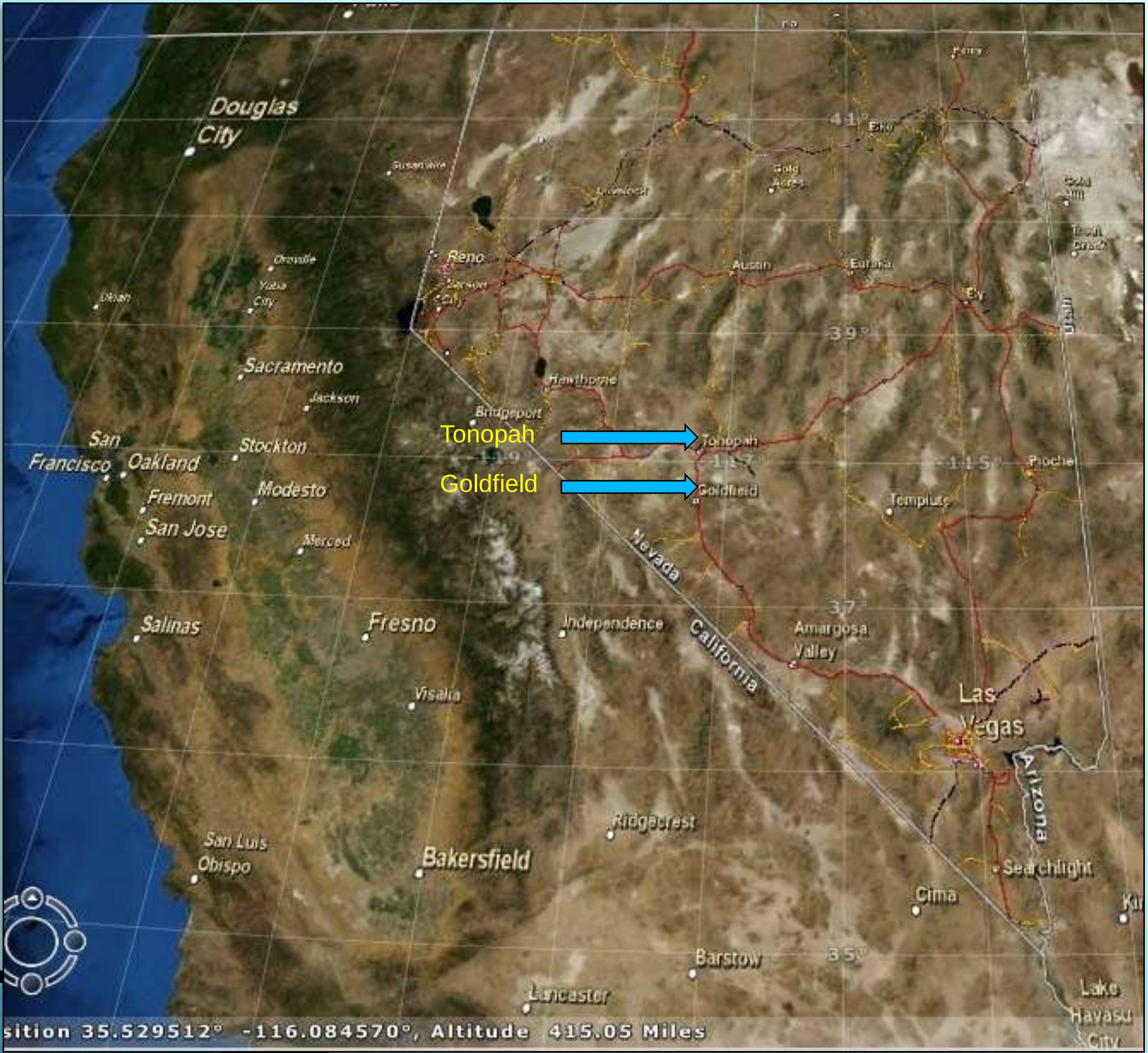
EDACS (800 MHz radio):

Transmit: 180 watts, 12 VDC, 10 seconds every 10 minutes (0.4 hours per day, 7 days)

Receive: 26.4 watts, 12 VDC, 10 seconds every 10 minutes (0.4 hours per day, 7 days)

Standby: 9.6 watts, 12 VDC, 580 seconds every 10 minutes (23.2 hours per day, 7 days)

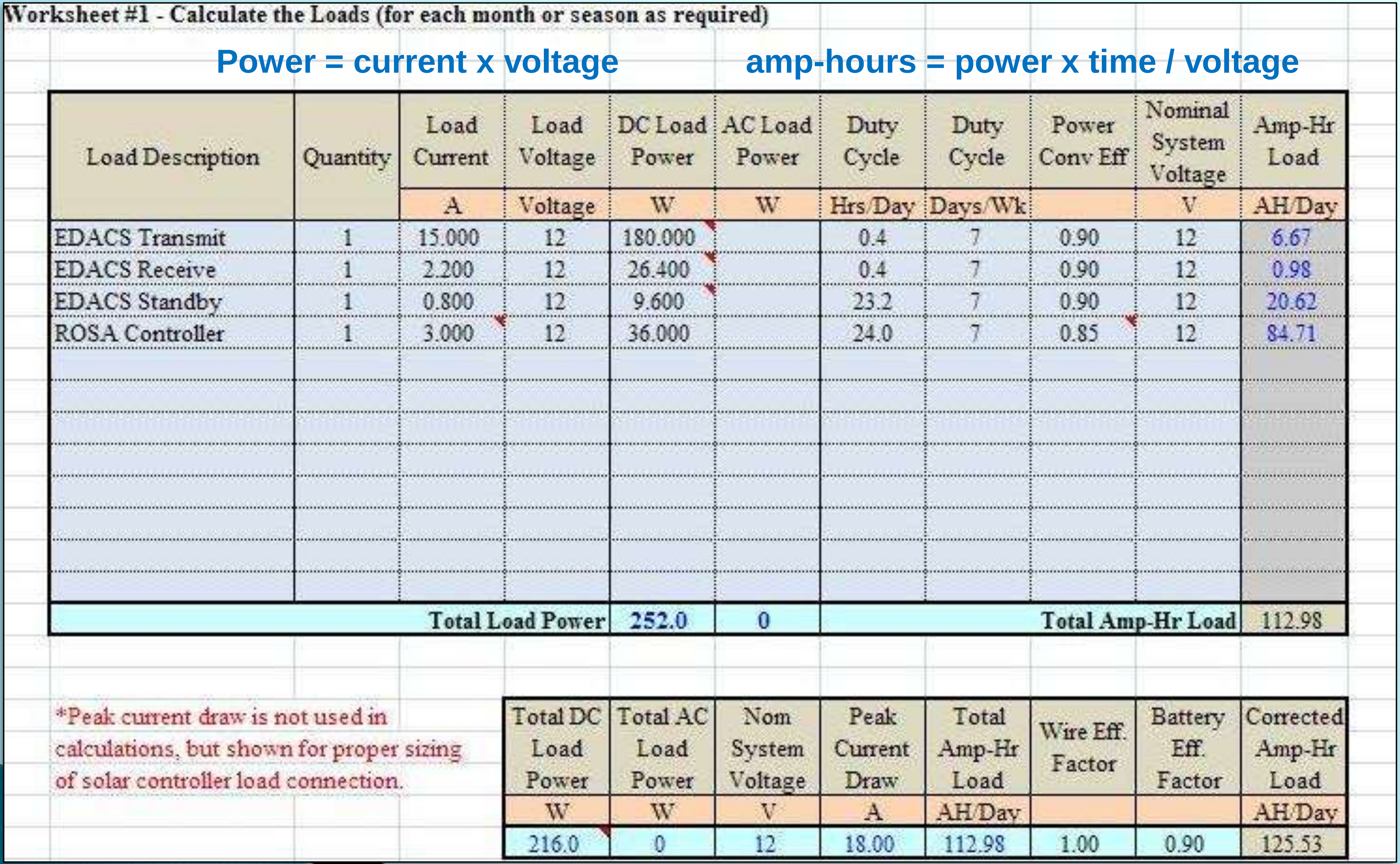
Location Map for Design Example
ArcGIS



Load Calculation Method

1) List each component of the load and power consumption.
2) List AC and DC separately.
3) Calculate Power = current x voltage (P=I x E).
4) Duty cycle: average number of hours per day that the load is active.
5) Power conversion efficiency: Account for battery, controller, and inverter losses. This increases the load requirements.
6) Nominal PV system voltage: 12V or 24V typical.
7) Convert power (watts) to amp-hours (Ah). This will be used to calculate required battery storage and PV array size.
8) Amp-hour (Ah) load: Power / voltage x duty cycle = amp-hours. This quantity is used to determine the size and quantity of the system backup batteries.
9) Amp-hour is a measure of charge. The amp-hour is equivalent to 3,600 coulombs (SI unit) of charge (1 coulomb/sec *3,600 sec/hour). One amp-hour is equivalent to 1 amp of current for one hour; 2 amps for 30 minutes; 0.5 amps for 2 hours, etc. A 100 Ah battery will supply 20 amps of current for 5 hours.

Load Calculation Worksheet



Worksheet #1 - Calculate the Loads (for each month or season as required)

Power = current x voltage **amp-hours = power x time / voltage**

Load Description	Quantity	Load Current	Load Voltage	DC Load Power	AC Load Power	Duty Cycle	Duty Cycle	Power Conv Eff	Nominal System Voltage	Amp-Hr Load
		A	Voltage	W	W	Hrs/Day	Days/Wk		V	AH/Day
EDACS Transmit	1	15.000	12	180.000		0.4	7	0.90	12	6.67
EDACS Receive	1	2.200	12	26.400		0.4	7	0.90	12	0.98
EDACS Standby	1	0.800	12	9.600		23.2	7	0.90	12	20.62
ROSA Controller	1	3.000	12	36.000		24.0	7	0.85	12	84.71
			Total Load Power	252.0	0				Total Amp-Hr Load	112.98

*Peak current draw is not used in calculations, but shown for proper sizing of solar controller load connection.

Total DC Load Power	Total AC Load Power	Nom System Voltage	Peak Current Draw	Total Amp-Hr Load	Wire Eff. Factor	Battery Eff. Factor	Corrected Amp-Hr Load
W	W	V	A	AH/Day			AH/Day
216.0	0	12	18.00	112.98	1.00	0.90	125.53

Calculate Design Current and PV Module Tilt

- Design current is used to determine the size and number of PV modules to be used in the PV array.

- Design current is found by taking the average load demand (Ah) and dividing by the peak solar hours for each month. In some cases the load will vary by month.

- Calculations are done at three array tilts:

Latitude -15º: Optimal tilt during the winter.
Latitude: Optimal tilt at equinox (or year round average)
Latitude +15º: Optimal tilt during the summer.

<u>Calculation Steps</u>:

1. List the expected load (Ah/day) and Peak Sun Hours/Day (Use NREL data for nearest location if local data not available) for each month/tilt. Divide the load by peak sun hours for each month/tilt to determine the corresponding design current.

2. Select the worst case (highest) design current for each tilt (usually in December).

3. Select the array tilt with the lowest design current (usually +15º for non-varying loads).

4. This will be the optimal array tilt and the magnitude of current needed from the PV array for the design load.

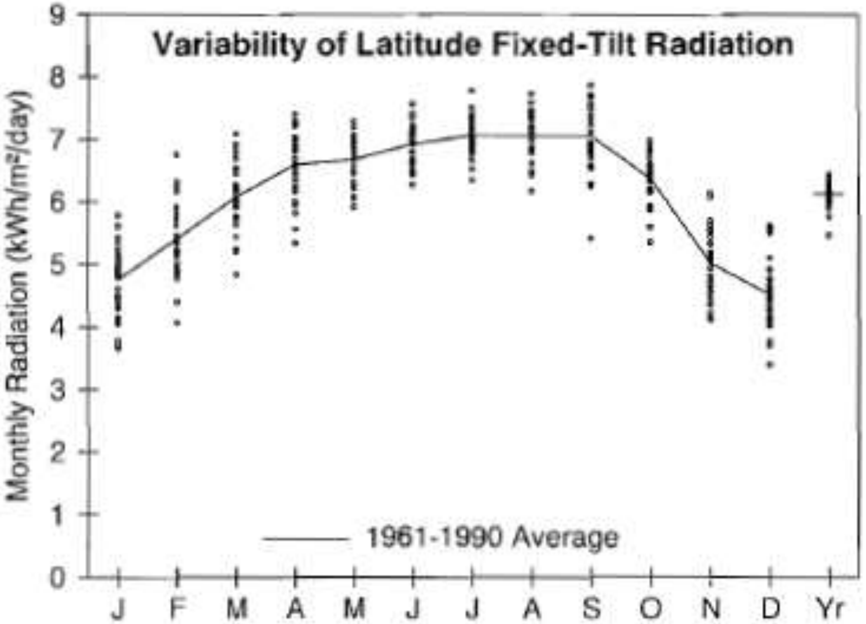
Solar Insolation Data for Tonopah, NV
www.nrel.gov
NREL Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors

Tonopah, NV

WBAN NO. 23153

LATITUDE: 38.07° N
LONGITUDE: 117.13° W
ELEVATION: 1653 meters
MEAN PRESSURE: 834 millibars

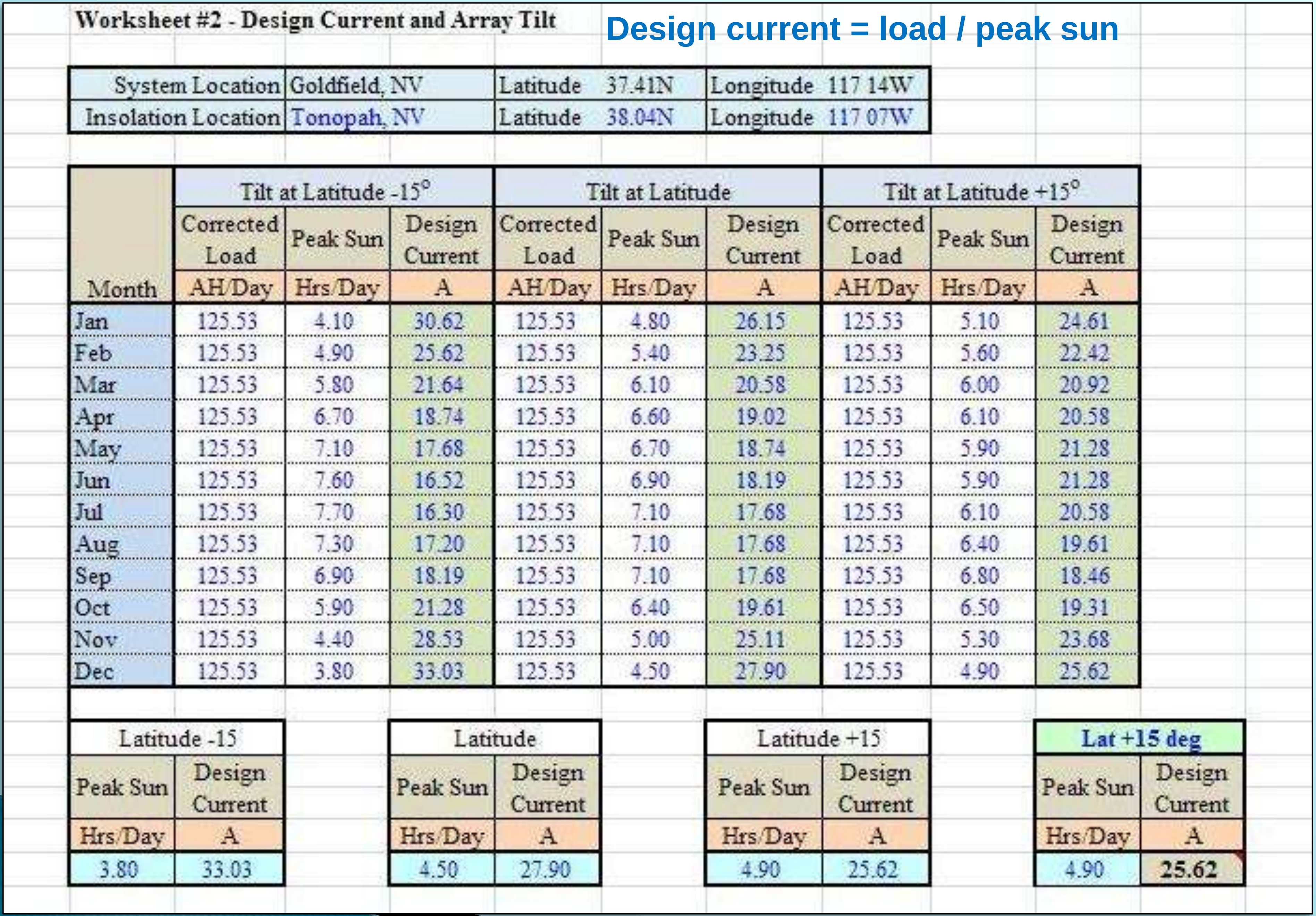
STATION TYPE: Secondary



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	2.7	3.6	4.8	6.2	7.1	7.9	7.8	7.0	5.9	4.4	3.0	2.4	5.2
	Min/Max	2.3/3.0	2.9/4.2	4.0/5.5	5.2/6.8	6.3/7.8	7.1/8.6	6.9/8.6	6.1/7.6	4.7/6.5	3.9/4.7	2.6/3.4	2.0/2.8	4.8/5.4
Latitude -15	Average	4.1	4.9	5.8	6.7	7.1	7.6	7.7	7.3	6.9	5.9	4.4	3.8	6.0
	Min/Max	3.2/4.9	3.8/6.0	4.7/6.7	5.5/7.5	6.3/7.8	6.9/8.3	6.8/8.4	6.4/8.0	5.4/7.7	5.0/6.4	3.7/5.3	3.0/4.7	5.4/6.3
Latitude	Average	4.8	5.4	6.1	6.6	6.7	6.9	7.1	7.1	7.1	6.4	5.0	4.5	6.1
	Min/Max	3.7/5.8	4.1/6.8	4.8/7.1	5.3/7.4	5.9/7.3	6.3/7.6	6.3/7.8	6.2/7.7	5.4/7.9	5.4/7.0	4.1/6.1	3.4/5.6	5.5/6.4
Latitude +15	Average	5.1	5.6	6.0	6.1	5.9	5.9	6.1	6.4	6.8	6.5	5.3	4.9	5.9
	Min/Max	3.9/6.3	4.2/7.1	4.7/7.0	4.9/6.9	5.2/6.4	5.4/6.4	5.5/6.7	5.6/7.0	5.2/7.6	5.4/7.2	4.3/6.6	3.6/6.2	5.2/6.2
90	Average	4.7	4.8	4.4	3.7	2.9	2.6	2.8	3.5	4.6	5.2	4.8	4.6	4.0
	Min/Max	3.5/5.9	3.4/6.0	3.4/5.1	3.0/4.1	2.7/3.1	2.4/2.7	2.6/2.9	3.2/3.7	3.5/5.1	4.3/5.8	3.8/6.0	3.3/5.9	3.5/4.3

Design Current Worksheet



Design current = load / peak sun

Worksheet #2 - Design Current and Array Tilt

System Location	Goldfield, NV	Latitude 37.41N	Longitude 117 14W
Insolation Location	Tonopah, NV	Latitude 38.04N	Longitude 117 07W

Month	Tilt at Latitude -15°			Tilt at Latitude			Tilt at Latitude +15°		
	Corrected Load	Peak Sun	Design Current	Corrected Load	Peak Sun	Design Current	Corrected Load	Peak Sun	Design Current
	AH/Day	Hrs/Day	A	AH/Day	Hrs/Day	A	AH/Day	Hrs/Day	A
Jan	125.53	4.10	30.62	125.53	4.80	26.15	125.53	5.10	24.61
Feb	125.53	4.90	25.62	125.53	5.40	23.25	125.53	5.60	22.42
Mar	125.53	5.80	21.64	125.53	6.10	20.58	125.53	6.00	20.92
Apr	125.53	6.70	18.74	125.53	6.60	19.02	125.53	6.10	20.58
May	125.53	7.10	17.68	125.53	6.70	18.74	125.53	5.90	21.28
Jun	125.53	7.60	16.52	125.53	6.90	18.19	125.53	5.90	21.28
Jul	125.53	7.70	16.30	125.53	7.10	17.68	125.53	6.10	20.58
Aug	125.53	7.30	17.20	125.53	7.10	17.68	125.53	6.40	19.61
Sep	125.53	6.90	18.19	125.53	7.10	17.68	125.53	6.80	18.46
Oct	125.53	5.90	21.28	125.53	6.40	19.61	125.53	6.50	19.31
Nov	125.53	4.40	28.53	125.53	5.00	25.11	125.53	5.30	23.68
Dec	125.53	3.80	33.03	125.53	4.50	27.90	125.53	4.90	25.62

Latitude -15	
Peak Sun	Design Current
Hrs/Day	A
3.80	33.03

Latitude	
Peak Sun	Design Current
Hrs/Day	A
4.50	27.90

Latitude +15	
Peak Sun	Design Current
Hrs/Day	A
4.90	25.62

Lat +15 deg	
Peak Sun	Design Current
Hrs/Day	A
4.90	**25.62**

Battery Size and Quantity

Parameters used to determine size and quantity:

1. Daily load requirement (Ah/day)
2. Required autonomy (Number of days without PV output)
3. Rated battery capacity (Ah)
4. System voltage (12v or 24v typical)
5. Maximum depth of discharge (DOD)
6. Minimum and maximum temperatures

Battery Size and Number

Design Calculation Parameters

Entered Quantities:

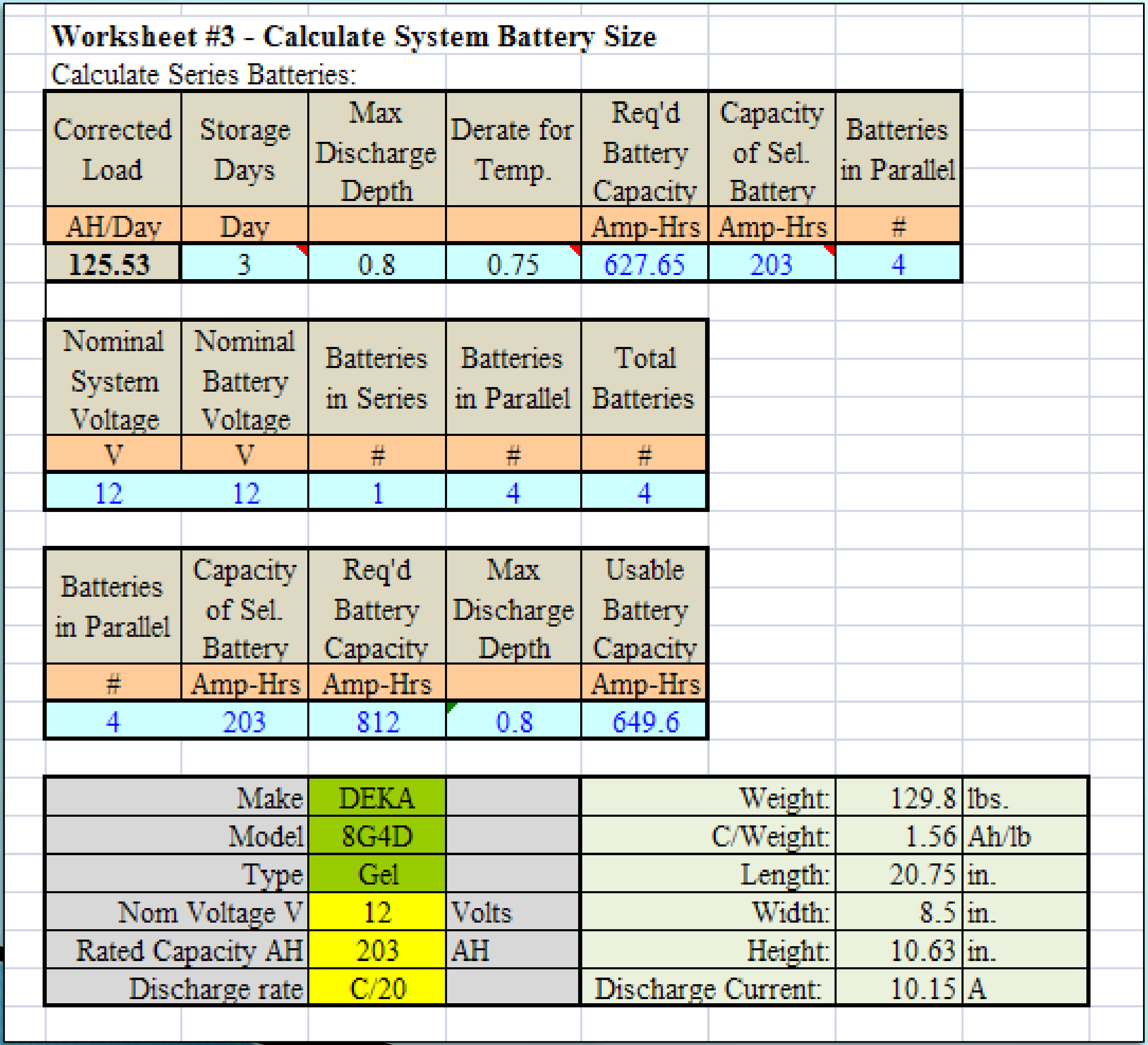
- **Calculated load**: from the load calculations (Ah/day)
- **Autonomous (storage) day**: This depends on equipment requirements, local climate, and the type of battery.
- **Maximum depth of discharge**: Recommend from 0.5 to 0.8.
- **Derate for temperature**: If sub-freezing temperatures are expected (usually between 0.75 and 0.90).

Calculated quantities:

- **Required battery capacity**: The daily load amp-hours x storage days / DOD / temperature derate.
- **Number of parallel batteries**: Required amp-hours / rated battery capacity. Battery currents add in parallel.
- **Number of series batteries**: System voltage / battery voltage. Battery voltages add in series.

Battery Calculation Worksheet

DEKA 8G4D 203 Ah C/20



Worksheet #3 - Calculate System Battery Size

Calculate Series Batteries:

Corrected Load	Storage Days	Max Discharge Depth	Derate for Temp.	Req'd Battery Capacity	Capacity of Sel. Battery	Batteries in Parallel
AH/Day	Day			Amp-Hrs	Amp-Hrs	#
125.53	3	0.8	0.75	627.65	203	4

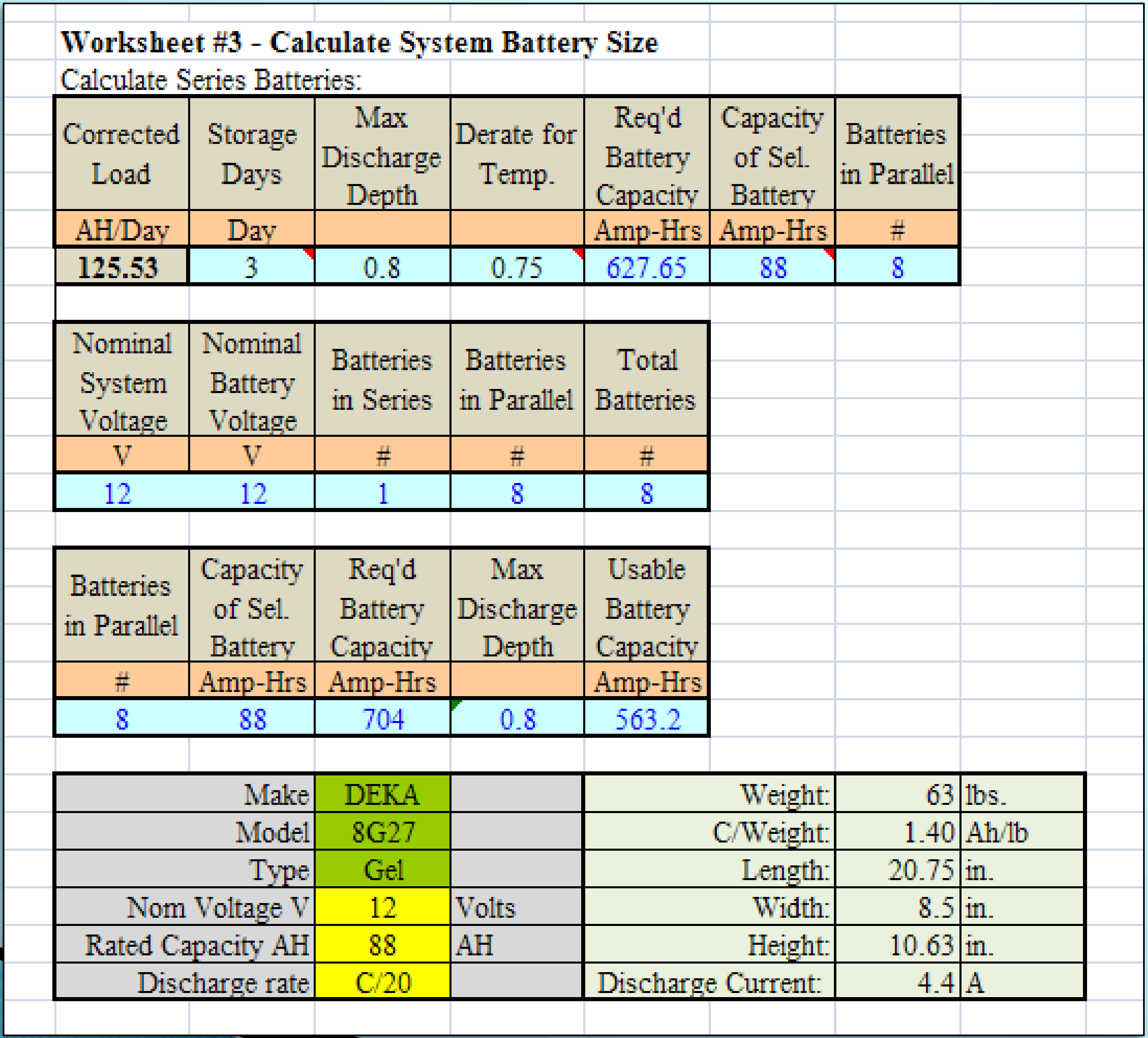
Nominal System Voltage	Nominal Battery Voltage	Batteries in Series	Batteries in Parallel	Total Batteries
V	V	#	#	#
12	12	1	4	4

Batteries in Parallel	Capacity of Sel. Battery	Req'd Battery Capacity	Max Discharge Depth	Usable Battery Capacity
#	Amp-Hrs	Amp-Hrs		Amp-Hrs
4	203	812	0.8	649.6

Make	DEKA		Weight:	129.8	lbs.
Model	8G4D		C/Weight:	1.56	Ah/lb
Type	Gel		Length:	20.75	in.
Nom Voltage V	12	Volts	Width:	8.5	in.
Rated Capacity AH	203	AH	Height:	10.63	in.
Discharge rate	C/20		Discharge Current:	10.15	A

Battery Calculation Worksheet

DEKA 8G27 88 Ah C/20



Worksheet #3 - Calculate System Battery Size

Calculate Series Batteries:

Corrected Load	Storage Days	Max Discharge Depth	Derate for Temp.	Req'd Battery Capacity	Capacity of Sel. Battery	Batteries in Parallel
AH/Day	Day			Amp-Hrs	Amp-Hrs	#
125.53	3	0.8	0.75	627.65	88	8

Nominal System Voltage	Nominal Battery Voltage	Batteries in Series	Batteries in Parallel	Total Batteries
V	V	#	#	#
12	12	1	8	8

Batteries in Parallel	Capacity of Sel. Battery	Req'd Battery Capacity	Max Discharge Depth	Usable Battery Capacity
#	Amp-Hrs	Amp-Hrs		Amp-Hrs
8	88	704	0.8	563.2

Make	DEKA		Weight:	63	lbs.
Model	8G27		C/Weight:	1.40	Ah/lb
Type	Gel		Length:	20.75	in.
Nom Voltage V	12	Volts	Width:	8.5	in.
Rated Capacity AH	88	AH	Height:	10.63	in.
Discharge rate	C/20		Discharge Current:	4.4	A

Battery Backup
Estimating Capacity at various discharge rates

:

The rated discharge rate of deep cycle batteries varies with the discharge rate. This is an important consideration when entering the rated battery capacity in the calculations. Most manufacturers will provide a graph or table of the rated capacity at several discharge rate. This can also be estimated from an equation known as Peuker's Law

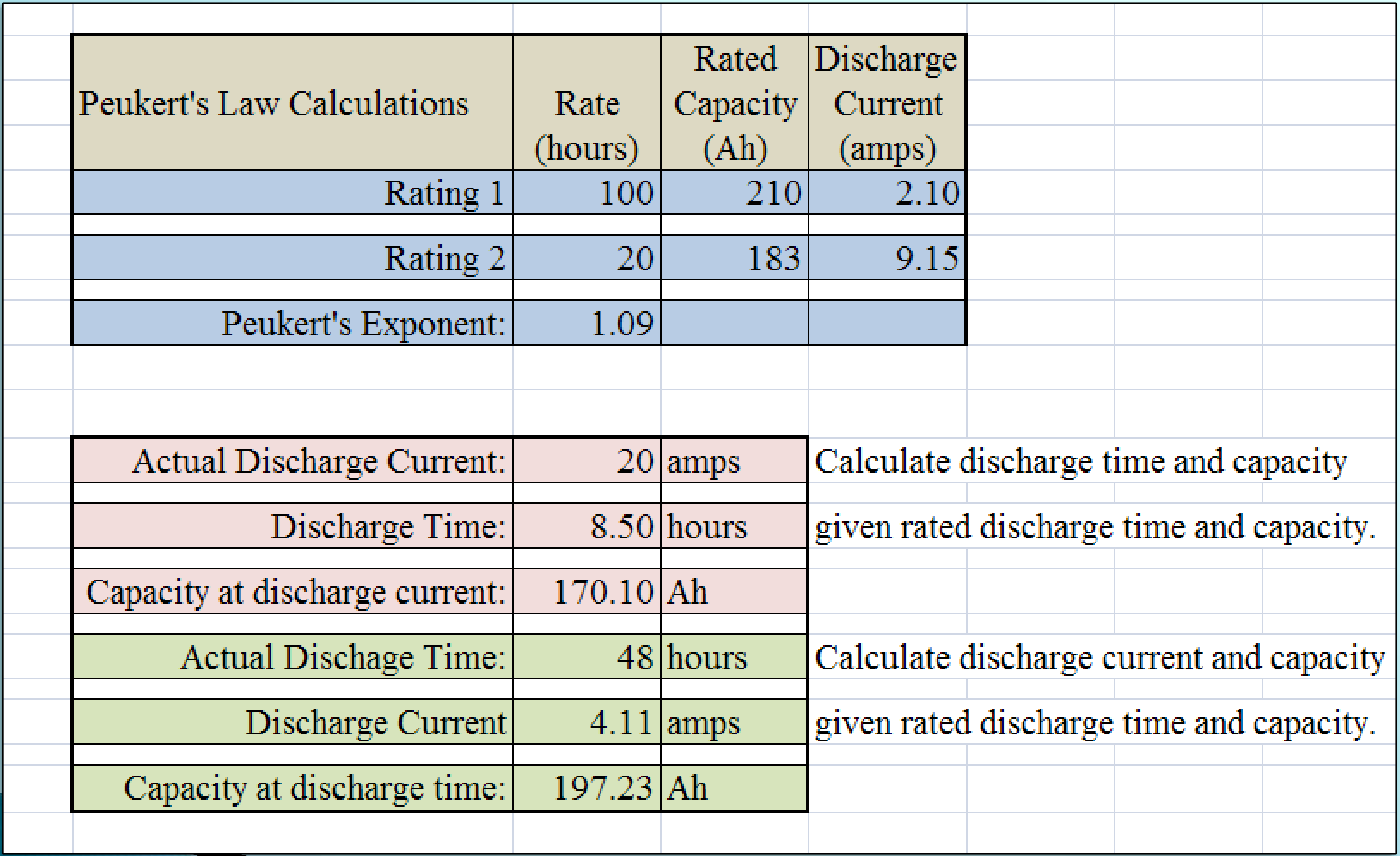
Peuker's Law: Most batteries capacity is based on slow discharge rate (24 hours for a 120 Ah battery would be 0.5 A per hour). The actual capacity decreases as the discharge rate increases. The equation is:

$$I \times t = C \times (C/(I \times H))^{(k-1)}$$

Where C =rated capacity for discharge time of H

The exponent k = 1.1 to 1.3 and can be determined from the battery's rated capacity at two different discharge rates. This can be used to extrapolate the value at various current draw levels.

Peukert’s Law for Battery Capacity



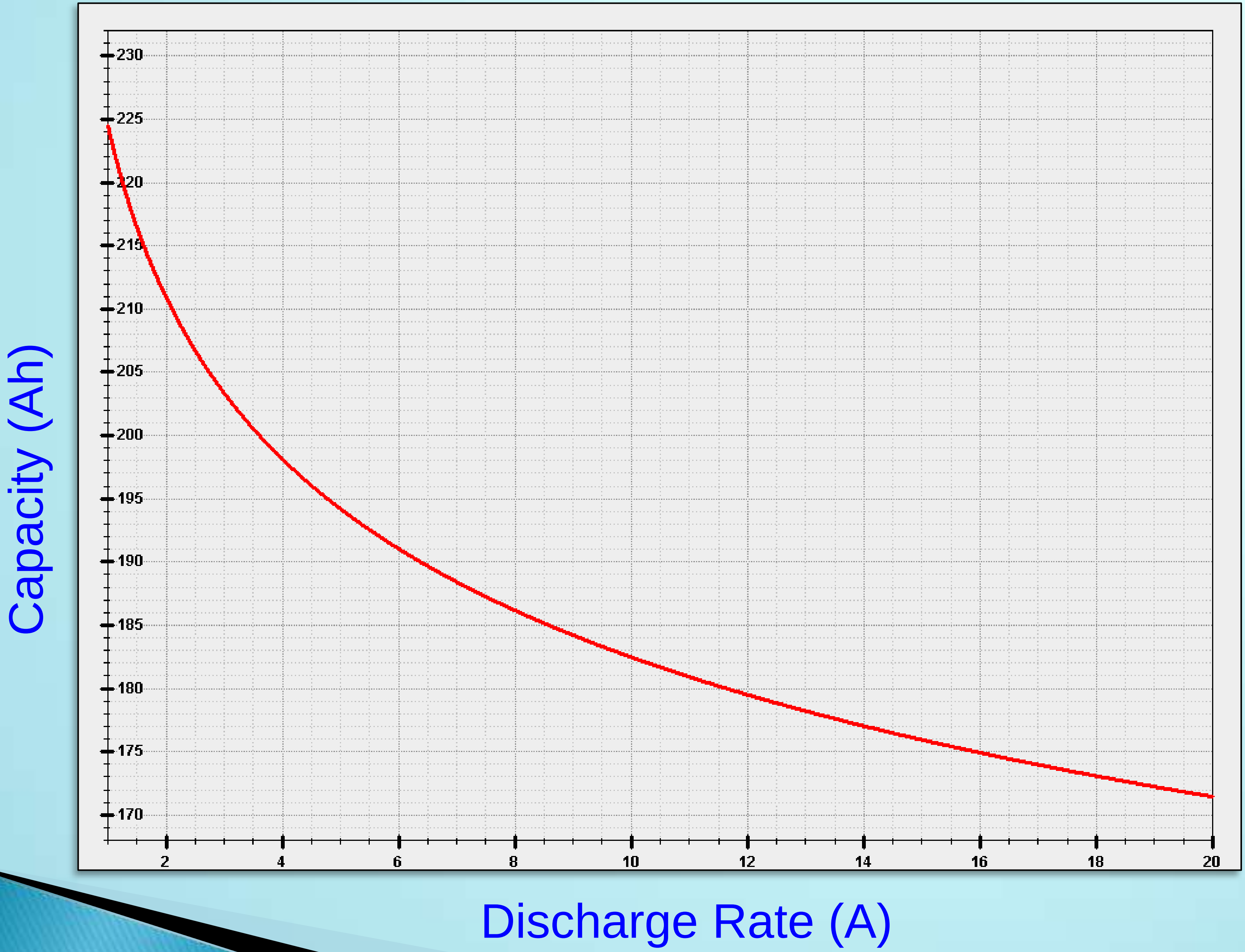
Peukert's Law Calculations	Rate (hours)	Rated Capacity (Ah)	Discharge Current (amps)
Rating 1	100	210	2.10
Rating 2	20	183	9.15
Peukert's Exponent:	1.09		

Actual Discharge Current:	20	amps
Discharge Time:	8.50	hours
Capacity at discharge current:	170.10	Ah
Actual Dischage Time:	48	hours
Discharge Current	4.11	amps
Capacity at discharge time:	197.23	Ah

Calculate discharge time and capacity given rated discharge time and capacity.

Calculate discharge current and capacity given rated discharge time and capacity.

Battery Capacity vs. Discharge Rate in Amperes



PV Module Size and Quantity

Design Calculations:

Enter the following parameters:

1. **Design Current**: from the load calculations (Ah/day)
2. **Module derate factor**: To compensate for reduced PV module output. Rated output is for a new module under ideal lab conditions.
3. **Rated module current**: Use the short-circuit, I_{sc} current if operating at 12V; use I_{mpp} if operating at maximum power point.
4. **Battery voltage**: Minimum voltage required to fully charge and float charge the backup batteries. It is important that the PV voltage always exceeds the battery voltage.
5. **Module voltage**: Use the maximum power point voltage, V_{mpp}.

Calculated quantities:

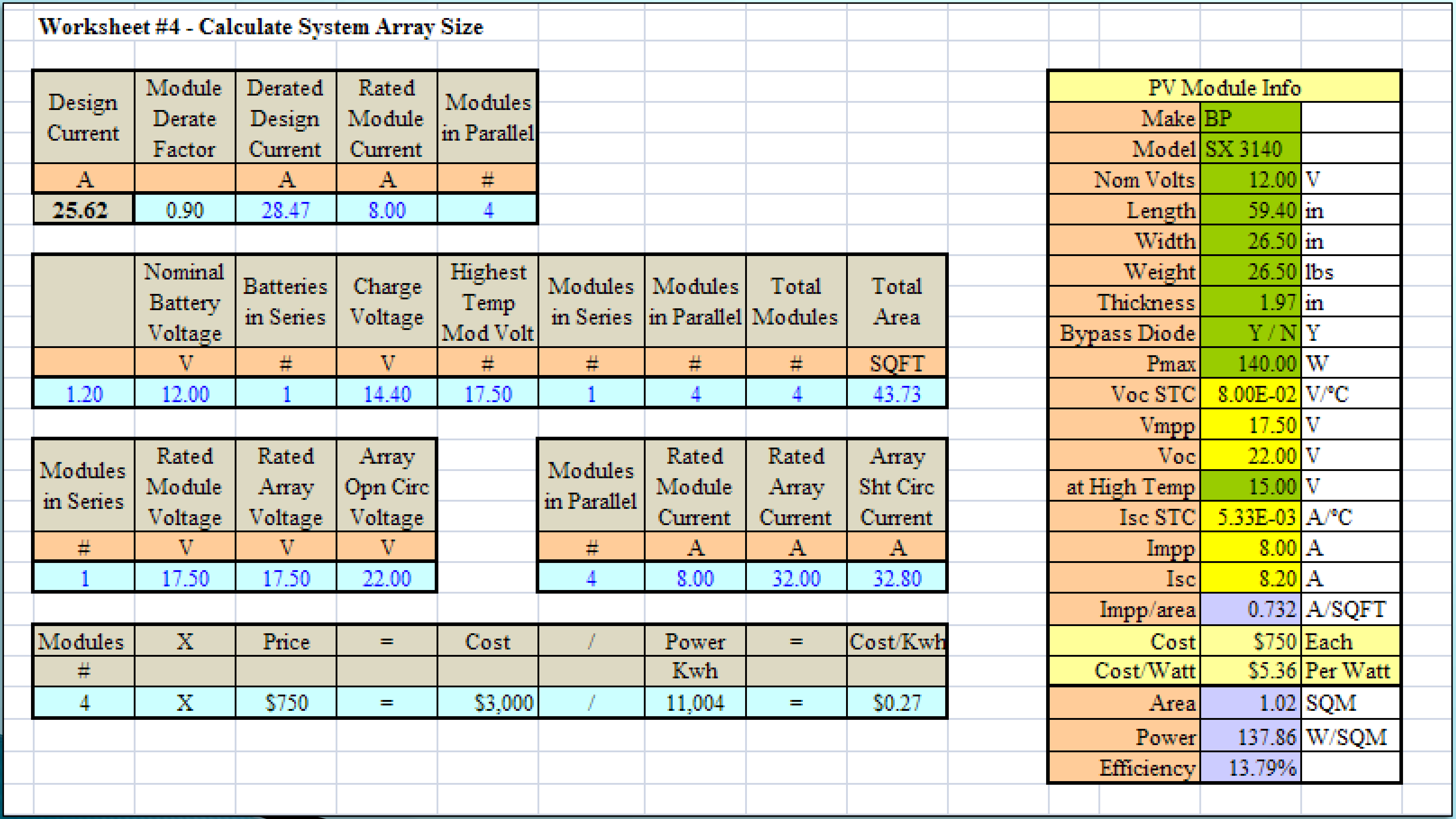
1.Derated design current: Increase in current requirement due to PV module inefficiencies.

2.Number of parallel modules: Derated design current / module current. Currents are added for modules connected in parallel.

3.Number of series modules: Module voltage / highest battery charge voltage. Voltages are added for modules connected in series.

Array Calculation Worksheet

BP SX 3140 140W Module



Worksheet #4 - Calculate System Array Size

Design Current	Module Derate Factor	Derated Design Current	Rated Module Current	Modules in Parallel
A		A	A	#
25.62	0.90	28.47	8.00	4

	Nominal Battery Voltage	Batteries in Series	Charge Voltage	Highest Temp Mod Volt	Modules in Series	Modules in Parallel	Total Modules	Total Area
	V	#	V	#	#	#	#	SQFT
1.20	12.00	1	14.40	17.50	1	4	4	43.73

Modules in Series	Rated Module Voltage	Rated Array Voltage	Array Opn Circ Voltage
#	V	V	V
1	17.50	17.50	22.00

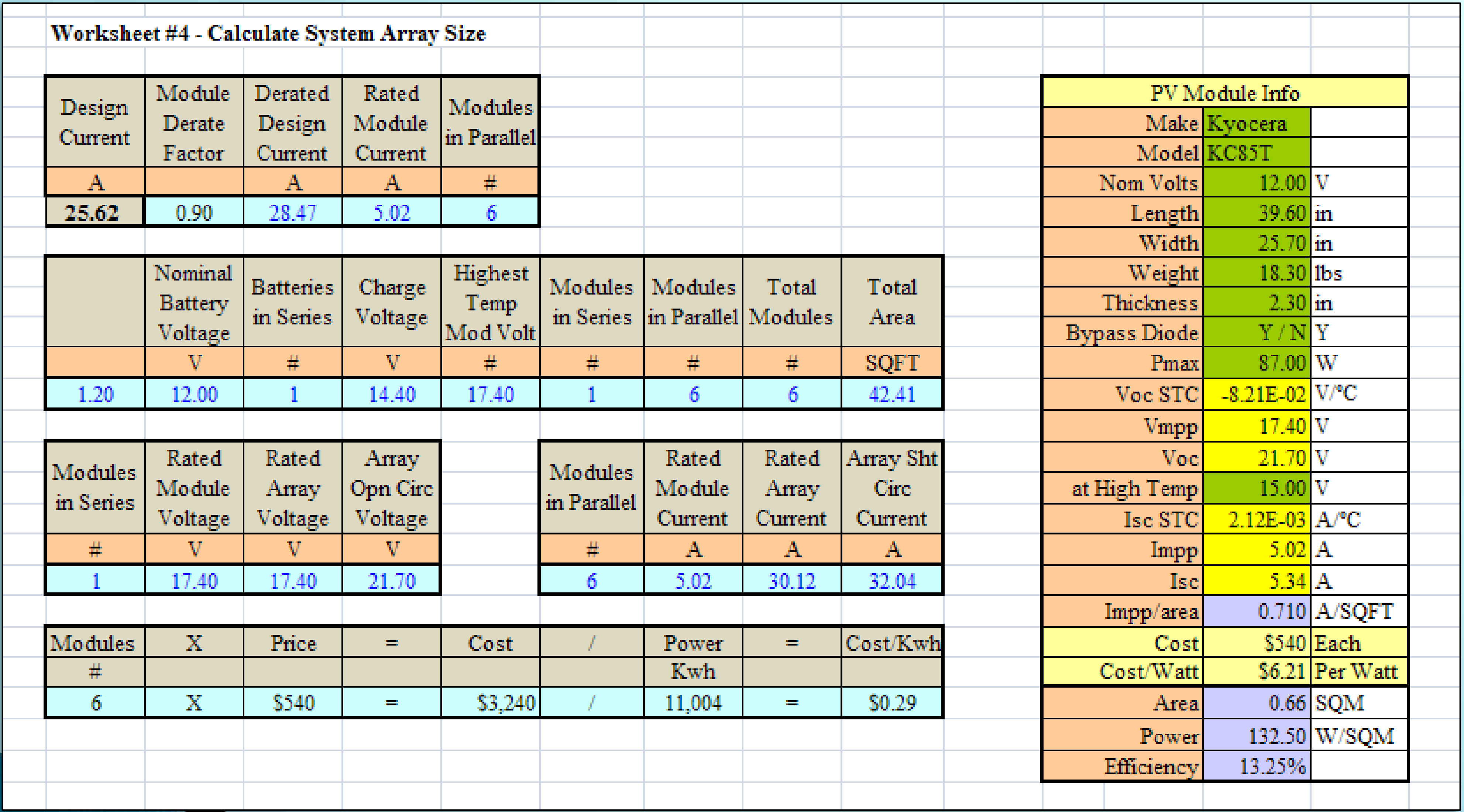
Modules in Parallel	Rated Module Current	Rated Array Current	Array Sht Circ Current
#	A	A	A
4	8.00	32.00	32.80

Modules	X	Price	=	Cost	/	Power	=	Cost/Kwh
#						Kwh		
4	X	$750	=	$3,000	/	11,004	=	$0.27

PV Module Info		
Make	BP	
Model	SX 3140	
Nom Volts	12.00	V
Length	59.40	in
Width	26.50	in
Weight	26.50	lbs
Thickness	1.97	in
Bypass Diode	Y / N	Y
Pmax	140.00	W
Voc STC	8.00E-02	V/°C
Vmpp	17.50	V
Voc	22.00	V
at High Temp	15.00	V
Isc STC	5.33E-03	A/°C
Impp	8.00	A
Isc	8.20	A
Impp/area	0.732	A/SQFT
Cost	$750	Each
Cost/Watt	$5.36	Per Watt
Area	1.02	SQM
Power	137.86	W/SQM
Efficiency	13.79%	

Array Calculation Worksheet

Kyocera KC85T 85W Module



Worksheet #4 - Calculate System Array Size

Design Current	Module Derate Factor	Derated Design Current	Rated Module Current	Modules in Parallel
A		A	A	#
25.62	0.90	28.47	5.02	6

	Nominal Battery Voltage	Batteries in Series	Charge Voltage	Highest Temp Mod Volt	Modules in Series	Modules in Parallel	Total Modules	Total Area
	V	#	V	#	#	#	#	SQFT
1.20	12.00	1	14.40	17.40	1	6	6	42.41

Modules in Series	Rated Module Voltage	Rated Array Voltage	Array Opn Circ Voltage
#	V	V	V
1	17.40	17.40	21.70

Modules in Parallel	Rated Module Current	Rated Array Current	Array Sht Circ Current
#	A	A	A
6	5.02	30.12	32.04

Modules	X	Price	=	Cost	/	Power	=	Cost/Kwh
#						Kwh		
6	X	$540	=	$3,240	/	11,004	=	$0.29

PV Module Info		
Make	Kyocera	
Model	KC85T	
Nom Volts	12.00	V
Length	39.60	in
Width	25.70	in
Weight	18.30	lbs
Thickness	2.30	in
Bypass Diode	Y / N	Y
Pmax	87.00	W
Voc STC	-8.21E-02	V/°C
Vmpp	17.40	V
Voc	21.70	V
at High Temp	15.00	V
Isc STC	2.12E-03	A/°C
Impp	5.02	A
Isc	5.34	A
Impp/area	0.710	A/SQFT
Cost	$540	Each
Cost/Watt	$6.21	Per Watt
Area	0.66	SQM
Power	132.50	W/SQM
Efficiency	13.25%	

Lifecycle Cost Analysis

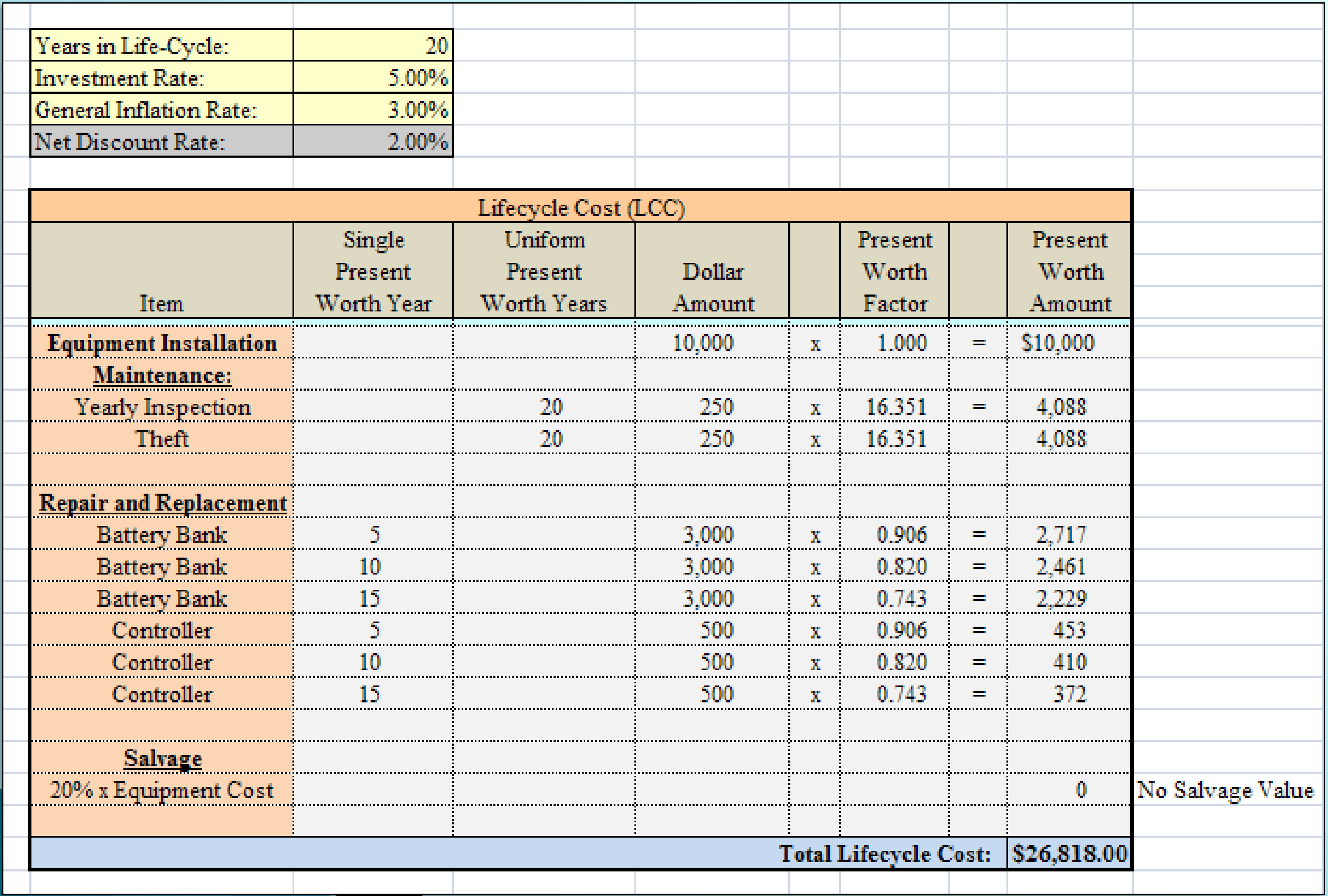
•Lifecycle cost (LCC) analysis is a method of comparing the long term cost among two or more alternative designs for a project.

•LCC for rural ITS begins by comparing the cost of municipal power (if available) to the cost of a PV system.

•The typical term for the LCC for PV installations is 20 years.

•If the initial analysis finds PV to be the best option, then LCC can be calculated for two or more alternative designs.

Lifecycle Cost Analysis Worksheet
PV System with Battery Backup

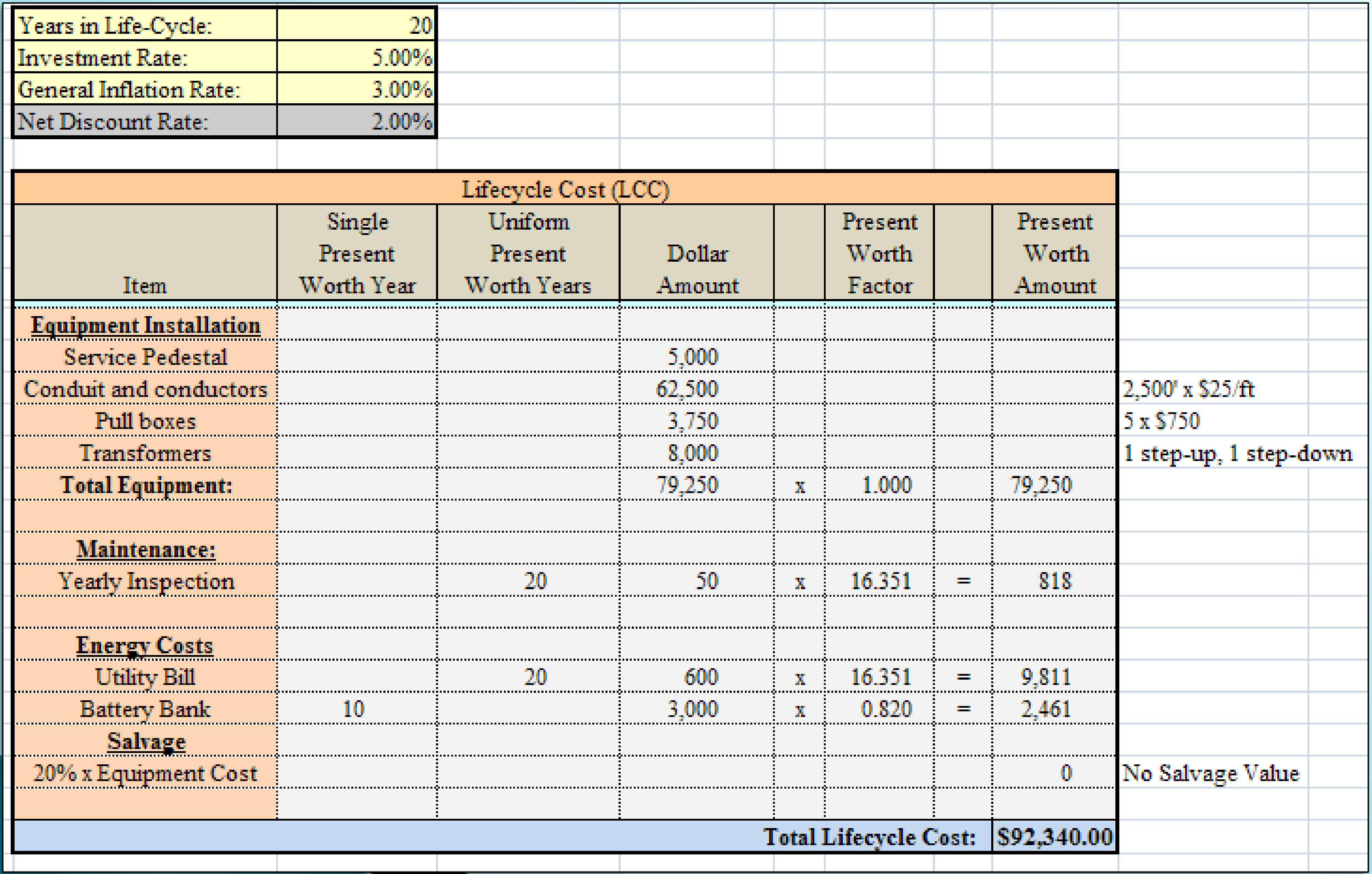


Years in Life-Cycle:	20
Investment Rate:	5.00%
General Inflation Rate:	3.00%
Net Discount Rate:	2.00%

Lifecycle Cost (LCC)

Item	Single Present Worth Year	Uniform Present Worth Years	Dollar Amount		Present Worth Factor		Present Worth Amount	
Equipment Installation			10,000	x	1.000	=	$10,000	
Maintenance:								
Yearly Inspection		20	250	x	16.351	=	4,088	
Theft		20	250	x	16.351		4,088	
Repair and Replacement								
Battery Bank	5		3,000	x	0.906	=	2,717	
Battery Bank	10		3,000	x	0.820	=	2,461	
Battery Bank	15		3,000	x	0.743	=	2,229	
Controller	5		500	x	0.906	=	453	
Controller	10		500	x	0.820	=	410	
Controller	15		500	x	0.743	=	372	
Salvage								
20% x Equipment Cost							0	No Salvage Value
					Total Lifecycle Cost:		**$26,818.00**	

Lifecycle Cost for RWIS with Commercial AC Power, Long Distance

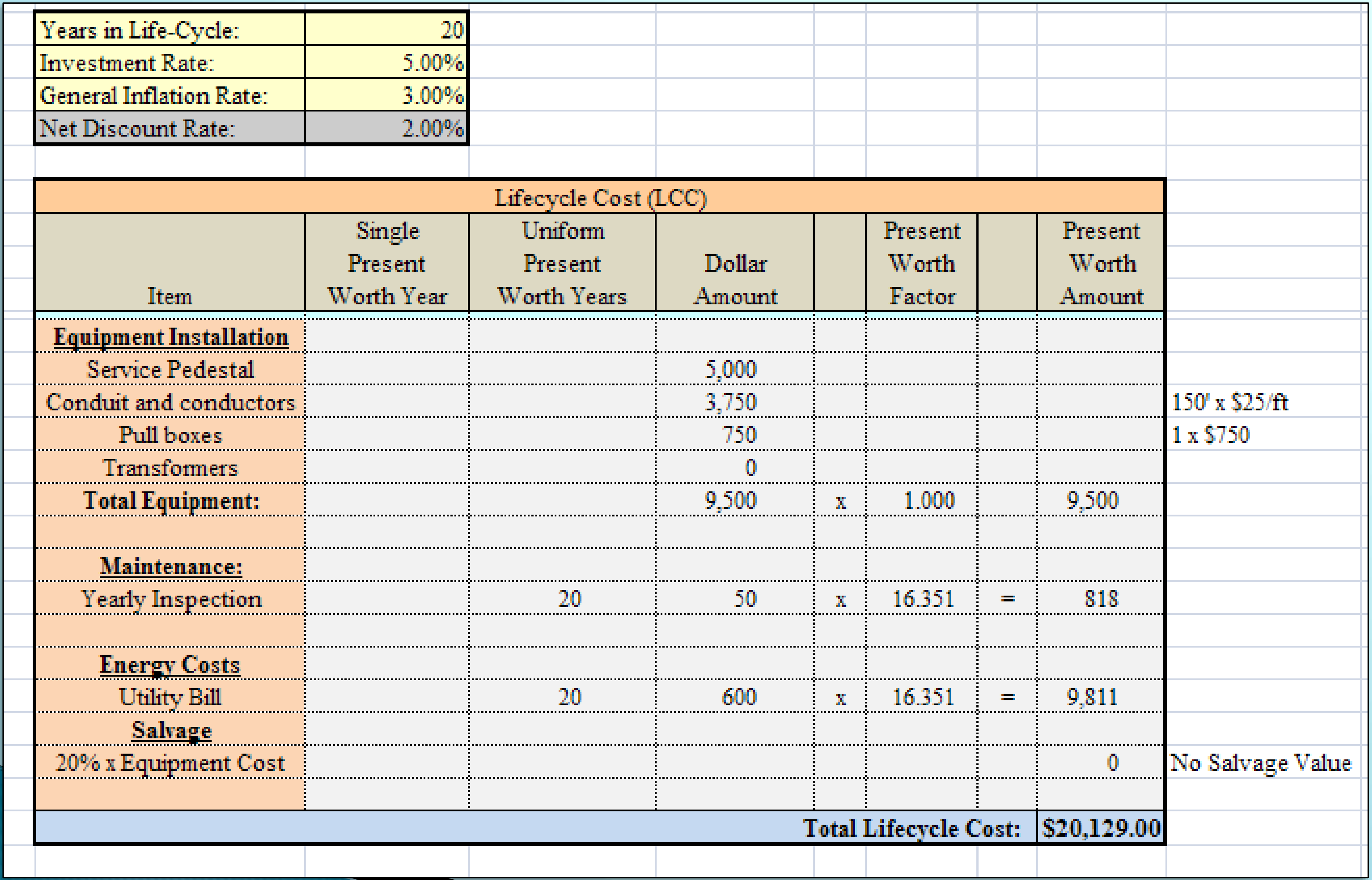


Years in Life-Cycle:	20
Investment Rate:	5.00%
General Inflation Rate:	3.00%
Net Discount Rate:	2.00%

Lifecycle Cost (LCC)

Item	Single Present Worth Year	Uniform Present Worth Years	Dollar Amount		Present Worth Factor		Present Worth Amount	
Equipment Installation								
Service Pedestal			5,000					
Conduit and conductors			62,500					2,500' x $25/ft
Pull boxes			3,750					5 x $750
Transformers			8,000					1 step-up, 1 step-down
Total Equipment:			79,250	x	1.000		79,250	
Maintenance:								
Yearly Inspection		20	50	x	16.351	=	818	
Energy Costs								
Utility Bill		20	600	x	16.351	=	9,811	
Battery Bank	10		3,000	x	0.820	=	2,461	
Salvage								
20% x Equipment Cost							0	No Salvage Value
						Total Lifecycle Cost:	**$92,340.00**	

Lifecycle Cost for RWIS with Commercial AC Power, Short Distance



Years in Life-Cycle:	20
Investment Rate:	5.00%
General Inflation Rate:	3.00%
Net Discount Rate:	2.00%

Lifecycle Cost (LCC)

Item	Single Present Worth Year	Uniform Present Worth Years	Dollar Amount		Present Worth Factor		Present Worth Amount	
Equipment Installation								
Service Pedestal			5,000					
Conduit and conductors			3,750					150' x $25/ft
Pull boxes			750					1 x $750
Transformers			0					
Total Equipment:			9,500	x	1.000		9,500	
Maintenance:								
Yearly Inspection		20	50	x	16.351	=	818	
Energy Costs								
Utility Bill		20	600	x	16.351	=	9,811	
Salvage								
20% x Equipment Cost							0	No Salvage Value
						Total Lifecycle Cost:	**$20,129.00**	

Equipment Reliability in Rural ITS Applications:

Photovoltaic Modules: The PV modules used (Kyocera and BP) have operated very reliably without any failures. The panels are rated to operate for 20 years without diminished performance. The only replacement required so far is from vandalism or theft. PV modules can sustain damage from vandalism (gunshot or struck by thrown objects) and continue to operate at a diminished level.

Solar charger/controllers: All the solar controllers used for rural ITS applications are field hardened and have performed well in the field. The controllers normally last about 5-7 years before replacement, well beyond the 3 year warranty.

Back up Batteries: The back up batteries used are sealed Gel Cell and typically last about 3-4 years before replacement. There are some that have lasted up to 6 years. These batteries have held up well in cold weather locations, where sub-zero temperatures are common in winter.

Overall, the components used by NDOT have been very reliable and have withstood the temperature extremes (100º in summer to subzero in winter). All system components are specified to be field hardened and designed for outdoor use. Failures, when they occur, are usually a result of improper design, mismatched components, or improper installation.

PV Systems Maintenance Schedule

District 2 performs a pre-winter inspection of all sites beginning each September:

1. Physically inspect pole, foundation, mounting hardware, cabinets, PV modules, batteries, cables and connectors.
2. Perform testing of all system components to verify PV output, controller performance, and battery SOC and capacity.
3. Repair or replace all faulty or under performing equipment. Clean batteries and equipment and tighten all loose connections.
4. Clean PV panels. Adjust panel mount and tighten if necessary.

Potential Pitfalls and Lessons Learned
Site Analysis

This seems completely obvious, but can be overlooked, especially if the site survey is done in the summer. Always consider the effect of solar azimuth/elevation on shading from nearby vegetation, structures, and geography during different times of the year. These sites currently experience several hours of inoperability each day in the winter.

Secret Creek, Lake Tahoe

Zephyr Cove, Lake Tahoe

Potential Pitfalls and Lessons Learned
Extreme Weather Conditions

Many locations in Nevada are subject to heavy winter snows and accumulating ice. These locations were often inoperable during the winter. Tilting the array at summit locations a few degrees above the recommended latitude + 15º has significantly reduced snow and ice accumulation on the modules. Reducing or eliminating down time has been worth the relatively small reduction in PV output.

Matching System Components

Pitfall:

- Though not a PV system, this provides an example of improperly sized BOC (balance of system) components.
- A controller (same as used in PV systems) was used to charge a Trailblazer back up battery system at night (when the street lighting system was active). The system runs off the batteries during the daytime (when AC is off).
- Some of the trailblazers in Las Vegas were failing because the controller used did not supply enough current to fully charge the batteries during the limited cycle time (worse in summer).

Lesson Learned:

The selection of the solar charger/controller should not be done until the size and number of back up batteries have been determined.

The controller should be sized to 1.25 x the minimum amount of current needed to fully charge the batteries during each cycle.

Future System Improvements

1. Upgrade to controllers with communication ports (Ethernet for IP), metering, and data logging to allow remote polling and monitoring of PV system state . The benefits of this would be:

- Allow maintenance to check equipment without having to access cabinets (especially in winter when heavy snow makes access difficult).
- Allow remote monitoring of PV system components from District TMC.
- Analysis of historical data would facilitate optimization of future designs and specifications.

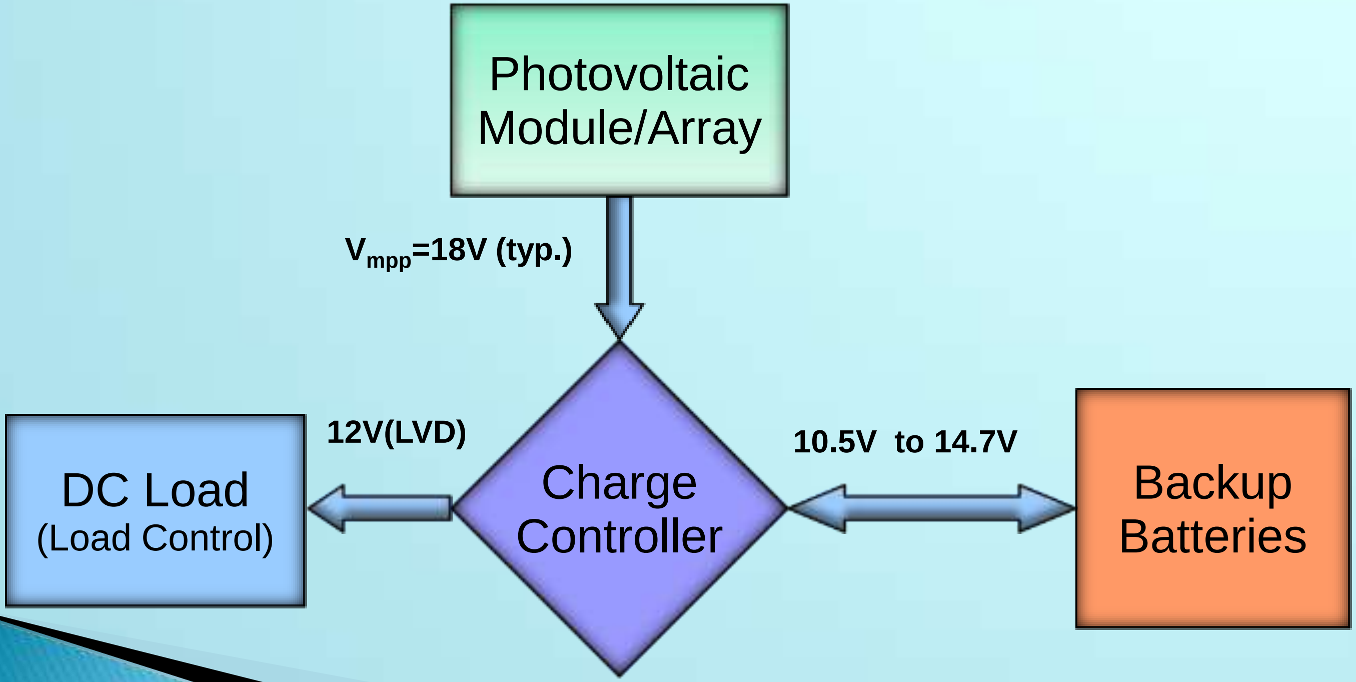
2. Specify MPPT controllers in some future installations (locations subject to harsh weather conditions or several autonomous days) to optimize PV output to batteries, possibly reduce the number of PV modules required, and reduce risk of system downtime.
3. Specify AGM batteries for future installations. AGM batteries are almost maintenance free, more resistant to harsh environments, and can be placed in pull boxes. Cost of AGM’s has become comparable to current sealed Gel Cell batteries.
4. Look into hybrid systems to:

- Allow PV systems for larger loads (small DMS, CCTV with heaters).
- Reduce size and number of batteries, and/or increase days of autonomy.

Current Intallations
Photovoltaic System Block Diagram
Solar Flasher Sign

System Components:

- **PV Module**: Two (2) KC85TS, 87W, 17.4 V_{mp}, 5.34 I_{sc}
- **Solar Controller**: High Sierra Electronics Model 5315-01
10A PV in, 10A maximum charge current, LVD with flasher control
- **Batteries**: Two (2) 8G27 DEKA Sealed Gel Cell
108 Ah @ C/20, 12V
- **Load:** Two (2) Leotek Model TSL-12Y-MG-B1 LED Amber Lamp
18W, 12VDC



Photovoltaic Module/Array

V_{mpp}=18V (typ.)

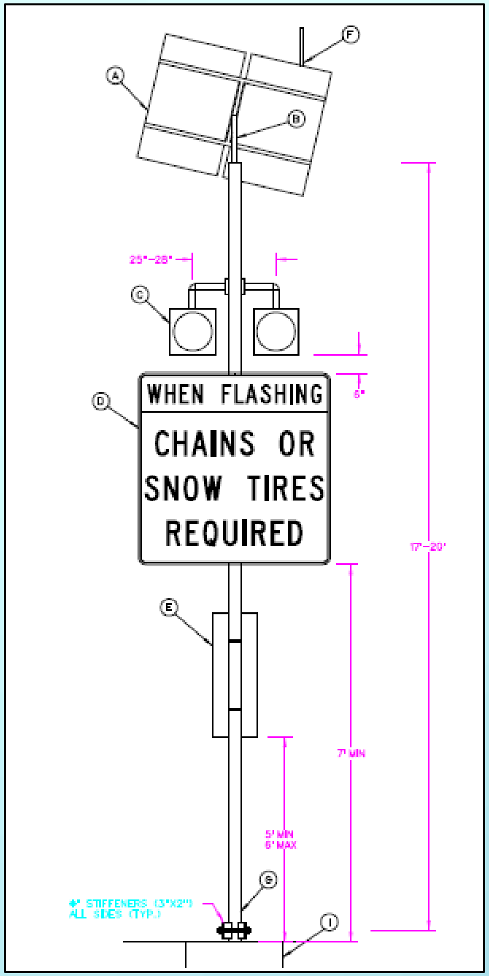
Charge Controller

12V(LVD)

DC Load
(Load Control)

10.5V to 14.7V

Backup Batteries

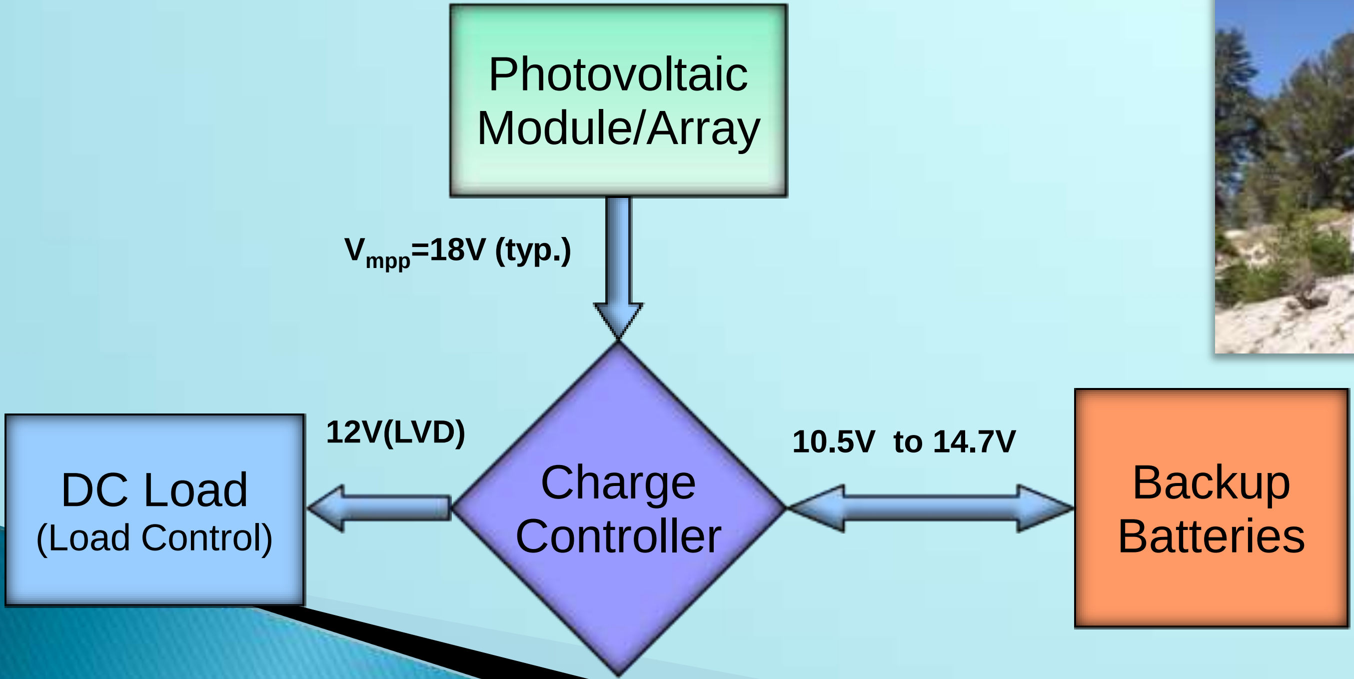


Current Installations
Solar Flasher Sign

Current Installations
Photovoltaic System Block Diagram
Road Weather Information System (RWIS)

System Components:

- **PV Module**: Seven (7) KC85TS
87W, 17.4 V_{mp}, 5.34 I_{sc}
- **Solar Controller**: Sunsaver Prostar 30
30A PV in, 30A maximum charge current, temperature compensation, PWM 3-stage series charging
- **Batteries**: Eight (8) 8G27 DEKA Sealed Gel Cell
108 Ah @ C/20, 12V
- **Load**: ROSA Controller (36W), EDACS 800 MHz Radio (180W max.)



Photovoltaic Module/Array

V_{mpp}=18V (typ.)

Charge Controller

12V(LVD)

DC Load
(Load Control)

10.5V to 14.7V

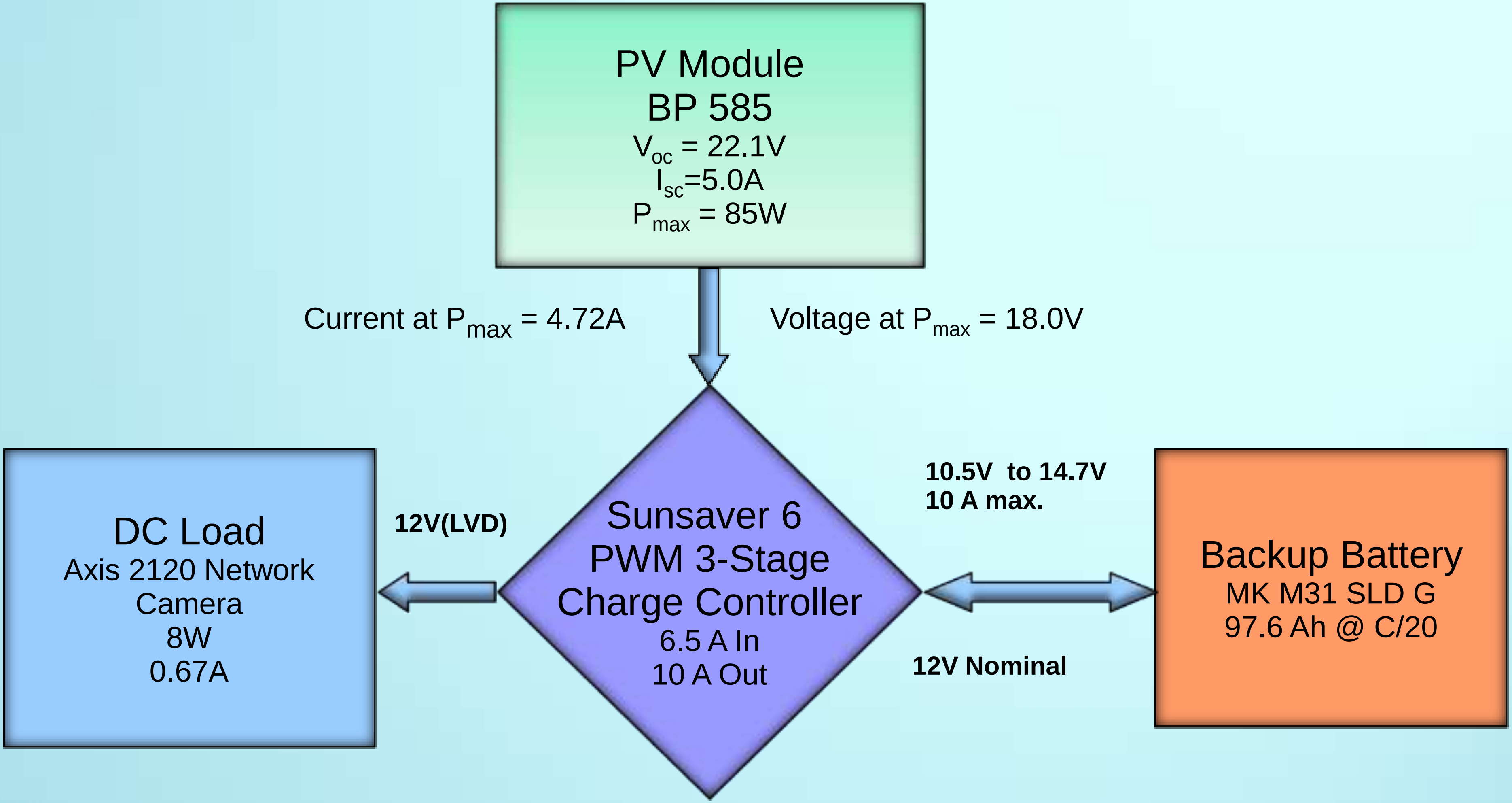
Backup Batteries

Live Demonstration Equipment

A live demonstration consisting of a scaled down replica of a PV system typical of those used for rural applications in Nevada:

- PV module: BP 585, 85W, Vmp=18V, Imp=4.72A, Voc=22.1V, Isc= 5.0A.
- Battery: MK M31 SLD G, Sealed Gel Cell, 108 Ah (C/100)
- Solar Controller: Sunsaver-6, 3-stage PWM, PV input current=6.5A, Load output current=10A, System Voltage=12VDC.
- Load: CCTV camera, Axis 2120 Network Camera, 12 VDC, 8W (0.67A).
- Fully charged, this system will operate for 6.75 days without sun.

Live Demonstration Block Diagram



PV Module
BP 585
V_{oc} = 22.1V
I_{sc}=5.0A
P_{max} = 85W

Current at P_{max} = 4.72A

Voltage at P_{max} = 18.0V

DC Load
Axis 2120 Network Camera
8W
0.67A

12V(LVD)

Sunsaver 6
PWM 3-Stage
Charge Controller
6.5 A In
10 A Out

10.5V to 14.7V
10 A max.

12V Nominal

Backup Battery
MK M31 SLD G
97.6 Ah @ C/20

Conclusion

- Photovoltaic Systems offer a cost effective solution to providing power for rural ITS applications where commercial power is either unavailable or too costly.

- While it is always desirable to use commercial AC power, PV systems allow rural ITS devices to be placed where needed without the constraint of having to locate near existing AC facilities.

- PV systems are relatively easy to design, install, and maintain.

- Future systems will offer greater benefits with cost reductions and improvements in system components.

Special Thanks to:

Jessie Lidder, District 2 Communications
Kevin Chatfield, District 2 Communications
Bill Hance, District 3 Communications
Dan Preslar, Vice President, Transcore, Inc.

For providing invaluable input and support.