Stand Alone PV System Sizing
Worksheet (example)

Application: **Stand alone camp system 7 miles off grid**

Location: **Baton Rouge, La** Latitude: **31.53 N**

A. Loads

A1	Inverter efficiency	**85**
A2	Battery Bus voltage	**24** volts
A3	Inverter ac voltage	**110** volts

Appliance	A4 Rated Wattage	A5 Adjustment Factor 1.0 for dc (A1) for ac	A6 Adjusted Wattage (A4/A5)	A7 Hours per day Used	A8 Energy per day (A6xA7)
(5) 30w lights	**150**	**.85**	**176**	**2**	**352**
Refrigerator	**500**	**.85**	**588**	**5**	**2940**
(3) 45w fans	**135**	**.85**	**159**	**8**	**1272**
Washer	**1500**	**.85**	**1765**	**.86**	**1518**
Tv	**200**	**.85**	**235**	**4**	**940**
Toaster	**1500**	**.85**	**1765**	**.025**	**441**

A9	Total energy demand per day (sum of A8)	**7463**	watt-hours
A10	Total amp-hour demand per day (A9/A2)	**311**	amp-hours
A11	Maximum ac power requirement (sum of A4)	**3985**	watts
A12	Maximum dc power requirement (sum of A6)	**4688**	watts

B. Battery Sizing

Design temperature **25 degrees C / 77 degrees F**

B1	Days of storage desired/required	**7**	days
B2	Allowable depth-of-discharge limit (decimal)	**0.8**	
B3	Required battery capacity ((A10 x B1) / B2)	**2721**	amp-hours
B4	Amp-Hour capacity of selected battery *	**478**	amp-hours
B5	Number of batteries in parallel (B3 / B4)	**6**	
B6	Number of batteries in series (A2 / selected battery voltage)	**2**	

B7	Total Number of Batteries (B5xB6)	**12**	
B8	Total battery amp-hour capacity (B5xB4)	**2868**	amp-hours
B9	Total battery kilowatt-hour capacity ((B8xA2)/1000)	**68.8**	Kw-hours
B10	Average daily depth of discharge (.75xA10/B8)	**.08**	

*Use amp hour capacity at a rate of discharge corresponding to the total storage period B1 from battery spec sheet (B4).

C. PV Array Sizing

Design Tilt (Latitude + 15 degrees) **46.53** Design month: **December**

C1	Total energy demand per day (A9)	**7463**	watt-hours
C2	Battery round trip efficiency (0.70-0.85)	**0.85**	
C3	Required array output per day (C1 / C2)	**8780**	watt-hours
C4	Selected PV module max power voltage at STC (x.85)	**14.8**	Volts
C5	Selected PV module guaranteed power output at STC	**47.7**	watts
C6	Peek sum hours at design tilt for design month	**3.8**	hours
C7	Energy output per module per day (C5xC6)	**181**	watt-hours
C8	Module energy output at operating temperature (DFxC7) DF = 0.80 for hot climates and critical applications. DF = 0.90 for moderate climates and non-critical applications.	**163**	watt-hours
C9	Number of modules required to meet energy requirements (C3 / C8)	**54**	modules
C10	Number of modules required per string (A2 / C4) rounded to the next higher integer.	**2**	modules
C11	Number of strings in parallel (C9 / C10) rounded to the next higher integer.	**27**	strings
C12	Number of modules to be purchased (C10 x C11)	**54**	modules
C13	Nominal rated PV module output	**53**	watts
C13	Nominal rated array output (C13 x C12)	**2862**	watts

D. Balance-of-System (BOS) Requirements

1. A voltage regulator is recommended unless array output current (at 1000 W/m^2 conditions), less any continuous load current, is less than 5 % of the selected battery bank capacity (at the 8 hour discharge rate0).

2. Wiring should be adequate to ensure that losses are less than 1% of the energy produced.

3. In low voltage (i.e., less than 50 volts) systems, germanium or Schottky blocking diodes are preferred over silicon diodes.

4. Fuses, fuse holders, switches, and other components should be selected to satisfy both voltage and current requirements.

5. All battery series branches should contain fuses.

6. Fused disconnects are strongly recommended to isolate the battery bank from the rest of the system.

7. Refer to electrical and mechanical design sections for other considerations.

APPLICATION: Stand-alone camp system 7 miles off grid

LOCATION: **Baton Rouge, La** LATITUDE: **31.53 degrees N**

A. <u>LOADS</u>

(A1): Inverter efficiency (decimal). This quantity is used as a power adjustment factor when current is changed from dc to ac. The efficiency of the inverter selected for this application is assumed to be **0.85**.

(A2): Battery bus voltage. This is nominal dc operating voltage of the system. The battery bus voltage for this application is **24 volts**. Which corresponds to the required dc input voltage for the inverter.

(A3): Inverter ac voltage. The output voltage of the inverter selected for this application is **110 volts**.

The components (appliances) that the system will power are:

5 lights (30w each0, combined rated wattage 150, used 2 hours/day.
Refrigerator, rated wattage 500, used 5 hours/day.
3 ceiling fans (45w each0, combined rated wattage 135, used 8 hours/day.
Washer, rated wattage, 1500, used 6 hours/week or 0.86 hours/day.
Television, rated wattage 200, used 4 hours/day.
Toaster, rated wattage 1500, used 0.25 hours/day.

The appliances are listed under the column heading **Appliance.**

(A4): The rated wattage is listed for each appliance in column (A4). Note that the rated wattage for some appliances may vary from the actual power consumed due to the load variation or cycling (i.e. refrigeration, motors, etc.)

Appliance	(A4) Rated Wattage
5 lights (30w each)	150
Refrigerator	500
3 ceiling fans (45w each0	135
Washer	1500
Television	200
Toaster	1500

(A5): Adjustment factor. The adjustment factor is related to the efficiency of the inverter and reflects the actual power consumed from the battery bank to operate ac loads from the inverter. For ac loads, the value (A1) is inserted in column (A5). For this application the adjustment factor is **0.85**. For dc loads operating from the battery bank an adjustment factor of **1.0** is used.

(A6): Adjusted wattage. Dividing the rated wattage 9A4) by the adjustment factor (A5) adjusts the wattage to compensate for the inverter inefficiency and gives the actual wattage consumed from the battery bank (A4 / A5).

Appliance	(A4 / A5)	=	Adjusted Wattage (A6)
5 lights (30w each)	150 / 0.85	=	176
Refrigerator	500 / 0.85	=	588
3 ceiling fans (45w each)	135 / 0.85	=	159
Washer	1500 / 0.85	=	1765
Television	200 / 0.85	=	235
Toaster	1500 / 0.85	=	1765

(A7): Hours per day used. The number of hours each appliance is used per day is listed in column (A7). The duty cycle, or actual time of load operation, must be considered here. For example, a refrigerator may be functional 24 hours a day, but the compressor may only operate 5 hours per day.

(A8): Energy per day. The amount of energy each appliance requires per day is determined by multiplying each appliance's adjusted wattage (A6) by the number of hours used per day (A7). (A6) x (A7)

			LOADS
Appliance	(A6) x (A7)	=	Energy Per Day (A8)
5 lights (30w each)	176 x 2	=	352
Refrigerator	588 x 5	=	2940
3 Ceiling fans (45 w each)	159 x 8	=	1272
Washer	1765 x 0.86	=	1518
Television	235 x 4	=	940
Toaster	1765 x 0.25	=	441
	Total	=	7463

(A9): Total energy demand per day. The Sum of the Quantities in column (A8) determines the total energy demand required by the appliances per day. For this application the total energy per day for the load is **7463 watt-hours.**

(A10): Total amp-hour demand per day. The battery storage subsystem is sized independently of the photovoltaic array. In order to size the battery bank the total electrical load is converted from watt-hours to amp-hours. Amp-hours are determined by dividing the total energy demand per day (A9) by the battery bus voltage (A2). (A9) / (A2).

7463 watt-hours / 24 volts = **311 amp-hours.**

(A11): maximum ac power requirement. The sum of the rated wattages (A4) for all appliances is equal to **3985 watts.** Note that this is the maximum continuous power required and does not include surge requirements. This value (A11) is the maximum continuous ac power output required of the inverter if all loads were to operate simultaneously. The Peak, or surge requirement (due to motor starting, etc.) must also be considered when selecting an inverter.

(A12): maximum dc power requirement. The sum of the adjusted wattages (A6), or dc power, for all appliances is equal to **4688 watts.** This value (A12) is the maximum dc input power required by the inverter and is necessary to determine wire sizes fusing and disconnect requirement. If load management techniques are employed to eliminate the possibility of loads operating simultaneously, the inverter maximum output requirements may be reduced accordingly.

B. BATTERY SIZING

DESIGN TEMPERATURE: The location where batteries are stored should be designed to minimize fluctuations in battery temperature. For this application the design temperature is assumed to be **25 degrees C.**

(B1): Days of storage desired/required (autonomy). The loss of electricity for the residence in this application, although undesirable, would not be catastrophic. Consequently, the battery storage system is designed to provide the necessary electrical energy for a period equivalent to 7 days without any sunshine. This time period is considered a moderate level of storage for the southeastern U.S. for non-critical applications. Less critical applications may use 3 to 4 days of storage, although this would increase the depth of the battery cycling and reduce battery life. For critical applications such as those that would impact public safety, more days of storage may be desirable.

(B2): Allowable depth-of-discharge limit (decimal). The maximum fraction of capacity that can be withdrawn from the battery as specified by the designer. Note that the battery selected must be capable of this limit or greater depth of discharge. For this application the allowable depth- of-discharge is **0.8.**

(B3): Required battery capacity. The required battery capacity is determined by first multiplying the total amp-hours per day (A10) by the days of storage required (B1), 311 x 7 = 2177, and then dividing this number by the allowable depth of discharge limit (B2). [(A10) x ((B1) / (B2))]

311 x (7 / .8) = **2721 amp-hours**

(B4): Amp-hour capacity of selected battery. Once the required number of amp-hours has been determined (B3), batteries or battery cells can be selected using manufacturers' information. Exide 6E95-11 industrial grade batteries were selected for this application because of their long cycle life and rugged construction. ***Figure B.4*** shows that Exide 6E95-11's capacity for a 5 day rate is **478 amp-hours.** Since battery capacity may vary with the rate of discharge, the amp-hour capacity that corresponds to the required days of storage should be used.

			20 DAY (480 HR)		10 DAY (240 HR)		5 DAY (120 HR)		3 DAY (72 HR)		
TYPE	VOLTS PER UNIT	NORMAL A.H. CAP	A.H	AMPS	A.H	AMPS	A.H	AMPS	A.H	AMPS	32° F (0° C) 500 HR A.H.
6E95-5	12	180	192	0.40	192	0.80	192	1.60	192	2.67	184
6E95-7	12	270	288	0.60	288	1.20	288	2.40	288	4.00	276
6E95-9	12	360	383	0.80	383	1.60	383	3.19	383	5.32	368
6E95-11	12	450	478	1.00	478	1.99	478	3.98	478	6.64	459
6E120-9	12	500	538	1.12	538	2.24	538	4.48	538	7.47	516
6E120-11	12	625	673	1.40	673	2.80	673	5.61	673	9.35	646
6E120-13	12	750	808	1.68	808	3.37	808	6.73	808	11.22	776
6E120-15	12	875	942	1.96	942	3.93	942	7.85	942	13.08	904
3E120-17	6	1000	1077	2.24	1077	4.49	1077	8.98	1077	14.96	1034
3E120-19	6	1125	1212	2.53	1212	5.05	1212	10.10	1212	16.83	1163
3E120-21	6	1250	1346	2.80	1346	5.61	1346	11.22	1346	18.69	1292
3E120-23	6	1375	1481	3.09	1481	6.17	1481	12.34	1481	20.57	1422
3E120-25	6	1500	1616	3.37	1616	6.73	1616	13.47	1616	22.44	1551
3E120-27	6	1625	1750	3.65	1750	7.20	1750	14.58	1750	24.31	1680
3E120-29	6	1750	1885	3.93	1885	7.85	1885	15.71	1885	26.18	1809

Figure B.4 – Exide Battery Specification Sheet

(B5): Number of batteries in parallel. The number of batteries or battery cells needed to provide the required battery capacity (B3) by the amp-hour capacity of the selected battery (B4). (B3) / (B4).

2721 amp-hours / 478 amp-hours = 6 (round up from 5.6).

(B6): Number of batteries in series. The number of batteries needed to provide the necessary dc system voltage is determined by dividing the battery bus voltage (A2) by the selected battery or battery cell voltage (taken from manufacturer's information). (A2) / battery voltage.

24 volts / 12 volts = **2.**

(B7): Total Number of batteries. Multiplying the number of batteries in parallel (B5) by the number of batteries or battery cells in series (B60 determines the total number of batteries needed. (B5) x (B6).

6 x 2 = **12.**

(B8): Total battery amp-hour capacity. The total rated capacity of selected batteries is determined by multiplying the number of batteries in parallel (B5) by the amp-hour capacity of the selected battery (B4). (B5) x (B4).

6 x 478 amp-hours = **2868 amp-hours.**

(B9): Total battery kilowatt-hour capacity. Based on the selected batteries, the kWh or energy capacity is determined by first multiplying the total amp-hour capacity (B8) times the battery bus voltage (A2), and then dividing this number by 1000. [(B8) x (A2)] / 1000.

[2868 amp-hours x 24 volts] / 1000 = **68.8 kilowatt-hour.**

(B10): Average daily depth of discharge. The actual daily depth of discharge to be expected on the average for the selected battery subsystem is determined by first multiplying 0.75 by the total amp-hour demand per day (A10), and then dividing this number by the total battery amp-hour capacity (B8). The 0.75 factor is used by assuming that the PV array meets the load during peak sun hours or 0.25 of the day and the batteries supply the load for the other 0.75 of the day. For the lighting load profile that operates only at night this factor would be 1.0, due to the load being entirely supplied by the batteries. [0.75 x (A10)] / (B8).

(0.75 x 311) / 2868 = **0.08**

C. PHOTOVOLTAIC ARRAY SIZING

The size of the photovoltaic array is determined by considering the available solar insulation, the tilt and orientation of the array and the characteristics of the photovoltaic modules being considered. The array is sized to meet the average daily load requirements for the month or season of the year with the lowest ratio daily insulation to the daily load.

The available insulation striking a photovoltaic array varies throughout the year and is a function of the tilt angle and azimuth orientation of the array. If the load is constant, the designer must consider the time of the year with the minimum amount of sunlight (in the Northern hemisphere, typically December or January). Knowing the insulation available (at tilt) and the power output required, the array can be sized using module specifications supplied by manufacturers.

Using module power output and daily insulation (in peak sun hours), the energy (watt-hours or amp-hours) delivered by a photovoltaic module for an average day can be determined. Then, knowing the requirements of the load and the output of a single module, the array can be sized.

The array is sized to meet the average daily demand for electricity during the worst insulation month of the year, which is December in Baton Rouge. The array will face south and because the sun is low in the sky during December will be tilted at an angle of 46.53 degrees from the horizontal in order to maximize the insulation received during December.

DESIGN MONTH: December

DESIGN TILT: 46.53 degrees for maximum insulation during the design month.

(C1): Total energy demand per day (A9). **7463 watt-hours.**

(C2): Battery round trip efficiency. A factor between 0.70 and 0.85 is used to estimate battery round trip efficiency. For this application **0.85** is used because the battery selected is relatively efficient and because a significant percentage of the energy is used during daylight hours.

(C3): Required array output per day. The watt-hours required by the load are adjusted (upwards) because batteries are less than 100% efficient. Dividing the total energy demand per day (C1) by the battery round trip efficiency (C2) determines the required array output per day. (C1) / (C2).

7463 watt-hours / 0.85 = **8780 watt-hours.**

(C4): Selected PV module max power voltage at STC x 0.85. Maximum power voltage is obtained from the manufacturer's specifications for the selected photovoltaic module, and this quantity is multiplied by 0.85 to establish a design operating voltage for each module (not the array) to the left of the maximum power voltage and to ensure acceptable module output current.

Siemens Solar M55 modules are used in this application. According to ***Figure C.4*** the maximum power voltage at STC for the Siemens Solar M55 is 17.4 volts.

17.4 volts x 0.85 = **14.8 volts.**

Power Specifications*

Model	**M55**
Power (typical +/- 10%)	53.0 Watts
Current (typical at load)	3.05 Amps
Voltage (typical at load)	17.4 Volts
Short Circuit Current (typical)	3.27 Amps
Oopen Circuit Voltage (typical)	2.18 Volts

Physical Characteristics

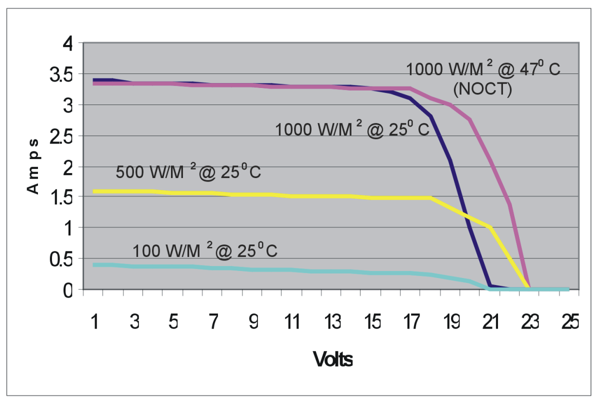
Length	50.9 in/1293 mm
Width	13 in/330 mm
Depth	1.4 in/36 mm
Weight	12.6 lb/5.7 kg

*Power specifications are at standard test conditions of: 1000 W/M², 25° C cell temperature and spectrum of 1.5 air mass.

Performance Characteristics

@ 25° C

1000 W/M² @ 47° C (NOCT)



The IV curve (current vs. Voltage) above demonstrates typical power response to various light levels at 25° C cell temperature, and at the NOCT (Normal Cell Operating Temperature), 47° C.

Figure C.4 – Siemens Solar M55 module specifications

(C5): Selected PV module guaranteed power output at STC. This number is also obtained from the manufacturer's specifications for the selected module. Figure 6.3 shows the nominal power output at 1000 watts/m^2 and 25 degrees C is 53 watts. The guaranteed power output is 90% of this value, or **47.7 watts.**

(C6): Peak sun hours at optimum tilt. This figure is obtained from solar radiation data (shown in ***Figure C.6***) for the design location and array tilt for an average day during the worst month of the year. Peak sun hours at Latitude + 15 degrees for Baton Rouge in December equal **3.8 hours.**

Solar Radiation for Baton Rouge, Louisiana (30 year average)

	J	F	M	A	M	J	J	A	S	O	N	D	YA
Lat + 15 Average"	3.8	4.5	4.9	5.1	4.9	4.7	4.6	4.9	5.0	5.4	4.4	3.8	4.7
Minimum"	2.9	3.6	4.0	4.3	4.4	3.9	4.2	4.3	4.2	4.0	2.9	3.0	4.4
Maximum"	4.9	5.6	6.0	6.3	5.6	5.2	5.4	5.7	5.8	6.5	5.2	4.9	4.9

Figure C.6 - Insolation Data for Baton Rouge, LA

Note: You can obtain insolation data for additional cities @ *http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/*

(C7): Energy output per module per day. The amount of energy produced by the array per day during the worst month is determined by multiplying the selected photovoltaic power output at STC (C5) by the peak sun hours at design tilt (C6). (C5) x (C6).

(C8): Module energy output at operating temperature. A de-rating factor of 0.90 (for moderate climates and non-critical applications) is used in this application to determine the module energy output at operating temperature. Multiplying the de-rating factor (DF) by the energy output module (C7) establishes an average energy output from one module. DF x (C7).

0.90 x 181 watt-hours = **163 watt-hours.**

(C9): Number of modules required to meet energy requirements. Dividing the required output per day (C3) by the module energy output at operating temperature (C8) determines the number of modules required to meet energy requirements. (C3 / (C8).

8780 watt-hours / 163 watt-hours = **54 modules**

(C10): Number of modules required per string. Dividing the battery bus voltage (A2) by the module design operating voltage (C4), and then rounding this figure to the next higher integer determines the number of modules required per string. (A2) / (C4).

24 volts / 14.8 volts = 1.62 (rounded to **2 modules**).

(C11): Number of string in parallel. Dividing the number of modules required to meet energy requirements (C9) by the number of modules required per string (C10) and then rounding this figure to the next higher integer determines the number of string in parallel. (C9) / (C10).

54 modules / 2 modules = **27 strings** (if not a whole number round to next integer)

(C12): Number of modules to be purchased. Multiplying the number of modules required per string (C10) by the number of strings in parallel (C11) determines the number of modules to be purchased. (C10) x (C11).

2 x 27 = **54 modules**

(C13): Nominal rated PV module output. The rated module output in watts as stated by the manufacturer. Photovoltaic modules are usually priced in terms of the rated module output ($/watt). The Siemens Solar M55's rated module power is **53 watts.**

(C14): Nominal rated array output. Multiplying the number of modules to be purchased (C12) by the nominal rated module output (C13) determines the nominal rated array output. This number will be used to determine the cost of the photovoltaic array. (C12) x (C13).

54 modules x 53 watts = **2862 watts.**

Stand Alone PV System Sizing
Worksheet (BLANK)

Application ____

Location ______________________ Latitude __________________

A. Loads

A1	Inverter efficiency (decimal)	______	
A2	Battery bus voltage	______	volts
A3	Inverter ac voltage	______	volts

Appliance	A4 Rated Wattage	A5 Adjustment Factor 1.0 for dc (A1) for ac	A6 Adjusted Wattage (A4/A5)	A7 Hours /day Used	A8 Energy /day (A6xA7)
____________	_______	_______	_______	____	______
____________	_______	_______	_______	____	______
____________	_______	_______	_______	____	______
____________	_______	_______	_______	____	______
____________	_______	_______	_______	____	______
____________	_______	_______	_______	____	______

A9	Total energy demand per day (sum of A8)	_____	watt-hours
A10	Total amp-hour demand per day (A9/A2)	_____	amp-hours
A11	Maximum ac power requirement (sum of A4)	_____	watts
A12	Maximum dc power requirement (sum of A6)	_____	watts

B. Battery Sizing Design Temperature __________

B1	Days of storage desired / required	_____	days
B2	Allowable depth-of-discharge limit (decimal)	_____	
B3	Required battery capacity ((A10 x B1) / B2)	_____	amp-hours
B4	Amp-hour capacity of selected battery *	_____	amp hours
B5	Number of batteries in parallel (B3 / B4)	_____	
B6	Number of batteries in series (A2 / selected battery voltage)	_____	
B7	Total number of batteries (B5 x B6)	_____	
B8	Total battery amp-hour capacity (B5 x B4)	_____	amp-hours
B9	Total battery kilowatt-hour capacity ((B8 x A2) / 1000)	_____	kilowatt-hours
B10	Average daily depth of discharge (.75 x A10 / B8)	_____	

**Use amp hour capacity at a rate of discharge corresponding to the total storage period B1 from battery spec sheet(B4).*

C. PV Array Sizing

Design Tilt (Latitude + 15 degrees) _____ Design Month ____________

C1	Total energy demand per day (A9)	_____	watt-hours
C2	Battery round trip efficiency (0.70 – 0.85)	_____	
C3	Required array output per day (C1 / C2)	_____	watt-hours
C4	Selected PV module max power voltage at STC (x .85)	_____	volts
C5	Selected PV module guaranteed power output at STC	_____	watts
C6	Peek sun hours at design tilt for design month	_____	hours
C7	Energy output per module per day (C5 x C6)	_____	watt-hours
C8	Module energy output at operating temperature. (DF x C7) DF = 0.80 for hot climates and critical applications. DF = 0.90 for moderate climates and non-critical applications.	_____	watt-hours
C9	Number of modules required to meet energy requirements (C3 / C8)	_____	modules
C10	Number of modules required per string (A2 / C4) rounded to next higher integer	_____	modules
C11	Number of strings in parallel (C9 /C10) rounded to next higher integer	_____	strings
C12	Number of modules to be purchased (C10 x C11)	_____	modules
C13	Nominal rated PV module output	_____	watts
C14	Nominal rated array output (C13 x C12)	_____	watts

D. Balance-of-System (BOS) Requirements

1. A voltage regulator is recommended unless array output current (at 1000 W/m^2 conditions), less any continuous load current, is less than 5% of the selected battery bank capacity (at the 8 hour discharge rate).

2. Wiring should be adequate to ensure that losses are less than 1% of the energy produced.

3. In low voltage (i.e., less than 50 volts) systems, germanium or Schottky blocking diodes are preferred over silicon diodes.

4. Fuses, fuse holders, switches, and other components should be selected to satisfy both voltage and current requirements.

5. All battery series branches should contain fuses.

6. Fused disconnects are strongly recommended to isolate the battery bank from the rest of the system.

Refer to electrical and mechanical design sections for other considerations.