SOLAR PV STAND-ALONE SYSTEMS

Good Practice Guide: Small System Sizing

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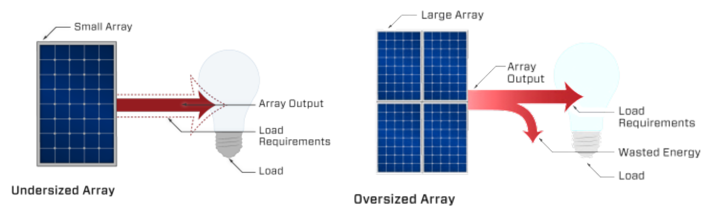
Sizing for Sustainability

Sizing of stand-alone systems requires a fine balance between cost, energy supply and demand as well as responsible behavior of operator/end-user



- ✓ Educate end-user on system expectations and budget requirements
- ✓ Select appropriate, energy-efficient components based on load levels
- ✓ Comply to respective system design and product standards
- ✓ Integrate components into sustainable system
- ✓ Thorough training of end-user in operations and maintenance is essential for sustainability!

Energy Assessment

Step 1: Determine Daily Energy Requirement

- ➢ List all DC appliances (loads) with their power ratings and daily usage
- ➢ Calculate average daily energy consumption for each DC appliance: ④ = ① x ② x ③
- ➢ Total DC energy requirement from battery ⑤ = sum of individual DC load energy consumptions

Example: Total DC Energy Requirements = 228 Wh/day

- ➢ List all AC appliances (if applicable) with their power ratings and daily usage
- ➢ Calculate average daily energy consumption for each AC appliance: ⑨ = ⑥ x ⑦ x ⑧
- ➢ Sum up total AC load (energy) consumption ⑩
- ➢ Determine system wiring losses ⑪ (typically 5-10% - SEIAPI recommends max. 5%)

Example: Wiring Losses = 5%

- ➢ Determine inverter losses ⑫ for AC loads (typical inverter efficiency: 80-90%)

Example: Inverter Efficiency = 85%

- ➢ Calculate total energy requirement from battery = total DC energy requirement + total AC load energy requirement (through inverter): ⑬ = ⑤/(1-⑪) + (⑩/⑫)

Example: Average Daily DC Energy Consumption = 459 Wh/day

Example:

LOAD ANALYSIS

DC LOADS

Appliance (Load)	① Quantity	② Power Rating (W)	③ Use hours/day	④ Average Energy Consumption (Wh/day) = ① x ② x ③
Fluorescent light	3	15	4	180
Security light (CFL)	1	6	8	48
⑤ Total DC Energy Requirement				228

AC LOADS

Appliance (Load)	⑥ Quantity	⑦ Power Rating (W)	⑧ Use hours/day	⑨ Average Energy Consumption (Wh/day) = ⑥ x ⑦ x ⑧
Color TV	1	60	3	180
Cell phone charger	1	3	2	6
⑩ Total AC Energy Requirement				186

Total DC Power	51 W
Total AC Power	63 W
⑤ Total DC Energy Consumption	228 Wh
⑩ Total AC Energy Consumption	186 Wh
⑪ Wiring Losses	5%
⑫ Inverter Efficiency	85%
⑬ Avg. Daily DC Energy Consumption = (⑤ / (1-⑪)) + (⑩ / ⑫)	459 Wh/day

Critical Design Month

Step 2: Determine Critical Design Month

- ➢ Find monthly mean solar insolation data in kWh/m^2/day or peak sun hours (psh) for installation sites (e.g. NASA website http://eosweb.larc.nasa.gov/sse/)
- ➢ Divide daily DC energy requirements by available solar insolation values for different tilt angles: ③ = ① / ②
- ➢ The critical design month is the month with the highest ratio of load to solar insolation. It defines the optimal tilt angle that results in the smallest array possible
- ➢ Since lowest irradiation month mostly falls in the winter solstice, the best tilt angle for constant loads is "Latitude + 15 degree"

Example: Location: Rarotonga, Cook Islands"; Latitude : 21° 12' South, Longitude: 159° 46' West Critical design month is June with 4.49 psh for 36° tilt angle

Example:

CRITICAL DESIGN MONTH ANALYSIS

Month	① Average Daily DC Energy Consumption (Wh/day)	Array Orientation 1 Latitude-15° 6° ② Insolation (PSH/day)	Array Orientation 1 ③ Design Ratio = ① / ②	Array Orientation 2 Latitude 21° ② Insolation (PSH/day)	Array Orientation 2 ③ Design Ratio = ① / ②	Array Orientation 3 Latitude+15° 36° ② Insolation (PSH/day)	Array Orientation 3 ③ Design Ratio = ① / ②
January	459	6.33	72	5.90	78	5.19	88
February	459	6.01	76	5.82	79	5.34	86
March	459	5.80	79	5.86	78	5.62	82
April	459	4.74	97	5.04	91	5.08	90
May	459	4.08	112	4.56	101	4.80	96
June	459	3.69	124	4.20	109	4.49	102
July	459	3.86	119	4.35	105	4.60	100
August	459	4.66	98	5.07	90	5.22	88
September	459	5.23	88	5.39	85	5.27	87
October	459	5.86	78	5.74	80	5.35	86
November	459	6.52	70	6.11	75	5.41	85
December	459	6.59	70	6.51	70	6.11	75
Annual Average		5.28		5.38		5.21	

Critical Design Month	June	
Optimal Orientation	36°	
Average Daily DC Energy Consumption	459	Wh/day
Insolation	4.49	PSH/day

Battery Sizing

Step 3: Size Battery Bank

- ➢ Determine ② DC system voltage, typically 12 V for small (< 1 kWh) and 24V for intermediate daily loads

Example: 12V system voltage

- ➢ Determine ③ the number of days a fully charged battery system can supply power without further charging (days of autonomy), typically 3 – 5 days
- ➢ Calculate ④ daily battery capacity demand = ① total daily energy requirement / ② system voltage * ③ days of autonomy

Example: 459Wh/day / 12V x 5 days = 191Ah

- ➢ Determine ⑤ depth of discharge (DoD) factor for selected battery, typically 20 - 80%
- ➢ Calculate ⑥ required battery capacity = ④ daily battery capacity demand /⑤ DoD

Example: 191Ah / 0.75 = 255Ah

- ➢ Select deep discharge batteries, if possible

Example: 2 x 6V batteries in series with 256Ah capacity

Example:

BATTERY BANK SIZING

① Average Daily DC Energy Consumption for Critical Design Month	459	Wh/day
② DC System Voltage	12	VDC
③ Autonomy	5	days
④ Required Battery-Bank Output = ① / ② * ③	191	Ah
⑤ Allowable Depth-of-Discharge	75%	
⑥ Battery-Bank Rated Capacity = ④ / ⑤	255	Ah
Selected Battery Nominal Voltage	6	VDC
Selected Battery Rated Capacity	256	Ah
Number of Batteries in Series	2	
Number of Battery Strings in Parallel	1	
Total Number of Batteries	2	
Actual Battery-Bank Rated Capacity	256	Ah

PV Array Sizing

Step 4: Size PV Array

- ➢ Estimate ④ battery charging efficiency (typically 80 – 90%)
- ➢ Estimate ⑤ soiling factor for installation (typically 0.9 – 1.0)
- ➢ Calculate required charging current from PV array = daily demand on battery capacity / critical design month insolation / system voltage / battery charging efficiency / soiling factor: ⑥ = ①/②/③/④/⑤

Example: 459Wh/day / 4.49 psh/day / 12V / 0.90 / 0.95 = 10A

- ➢ Estimate ⑧ maximum module temperature & ⑨ rating reference temperature (typically 25°C)
- ➢ Calculate required charging voltage from PV array = system voltage - (system voltage x temperature coefficient x (Max.Temperature - Reference Temperature)): ⑩ = ③ - (③ x ⑦ x (⑧ - ⑨))

Example: 12V-(12V x -0.004 x (60°C - 25°C)) = 13.7V

- ➢ Calculate required charging power from PV array = 1.2 x required charging voltage from PV array x required charging current from PV array = 1.2 x ⑩ x ⑥

Example: 1.2 x 13.7V x 10A = 164 W

- ➢ Select appropriate PV modules, e.g. for 12 V system voltage
- ➢ Calculate (round up) number of PV modules in series = required charging voltage / module rated voltage: ⑭ = ⑩ / ⑫

Example: 13.7 V / 18.3 V = 1 module

- ➢ Calculate (round up) number of PV modules in parallel = required charging current / module rated current: ⑮ = ⑥ / ⑪

Example: 10 A / 5.04 A = 2 modules

- ➢ Calculate total number of modules in array = number of modules in series x number of modules in parallel: ⑬ = ⑪ x ⑫

Example: 1 x 2 = 2 modules with 180 W total peak power

Note: The factor 1.2 accounts for wiring losses, charge controller loss, PV module overrating and other losses.

Example:

ARRAY SIZING

① Average Daily DC Energy Consumption for Critical Design Month	459	Wh/day
② Critical Design Month Insolation	4.49	PSH/day
③ DC System Voltage	12.0	VDC
④ Battery Charging Efficiency	90%	
⑤ Soiling Factor	95%	
⑥ Required Array Maximum-Power Current = ①/②/③/④/⑤	10	A
⑦ Temperature Coefficient for Voltage	-0.004	/ °C
⑧ Maximum Expected Module Temperature	60	°C
⑨ Rating Reference Temperature	25	°C
⑩ Required Array Maximum-Power Voltage = ③ - (③ x ⑦ x (⑧ - ⑨))	13.7	VDC
Required Array Maximum-Power Voltage = 1.2 x ⑩ x ⑥	164	W
⑪ Module Nameplate Rated Maximum-Power Current	5.04	A
⑫ Module Nameplate Rated Maximum-Power Voltage	18.3	VDC
⑬ Module Nameplate Rated Maximum Power	90	W
⑭ Number of Modules in Series = ⑩ / ⑫	1	
⑮ Number of Modules in Parallel = ⑥ / ⑪	2	
⑯ Total Number of Modules = ⑭ x ⑮	2	
Actual Array Rated Power	180	W

Module nameplate rating:

Maximum Power at STC (Pmax)	90W
Voltage at Pmax (Vmp)	18.3V
Current at Pmax (Imp)	5.04A
Open circuit voltage (Voc)	22.2V
Short circuit current (Isc)	5.38A

Controller Sizing

Step 5: Size Charge Controller and Inverter

- ➢ Look up short circuit current of PV module
- ➢ Calculate charge controller minimum power current = short circuit current of PV module x number of modules in parallel x 1.25: ③ = ① x ② x 1.25

Example: 5.38 A x 2 x 1.25 = 13.5 A

- ➢ Select appropriate charge controller
- ➢ Calculate inverter minimum power size = power of all AC appliances x 1.25: ⑤ = ④ x 1.25

Example: 63 W x 1.25 = 78.8 W

- ➢ Select appropriate inverter

Note: The factor 1.25 is the safety factor for continuous operation

Example:

CONTROLLER SIZING

① Short-Circuit Current of PV Module	5.38	A
② Number of PV Modules in Parallel	2	
③ Charge Controller Minimum Power Current = 1.25 x ① x ②	13.5	A
④ Total AC Power of AC Appliances	63	W
⑤ Inverter Minimum Power = 1.25 x ④	78.8	W

Note: After correcting for voltage losses due to module temperature, ensure that voltage input from PV array is within voltage window of charge controller