STAND-ALONE SYSTEM SIZING

Load Analysis

① n_{load} Enter number of loads of a given description. All loads within a description must use the same power type (AC or DC) and have the same power rating and operation time. AC loads and DC loads are listed separately, but require the same types of information.

② P_{load} Enter the power rating of the load type.

③ t_{load} Enter the operating time of the load type.

④ E_{load} Calculate the daily energy consumption of each load type individually.

$$E_{load} = n_{load} \times P_{load} \times t_{load}$$

④ = ① × ② × ③

⑤ P_{AC} Calculate the total AC power requirement, if every load operated simultaneously.

P_{AC} = sum of all P_{load} for AC loads

⑤ = sum of all ② for AC loads

⑥ P_{DC} Calculate the total DC power requirement, if every load operated simultaneously.

P_{DC} = sum of all P_{load} for DC loads

⑥ = sum of all ② for DC loads

⑦ E_{AC} Calculate the total energy consumption by all AC loads.

E_{AC} = sum of all E_{load} for AC loads

⑦ = sum of all ④ for AC loads

⑧ E_{DC} Calculate the total energy consumption by all DC loads.

E_{DC} = sum of all E_{load} for DC loads

⑧ = sum of all ④ for DC loads

⑨ η_{inv} Enter the inverter power conversion efficiency. This value should be in the inverter specifications. Typical values are 90% to 95% (0.90 to 0.95).

⑩ t_{op} Calculate the weighted average operating time for all of the loads. Each load's energy consumption and operating time is included. If the system includes AC loads, their AC energy consumption is first converted to equivalent DC energy consumption by dividing by the inverter efficiency.

$$t_{op} = \frac{(E_1 \times t_1) + (E_2 \times t_2) + \ldots + (E_n \times t_n)}{E_1 + E_2 + \ldots + E_n}$$

⑩ = ((④ × ③) + (④ × ③) + … + (④ × ③)) / (④ + ④ + … + ④)

⑪ E_{SDC} Calculate the total daily DC energy required to supply all of the loads during this month.

$$E_{SDC} = \frac{E_{AC}}{\eta_{inv}} + E_{DC}$$

⑪ = ⑦ / ⑨ + ⑧

A load analysis must be done for each month individually, unless the load operations are constant throughout the year.

Load Analysis Worksheet

AC LOADS Month:

Load Description	Qty	Power Rating (W)	Operating Time (hr/day)	Energy Consumption (Wh/day)
	①	②	③	④

DC LOADS

Load Description	Qty	Power Rating (W)	Operating Time (hr/day)	Energy Consumption (Wh/day)
	①	②	③	④

Total AC Power	⑤	W
Total DC Power	⑥	W
Total Daily AC Energy Consumption	⑦	Wh/day
Total Daily DC Energy Consumption	⑧	Wh/day
Inverter Efficiency	⑨	
Weighted Operating Time	⑩	hr/day
Average Daily DC Energy Consumption	⑪	Wh/day

STAND-ALONE SYSTEM SIZING

Critical Design Analysis

11 E_{SDC} Enter the total required daily system DC energy calculated from the load analyses for each month.

12 PSH Enter the average daily insolation for the location and possible array orientations for each month. This information may be found in the solar radiation data set for the nearest location.

13 *design ratio*

Calculate the design ratio for each month and each array orientation.

$$design\,ratio = \frac{E_{SDC}}{PSH}$$

$$13 = \frac{11}{12}$$

14 *critical design month*

Determine the critical design month. For each orientation, identify the month with the highest design ratio. This is the critical design month for this orientation. If there are multiple orientations in the analysis, identify the orientation corresponding to the lowest critical design month design ratio. This is the selected array orientation. This orientation's critical design month is the selected critical design month.

15 E_{crit} Enter the total required daily system DC energy for the critical design month.

16 t_{PSH} Enter the average daily insolation for the selected array orientation during the critical design month.

Critical Design Analysis Worksheet

Month	Average Daily DC Energy Consumption (Wh/day)	Array Orientation 1		Array Orientation 2		Array Orientation 3	
		Insolation (PSH/day)	Design Ratio	Insolation (PSH/day)	Design Ratio	Insolation (PSH/day)	Design Ratio
January	11	12	13	12	13	12	13
February							
March							
April							
May							
June							
July							
August							
September							
October							
November							
December							

Critical Design Month	14	
Optimal Orientation	14	
Average Daily DC Energy Consumption	15	**Wh/day**
Insolation	16	**PSH/day**

STAND-ALONE SYSTEM SIZING

Battery-Bank Sizing

15 E_{crit} Enter the total required daily system DC energy for the critical design month.

17 V_{SDC} Enter the nominal DC-system voltage.

18 t_a Enter the desired system autonomy.

19 B_{out} Calculate the required battery-bank output.

$$B_{out} = \frac{E_{crit} \times t_a}{V_{SDC}}$$

$$19 = \frac{15 \times 18}{17}$$

20 DOD_a Enter an allowable depth of discharge. For deep-cycle lead-acid batteries, a typical value if 80% (0.80).

10 t_{op} Enter the weighted average operating time for all of the loads. This value is calculated in the load analysis for the critical design month.

21 r_d Calculate the average battery-bank discharge rate.

$$r_d = \frac{t_{op} \times t_a}{DOD_a}$$

$$21 = \frac{10 \times 18}{20}$$

22 T_{min} Enter the minimum expected operating temperature for the battery bank.

23 $C_{T,rd}$ Determine the derating factor associated with the batteries' minimum operating temperature and discharge rate. This information is typically found on charts or graphs available from the battery manufacturer.

24 B_{rated} Calculate the rated capacity required for the battery bank.

$$B_{rated} = \frac{B_{out}}{DOD_a \times C_{T,rd}}$$

$$24 = \frac{19}{20 \times 23}$$

25 V_{batt} Enter the nominal voltage of the selected battery.

26 B_{batt} Enter the rated capacity of the selected battery.

27 n_{series} Calculate the number of batteries required to be connected in series.

$$n_{series} = \frac{V_{SDC}}{V_{batt}}$$

$$27 = \frac{17}{25}$$

Battery-Bank Sizing Worksheet

Average Daily DC Energy Consumption for Critical Design Month	15	Wh/day
DC System Voltage	17	VDC
Autonomy	18	days
Required Battery-Bank Output	19	Ah
Allowable Depth-of-Discharge	20	
Weighted Operating Time	10	hrs
Discharge Rate	21	hrs
Minimum Expected Operating Temperature	22	°C
Temperature/Discharge Rate Derating Factor	23	
Battery-Bank Rated Capacity	24	Ah
Selected Battery Nominal Voltage	25	VDC
Selected Battery Rated Capacity	26	Ah
Number of Batteries in Series	27	
Number of Battery Strings in Parallel	28	
Total Number of Batteries	29	
Actual Battery-Bank Rated Capacity	30	Ah
Load Fraction	31	
Average Daily Depth-of-Discharge	32	

28 $n_{parallel}$ Calculate the number of battery strings required to be connected in parallel. Round the result up to the nearest whole number.

$$n_{parallel} = \frac{B_{rated}}{B_{batt}}$$

$$28 = \frac{24}{26}$$

29 n_{batt} Calculate the total number of batteries required for the battery bank.

$$n_{batt} = n_{series} \times n_{parallel}$$

$$29 = 27 \times 28$$

30 B_{actual} Calculate the actual battery-bank rated capacity.

$$B_{actual} = B_{batt} \times n_{parallel}$$

$$30 = 26 \times 28$$

31 LF Determine the load fraction for the battery-bank operation. A typical value is 0.75

32 DOD_{avg} Calculate the average daily depth of discharge.

$$DOD_{avg} = \frac{LF \times E_{day}}{B_{actual} \times V_{SDC}}$$

$$32 = \frac{31 \times 15}{30 \times 17}$$

STAND-ALONE SYSTEM SIZING

Array Sizing

15 E_{crit} Enter the total required daily system DC energy for the critical design month. This information is from the critical design analysis.

16 V_{SDC} Enter the nominal DC-system voltage.

17 t_{PSH} Enter the average daily insolation, in peak sun hours, for the selected array orientation during the critical design month. This information is from the critical design analysis.

33 η_{batt} Enter battery charging efficiency. Typical values for most battery systems range from 85% to 95% (0.85 to 0.95).

34 I_{array} Calculate the required array maximum-power current.

$$I_{array} = \frac{E_{crit}}{\eta_{batt} \times V_{SDC} \times t_{PSH}}$$

$$34 = \frac{15}{33 \times 16 \times 17}$$

35 C_S Enter the derating factor for array soiling. Typical values for most systems range from 90% to 95% (0.90 to 0.95).

36 I_{rated} Calculate the required array maximum-power current rating.

$$I_{rated} = \frac{I_{array}}{C_S}$$

$$36 = \frac{34}{35}$$

37 $C_{\%V}$ Enter the relative temperature coefficient for voltage. This value may be given by the module manufacturer. Otherwise, a typical value is –0.4%/°C (–0.004/°C).

38 T_{max} Enter the maximum expected ambient temperature for the array location. This information can be found in the solar radiation data set for the nearest location.

39 T_{ref} Enter the reference temperature associated with the maximum-power voltage rating. This value is typically 25°C.

40 V_{rated} Calculate the required array maximum-power voltage rating.

$$V_{rated} = 1.2 \times \{V_{SDC} + [V_{SDC} \times C_{\%V} \times (T_{max} - T_{ref})]\}$$

$$40 = 1.2 \times \{17 + [17 \times 37 \times (38 - 39)]\}$$

41 I_{mp} Enter the maximum-power current rating for the selected module.

42 V_{mp} Enter the maximum-power voltage rating for the selected module.

43 P_{mp} Enter the maximum power rating for the selected module.

Array Sizing Worksheet

Average Daily DC Energy Consumption for Critical Design Month	15	Wh/day
DC System Voltage	16	VDC
Critical Design Month Insolation	17	PSH/day
Battery Charging Efficiency	33	
Required Array Maximum-Power Current	34	A
Soiling Factor	35	
Rated Array Maximum-Power Current	36	A
Temperature Coefficient for Voltage	37	/°C
Maximum Expected Module Temperature	38	°C
Rating Reference Temperature	39	°C
Rated Array Maximum-Power Voltage	40	VDC
Module Rated Maximum-Power Current	41	A
Module Rated Maximum-Power Voltage	42	VDC
Module Rated Maximum Power	43	W
Number of Modules in Series	44	
Number of Module Strings in Parallel	45	
Total Number of Modules	46	
Actual Array Rated Power	47	W

44 n_{series} Calculate the number of modules required to be connected in series. Round the result up to the nearest whole number.

$$n_{series} = \frac{V_{rated}}{V_{mp}}$$

$$44 = \frac{40}{42}$$

45 $n_{parallel}$ Calculate the number of module strings required to be connected in parallel. Round the result up to the nearest whole number.

$$n_{parallel} = \frac{I_{rated}}{I_{mp}}$$

$$45 = \frac{36}{41}$$

46 n_{mod} Calculate the total number of modules in the array.

$$n_{mod} = n_{series} \times n_{parallel}$$

$$46 = 44 \times 45$$

47 P_{actual} Calculate the actual array rated power.

$$P_{actual} = P_{mp} \times n_{mod}$$

$$47 = 43 \times 46$$