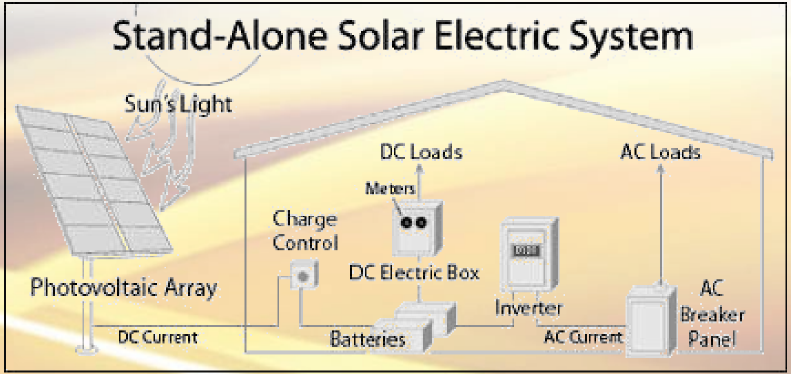
Updates to NEC Article 690 and IEEE Standards 1013 and 1562 for PV/Solar Installations

Who Am I?

- Immediate Past-Chair of IEEE PES-ESSB
  - WG Chair for IEEE 1635 / ASHRAE 21 (Battery Gassing); IEEE 1657 (Battery Tech Curriculum), 1526 (Stand-Alone PV Performance), 1561, (Optimizing Lead-Acid Life in Hybrid PV), 1562 (Sizing Stand-Alone PV Arrays), and P2962 (Li-ion Maintenance)
    - WG Vice-Chair for IEEE 1188 (VRLA Maintenance), and P2685 (Engine Starting Energy Storage Devices)
- Member of NFPA 855 (Energy Storage Systems)
- Training Director for American Power Systems LLC (a DC Services Subsidiary of Deka East Penn Battery Manufacturing)
- Master Electrician in the State of Colorado
- Private Solar Owner
  - 2.3 kW Grid-Connected Panels on my Primary Home
  - Off-Grid Hybrid 2 kW PV, 15 kW LPG Generator, 30 kWh Battery on Cabin

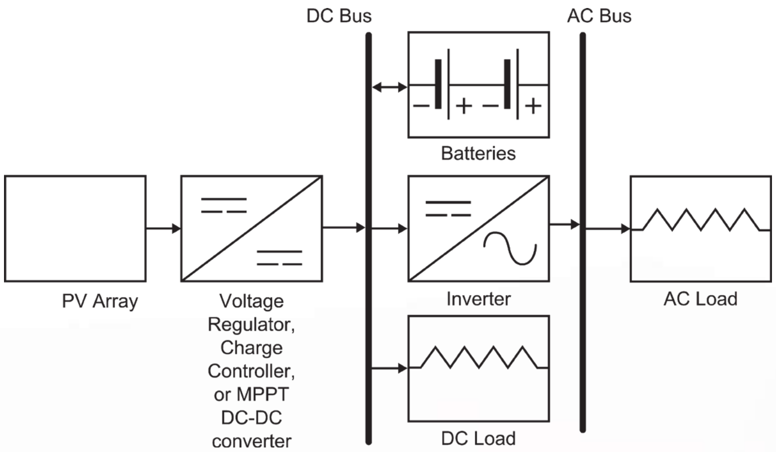
What Are We Going to Talk About?

- Updates to IEEE 1013/1526 (Lead-Acid Battery and PV Array Sizing for Stand-Alone Systems)
  - Forthcoming Combo Calculator (Includes Other Battery Types) to be Available on IEEE PES Resource Center
- Latest (2020 Edition) in NEC Article 690 (Solar PV Systems)
- Whatever Else You Want to Discuss Regarding Solar, Fuel Cells, DG (Distributed Generation), and Energy Storage



Changes to IEEE 1013 from 2007 to 2019

- Drawing to Explain System Added
- References to 1361 (More Help on Selecting Lead-Acid) Added
- Recommend no EOL < 50%
- Fixed the Slight Error in Example B.3 on the Average Daily Ah Usage



1013 Worksheet 1

9.1 Worksheet 1—Battery sizing

1) Project name and description:

2) Nominal system voltage: _________ V

3) Days of autonomy: _________ days

4) Load data (see Table 1)

5) Load data summary

a) Maximum momentary current I_{coin} from above table (or line 5a of Worksheet 3) (refer to load profile diagram): _________ A

b) Maximum running current I_{coin} from above table (or line 5b of Worksheet 3) (refer to load profile diagram): _________ A

c) Total daily load from above table (or line 5c of Worksheet 3): _________ Ah/day

d) Maximum daily load from Worksheets 2 if used: _________ Ah/day

e) Greatest value of $I_{noncoin}$ momentary currents from above table (or line 5d of Worksheet 3): _________ A

f) Maximum momentary current draw from battery (greater of line 5a or line 5e): _________ A

g) Greatest value of $I_{noncoin}$ for running currents from above table (or line 5e of Worksheet 3): _________ A

h) Maximum running current draw from battery (greater of line 5b or line 5g): _________ A

i) Maximum current draw from battery (greater of line 5f or line 5h): _________ A

j) Lowest value of V_{max} from above table (or line 5f of Worksheet 3): _________ V

k) Greatest value of V_{min} from above table (or line 5g of Worksheet 3): _________ V

6) Battery capacity

a) Unadjusted battery capacity (line 3 × line 5c): _________ Ah

b) Maximum allowable depth of discharge (MDOD): _________ %

c) Capacity adjusted for MDOD (line 6a ÷ line 6b): _________ Ah

d) Maximum daily depth of discharge (MDDOD): _________ %

e) Capacity adjusted for MDDOD (line 5c ÷ line 6d) (or line 5d ÷ line 6d if Worksheet 3 is used): _________ Ah

f) Percent of capacity at end of life (EOL): _________ %

g) Capacity adjusted for EOL (line 6a ÷ line 6f): _________ Ah

h) Capacity adjusted for depths of discharge and end of life (greatest of line 6c, line 6e, or line 6g): _________ Ah

i) Minimum operating temperature: _________ °C

j) Associated temperature correction factor: _________

k) Capacity adjusted for temperature: _________ Ah

l) Design margin factor (≥ 1): _________

m) Capacity adjusted for design margin (line 6k × line 6l): _________ Ah

7) Functional-hour rate (line 6m ÷ line 5h): _________ h

8) Voltage-window adjustment

a) Controller low-voltage disconnect set point: _________ V

b) Adjusted V_{min} (greater of line 5k or line 8a): _________ V

c) Controller full-charge voltage set point: _________ V

d) Adjusted V_{max} (lesser of line 5j or line 8c) (at the lowest battery temperature when a temperature-compensated charge controller is used): _________ V

9) Number of series-connected cells

a) Recommended full-charge voltage for selected cell: (limited by line 8d): _________ V

b) Maximum number of cells in series, round down (line 8d ÷ line 9a): _________

c) Recommended end of discharge (EOD) voltage for selected cell: _________ V

d) Calculated EOD voltage for cell (line 8b ÷ line 9b): _________ V

NOTE—If line 9d > line 9c, proceed to line 9g; otherwise, continue with line 9e.

e) Decrement number of series cells (line 9b – 1): _________

f) Calculated cell charge voltage (line 8d ÷ line 9e): _________ V

NOTE—If line 9f is within charge voltage range specified by manufacturer, proceed to line 9d; otherwise, at least one of the following has to be done: select different battery type, go to line 6b; change controller full-charge voltage set point, go to line 8c; select different controller, go to line 8a).

g) Enter the selected number of series cells (line 9b or line 9e), as appropriate: _________

10) Cell selection and final capacity determination

a) Smallest practical cell capacity available of selected type greater than or equal to line 6m, or largest practical cell capacity less than line 6m, when discharged to the calculated EOD voltage (line 9d), at the functional-hour rate (line 7): _________ Ah

b) Number of parallel strings, round up (line 6m ÷ line 10a): _________

c) Final battery capacity (line 10a × line 10b): _________ Ah

11) Checks/considerations

a) Maximum charge rate

i) Recommended maximum charge current during recharge: _________ A

ii) Maximum available charging current during recharge: _________ A

NOTE—If line 11aii > line 11ai, the battery may be damaged.

b) Excessive overcharging

i) Recommended maximum charge current after reaching regulation voltage at the battery's average temperature of _________ °C: _________ A

ii) Maximum available charging current after reaching regulation voltage: _________ A

NOTE—If line 11bii > line 11bi, the battery may be damaged.

c) Undercharging—Array-to-load ratio for the minimum design month: _________

NOTE—If line 11c < 1.3, there may be insufficient array energy to recharge the battery.

d) High-rate discharge—Maximum discharge current: _________ A (This is the same value as line 5i.)

NOTE—If line 10c ÷ line 11d < 20, the cell voltage may drop below the allowable EOD voltage when this condition occurs near the end of discharge of the battery.

e) Freezing of electrolyte—Freezing temperature of electrolyte at MDOD: _________ °C

NOTE—If line 6i < line 11e, the battery may freeze.

f) Battery self discharge

i) Battery's self discharge: _________ Ah/day

ii) Battery's capacity for each day of autonomy (line 10c ÷ line 3): _________ Ah/day

NOTE—If line 11fi ÷ line 11fii > 0.05 and self-discharge was not included in the load considerations, the battery may be undersized.

g) Electrolyte reserve—Battery electrolyte reserve capacity estimated in days: _________ day

NOTE—If line 11 g < anticipated maintenance interval, the battery may be damaged.

Considerations resolved:

a) Maximum charge rate [ ]

b) Excessive overcharging [ ]

c) Undercharging [ ]

d) High-rate discharge [ ]

e) Freezing of electrolyte [ ]

f) Battery self discharge [ ]

g) Electrolyte reserve [ ]

h) Battery's size and weight [ ]

12) Summary

Battery manufacturer and model: ______________________________.

Final battery is _________ cells in series by _________ strings in parallel.

Battery capacity is _________ Ah rated at the _________ h functional-hour rate.

Battery full-charge voltage is _________ V.

Battery end-of-discharge voltage is _________ V.

1013 Table 1

Table 1—Load data

4a DC load device	4b Voltage window		4c Momentary currents		4d Running currents[a]		4e Constituents of maximum running current	4f Number of occurrences	4g Duration	4h Run time	4i Daily load
	V_{max}, V	V_{min}, V	I_{coin}, A	$I_{noncoin}$, A	I_{coin}, A	$I_{noncoin}$, A		Number/day	Hours/ occurrence	Hours/day	Ah/day
											Total daily load Ah

[a]Including parasitic currents

1013 Optional Worksheets 2 and 3

9.2 Worksheet 2—Supplemental battery sizing for duty cycle periods > 24 h

Complete Worksheet 2 for each day (24 h period) for which a distinct daily loads exists. Summarize the data in Worksheet 3 and transfer to Worksheet 1:

Load data (see Table 2)

Day: __________

Maximum momentary current I_{coin} (refer to load profile diagram): __________ A

Maximum running current I_{coin} (refer to load profile diagram): __________ A

Number of repetitions: __________

9.3 Worksheet 3—Load-Data Summary

5) Load-data summary

a) Greatest value of the maximum I_{coin} currents: __________ A

b) Greatest value of the maximum running I_{coin} currents: __________ A

c) Average daily load:

i) Determine the series of repetitions that is going to result in the greatest load, over the autonomy period.

ii) Total the load over the autonomy period and divide by the number of days of autonomy: __________ Ah/day

d) Greatest value of $I_{noncoin}$ for momentary currents for any of the above load devices: __________ A

e) Greatest value of $I_{noncoin}$ for running current for any of the above load devices: __________ A

f) Lowest value of V_{max} for any of the above load devices: __________ V

g) Greatest value of V_{min} for any of the above load devices: __________ V

1013 Optional Table 2

Table 2—Load data

4a DC load device	4b Voltage window		4c Momentary currents		4d Running currents[a]		4e Constituents of maximum running current	4f Number of occurrences	4g Duration	4h Run time	4i Daily load
	V_{max}, V	V_{min}, V	I_{coin}, A	$I_{noncoin}$, A	I_{coin}, A	$I_{noncoin}$, A		Number/day	Hours/occurrence	Hours/day	Ah/day
											Total daily load Ah

[a]Including parasitic currents

1013 Example B.1 (Remote Brazil Vaccine Store)

B.1 Refrigerator/freezer for vaccine storage

Example B.1 describes the battery sizing for a vaccine storage refrigerator intended for remote use. The refrigerator is to be located near the equator in a tropical climate. Vaccines are delivered quarterly. At the same time deliveries are made, a technician is available for system maintenance. There is a constraint on the physical size of the battery that can be installed in the refrigerator's battery box. Figure B.1 shows a typical load profile diagram for this application.

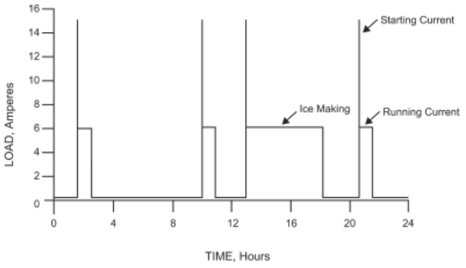


Figure B.1—Simulated load-profile diagram for vaccine storage refrigerator/freezer

B.1.1 Example B.1

Worksheet 1—Battery sizing

1) Project name and descriptionRemote refrigerator/freezer, Brazilian village, tropical climate. High availability required, quarterly maintenance, four starts each 24 h period (including one for ice pack freezing)

2) Nominal system voltage: 12 V

3) Days of autonomy: 6 days

4) Load data (see Table 3)

5) Load data summary

a) Maximum momentary current I_{coin} from above table (or line 5a of Worksheet 3) (refer to load profile diagram): 15.1 A

b) Maximum running current I_{coin} from above table (or line 5b of Worksheet 3) (refer to load profile diagram): 6.1 A

c) Total daily load from above table (or line 5c of Worksheet 3): 51.4 Ah/day

d) Maximum daily load from Worksheets 2 if used: — A

e) Greatest value of $I_{noncoin}$ momentary currents from above table (or line 5d of Worksheet 3): 0 A

f) Maximum momentary current draw from battery (greater of line 5a or line 5e): 15.1 A

g) Greatest value of $I_{noncoin}$ for running currents from above table (or line 5e of Worksheet 3): 0 A

h) Maximum running current draw from battery (greater of line 5b or line 5g): 6.1 A

i) Maximum current draw from battery (greater of line 5f or line 5h): 15.1 A

j) Lowest value of V_{max} from above table (or line 5f of Worksheet 3): 15.0 A

k) Greatest value of V_{min} from above table (or line 5g of Worksheet 3): 10.5 A

6) Battery capacity

a) Unadjusted battery capacity (line 3 × line 5c): 308 Ah

b) Maximum allowable depth of discharge (MDOD): 80%

c) Capacity adjusted for MDOD (line 6a ÷ line 6b): 385 Ah

d) Maximum daily depth of discharge (MDDOD): 20%

e) Capacity adjusted for MDDOD (line 5c ÷ line 6d) (or line 5d ÷ line 6d if Worksheet 3 is used): 257 Ah

f) Percent of capacity at end of life (EOL): 80%

g) Capacity adjusted for EOL (line 6a ÷ line 6f): 385 Ah

h) Capacity adjusted for depths of discharge or end of life (greatest of line 6c, line 6e, or line 6g): 385 Ah

i) Minimum operating temperature: 25 °C

j) Associated temperature correction factor: 1 v

k) Capacity adjusted for temperature: 385 Ah

l) Design margin factor (≥ 1): 1.1 .

m) Capacity adjusted for design margin (line 6k × line 6l): 424 Ah

7) Functional-hour rate (line 6m ÷ line 5h): 70 h

8) Voltage-window adjustment

a) Controller low-voltage disconnect set point: 10.8 V

b) Adjusted V_{min} (greater of line 5k or line 8a): 10.8 V

c) Controller full-charge voltage set point: 14.7 V

d) Adjusted V_{max} (lesser of line 5j or line 8c) (at the lowest battery temperature when a temperature-compensated charge controller is used): 14.7 V

9) Number of series-connected cells

a) Recommended full-charge voltage for selected cell: (limited by line 8d): 2.45 V

b) Maximum number of cells in series, round down (line 8d ÷ by line 9a): 6 v

c) Recommended end of discharge (EOD) voltage for selected cell: 1.80 V

d) Calculated EOD voltage for cell (line 8b ÷ line 9b): 1.80 V

NOTE—If line 9d > line 9c, proceed to line 9g; otherwise, continue with line 9e.

e) Decrement number of series cells (line 9b − 1): — .

f) Calculated cell charge voltage (line 8d ÷ line 9e): — V

NOTE—If line 9f is within charge voltage range specified by manufacturer, proceed to line 9g; otherwise, at least one of the following has to be done: decrement number of series cells (repeat line 9e and line 9f); select different battery type, go to line 6b; change controller full-charge voltage set point, go to line 8c; select different controller, go to line 8a.

g) Enter the selected number of series cells (line 9b or line 9e, as appropriate): 6 .

10) Cell selection and final capacity determination

a) Smallest practical cell capacity available of selected type greater than or equal to line 6m, or largest practical cell capacity less than line 6m, when discharged to the calculated EOD voltage (line 9d), at the functional-hour rate (line 7): 110 Ah

b) Number of parallel strings, round up (line 6m ÷ line 10a): 4 v

c) Final battery capacity (line 10a × line 10b): 440 Ah

11) Checks/considerations

a) Maximum charge rate

i) Recommended maximum charge current during recharge: 80 A

ii) Maximum available charging current during recharge: 35 A

NOTE—If line 11aii > line 11ai, the battery may be damaged.

b) Excessive overcharging

i) Recommended maximum charge current after reaching regulation voltage at the battery's average temperature of 40.6 °C: 1* A

*4A for the four parallel strings.

ii) Maximum available charging current after reaching regulation voltage: 0* A

Disconnecting charge controller is used.

NOTE—If line 11bii > line 11bi, the battery may be damaged.

c) Undercharging—Array-to-load ratio for the minimum design month: 1.5 v

NOTE—If line 11c < 1.3, there may be insufficient array energy to recharge the battery.

More From 1013 Example B.1

d) High-rate discharge—Maximum discharge current: _15.1_ A (This is the same value as line 5i.)

NOTE—If line 10c ÷ line 11d < 20, the cell voltage may drop below the allowable EOD voltage when this condition occurs near the end of discharge of the battery.

e) Freezing of electrolyte—Freezing temperature of electrolyte at MDOD: _6.7_ °C

NOTE—If line 6i < line 11e, the battery may freeze.

f) Battery self discharge

i) Battery's self discharge: _0.5_ Ah/day

ii) Battery's capacity for each day of autonomy (line 10c ÷ line 3): _73_ Ah/day

NOTE—If line 11fi ÷ line 11fii > 0.05 and self-discharge was not included in the load considerations, the battery may be undersized.

iii) Electrolyte reserve—Battery electrolyte reserve capacity estimated in days: _120 d*_

*Cells with extra headspace selected.

NOTE—If line 11 g < anticipated maintenance interval, the battery may be damaged.

Considerations resolved:

a) Maximum charge rate [X]
b) Excessive overcharging [X]
c) Undercharging [X]
d) High-rate discharge [X]
e) Freezing of electrolyte [X]
f) Battery self discharge [X]
g) Electrolyte reserve [X]
h) Battery's size and weight [X]

12) Summary

Battery manufacturer and model: _XYZ Co. y_

Final battery is _6_ cells in series by _4_ strings in parallel.

Battery capacity is _440_ Ah rated at the _70_ h functional-hour rate.

Battery full-charge voltage is _14.7_ V.

Battery end-of-discharge voltage is _10.8_ V.

NOTE—*Because of this application's enclosed container and high ambient temperature, caution should be exercised if a valve-regulated battery is selected. The potential for thermal runaway exists for these conditions.*

Table B.1—Load data

4a DC load device	4b Voltage window		4c Momentary currents		4d Running currents[a]		4e Constituents of maximum running current	4f Number of occurrences	4g Duration	4h Run time	4i Daily load
	V_{max}, V	V_{min}, V	I_{coin}, A	$I_{noncoin}$, A	I_{coin}, A	$I_{noncoin}$, A		Number/day	Hours/ occurrence	Hours/day	Ah/day
Run 1 compressor	15.0	10.5			6		X	3	1	3	18
							or				
Run 2 compressor[b] Start Compressor	15.0 15.0	10.5 10.5	15		6		X	1 4	5 0.0167	5	30 1
Parasitics					0.1		X			24	2.4
Total daily load 51.4 Ah											

[a]Including parasitic currents.
[b]For ice pack freezing.

Sample Solar Battery Data Sheets

8GGC2-DEKA

SPECIFICATIONS

Nominal Voltage (V)	6V
Capacity at C/100	198Ah
Capacity at C/20	180Ah
Weight	69 lbs. (31 kg)
Plate Alloy	Lead Calcium
Posts	Forged Terminals & Bushings
Container/Cover	Polypropylene
Operating Temperature Range	-76°F (-60°C) - 140°F (60°C)

For Charging Parameters please refer to www.mkbattery.com
Click on Technical Data, then on Photovoltaic Charging Parameters in the PV/Solar section

Vent	Self-sealing
Electrolyte	Sulfuric acid thixotropic gel
Terminal	U (SAE/STUD)

Rated non-spillable by ICAO, IATA and DOT

Made in the U.S.A. by East Penn Manufacturing Co, Inc.

Distributed by:

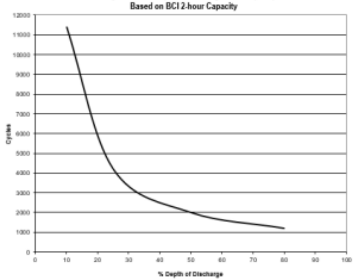
Valve-Regulated, Gelled-Electrolyte Battery

DIMENSIONS

Inches (mm)

Length	**10.25 (260 mm)**
Width	**7.09 (180 mm)**
Height	**10.88 (276 mm)** *Including terminal*

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



Rolls

FLOODED DEEP CYCLE BATTERY — 12 EHG 210P

Series	4000	Warranty	3 Years
Volts	12	BCI	4DH
Cells	4	Plates/Cell	17
Terminal Type		Flag	
Included Hardware		S/S Hex Cap Screw, Nut, Lock & Flat Washer	
Size & Thread		5/16"-18	

Charge

Charge Voltage Range	14.7-15 V/cell @ 25°C (77°F)
Self-Discharge Rate	5%-10% per month at 25°C (77°F)

Capacity

Cold Crank Amps (CCA) 0°F / -18°C	778
Marine Crank Amps (MCA) 32°F / 0°C	972
Reserve Capacity (RC @ 25A)	504 Minutes
Reserve Capacity (RC @ 75A)	168 Minutes

Hour Rate	Capacity / AMP Hour	Current / AMPs
@ 100 Hour Rate	**279 AH**	**2.79 A**
@ 72 Hour Rate	**265 AH**	**3.68 A**
@ 50 Hour Rate	**250 AH**	**5 A**
@ 20 Hour Rate	**210 AH**	**10.5 A**
@ 15 Hour Rate	**200 AH**	**13.3 A**
@ 10 Hour Rate	**185 AH**	**18.48 A**
@ 8 Hour Rate	**181 AH**	**22.58 A**
@ 5 Hour Rate	**166 AH**	**33.18 A**
@ 1 Hour Rate	**84 AH**	**84 A**

Ampere hour capacity ratings based on specific gravity of 1.280 at 27°C (80°F). Reduce capacities 5% for specific gravity of 1.265 and 10% for 1.250.

Specifications

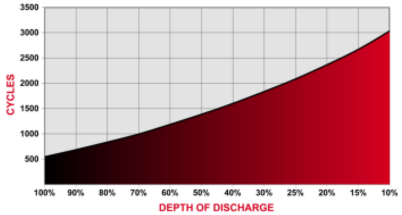
Certified System — SAI GLOBAL ISO 9001 Quality

Weight		62.5 kg	138 lbs
Length		52.7 cm	20.75"
Width		22.2 cm	8.75"
Height Inc. Term.		31.4 cm	12.38"

Product measurements & weights are calculated based on sample data. Individual specifications are subject to vary due to the manufacturing process, battery components & electrolyte levels.

Electrolyte Reserve	57 mm	2.25"
Container (Inner)	Polypropylene	
Cover (Inner)	Polypropylene - heat sealed to inner container	
Container (Outer)	High Density Polyethylene	
Cover (Outer)	High Density Polyethylene snap fit to outer container	
Handles	Molded	

Cycle Life vs. Depth of Discharge



Rev.#3 | May 2018

More Sample Solar Battery Data Sheets

Deka SOLAR

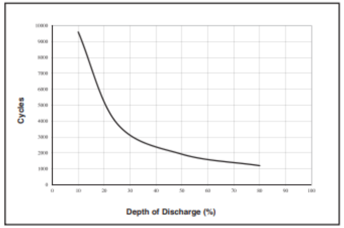
ISO 9001 ISO/TS 16949 ISO 14001

UL Recognized Component

Photovoltaic Charging Parameters		
Bulk Charge	Max Current (amps)	15% of 20 Hr Rate
Absorption (Regulation) Charge	Constant Voltage	2.37 - 2.42 vpc
Float Charge	Constant Voltage	2.25 - 2.30 vpc
Equalize Charge	Constant Voltage	2.43 - 2.48 vpc
Temperature Coefficient	0.003 v / °C	

Cut-off parameters per charge & equalize intervals are application specific and will vary dependent upon site specific characteristics such as temperature, days of autonomy, array to load ratio, etc.

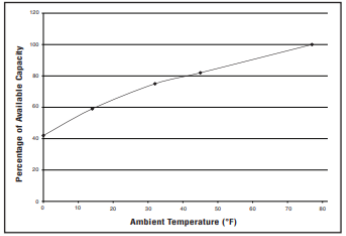
Cycle Life vs Depth of Discharge at +25°C (77°F)*



The solar battery excels in cycling applications.

**Dependent upon proper charging and ambient temperatures.*

Capacity vs. Operating Temperature



Capacity vs. Operating Temperatures: Above are the changes in capacity for wider ambient temperature range, giving the available capacity, as a percentage of the rated capacity, at different ambient temperatures. The curves show the behavior of the battery after a number of cycles.

Cell Performance – Photovoltaic Batteries

Amp Hours at 77°F (25°C) to 1.75 v.p.c.

Cell Type	10	20	24	100	Cell Weights**
G45-5	95	104	107	127	22
G45-7	141	155	159	189	29
G45-9	188	207	212	252	37
G45-11	236	259	265	316	45
G45-13	283	311	319	379	54
G45-15	330	362	371	441	67
G45-17	377	414	424	505	73
G45-19	424	466	477	568	82
G45-21	472	518	531	632	90
G45-23	518	569	583	694	99
G45-25	565	621	636	757	108
G45-27	613	673	689	821	117
G45-29	660	725	743	884	125
G45-31	707	776	795	946	134
G45-33	754	828	848	1010	143

Amp Hours at 77°F (25°C) to 1.75 v.p.c.

Cell Type	10	20	24	100	Cell Weights**
G75-5	158	173	177	211	34
G75-7	236	259	265	316	46
G75-9	314	345	353	421	59
G75-11	392	431	442	526	71
G75-13	472	518	531	632	85
G75-15	550	604	619	737	105
G75-17	628	690	707	841	115
G75-19	707	776	795	946	130
G75-21	786	863	884	1052	142
G75-23	864	949	972	1157	150
G75-25	942	1035	1060	1262	162
G75-27	1021	1121	1148	1367	174
G75-29	1100	1208	1237	1473	182
G75-31	1178	1294	1326	1578	193
G75-33	1257	1380	1414	1683	206

Amp Hours at 77°F (25°C) to 1.75 v.p.c.

Cell Type	10	20	24	100	Cell Weights**
G105-5	220	242	248	295	45
G105-7	330	362	371	441	63
G105-9	440	483	495	589	81
G105-11	550	604	619	737	100
G105-13	660	725	743	884	117
G105-15	769	845	866	1030	138
G105-17	880	966	990	1178	155
G105-19	990	1087	1114	1326	173
G105-21	1100	1208	1237	1473	192
G105-23	1209	1328	1360	1620	210
G105-25	1319	1449	1484	1767	229
G105-27	1430	1570	1608	1915	247

*** = Cell weight does not include steel tray*

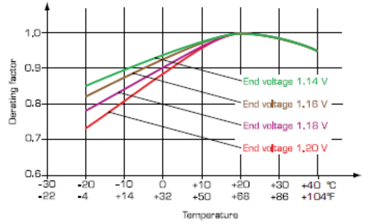
A full range of solutions
for a world of photovoltaic needs

Sunica.plus type	Capacity C_{120} 120 h 1.0 V Ah	Capacity C_5 5 h 1.0 V Ah	Height mm	Height in	Width mm	Width in	Length per block: 1 cell mm	1 cell in	2 cells mm	2 cells in	3 cells mm	3 cells in	4 cells mm	4 cells in	5 cells mm	5 cells in	6 cells mm	6 cells in	8 cells mm	8 cells in	9 cells mm	9 cells in	10 cells mm	10 cells in	Approx. weight per cell kg	Approx. weight per cell lb
SUN® 45	45	43	405	15.95	195	7.68					88	3.46	113	4.49	137	5.39	162	6.38	212	8.35	237	9.33	261	10.28	3.2	7.1
SUN® 90	90	85	405	15.95	195	7.68					121	4.76	157	6.18	192	7.56	228	8.98	300	11.81	336	13.23	371	14.61	4.9	10.8
SUN® 105	105	100	405	15.95	195	7.68					157	6.18	205	8.07	252	9.92	300	11.81	396	15.59	444	17.48			6.2	13.7
SUN® 140	140	128	405	15.95	195	7.68					157	6.18	205	8.07	252	9.92	300	11.81	396	15.59					6.7	14.8
SUN® 185	185	171	405	15.95	195	7.68					193	7.60	253	9.96	312	12.28	372	14.65							8.4	18.5
SUN® 230	230	213	405	15.95	195	7.68			159	6.26	232	9.13	305	12.01	377	14.84									9.9	21.8
SUN® 275	275	256	405	15.95	195	7.68			183	7.21	268	10.55	353	13.90	437	17.21									11.5	25.4
SUN® 320	320	300	405	15.95	195	7.68			228	8.98	336	13.23													15.1	33.3
SUN® 370	370	341	405	15.95	195	7.68			252	9.92	372	14.65													16.8	37.0
SUN® 415	415	384	405	15.95	195	7.68	146	5.75	278	10.95															18.3	40.4
SUN® 460	460	427	405	15.95	195	7.68	159	6.26	304	11.97															19.8	43.7
SUN® 505	505	469	405	15.95	195	7.68	171	6.73	328	12.91															21.4	47.2
SUN® 555	555	512	405	15.95	195	7.68	183	7.21	353	13.90															23.0	50.7
SUN® 645	645	597	405	15.95	195	7.68	219	8.62																	28.2	62.2
SUN® 735	735	682	405	15.95	195	7.68	244	9.61																	31.3	69.0
SUN® 830	830	768	405	15.95	195	7.68	268	10.55																	34.5	76.1
SUN® 920	920	853	405	15.95	195	7.68	304	11.97																	39.6	87.3
SUN® 1110	1110	1024	405	15.95	195	7.68	352	13.86																	46.0	101

Sunica.plus complies with IEC 62259 standard.

Derating factor according to temperature and end voltage

For typical solar application with
3 days or more backup time



Sample Li-ion Solar Battery Data Sheet

The LiFePO4 Battle Born Battery

The pinnacle of quality and safety at an unbeatable price point.

Please Read Before Installation

USA

Model BB10012

100 Amp Hours
Deep Cycle Efficiency and Performance

This 12 volt 100 amp hour deep cycle LiFePO4 battery offers 2 to 3 times the power in the same physical space as a lead acid. The stable chemical composition and built-in battery management system in our batteries provides you with safe and reliable power.

These low-maintenance batteries are a fifth of the weight of a comparable lead acid. Our batteries are capable of being discharged to 100% of their rated capacity every time. They can be charged 5 times faster than lead acid, so you can get out there and stay out there longer!

Our batteries are built to last 10 to 15 years and are backed by an industry leading 10-year warranty, making battery anxiety a thing of the past.

UN38.3 PASSED

Specifications

- 100 Amp Hour, 12 Volt Battery
- LiFePO4 Chemistry
- 3000-5000 Cycles
- Dimensions (L x W x H): 12.76" x 6.86" x 8.95" *See QR Code below
- 31 lbs.
- Operating Temp Range: -4°F (-20°C) to 135°F (57.2°C)
- Water Resistant and Sealed (Batteries should not be submerged)
- Designed and Assembled in the USA
- Built-in BMS (Battery Management System)
- Made with Cylindrical Cells

Charging Parameters

- Absorption Voltage: 14.2V to 14.6V
- Float Voltage: 13.4V to 13.8V
- Equalization Voltage: 14.4V (if Applicable)
- Absorption Time: 30 minutes per 100Ah battery bank
- No Temperature Compensation
- Charge Rate: .5c

Built-in Battery Management System

Our BMS keeps you and your battery safe and ensures your battery will last for many years.

- 100 Amps Continuous
- 200 Amps Surge for 30 Seconds
- ½ Second Surge for Loads Over 200 Amps
- High/Low Voltage Protection
- Short Circuit Protection
- High/Low Temperature Protection
- Cold Charging Protection
- Automatic Cell Balancing at Top of Charge

**Please Note: This built-in protection will reset after 5 seconds in most fault conditions. Disconnecting the battery from loads will also reset the BMS.*

Get out there, stay out there.™

*QR Code

Questions? Call 855-292-2831 or email us at info@battlebornbatteries.com

Changes to IEEE 1562 from 2007 to 2021

- Slightly Changed Language in the Document So Non-Lead-Acid Battery Types could Theoretically Use the Principles in it
- Added Sizing Using the now common MPPT Charge Controllers
  - This Also Caused Increased Need to Account for the Effects of Minimum and Maximum Panel Operating Temperatures
    - Especially When Using 60 Cell Panels in Higher Summer Temperatures
- Footnote Warning Added for Those Who Like to Think They Can Get Away with Fewer than 5 Days Backup in Standalone Sites
- Provided Guidance Towards the NREL RedBook to Get Solar Irradiance (Sun-hr) Data Pre-Adjusted for Tilt Angles and Such
  - Gave Footnote Approximations for Insolation Derating if no NREL Data

More Changes to IEEE 1562 from 2007 to 2021

- Covered More Areas of Potential Electrical Loss and Increased the Typical Percentage of These Losses
- Reworked the Calculation Worksheet to Consider More Loss Factors, Temperature Factors, Charge Controller Types, etc.
  - Color-Coded the Worksheet to help the user know what Data needs to be Gathered, what needs to be Decided by them, and what needs to be Calculated
  - Modified the Examples in the Annexes Using Revised Worksheets and Charge Controller Types
- Removed the Old Annex A on PV Technologies, since those Change Faster than the periodic Reissuance of this Document
- Added a Cautionary Note about Using Tracking Arrays in Windy Areas

1562 Worksheet 1

Worksheet 1—System sizing

1) Project name and description[14]: ____

2) Nominal system ____ dc voltage.
3) Days of autonomy desired: ____.
4) Total daily load (may be obtained from line 5c of Worksheet 1—Battery Sizing, from IEEE Std 1013-2019): ____ Ah/day.
5) Max battery voltage (may be obtained from line 8d of Worksheet 1—Battery Sizing, from IEEE Std 1013-2019): ____ volts direct current (Vdc).
6) Battery capacity (may be obtained from line 12 of Worksheet 1—Battery Sizing, from IEEE Std 1013-2019): ____ Ah rated at the ____ hour rate.
7) System losses:

7a Description of system loss (percent of system load)	7b Typical % window		7c System loss	7d multiplier[15]
	max %	min %	%	decimal
Parasitic[16] load (losses) of the charge controller	5	1		
Coulombic losses of battery (refer to IEEE Std 1361-2014, Annex A.9)[17]	20	1		
Wire losses	5	0		
Module mismatch losses	5	0		
Module aging[18]	20	0		
Dust	20	0		
Other				
Other				
Other				
7e) Total system losses [multiply all of column 7d, subtract this from 1, then multiply by 100]: ____ %				

8) Determine the number of peak sun hours: ____.
9) Decide on an A:L: ____.
10) Choose a PV module (manufacturer and model): ____.
    a) Maximum power current (I_{mp}): ____ A.
    b) Short circuit current (I_{sc}): ____ A.
    c) Nominal voltage: ____ Vdc.
    d) Open circuit voltage (V_{oc}): ____ Vdc.
    e) Maximum power point voltage (V_{mp}): ____ Vdc.
    f) Maximum power (P_{max}): ____ W.
    g) Percentage temperature coefficient of V_{oc}: ____ %/°C or %/K.
    h) Temperature coefficient of V_{oc} [line 10d × 10g ÷ 100]: ____ V/°C or V/K.
    i) Percentage temperature coefficient of P_{max}: ____ %/°C or %/K.
    j) Temperature coefficient of P_{max} [line 10f × 10i ÷ 100]: ____ W/°C or W/K.
    k) Percentage temperature coefficient of I_{sc}: ____ %/°C or %/K.
    l) Temperature coefficient of I_{sc} [line 10b × 10k ÷ 100]: ____ W/°C or W/K.
    m) Maximum operating ambient temperature: ____ °C.
    n) Nominal operating cell temperature (NOCT): ____ °C.
    o) Maximum operating temperature delta of PV module [line 10m + 10n – 25 °C]: ____ °C.
    p) V_{mp} at max. module operating temperature [line 10e + (10h × (10o – 25 °C))]: ____ Vdc.
    q) P_{max} at max. module operating temperature [line 10f + (10j × (10o – 25 °C))]: ____ W.
    r) I_{mp} at maximum module operating temperature [line 10a + (10ℓ × (10o – 25 °C))]: ____ A.
11) Multiply line 4 times line 9: ____ Ah/day.
12) Divide line 7e by 100 (this converts the percentage to a decimal) and subtract from 1: ____.

Shunt, series, and PWM controller calculations:

13) Multiply line 12 times line 8 times line 10r: ____ Ah/day.
14) Divide line 11 by line 13: ____.
15) Round line 14 up to the nearest whole number: ____. This is the number of parallel PV module strings required.
16) Divide line 5 by line 10p and round up to the nearest whole number: ____. This is the number of modules to be wired in series in each string.
17) Multiply line 15 by line 16: ____. This is the total number of PV modules required for the system.

MPPT controller calculations:

18) Choose a charge controller (manufacturer and model): ____.
    a) MPPT charge controller (if that is the type used) efficiency[19]: ____ %
19) Multiply line 11 times line 2: ____ Wh/day. This is the daily load in Wh.
20) Multiply line 12 times line 8 times line 10q times line 18a divided by 100: ____ Wh/day. This is the individual module daily production.
21) Divide line 19 by line 20: ____.
22) Round line 21 up to the nearest whole number: ____. This is the minimum number of PV modules required for the system.
23) Divide line 2 by line 10c: ____. This is the number of PV modules per PV "string."
24) Divide line 22 by line 23 and round up to the nearest whole number: ____. This is the number of PV "strings."
25) Multiply line 23 by line 24: ____. This is the actual total number of PV modules needed.

[14] Fields in this worksheet highlighted in yellow are provided/decided by the user/designer. Those highlighted in green come from other documents or manufacturer datasheets/manuals. Those highlighted in light blue are calculations.

[15] Calculate each value in column 7d by dividing each value in column 7c by 100, then subtracting that from 1.0.

[16] This is only the losses due to the need to keep the electronics and lights of the charge controller in an operating state, and not the dc-dc conversion losses of an MPPT charge controller (see 18a for those losses). Typical parasitic controller losses are no more than 1%-2%.

[17] Additional information on coulombic conversion losses in batteries can be found in Table B.2 of IEEE Std 1635/ASHRAE 21 [B2].

[18] Modules have an average life of 25 years and lose capacity at a rate of about 1%-1.25 %/yr for the first 2-3 years; after which they age with a capacity loss of about 0.5%-0.88 %/yr, depending on the manufacturer and model.

[19] MPPT converter efficiency on the data sheet is typically the peak/optimal value. Derating this by 1%-2% usually yields a more accurate true efficiency.

1562 Example D.2 (Remote Brazil Vaccine Store)

D.2 Refrigerator/freezer for vaccine storage

This example describes the system sizing for a remote vaccine storage refrigerator (site is expected to be operational for 15 years) using vented lead-acid (VLA) batteries. The refrigerator is to be located near the equator in a tropical climate. Vaccines are delivered quarterly, and at that time a technician is available for system maintenance. Calculations are run with both a PWM controller and an MPPT controller to show the difference (MPPT controllers sometimes require fewer panels).

Worksheet 1—System sizing

(Refer to Annex B.1 of IEEE Std 1013™-2019)

1) Project name and description: Remote refrigerator/freezer, Brazilian village, tropical climate. High availability required, quarterly maintenance, four starts per day (including one for ice pack freezing).

2) Nominal system voltage: *12* Vdc.

3) Days of autonomy desired: *6* days.

4) Total daily load (may be obtained from line 5c of Worksheet 1—Battery Sizing from IEEE Std 1013-2019): *51.4* Ah/day.

5) Max battery voltage (may be obtained from line 8d of Worksheet 1—Battery Sizing, from IEEE Std 1013-2019): *14.7* Vdc.

6) Battery capacity (may be obtained from line 12 of Worksheet 1—Battery Sizing, from IEEE Std 1013-2019): *440* Ah, rated at the *120-hour* rate.

7) System losses:

7a Description of system loss	7b typical % window		7c system loss	7d multiplier
	max %	min %	%	decimal
Parasitic load (losses) of the charge controller	5	1	*1*	*0.99*
Coulombic effect of battery (refer to IEEE Std 1361™-2014, Annex A.9)	20	1	*17*	*0.83*
Wire losses	5	0	*3*	*0.97*
Module mismatch losses	5	0	*0*	*1.0*
Module aging	20	0	*11*	*0.89*
Dust	20	0	*1*	*0.99*
Other				
Other				
Other				
7e) Total system losses [multiply all of column 7d, subtract this from 1, then multiply by 100]: *30*%				

8) Determine the number of peak sun hours: *4.4*.[21]

9) Decide on an A:L: *1.2*.

10) Choose a PV module: *Brand XYZ, 50 W*.

   a) Maximum power current (I_{mp}): *3.0* A.

   b) Short circuit current (I_{sc}): *3.2* A.

   c) Nominal voltage: *12* Vdc.

   d) Open circuit voltage (V_{oc}): *21.8* Vdc.

   e) Maximum power point voltage (V_{mp}): *18.3* Vdc.

   f) Maximum power (P_{max}): *50* W.

   g) Percentage temperature coefficient of V_{oc}: *-0.33*%/°C.

   h) Temperature coefficient of V_{oc} [line 10d × 10g ÷ 100]: *-0.072* V/°C.

   i) Percentage temperature coefficient of P_{max}: *-0.23*%/°C.

   j) Temperature coefficient of P_{max} [line 10f × 10i ÷ 100]: *-0.12* W/°C.

   k) Percentage temperature coefficient of I_{sc}: *0.04*%/°C.

   l) Temperature coefficient of I_{sc} [line 10b × 10k ÷ 100]: *0.0013* A/°C.

   m) Maximum operating ambient temperature: *30*[22] °C.

   n) Nominal operating cell temperature (NOCT): *45* °C.

[21] Solar radiation data from RETScreen® Solar Resource and System Load Calculation at www.retscreen.net. (RETScreen® is a registered trademark of the Minister of Natural Resources Canada.) Location: Brasilia, Brazil. The month with the lowest radiation was January with a tilt of 15° (equals latitude).

[22] Maximum expected ambient operating temperature obtained from weather service data for the area.

   o) Maximum operating temperature delta of PV module [line 10m + 10n – 25 °C]: *50* °C.

   p) V_{mp} at max. module operating temperature [line 10e + (10h × (10o – 25 °C))]: *16.5* Vdc.

   q) P_{max} at max module operating temperature [line 10f + (10j × (10o – 25 °C))]: *47* W.

   r) I_{mp} at maximum module operating temperature [line 10a + (10l × (10o – 25 °C))]: *3.03* A.

11) Multiply line 4 times line 9: *61.7* Ah/day.

12) Divide line 7e by 100 (this converts the percentage to a decimal) and subtract from 1: *0.70*.

Shunt, series, and PWM controller calculations:

13) Multiply line 12 times line 8 times line 10r: *9.34*.

14) Divide line 11 by line 13: *6.61*.

15) Round line 14 up to the nearest whole number: *7*. This is the number of parallel PV module strings required.

16) Divide line 5 by line 10p and round up to the nearest whole number: *1*. This is the number of modules to be wired in series in each string.

17) Multiply line 15 by line 16: *7*. This is the total number of PV modules required for the system.

MPPT controller calculations:

18) Choose a charge controller (manufacturer and model): Brand LMN, 60 A.

19) MPPT charge controller (if that is the type used) efficiency: 96%.

20) Multiply line 11 times line 2: 740 Wh/day. This is the daily load in Wh.

21) Multiply line 12 times line 8 times line 10q times line 18a divided by 100: 139 Wh/day. This is the individual module daily production.

22) Divide line 19 by line 20: 5.32.

23) Round line 21 up to the nearest whole number: 6. This is the minimum number of PV modules required for the system.

24) Divide line 2 by line 10c: 1. This is the number of PV modules per PV string.

25) Divide line 22 by line 23 and round up to the nearest whole number: 6. This is the number of PV strings.

26) Multiply line 23 by line 24: 6. This is the actual total number of PV modules needed.

Sample Solar Panel Data

RENOGY
THE FUTURE OF CLEAN ENERGY

Address: 2775 E. Philadelphia St.,
Ontario, CA, 91761
Tel: 800-330-8678
Fax: 888-543-1164
Web: www.renogy.com

Module Type:	RNG-50D
Max Power at STC (P_{max})	50 W
Open-Circuit Voltage (V_{oc})	22.7 V
Short-Circuit Current (I_{sc})	2.84 A
Optimum Operating Voltage (V_{mp})	18.5 V
Optimum Operating Current (I_{mp})	2.70 A
Temp Coefficient of P_{max}	-0.23%/^{o}C
Temp Coefficient of V_{oc}	-0.33%/^{o}C
Temp Coefficient of I_{sc}	0.05%/^{o}C
Max System Voltage	600VDC (UL)
Max Series Fuse Rating	15 A
Fire Rating	Class C
Weight	4.5kgs / 9.9lbs
Dimensions	630x541x30mm / 24.8x21.3x1.2in
STC	Irradiance 1000 W/m^2, T = 25^{o}C, AM=1.5

Forthcoming 1013/1562 PES Resource Center Calculator Battery Sizing Page 1

Main Battery Sizing Worksheet (1) for Standalone Off-Grid PV Systems

Step — fill in the blue-highlighted cells

1) Project Name/Description: *Example*

2) Nominal System Voltage: 12 VDC (choose from the drop down list or enter your own value)

3) Days of Autonomy desired: 6 days

4) TABLE 1

4a DC load device	4b Voltage window V_{max}	4b V_{min}	4c momentary currents I_{coin}[a]	4c $I_{noncoin}$[d]	4d[e] running currents[b] I_{coin}[c]	4d $I_{noncoin}$[d]	4e constituents of max running current	4f occurences per day	4g duration hrs/occurrence[f]	4h run time hrs/day	4i daily load Ah/day
run 1 compresso	15.0	10.5			6.0		X	3	1.00	3.00	18.0
							or				
Run 2 compress	15.0	10.5				6.0	X	1	5.00	5.00	30.0
Start compress	15.0	10.5	15.0					4	0.02	0.07	1.0
Parasitics			0.1		0.1		X			24.00	2.4
										Total daily load in Ah:	51.4

Notes to Table 1:

- [a] includes parasitic currents
- [b] repeat constant loads in both the momentary and running current columns
- [c] coincidental (I_{coin}) loads occur at the same time as other loads, and are thus additive
- [d] non-coincidental ($I_{noncoin}$) loads never occur at the same time as other loads
- [e] for equipment that has both momentary and constant loads, and/or coincidental and non-coincidental loads put those loads on separate rows
- [f] 1 minute = 0.0167 h, and 1 second = 0.000278 h

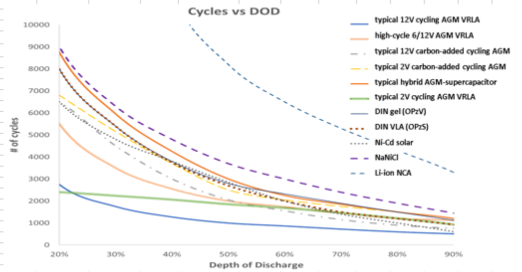
5)	Load data summary:			
a)	max momentary current I_{coin} from 4c above:	15.1	A	
b)	max running current I_{coin} from4d column above:	6.1	A	
c)	Total Daily Load from sum of 4i above:	51.4	Ah/day	
e)	highest value of $I_{noncoin}$ momentary current from 4c above	0.0	A	
f)	max momentary current draw from the battery (greater of line 5a or 5e):	15.1	A	
g)	highest value of $I_{noncoin}$ running current from 4d above	6.0	A	
h)	max Running Current draw from the battery (greater of line 5b or 5g):	6.1	A	
i)	maximum current draw from the battery (greater of line 5f or 5h):	15.1	A	
j)	lowest value of V_{max} from 4b column above	15.0	V	
k)	highest value of V_{min} from 4b column above	10.5	V	
6)	Battery Capacity:			
a)	unadjusted battery capacity (line 3 x line 5c):	308	Ah	
b)	Maximum Allowable depth of discharge (DOD):	80%		(typically choose somewhere between 50-80%)
c)	battery capacity adjusted for max allowable DOD (line 6a ÷ 6b):	386	Ah	
d)	typical maximum daily DOD:	20%		(typically choose somewhere between 10-40%)
e)	battery capacity adjusted for maximum daily DOD (line 5c ÷ 6d):	257	Ah	
f)	Percent of Capacity at end-of-life (EOL):	80%		(80% typical for lead-acid; 70-80% for Ni-Cd & Li-ion)
g)	battery capacity adjusted for EOL (line 6a ÷ 6f):	386	Ah	
h)	battery capacity adjusted for DOD and EOL (largest of lines 6c, 6e, or 6g):	386	Ah	
i)	minimum battery operating temperature (calculate °C from °F at right if needed):	13	°C	°F = °C
	average battery operating temperature (calculate °C from °F at right if needed):	19.6	°C	°F = °C
	Battery Type:	VRLA (most gel or AGM)		
	Do your vented batteries (VLA, Ni-Cd, or NiFe) use catalyst recombiner vents?:	N/A		(choose N/A for Li-ion, VRLA, & vented with self-watering)
j)	associated temperature correction factor (based on curves in IEEE 1635):	1.13		(this is calculated based on battery type chosen)
k)	battery capacity adjusted for temperature (line 6h x 6j):	435	Ah	
ℓ)	Design Margin factor (≥ 1):	1.10		(typically choose somewhere between 1.1 and 1.25)
m)	adjust the Battery Capacity for the design margin (line 6k x 6ℓ):	479	Ah	
7)	functional-Hour Rate (line 6m ÷ 5h):	78	h	
8)	Voltage Window Adjusment:			
a)	Charge controller low-voltage battery disconnect (LVBD) set point:	10.8	V	(related to max DOD in 6b & battery type)
b)	adjusted V_{min} (higher of line 5k or 8a):	10.8	V	
c)	Charge controller "finish"/"absorption" full charge voltage set point:	14.7	V	
d)	adjusted V_{max} (lower of line 5j or 8c) - at lowest batt temp for temp comp charg	14.7	V	(adjust charge controller to this if needed)
9)	Number of Series-connected Cells:			
a)	Recommended Max (full) charge Voltage per Cell for selected battery (limited	2.35	V/cell	(for 12V VRLA blocs, divide max bloc V by 6)
b)	maximum # of cells in series string (round down line 8d ÷ 9a):	6		
c)	recommended lowest (max)end of discharge (EOD) voltage per cell (evpc/mvpc	1.80	V/cell	(this value typically rises for more run days)
d)	calculated EOD voltage per cell (evpc/mvpc) [line 8b ÷ 9b]:	1.80	V/cell	(if line 9d≥9c skip to 9g, otherwise go to 9e)
e)	decrement number of series cells (line 9b - 1):			
f)	new calculated cell charge voltage (line 8d ÷ 9e):			
g)	selected number of Series Cells (line 9b or 9e), as appropriate:			

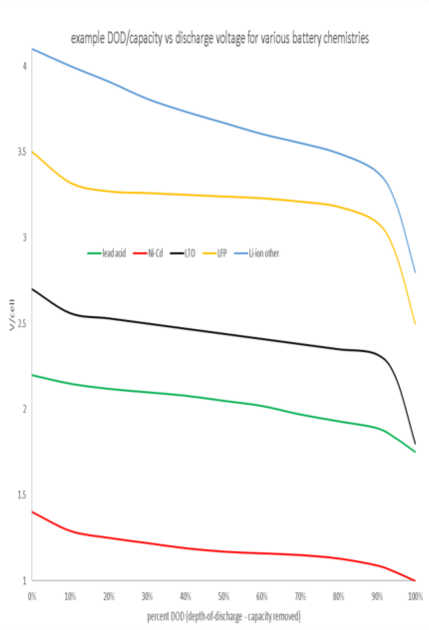
highest recommended max charge V per cell per battery type

VLA	VRLA	Ni-Cd	LFP	LTO	other Li-ion
2.50	2.35	1.65	3.65	2.85	4.20

owest avg mvpc you should ever choose per battery type for a standalone solar sit

lead-acid	Ni-Cd	LFP	LTO	other Li-ion
1.75	1.00	2.50	1.50	2.80





Notes | Battery Sizing Worksheet 1 | PV Array Sizing Worksheet 1 | Reference Data

Forthcoming 1013/1562 PES Resource Center Calculator Battery Sizing Page 2

68	10) Cell Selection and final Capacity determination:			
69	a) smallest practical Cell Capacity available of selected type greater than or equal to line 6m; or largest practical cell capacity less than line 6m, when discharged to the calculated EOD voltage (line 9d), at the functional-hour rate (line 7):	172	Ah	(Note that this capacity can also be met with parallel strings of lower Ah cells - see line 10b)
70	b) number of Parallel Strings (round up line 6m ÷ 10a):	3		
71	c) final Battery Capacity (line 10a x 10b):	515	Ah	(not the stamped rating, but @ hr rate of 7)
72	11) Checks/Considerations:			
73	a) Maximum Charge Rate:			(this subsection typically N/A for lead-acid and Ni-Cd)
74	i) recommended maximum charge current during recharge:	80	A	(this data comes from the battery mfr)
75	ii) maximum available charge current during recharge:	35	A	(this depends on controller & # of strings)
76	NOTE – if line 11aii > 11ai, the battery could be damaged – is there an issue?:	NO		
77	b) Excessive Overcharging:			(this subsection typically N/A for CV charging)
78	i) recommended max charge current @ regulation V @ avg battery temp of 19.6 °C:	1	A/string	(this data comes from battery mfr)
79	ii) maximum available charging current after reaching regulationo voltage:	0	A	
80	NOTE – if line 11bii > 11bi, the battery could be damaged – is there an issue?:	NO		
81	c) Undercharging – Array-to-load (A:L) ratio for the minimum design month:	1.3		(this will be copied as the A:L on the Array Sizing Worksheet)
82	NOTE – if line 11c < 1.3, there may be insufficient energy to recharge the battery – issue?:	NO		
83	d) High-rate Discharge – maximum discharge current:	15.1	A	(this is the same value as line 5i)
84	NOTE – if line 10c ÷ 11d < 20, cell voltage may drop below mvpc at EOD – is there an issue?:	NO		
85	e) Freezing of Electrolyte – freeezing temperature of electolyte at maximum DOD:	-12.2	°C	(this data comes from the battery mfr)
86	NOTE – if line 6i < 11e, the battery may freeze – is there an issue?:	NO		
87	f) battery Self-Discharge:			
88	i) Battery's self-discharge (for all the strings in parallel [total/whole battery]):	0.9	Ah/day	(calculated based on battery type chosen)
89	ii) battery's capacity for each day of autonomy (line 10c ÷ line 3):	85.8	Ah/day	
90	- if line 11fi ÷ 11fii > 0.05, & self-discharge wasn't in load calcs, battery may be undersized?:	NO		
91	g) Electrolyte Reserve – estimated battery electrolyte reserve capacity (re-watering inter	N/A	days	(calculated based on batterychosen)
92	expected battery maintenance interval:	365	days	
93	NOTE – if line 11g < anticipated maintenance interval, battery may be damaged – issue?:	N/A		
94	h) Does the battery fit in the alloted space and not overload the floor weight rating?:	Yes		
95	12) Summary:			
96	Battery Manufacturer and Model: *Example Co, model PDZ*			
97	Final Battery has cells in series in each of 3 strings.			
98	total Battery Capacity is 514.5 Ah, rated at the 78 h functional-hour rate			
99	Battery full-charge (finish/absorption) voltage is 14.7 VDC.			
100	Battery normal end-of-discharge voltage is 10.8 VDC.			
101				
102				
103				

Notes | **Battery Sizing Worksheet 1** | PV Array Sizing Worksheet 1 | Reference Data

Forthcoming 1013/1562 PES Resource Center Calculator Array Sizing Page 1

Solar/PV Array Sizing Worksheet (1) for Standalone Off-Grid PV Systems

Step — fill in the blue-highlighted cells

Step			
1)	Project Name/Description (from line 1 of Battery Worksheet):	*Example*	
2)	Nominal System Voltage (from line 2 of Battery Worksheet):	12	VDC
3)	Days of Autonomy desired (from line 3 of Battery Worksheet):	6	days
4)	Total Daily Load (from line 5c of Battery Worksheet):	51.4	Ah/day
5)	Max Battery Voltage (from line 8d of Battery Worksheet):	14.7	VDC
6)	Battery Capacity (from line 12 [10c] of Battery Worksheet):	515	Ah

7) System Losses:

7a Description of System Loss	7b typical % window max %	min %	7c system loss	7d multiplier decimal[11]
Parasitic load (losses)[12] of the charge controller	5	1	1%	0.99
Coulombic losses of battery charging[13]	20	1	9%	0.91
Wire losses[†]	5	0	3%	0.97
module mismatch losses[‡]	5	0	0%	1.00
Module Aging[14]	20	0	11%	0.89
Dust[•]	20	0	1%	0.99
7e) Total System Losses [multiply all column 7d factors together, subtract from 1, then multiply by 100]:				23%

Notes to System Losses Table:

[11] value in column 7d is computed by dividing each value in column 7c by 100, then subtracting that from 1.0

[12] This is only the losses due to the need to keep the electronics and lights of the charge controller in an operating state. It does not include the DC-DC conversion losses of an MPPT charge controller (that is taken care of in Step 18a). Typical parasitic controller losses are no more than 1-2%.

[13] Additional info on coulombic efficiency of battery recharge can be found in Annex A.9 of IEEE 1361 and Table B2 of IEEE 1635 / ASHRAE 21. The value of the coulombic loss for this factor is calculated from those sources based on the battery type selected in the Battery Sizing Worksheet

[14] modules have an avg life of 25 yrs, and lose capacity at a rate of about 1-1¼ %/yr for the first few years, and than at a rate of about ½-⅞ %/yr, depending on mfr and model

[†] The NEC® suggests that voltage drop in any one leg of a system not exceed 3%, and no more than 5% for the whole system. 3-5% losses are typical here.

[‡] Module mismatches are no longer the problem they used to be. Unless you are dealing with older modules from differing mfrs / different models, this value is typically set to 0.

[•] Dust can be a problem in desert and/or windy climates. For those types of climates a loss factor of 10% is typical?

8) Determine # of peak sun hours (Sh) for location & array type: 4.4 hrs/day (this is typically looked up in sources like NREL RedBook)

Notes | Battery Sizing Worksheet 1 | PV Array Sizing Worksheet 1 | Reference Data

Forthcoming 1013/1562 PES Resource Center

Array Sizing Page 2

31	8)	Determine # of peak sun hours (Sh) for location & array type:	4.4	hrs/day	(this is typically looked up in sources like NREL RedBook)
32	9)	Decide on an A:L (array-to-load ratio):	1.3		(this was already chosen in line 11c of the Battery Sizing Worksheet)
33	10)	Choose a PV Module manufacturer and model:	*XYZ Co, model ABC*		
34		a) Maximum Power current (I_{mp}):	2.7	A	(this value is found on the panel manufacturer's spec sheet)
35		b) Short-circuit current (I_{sc}):	2.84	A	(this value is found on the panel manufacturer's spec sheet)
36		c) Nominal Voltage of the Panel	12	VDC	(if not stated on the panel manufacturer's spec sheet, use the data to the right)
37		d) Open Circuit Voltage (V_{oc}):	22.7	VDC	(this value is found on the panel manufacturer's spec sheet)
38		e) Maximum Power Point Voltage (V_{mp}):	18.5	VDC	(this value is found on the panel manufacturer's spec sheet)
39		f) Maximum Power (P_{max}) of the panel:	50	W	(this value is found on themanufacturer's spec sheet, & may be called peak power)
40		g) Percentage Temperature Coefficient of V_{oc}:	-0.33	%/°C	(although this coefficient is for V_{oc}, it can be applied to all voltages on the spec)
41		h) Temperature Coefficient of V_{oc} (line 10d x 10g ÷ 100):	-0.075	V/°C	
42		i) Percentage Temperature Coefficient of P_{max}:	-0.23	%/°C	(although the coefficient is for P_{max}, it's applicable to all Watt ratings on the spec)
43		j) Temperature Coefficient of P_{max} (line 10f x 10i ÷ 100):	-0.115	W/°C	
44		k) Percentage Temperature Coefficient of I_{sc}:	0.05	%/°C	(although the coefficient is for I_{sc}, it's applicable to all currents on the spec)
45		ℓ) Temperature Coefficient of I_{sc} (line 10b x 10k ÷ 100):	0.0014	A/°C	
46		m) max Operating Ambient (convert from °F at right if needed):	28	°C	°F = °C
47		n) Nominal Operating Cell Temperature (NOCT):	45	°C	(this value is found on the panel manufacturer's spec sheet)
48		o) maximum operating Temperature Delta of PV module:	48	°C	(line 10m + 10n - 25°C)
49		p) V_{mp} at maximum module operating temperature:	16.8	VDC	(line 10e + [10h x (10o - 25°C)])
50		q) P_{max} at maximum module operating temperature:	47	W	(line 10f + [10j x (10o - 25°C)])
51		r) I_{mp} at maximum module operating temperature:	2.73	A	(line 10a + [10ℓ x (10o - 25°C)])
52	11)	multiply line 4 times line 9	67	Ah/day	
53	12)	divide line 7e by 100 (converts % to decimal) and subtract from 1:	0.77		
54		Choose the type of charge ontroller being used:	MPPT		(if MPPT chosen, skip down to step 18)
55					
56					
57					
58					
59					
60					
61		MPPT Controller Calculations:			
62	18)	List the charge controller manufacturer and model	*DEF Co, model HU 40 A charge controller*		
63		a) MPPT charge controller efficiency:	96%		(this value is found in the MPPT charge controller literature and must be filled in)
64	19)	multiply line 11 by line 2:	802	Wh/day	
65	20)	multiply line 12 by line 8 by 10q by 18a, and divide by 100:	154	Wh/day	(this is the individual module daily production)
66	21)	divide line 19 by line 20:	5.21		
67	22)	round line 21 up to the nearest whole number:	6		(this is the minimum number of PV modules required for the system)
68	23)	divide line 2 by line 10c:	1		(this is the number of modules to be wired in series in each string)
69	24)	divide line 22 by line 23 and round up to the nearest whole #:	6		(this is the number of parallel PV panel 'strings')
70	25)	multiply line 23 by line 24:	6		(this is the actual total number of PV modules required for the system)

# cells	nom. V	# half-cells	nom. V
32-36	12		
60-72	24	120-144	24
78-84	30		
96	36		

Notes | Battery Sizing Worksheet 1 | PV Array Sizing Worksheet 1 | Reference Data

Some NEC 2020 Article 690 Revisions

- Industrial Roof Max Voltage Increased to 1000 VDC
  - Up from 600 for Residential
    - 1500 Allowed if Off of Roof
- Info Note on ASHRAE Handbook to Get Lowest ° Design Data
- Blocking Diodes Allowed to Also Serve as OCPDs
  - Moved from Informational Note to Body Text

- Conductors Not Color-Coded Must be Marked + and –
- Wiring Below 30 V Can Be Run w/o Conduit Indoors
- Circuits < 30 V Aren’t Required to Have Ground Fault Protection
- Any DC-DC Converter > 30 V w/o Ground Fault Protection Must Have External Ground Fault Protection Installed

- Ungrounded DC Systems with High Resistance Ground Fault Detection are Permitted

NEC 2020 Article 690 Revisions on Disconnects

- Disconnects > 30 V Must Be Protected From Easy Access by Unqualified Personnel

- Disconnects Not Rated for KAIC Have to Be So Marked
- Disconnects More than 10’ or Out of Sight Must be Locked
- MicroInverter Mating Connectors Can be Listed to Be Used as Disconnects

Contact Information

- Curtis Ashton
  - curtisashton@ampowersys.com
  - (720) 845-0846
- Special Thanks for His Expertise to Rob Rallo
  - robrallo@solarsystemservices.net
  - (443) 333-8104

Open Q&A