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IEEE Recommended Practice for Sizing Lead-Acid Batteries for Photovoltaic (PV) Systems

Sponsor

IEEE Standards Coordinating Committee 21,
Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage

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Abstract: A method for sizing both vented and valve-regulated lead-acid batteries used in terrestrial photovoltaic (PV) systems is described. Installation, maintenance, safety, testing procedures, and consideration of battery types other than lead-acid are beyond the scope of this document. Recommended practices for the remainder of the electrical systems associated with PV installations are also beyond the scope of this document.
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Introduction

[This introduction is not part of IEEE Std 1013-2000, IEEE Recommended Practice for Sizing Lead-Acid Batteries for Photovoltaic (PV) Systems.]

This recommended practice describes a method for sizing both vented and valve-regulated lead-acid batteries used in terrestrial photovoltaic (PV) systems. Installation, maintenance, safety, testing procedures, and consideration of battery types other than lead-acid are beyond the scope of this document. Recommended practices for the remainder of the electrical systems associated with PV installations are also beyond the scope of this document.

The Storage Systems Working Group of the Standards Coordinating Committee 21 on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage (SCC21) that developed this recommended practice consisted of the following members:

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The final conditions for approval of this standard were met on 30 March 2000. This standard was conditionally approved by the IEEE-SA Standards Board on 8 March 2000, with the following membership:

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IEEE Recommended Practice for Sizing Lead-Acid Batteries for Photovoltaic (PV) Systems

1. Overview

1.1 Scope

This recommended practice describes a method for sizing both vented and valve-regulated lead-acid batteries in photovoltaic (PV) systems. Installation, maintenance, safety, testing procedures, and consideration of battery types other than lead-acid are beyond the scope of this document. Recommended practices for the remainder of the electrical systems associated with PV installations are also beyond the scope of this document.

Sizing examples are given for various representative system applications. Iterative techniques to optimize battery costs, which include consideration of the interrelationship between battery size, PV array size, and weather, are beyond the scope of this document.

1.2 Purpose

This recommended practice is meant to assist system designers in sizing lead-acid batteries for residential, commercial, and industrial PV systems.

2. References

This recommended practice shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision should be used.

IEEE Std 485-1997, IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications.[1]

[1]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

IEEE Std 937-2000, IEEE Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic (PV) Systems.

3. Definitions

The following definitions apply specifically to this recommended practice. For other definitions, see *The Authoritative Dictionary of IEEE Standards Terms,* Seventh Edition [B1].[2]

3.1 array-to-load ratio: The array-to-load ratio is the average photovoltaic ampere hours available divided by the average daily load in ampere hours (Ah). The average daily PV ampere hours is calculated by taking the average daily solar resource for the month of interest in kilowatt hours per square meter (kWh/m^2) times the array current at its maximum power point under a solar irradiance of 1000 watts per square meter (W/m^2).

3.2 cycle life: The number of cycles (discharges and recharges), under specified conditions, that a battery can undergo before failing to meet its specified end-of-life capacity.

3.3 days of battery reserve: The number of days a fully charged battery can satisfy the load with no contribution from the photovoltaic array or auxiliary power source.

3.4 depth of discharge (DOD): The ampere hours removed from a fully charged battery, expressed as a percentage of its rated capacity at the applicable discharge rate.

3.5 discharge rate: The rate, in amperes, at which current is delivered by a battery. *See also:* **hour rate**.

3.6 energy capacity: The energy, usually expressed in watt hours (Wh), that a fully charged battery can deliver under specified conditions.

3.7 hour rate: The discharge rate of a battery expressed in terms of the length of time a fully charged battery can be discharged at a specific current before reaching a specified end-of-discharge voltage.

3.8 rated capacity (*C*): The capacity, in ampere hours (Ah), assigned to a cell by its manufacturer for a given constant-current discharge rate, with a given discharge time, at a specified electrolyte temperature and specific gravity, to a specific end-of-discharge voltage.

3.9 regulation voltage: The maximum voltage that a charge controller will allow the battery to reach under charging conditions. At this point the charge controller will either discontinue charging or begin to taper the charging current to the battery.

3.10 self discharge: The process by which the available capacity of a battery is reduced by internal chemical reactions (local action).

3.11 self-discharge rate: The amount of capacity reduction in a battery occurring per unit of time as the result of self-discharge.

3.12 valve-regulated lead-acid cell (VRLA): A lead-acid cell that is sealed except for a valve that opens to the atmosphere when the internal gas pressure in the cell exceeds the atmospheric pressure by a preselected amount. Valve-regulated cells provide a means for recombination of internally generated oxygen and the suppression of hydrogen gas evolution to limit water consumption.

[2]The numbers in brackets correspond to those of the bibliography in Annex C.

3.13 vented battery: A battery in which the products of electrolysis and evaporation are allowed to escape freely to the atmosphere. These batteries are commonly referred to as “flooded.”

4. Outline of sizing methodology

The function of a battery used in a PV system is to supply power when the system load exceeds the output of the PV array. For a satisfactory PV battery system, many factors should be considered to determine the necessary capacity and the number of cells composing the battery. These factors, as follows, will be discussed in subsequent clauses:

— Battery reserve considerations (Clause 5). The length of time that the load should be supported solely by the battery is established by system design requirements.

— Load determination (Clause 6). Requirements of the application determine the amount of current that is to be supplied by the battery over a period of time. The peak current and the operational voltage window are determined by the system’s load devices.

— Battery capacity and functional-hour rate determination (Clause 7). The battery capacity and its discharge functional-hour rate are determined by the specific application load, days of battery reserve, and battery characteristics (see Annex A).

— Determining number of series-connected cells (Clause 8). The system's voltage limits (voltage window) determines the required number of cells in series. Several criteria should be examined to assure a workable system.

— Cell capacity and battery size determination (Clause 9). Once the overall battery capacity and number of cells in series have been determined, the final selection of a specific cell can be made and the final battery size can be calculated.

NOTE—Because of the interaction of these factors, an iterative process may be needed to determine the optimum battery for the application.

— Battery sizing worksheets (Clause 10). Worksheets that provides a systematic approach to the sizing of a battery for a PV system is presented. The application of the worksheets is explained in accompanying text.

— Battery characteristics (Annex A). System performance, life, maintenance, and cost are influenced by the type of battery selected for a PV application. Information regarding lead-acid battery characteristics is presented.

— Examples (Annex B). Presented are examples demonstrating various aspects of battery sizing.

5. Battery reserve considerations

Photovoltaic power systems may require some battery reserve, both for reliability of service and to provide time for intervention in the event of an unanticipated occurrence such as unusually poor weather or failure of a system component. The number of days of battery reserve is commonly specified as a system design requirement, and is based on several considerations including the following:

a) System application. Critical load applications generally require more days of battery reserve than noncritical applications.

a) System availability. System availability is the minimum percentage of the time that the PV system should be able to satisfy the system loads.

b) Solar irradiance variability. Daily and seasonal variations in solar irradiance affect the required number of days of battery reserve.

c) Predictability of load. The load may or may not be predictable; also, there may be the possibility of adjusting the loads, e.g., dropping nonessential loads.

d) Backup power provisions. If the PV system includes provisions for backup power, the desired frequency and duration of operation of the backup power source needs to be considered.

e) Accessibility of site. The worst-case time required for correction of any problem should be considered.

6. Load determination

6.1 General considerations

The overall duty cycle imposed on the battery is the description of the dc load current and its duration within the days of battery reserve, during which it is assumed that no power is provided by the PV array or auxiliary power source. For ac loads supplied through an inverter, these loads should be tabulated separately, totaled, and combined with the inverter losses to determine the actual dc load on the battery.

The system's load can be expressed in a tabular or graphical form. As both descriptions start with a tabulation of the individual loads and their durations, the tabular form is more general. The load-profile diagram, the graphical representation, is necessary to visualize the interrelationships of the individual loads. For both load descriptions, all loads expected during a 24 h period are tabulated along with their anticipated durations. Worksheet 1 in Clause 10 provides a convenient method of tabulating load data in accordance with the sizing method of this document.

It may be necessary to consider a longer period of time when a 24 h period does not accurately describe the load profile. For those cases where the load profile exceeds 24 h, an average and a maximum daily load should be determined for subsequent battery capacity determinations. Worksheets 2 and 3 in Clause 10 provide a convenient method for determining these loads. The average daily load is used in the initial determination of the battery size.

Once the battery has been sized, the maximum daily load is used to determine the ability of this battery to sustain it. If the maximum daily load sequence cannot be established, the days should be arranged in the worst possible order, generally with the maximum load day last. The battery's capacity may need to be increased to satisfy the maximum daily load in this partially discharged state.

A load-profile diagram is a necessary aid in determining those areas where the battery's performance needs to be checked to assure load satisfaction. To make a load profile diagram, do the following:

a) Tabulate all the individual loads along with their starting and stopping times.

b) Total the coincident loads for their respective periods of time.

c) Plot the resulting total load versus time of day or elapsed time, as appropriate.

The resulting curve is the load-profile diagram. If the daily loads vary during the days of battery reserve, the individual daily load-profile diagrams, plotted in sequence, constitutes the system's load-profile diagram. See Annex B for examples.

6.2 Load data

The information that should be gathered for each load is discussed in 6.2.1 through 6.2.6.

6.2.1 Momentary current

Loads lasting one minute or less are designated "momentary" loads and are given special consideration. The ampere hour requirements of this type of load are usually very low, but their effect on battery terminal voltage may be considerable and should be taken into account. Momentary loads can occur repeatedly during the duty cycle. Typical momentary loads are as follows:

a) Motor starting currents
b) High inverter surge currents

6.2.2 Running current

Running current is the current required by a load after its starting current has subsided. Certain devices require a constant power, thus the current required will rise as the battery voltage falls. Since the battery voltage remains relatively constant until near the end of discharge, the running current may be approximated as the current required at 95% of the system voltage.

NOTE—For certain loads, it is necessary to consider both the momentary and running current components of the load. For example, if an electric motor starts during the duty cycle, both the starting (momentary) current and running current need to be considered. The starting current need not be considered if the load was operating at the beginning of the duty cycle, i.e., at the beginning of the days of battery reserve.

6.2.3 Parasitic current

Parasitic losses, such as those resulting from tare losses of charge controllers and inverters, should be included as currents. These currents should be included as part of the running-current loads. Consideration of the battery's self-discharge is recommended as a check (see 9.5) after the battery is selected.

6.2.4 Load duration

The load duration is the time, in hours, of operation of each load. For PV systems, it is very common for load duration to be expressed in terms of a daily cycle that repeats over the days of battery reserve. If the inception time of a load is known, but the shutdown time is indefinite, it should be assumed that the load will continue through the remainder of the days of battery reserve.

6.2.5 Load coincidence

Each load current (momentary or running) is classified as to whether or not it is coincident with any other loads, and tabulated accordingly. Loads that occur at random are assumed to be coincident loads. This information, portrayed in the load-profile diagram, is later used in battery selection and to check discharge rate (see 6.3).

6.2.6 Maximum and minimum load voltage

The maximum and minimum voltage at which each load operates properly should be determined and tabulated (see 8.2). Voltage drops, such as those associated with cabling, overcurrent protection, and connectors, between the battery and the loads are not to be considered as an adjustment to a load's maximum voltage. This is because the current and resulting voltage drops can be very low at times, thus exposing the device to battery terminal voltage. However, these voltage drops should be determined individually for each load device and added to its minimum operating voltage to ensure that the required minimum voltage will be present at the load.

6.3 Data analysis

6.3.1 Ampere hours

It is usually possible to calculate an equivalent daily load by multiplying each load current by its daily duration, and summing the results. If the duration of the momentary load is known, calculate the ampere hour load by multiplying this duration by the momentary current. If the duration of the momentary load is not known, assume the time to be 1 min and calculate the load accordingly. For voltage-drop considerations, a full-minute duration is used in either case.

If the duty cycle does not repeat each day, it is necessary to describe the load over all the days of battery reserve. Worksheet 2 in Clause 10 is provided for this purpose. If the graphical form of the load description is used, the ampere hour load is the total area under the load-profile curve.

6.3.2 Currents

The maximum momentary and maximum running currents are determined and are used to calculate the battery's maximum discharge current. Since the system loads may operate in various combinations, the maximum current (momentary or running) is the largest summation of the individual loads that can occur simultaneously. If the battery's maximum discharge current is greater than the 20 h discharge rate and the sequence of loads is known, the method described in IEEE Std 485-1997[3] may result in a less conservatively sized battery.

7. Battery capacity and functional-hour rate determination

The required battery capacity for a PV application is determined by the number of days of battery reserve and by the characteristics of the load, battery, and installation. A functional-hour rate for the application is determined by capacity and load calculations.

7.1 Unadjusted capacity

The unadjusted capacity, in ampere hours, is calculated by multiplying the days of battery reserve by the average daily load (in ampere hours/day as determined in Clause 6). This capacity will be adjusted in 7.3 for battery characteristics and operating conditions.

7.2 Battery type selection

A trial battery type should be selected before proceeding with the sizing process. This is necessary because performance characteristics, such as design depth of discharge and cycle life, are different for the various battery types.

If a vented battery is used, it should be selected for the intended application by considering watering intervals, the consequences of hydrogen and oxygen evolution, and wear-out mechanisms.

[3]Information on references can be found in Clause 2.

If a valve-regulated battery is used, it should be selected for the intended application by ensuring that recombination is effective and that dry-out, thermal runaway, and the consequences of hydrogen and oxygen evolution are considered (see A.4.3).

Annex A provides a more detailed catalog of battery characteristics that should be considered. Reevaluation of the applicability of the trial battery is recommended throughout the sizing process. Refer to manufacturer's literature for specific data on the type of battery selected.

7.3 Capacity adjustment

7.3.1 Discharge adjustments

The unadjusted capacity should be modified to assure satisfactory battery cycle life. Battery manufacturers rate lead-acid cells for maximum depth of discharge (MDOD), maximum daily depth of discharge (MDDOD) and end-of-life (EOL) capacity. The battery capacity should be adjusted in the following ways:

a) The capacity adjusted for MDOD is obtained by dividing the unadjusted capacity by MDOD (in percent).
b) The capacity adjusted for MDDOD is obtained by dividing the maximum daily ampere hours by MDDOD (in percent).
c) The capacity adjusted for life is obtained by dividing the unadjusted capacity by the end-of-life capacity expressed in percent of the rated capacity, commonly 80%.

The largest of these three capacities will satisfy the depth-of-discharge and end-of-life adjustments.

7.3.2 Temperature adjustment

The available capacity of a battery is affected by its operating temperature. Cell capacity ratings are generally standardized at 25 °C. Capacity increases at temperatures above 25 °C and decreases at temperatures below 25 °C. Capacity is rarely adjusted for warm temperature operation, but adjustments are routinely made for cold weather applications. Refer to the battery manufacturer's literature for temperature correction factors. The adjusted capacity determined in 7.3.1 should be corrected by this factor to yield capacity adjusted for temperature.

7.3.3 Design margin adjustment

It is prudent design practice to provide a capacity margin to allow for uncertainties in the load determination, e.g., less-than-optimum conditions and load growth. A common practice to provide this design margin is to add 10–25% to the capacity as determined in 7.3.2.

7.4 Functional-hour rate

In order to correctly size the battery, the discharge rate and ampere hour capacity should be considered together. In continuous load applications, the battery should have sufficient capacity to supply the constant discharge rate over the number of days of battery reserve. However, in noncontinuous load applications, the discharge rate varies and could include high rates of discharge periodically throughout the days of battery reserve. Using an average rate to size the battery could result in insufficient capacity to supply high currents above the minimum voltage late in the battery discharge. The functional-hour rate conservatively approximates a single discharge rate that is equivalent to the varying discharge rates of a particular duty cycle. The functional-hour rate used in 9.1, for cell selection, may be greater than the period of battery reserve.

The functional-hour rate can be calculated as follows:

a) Compare the sum of coincident running currents (I_{coin}) with the maximum noncoincident running current ($I_{noncoin}$) and select the larger.

b) Divide the adjusted capacity as determined in 7.3.3 by the maximum running current selected in step a).

Examples:

1—The adjusted battery capacity in a system with 5 days of battery reserve is 150 Ah, with a maximum current drain of 25 A. The functional-hour rate is 150 divided by 25, or 6 hours.

2—The adjusted battery capacity in a system with 5 days of battery reserve is 150 Ah with a continuous current drain of 1 A. The functional-hour rate is 150 divided by 1, or 150 hours.

8. Determining number of series-connected cells

A battery is usually composed of a number of identical cells connected in series. The maximum and minimum system voltages determine the number of series-connected cells of the battery.

8.1 Nominal system voltage

The lead-acid cell has a nominal voltage of 2 V; therefore, the number of cells may be estimated by dividing the nominal system voltage by 2. It is common practice to use 6 cells for a 12 V system, 12 cells for a 24 V system, etc., but it is possible that the allowable voltage limits may require adjustment to this general rule.

8.2 Voltage window

The system equipment will always have a voltage range within which the equipment will operate at rated capacity and efficiency. If the equipment is exposed to higher- or lower-than-specified voltages, it may be damaged or operate improperly. This high (V_{max}) and low (V_{min}) limit of system voltage is called the voltage window. The magnitude of this window has a direct effect on the number and capacity of battery cells selected. The narrower the window, the larger the cell's capacity needs to be; the wider the window, the smaller the cell's capacity can be.

From the tabulated maximum and minimum voltages in 6.2.6, the lowest maximum voltage (V_{max}) and the highest minimum voltage (V_{min}) define the voltage window within which all loads in the system will operate properly (see item 4b of Clause 10). If a charge controller is used, its setpoints should be within this voltage window.

When a temperature-compensated charge controller is used, the setpoints vary with the temperature of the battery. (The temperature used for the voltage compensation should be sensed at the battery.) The voltages associated with the anticipated temperature extremes of the battery should be used for this voltage window check. Since the charging voltage of the battery increases with decreasing temperature, generally only the voltage associated with the lowest anticipated temperature will be of significance.

NOTE—The battery may be excessively overcharged by a voltage less than V_{max}. It is recommended that a charge controller be used to limit the charge voltage. The consequences of excessive overcharging are described in item a) of 9.5.

8.3 Calculating the number of series-connected cells

The number of series-connected cells is a function of both the voltage window of the loads and the manufacturer's charging recommendation for the selected cell. An optimum number of cells is determined by iterative calculations.

8.3.1 Maximum number of cells allowed

The most important aspect of calculating the maximum number of series-connected cells is to ensure an optimal and safe cell recharge voltage. In determining the maximum number of cells allowed by the system, the following calculation is performed:

$$\text{Maximum number of cells (rounded down)} = \frac{V_{\text{max}}}{\text{cell recharge voltage}}$$

When the system has capability for cell equalization or temperature-compensated charging, the maximum associated voltage should be used for the above calculation provided it does not exceed the manufacturer's recommendations.

Example:

Assume 2.4 V per cell is the maximum recommended voltage for recharging. The maximum allowable system voltage is 58 V dc. Then:

$$\frac{58\text{ V}}{2.4\text{ V/cell}} = 24.17\text{ cells},$$

therefore, use 24 cells.

8.3.2 Minimum system voltage versus end-of-discharge voltage

To ensure that the battery is not operated below the manufacturer's recommended end-of-discharge (EOD) voltage, calculate the voltage per cell to which the low limit of the system voltage would allow the cell to be discharged. This calculated EOD cell voltage should not be below the manufacturer's limit at the functional-hour rate. This is determined as:

$$\text{Calculated EOD cell voltage} = \frac{V_{\text{min}}}{\text{number of cells calculated from 8.3.1}}$$

Example:

Assume the minimum system voltage is 42 V dc. Then:

$$\frac{42\text{ V}}{24\text{ cells}} = 1.75\text{ V per cell}$$

If the calculated EOD cell voltage is not satisfactory (i.e., is below the manufacturer's recommended EOD voltage at the functional-hour rate), an adjustment should be made to the minimum system voltage or a smaller number of cells should be used, or both.

NOTE—If the calculation results in an EOD voltage that is greater than that recommended by the manufacturer, the cell, when discharged to the calculated EOD voltage, will supply less capacity than if it were discharged to the recommended EOD cell voltage.

8.3.3 Multicell unit considerations

If the cell type selected is available only in multicell units, it may be necessary to use a different number of cells than previously calculated. The conversion from maximum system voltage to number of multicell units is:

$$\text{Total number of multicell units} = \frac{V_{\max}}{\text{maximum multicell recharge voltage}}$$

Fractional results are to be rounded down to the next lowest whole number. It is necessary to review the voltage window calculation to ensure that all system requirements are met.

8.3.4 Optimization

The calculation in 8.3.1 will provide the maximum number of allowable series-connected cells that should ensure proper system performance. It may be possible to use fewer series-connected cells and yet maintain proper system performance. See Clause 10 for the iterative process that can result in fewer series-connected cells. However, this could result in other problems, including thermal runaway, under certain conditions [see item a) of 9.5].

NOTE—Care should be taken to ensure that the chosen number of battery cells can be charged effectively by a commercially available photovoltaic charging system. Nonstandard equipment may be expensive and difficult to obtain.

9. Battery size determination

Battery size is determined by using the results of Clause 7 and Clause 8 to select an appropriate battery that meets the load and site requirements.

9.1 Cell size selection

The cell size is selected by using the same manufacturer's data that was used in 7.2. Choose a cell that meets the capacity requirements of 7.3.3 when discharged at the functional-hour rate determined by 7.4 to an EOD voltage that is greater than or equal to the EOD voltage determined by 8.3. When the cell available from the manufacturer does not meet the exact capacity requirement, the next larger capacity cell should be selected. If no single cell has the necessary capacity or its use is not practical for the application, then refer to 9.2. A manufacturer may list available capacities by one of the following:

a) The capacity of the cell itself

b) The capacity of an individual positive plate

If the manufacturer lists capacity of positive plates, the required number of positive plates may be determined by dividing the capacity requirement as found in 7.3.3 by the positive plate capacity. Fractional results are to be rounded up to the next higher whole number.

9.2 Number of parallel strings

Parallel strings are used in order to meet design requirements such as:

— Increasing capacity of an existing battery

— Providing redundancy

— Providing battery reserve while a string is disconnected for maintenance or testing

If cells of sufficiently large capacity are not available or practical, then two or more strings, of equal numbers of identical series-connected cells, may (consistent with the manufacturer's recommendations) be connected in parallel to obtain the necessary capacity.

The number of parallel strings is calculated by dividing the capacity found in 7.3.3 by the selected cell capacity determined by 9.1 (rounded up).

9.3 Final number of cells

The total number of cells can then be calculated by multiplying the number of series cells determined by 8.3 by the number of parallel strings.

9.4 Final battery capacity

The final battery capacity is calculated by multiplying the selected cell capacity by the number of parallel strings.

9.5 Checks and considerations

There are other considerations with respect to the PV system design, which may affect battery performance. These are as follows:

a) Excessive overcharging. Excessive overcharging may result from factors such as too high an end-of-charge voltage, no high-limit cutoff voltage, or excessive ampere hours recharged for the ampere hours discharged. For vented batteries, overcharging will result in the generation and release of potentially hazardous quantities of hydrogen and oxygen, and will accelerate water loss. For valve-regulated batteries, overcharging also will result in the generation of potentially hazardous quantities of hydrogen and oxygen that may be released. The quantity and composition depends on the rate and duration of the overcharge, the battery and its valve design, oxygen recombination efficiency (see A.2), thermal environment, and previous usage of the battery. Consequences of water loss are different for vented batteries, where the liquid can generally be replaced. In valve-regulated batteries, the water lost cannot be replaced and, therefore, life will be shortened. Overcharging valve-regulated batteries can also cause a potentially hazardous condition known as thermal runaway. This results in excess heat, which enables the battery to draw ever more current, a condition that continues until the battery releases all its water and the battery is destroyed. For both vented and valve-regulated batteries, excessive overcharging will increase the rate of positive grid corrosion and will shorten the battery's life. If any of the conditions that may lead to overcharging exist, discussion between the PV system designer and the battery manufacturer will be necessary to determine the preventive and corrective actions.

b) Undercharging. Insufficient time at the available charge rate or too low a charging voltage will result in an undercharged battery. If either of these conditions exist, discussion between the PV system designer and the battery manufacturer will be necessary to determine the corrective action.

c) High-discharge rate. A momentary load, particularly one occurring at or near the end of the days of battery reserve period, may cause the battery voltage to drop below the minimum system voltage. If such a momentary load is significantly larger than the average load, it is recommended that the battery capacity be sized in accordance with the method of IEEE Std 485-1997 (considering the required days of battery reserve for the load profile diagram), or a reexamination of the worst case loads be made and discussed with the PV system designer. If the method of IEEE Std 485-1997 is used, the resulting battery should be reevaluated according to the criteria given in this document. In most cases, if the momentary load is less than the 20 h discharge rate, then the discharge rate will not cause the battery voltage to drop below the minimum system voltage.

d) Freezing of the electrolyte. Freezing a battery's electrolyte can cause damage and, therefore, should be prevented. The freezing point of the electrolyte (refer to the manufacturer's literature) should be less than the lowest anticipated operating temperature based on the battery's lowest design state of charge. If not, consider thermal insulation for the battery or increasing the battery capacity and minimum system voltage.

e) Self-discharge as a battery load. All batteries suffer from an internal capacity loss mechanism known as self-discharge. The amount of self-discharge (Ah/month) is a function of battery operating temperature, type, and age. The self-discharge for the battery type selected, within its operating environment, should be obtained and the resulting capacity loss calculated and added to the calculated battery capacity, if appropriate.

10. Battery sizing worksheets

Worksheet 1 may be used to organize the manual applications of the procedures outlined previously. Examples of its use are in Annex B. Instructions for use follow; the numbering system corresponds to that of the worksheet.

1) Project name and description. Enter the necessary information.
2) Nominal system voltage. Enter the nominal system voltage (e.g., 12 V, 24 V).
3) Days of battery reserve. Enter the number of days of battery reserve.
4) Load data. Enter the necessary load information for each load device and calculate the daily load for each device. Worksheet 2 is to be used when the load duty cycle exceeds 1 day (24 hours). The following is an explanation of the terms used:
   a) DC load device: The identification of the dc loads.

      NOTES:

      1—If the load is an inverter, a separate calculation should be made of the loads run by the inverter plus inverter losses.

      2—If the load device has a momentary current as well as a running current, e.g., a motor, the load device should be treated as two distinct loads, one of which has only a momentary current, the other of which has only a running current.
   b) Voltage window: The maximum and minimum voltage, V_{max} and V_{min}, acceptable to each load. (V_{min} includes wiring voltage drops.)
   c) Momentary currents: The inrush or peak current of each load, e.g., the inrush current required to start a motor. If the momentary current and the running current are the same, enter the running current only (column 4d). The two columns, I_{coin} and $I_{noncoin}$, refer to the coincident and noncoincident currents. The $I_{noncoin}$ column is used only for loads that will never operate at the same time as other loads.
   d) Running currents: The normal running current of each load, I_{coin} and $I_{noncoin}$. The $I_{noncoin}$ column is used only for loads that never operate at the same time as other loads. Parasitic currents are entered as running currents.
   e) Constituents of maximum running currents: The loads that can operate in coincidence to generate the maximum running current are identified, if known. If the loads are random, the sum of all coincident running currents is used.

      NOTE—Columns 4f and 4g are provided to facilitate calculations when the load currents, and their duration per occurrence, are identical. Otherwise, enter the total run time in column 4h.
   f) Number of occurrences: The number of operational periods of each load for the day.

g) Duration: The hours per operational occurrence for each load.

h) Run time: The hours per day of operation of each load (line 4f times line 4g or the total time). If the run time varies from day to day, use Worksheet 2.

i) Daily load: The ampere hour per day requirements for each load. It is the product of each load current and its respective run time.

5) Load data summary (using the load data from 4, columns 4a through 4i)

a) Enter the maximum coincident momentary current [refer to the load-profile diagram(s)].

b) Enter the maximum coincident running current [refer to the load-profile diagram(s)].

c) Enter the total from the daily load column of Worksheet 1 or the average daily ampere hours from Worksheet 3, if used.

d) Enter the maximum daily load from Worksheets 2, if used.

e) Enter the greatest of the values in the momentary currents $I_{noncoin}$ column or from Worksheet 3, if used.

f) Enter the greater of line 5a or line 5e. This value will be used later when checking the ability of the battery selected to provide the maximum momentary current.

g) Enter the greatest of the values in the running currents $I_{noncoin}$ column or from Worksheet 3, if used.

h) Enter the greater of line 5b or line 5g. This will be used later to calculate the appropriate discharge rate for the battery.

i) Enter the greater of line 5f or line 5h.

j) Enter the lowest value from the voltage window V_{max} column or from Worksheet 3, if used.

k) Enter the highest value from the voltage window V_{min} column or from Worksheet 3, if used.

6) Battery capacity. To complete this section, it is necessary to have the following information:

— Maximum allowable depth of discharge (MDOD), in percent
— Maximum allowable daily depth of discharge (MDDOD), in percent
— End-of-life (EOL) capacity, in percent
— Minimum temperature at which battery is required to support the load, corresponding temperature correction factor from the manufacturer's literature, in percent
— Design margin, in percent

a) An unadjusted battery capacity is calculated. Enter the product of the days of battery reserve and the total daily load (line 3 times line 5c).

b) Enter MDOD.

c) Adjust the capacity for MDOD (line 6a divided by line 6b).

d) Enter MDDOD.

e) Adjust the capacity for MDDOD (line 5c divided by line 6d, or line 5d divided by line 6d if Worksheet 3 is used.)

f) Enter EOL.

g) Adjust the capacity for EOL (line 6a divided by line 6f).

h) Enter the largest of the above three capacities.

i) Enter the minimum operating temperature in degrees Celsius (°C).

j) Enter the appropriate temperature correction factor from the manufacturer's literature.

NOTE—Adjustments for temperatures above 25 °C are not typically made.

k) Adjust the capacity (line 6b) for temperature.

l) Enter the design margin factor (≥1); e.g., for a 10% oversize, enter the number 1.1.

m) Adjust the capacity for the design margin (line 6k times line 6l).

7) Functional-hour rate. Divide the adjusted capacity (line 6m) by the maximum running current from the battery (line 5h). The functional-hour rate may be greater than the period of battery reserve.

8) Voltage window adjustment. This section provides for any adjustment that may be necessary as a result of controller setpoints. The controller setpoints should determine the limits of the voltage window and provide as wide a voltage range as possible while protecting the loads and battery (see Note in 8.2.) When temperature-compensated charge controllers are used, the voltage window should correspond to the anticipated maximum and minimum battery temperature extremes.

a) Enter the setpoint of the low-voltage load disconnect of the controller, if used. The value should be greater than or equal to line 5k.

b) If a charge controller is used, enter line 8a, otherwise enter line 5k.

c) Enter the setpoint of the full-charge voltage cutout of the controller, if used. The value should be less than or equal to line 5j.

d) If a charge controller is used, enter line 8c, otherwise enter line 5j.

9) Number of series-connected cells. To complete this section, the following information is required from the battery manufacturer:

— Cell's charge voltage: the manufacturer's recommended charging voltage for the type of battery
— End-of-discharge (EOD) voltage (at the functional-hour rate)
— Cell voltage when the fully available capacity to MDOD is reached

a) Enter the cell's charge voltage.

b) Calculate the maximum number of cells connected in series that can be charged within the battery voltage window; round down (line 8d divided by line 9a).

c) Enter the manufacturer's recommended cell EOD voltage.

d) Calculate the cell's EOD voltage that corresponds to V_{min} (line 8b divided by line 9b). If equal to or greater than line 9c, proceed to step 9g; if less than line 9e, proceed to step 9e.

e) Decrease the number of series cells by 1.

f) Calculate the cell's charge voltage as determined by the system voltage window (line 8d divided by line 9e). If the result is within the manufacturer's recommended cell charge voltage range, proceed to step 9g. If the result is outside the range, do one of the following:

i) Repeat steps 9e and 9f.

ii) Select a different type of cell, e.g. different plate composition or specific gravity (go back to step 6b).

iii) Adjust the full-charge voltage setpoint on the controller, if used, downward to prevent excessive overcharge (go back to step 8c).

iv) Choose a different controller (go back to step 8a).

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

10) Cell selection

a) An appropriate cell capacity, considering functional-hour rate and calculated EOD (line 9d), is found in the manufacturer's literature and entered.

b) The number of parallel strings is determined by dividing the required capacity by the capacity of the selected cell (line 6m divided by line 10a). Round up to the next higher whole number.

c) The final capacity of the battery is the capacity of the selected cell multiplied by the number of parallel strings (line 10a times line 10b).

11) Checks and considerations. This section serves as a cross check between the selected battery and the other aspects of the PV system design (e.g., PV array/controller combination). As each check and consideration is resolved (a step that may require changes to the system design or the battery selection) the appropriate box is checked off. In order to complete this section, the following information is required:

— Maximum recommended charge current for the battery during recharge (line 11a, i)
— Maximum available charging current within the voltage window (line 11a, ii)
— Maximum recommended charging current for the battery after reaching the regulation voltage (line 11b.1) (this current is highly dependent on the battery's operating temperature.)
— Maximum available charging current at battery's regulation voltage (line 11b, ii)
— Array-to-load ratio for the minimum design month (line 11c)
— Maximum discharge current (line 11d)
— Electrolyte freezing temperature at the lowest state of charge (line 11e)
— Battery's self-discharge rate (line 11f)
— Electrolyte reserve capacity for vented cells (line 11g)
— Battery's physical characteristics (individual unit's weight and dimensions, handling restrictions, etc.).

Considerations resolved

a) Maximum charge rate. The available charging current should be checked against the battery's allowable charging current to ensure that the battery is not damaged from excessive current.

b) Excessive overcharging. For systems without disconnecting charge controllers, the array current equivalent to the battery's regulation voltage should be checked against the battery's allowable float current to assure that the battery is not damaged by overcharging [see item a) of 9.5].

c) Array-to-load ratio. The ampere hour output of the array over the load ampere hours for the minimum design month. The minimum design month array-to-load ratio value should be above 1.3 to recharge the battery while the daily load is supplied.

d) High-rate discharge. Momentary or short-duration loads occurring near the end of the days of battery reserve will cause voltage decay [refer to item c) of 9.5 if (line 10c divided by line 5i) < 20 hours].

e) Freezing of electrolyte. To prevent damage to the battery, the freezing point of the electrolyte at MDOD should be lower than the minimum operating temperature (line 11e should be less than line 6i).

f) Battery's self-discharge. The battery self-discharge may be a significant part of the overall battery capacity, particularly for a large number of days of battery reserve, e.g., 10 or more days. This should be checked to determine if the battery size is affected. (Other parasitic loads such as wiring, charge controller consumption, and tare losses of inverters should be included in the load data.)

g) Electrolyte reserve. If vented cells are used, they should be selected so that the electrolyte reserve capacity is adequate to sustain the anticipated maintenance interval.

h) Battery size and weight. The battery size and weight should be compatible with the application requirements and transportation modes.

12) Summary. The selected battery and its performance features are specified.

Worksheet 1—Battery sizing

1) Project name and description:

____

____

____

2) Nominal system voltage: _________ V

3) Days of battery reserve:_________ days

4) 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.

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, if Worksheet 3 is used
   f) Percent of capacity at end of life:_________%
   g) Capacity adjusted for end of life (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 61):_________Ah
7) Functional-hour rate (line 6m ÷ line 5h): _______ h
8) Voltage-window adjustment
   a) Controller low-voltage disconnect setpoint:_________V
   b) Adjusted V_{min} (greater of line 5k or line 8a):_________V
   c) Controller full-charge voltage setpoint:_________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 EOD voltage for selected cell:_________ V
   d) Calculated EOD voltage for cell (line 8b ÷ line 9b):_________ V

   NOTE —If 9d > 9c, proceed to 9g; otherwise continue with 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 9e and 9f); select different battery type, go to 6b; change controller full-charge voltage setpoint, go to 8c; select different controller, go to 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 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 11a, ii > line 11a, i, 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 11b, ii > line 11b, i, the battery may be damaged.

c) Undercharging—Array/load ratio for the minimum design month:________

NOTE—If line 11c < 1.3, there may be insufficient array energy to recharge this 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 battery reserve (line 10c ÷ line 3): ______ Ah/day

NOTE—If 11f, i/11f, ii> 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: ________days

NOTE—If line 11g < 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.

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 load exists. Summarize the data in Worksheet 3 and transfer to Worksheet 1:

Load data

Day: ____________

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.

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:_________

Worksheet 3—Summary

5) Load data summary
   a) Greatest value of the maximum momentary 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 period of days of battery reserve.
      ii) Total the load over the period of days of battery reserve and divide by the number of days of battery reserve:________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

Annex A

(informative)

Battery characteristics

This annex summarizes some factors that should be considered in selecting a battery design for a terrestrial photovoltaic (PV) application.

A.1 Capacity

The ampere hour capacity of a battery depends on the size and number of plates of the cells, the amount and concentration of electrolyte (particularly in valve-regulated cells), and the number of parallel strings of cells used. The conditions under which a battery is used can change the available capacity of the battery, as illustrated in the following examples:

a) Low temperatures reduce capacity.

b) High discharge rates reduce capacity.

c) High end-of-discharge voltages reduce capacity.

d) Limitations on the depth of discharge reduce capacity.

e) Failure to properly recharge a battery limits its capacity.

f) Excessive periods of high temperature and/or overcharge may result in the loss of electrolyte and limit capacity of batteries.

A.2 Type

The two generic types of lead-acid batteries are:

a) Vented. Vented batteries are characterized by plates immersed in liquid electrolyte. The volume of electrolyte is sufficient to allow for a reasonable loss of water by evaporation and by the electrolysis associated with overcharging. A vent in the cell's cover allows a free exchange of the resulting gases with the atmosphere. Catalytic recombiners may be incorporated in each cell vent to reduce water loss. In most of these types of batteries, the lost water can be replaced.

b) Valve-regulated. Valve-regulated level acid batteries (VRLA) are characterized by plates in contact with a limited amount of immobilized electrolyte. Water loss is minimized during overcharge by oxygen recombination. As long as the cell's recombination rate is not exceeded, the evolved oxygen is recombined at the cell's negative plates to reform water. However, other mechanisms, such as grid corrosion, consume oxygen and lead to water loss and hydrogen evolution. The cell or multi-cell container is sealed with the exception of a pressure-relief valve ("valve-regulated") that allows excess pressure (mostly hydrogen) resulting from overcharging to be released. In these types of batteries, the lost water generally cannot be replaced.

A.3 Cyclability

Lead-acid batteries for PV applications are generally categorized as deep-cycle and shallow-cycle.

A.3.1 Deep-cycle batteries

Deep-cycle batteries may be discharged up to 80% of their rated capacity on a daily basis. Typical deep-cycle-battery PV applications are those that have a low number of days of battery reserve, or are connected to a backup power source or a utility grid.

A.3.2 Shallow-cycle batteries

Usually, shallow-cycle batteries are discharged less than 25% of their rated capacity on a daily basis (MDDOD), and up to 80% over the period of battery reserve (MDOD). Manufacturers can supply the maximum number of permissible 80% discharges per year. Typical shallow-cycle-battery PV applications are those with larger numbers of days of battery reserve where neither a utility grid nor an emergency backup power source is available.

A.4 Cycle life

The life of a battery can be measured by the number of times it can be cycled before it is no longer able to deliver sufficient energy to satisfy the load requirements of the system. The number of cycles of operation a battery will provide depends on the following three factors:

a) Cell design
b) Use
c) Operating temperature

A.4.1 Design factors

Some of the design factors that affect cycle life are:

a) Plate thickness
b) Grid alloy and construction
c) Active material density
d) Active material retention systems
e) Electrolyte density and amount
f) Type of separator
g) Pressure setting of valve (valve-regulated batteries)

A.4.2 Use factors

How a battery is used has an effect on its cycle life. Some of the considerations are listed below:

a) Depth of discharge
b) Stratification of electrolyte
c) Excessive overcharge (see A.4.3)
d) Insufficient recharge
e) End-of-discharge voltage
f) Higher-than-rated operating temperatures (>25 °C)

A.4.3 Operating temperature

High temperatures decrease cycle life, while low temperatures decrease available capacity. A battery should be sized for operation at its coldest expected operating temperature, which, in effect, oversizes the battery for normal warmer operation, resulting in a reduced depth of discharge, which increases cycle life.

The VRLA battery's oxygen recombination cycle is exothermic (generating heat on charging). Thus this type of battery is more sensitive to conditions that can lead to thermal runaway, wherein the battery generates heat at a rate faster than it can be dissipated. Thermal runaway can result in deformation of the battery case and significant emission of gases. When thermal runaway occurs, it is typically the result of extended overcharging, which can be the result of shorted cells, coupled with an elevated temperature of the battery environment and an inadequately ventilated battery enclosure. Thermal runaway can be prevented or arrested by appropriate charging control including temperature compensation, spacing of the individual cells or units of the battery to allow for adequate air circulation, adequate ventilation of the battery enclosure, and appropriate periodic maintenance. To arrest thermal runaway, circuitry can be included to disconnect the battery from its charging source should the battery temperature rise significantly above the ambient temperature.

A.5 Economic considerations

The optimum battery will be the battery with lowest life-cycle cost. The life-cycle cost, expressed in dollars per kilowatt hour ($/kWh) of energy delivered, is a function of a number of variables. These include the following:

a) Initial cost
b) Cycle life
c) Maintenance costs
d) Battery/system reliability
e) Economic impact on PV system design including:
   1) Charge controller
   2) Structural design including battery support structure and enclosure
   3) Heating, ventilation, and cooling
f) Replacement costs
g) Salvage value/disposal costs
h) Energy efficiency
i) Accessory systems such as those for electrolyte agitation and water addition

A.6 Physical characteristics

Physical characteristics that may be important are:

a) Size and weight of the smallest transportable unit
b) Cell access requirements for maintenance, such as addition of water
c) Strength of cell containers for safety and if electrolyte freezing is a possibility
d) Terminal connection configuration
e) Accessory requirements

f) Vent fittings to attach tubing for external venting

g) Available enclosure space

h) Container flammability

A.7 Maintenance

The required maintenance of batteries depends on the batteries' design and use. Refer to IEEE Std 937-2000.

A.8 Safety

Batteries are potentially hazardous for a number of reasons, including generation and release of explosive gasses (see 9.5), stored electrical energy, and presence of corrosive liquids. Installation and maintenance personnel should be qualified in battery operating and safety procedures. Refer to IEEE Std 937-2000 for safety details.

Annex B

(informative)

Examples

The following examples, including the parameters used, show the application of this sizing method. They are illustrative only and are not intended to cover all possible sizing features.

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.

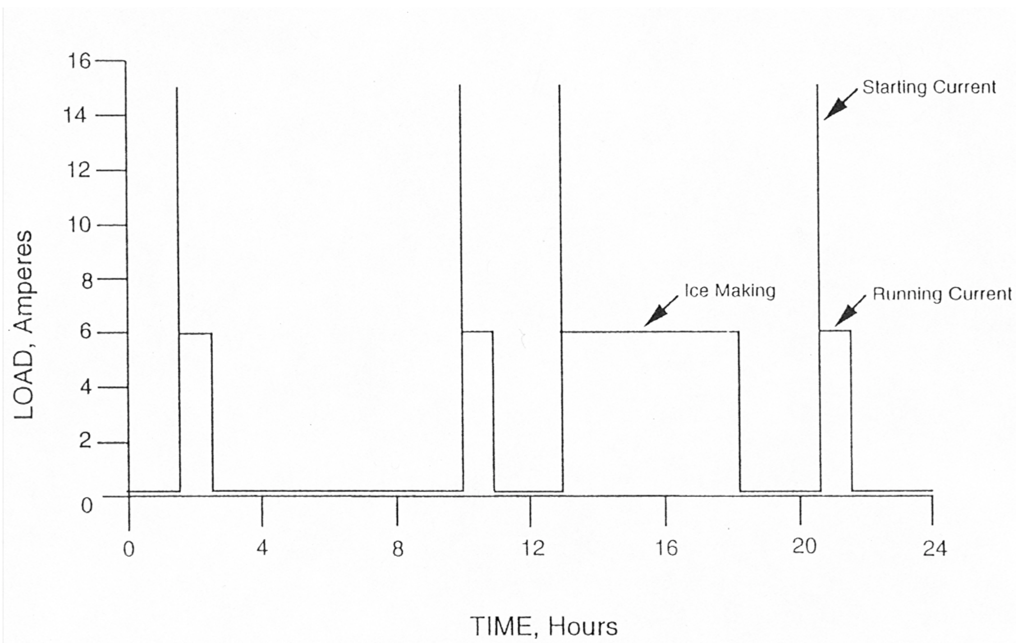

Figure B.1—Simulated load-profile diagram for vaccine storage refrigerator/freezer

Example B.1
Worksheet 1—Battery sizing

1) Project name and description:

   Remote 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 battery reserve: *6* days

4) 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*		√	*3*	*1*	*3*	*18*
							or				
Run 2[b] compressor	*15.0*	*10.5*			*6*		√	*1*	*5*	*5*	*30*
Start compressor	*15.0*	*10.5*	*15*					*4*	*0.0167*		*1*
Parasitics					*0.1*		√			*2.4*	*2.4*
							Total daily load				***51.4*** **Ah**

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

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: *—* Ah/day

   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* V

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

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:___*80*___%

g) Capacity adjusted for end of life (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*___

k) Capacity adjusted for temperature:___*385*___Ah

l) Design margin factor (≥1):___*1.1*___

m) Capacity adjusted for design margin (line 6k × line 61):___*424*___Ah

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

8) Voltage-window adjustment

a) Controller low-voltage disconnect setpoint:___*10.8*___V

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

c) Controller full-charge voltage setpoint:___*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 ÷ line 9a):___*6*___

c) Recommended EOD voltage for selected cell:___*1.80*___V

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

NOTE —If 9d > 9c, proceed to 9g; otherwise continue with 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 9e and 9f); select different battery type, go to 6b; change controller full-charge voltage setpoint, go to 8c; select different controller, go to 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 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*___

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 11a, ii > line 11a, i, 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 11b, ii > line 11b, i, the battery may be damaged.

c) Undercharging—Array/load ratio for the minimum design month: *1.5*

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

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 battery reserve (line 10c ÷ line 3): *73* Ah/day

NOTE—If 11f, i/11f, ii> 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: *120* days*

**Cells with extra headspace selected.*

NOTE—If line 11g < 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: *XYX Co.*

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.

B.2 Remote communications system

The following worksheet (Example B.2) describes the battery sizing for a 48 V (nominal) simplex communications system (single-mode operation). A battery reserve of 15 days was selected to ensure high system reliability. The system is not accessible during six months of the year. There is a weight limitation on battery transportation. Figure B.2 shows a simulated load-profile diagram for this application.

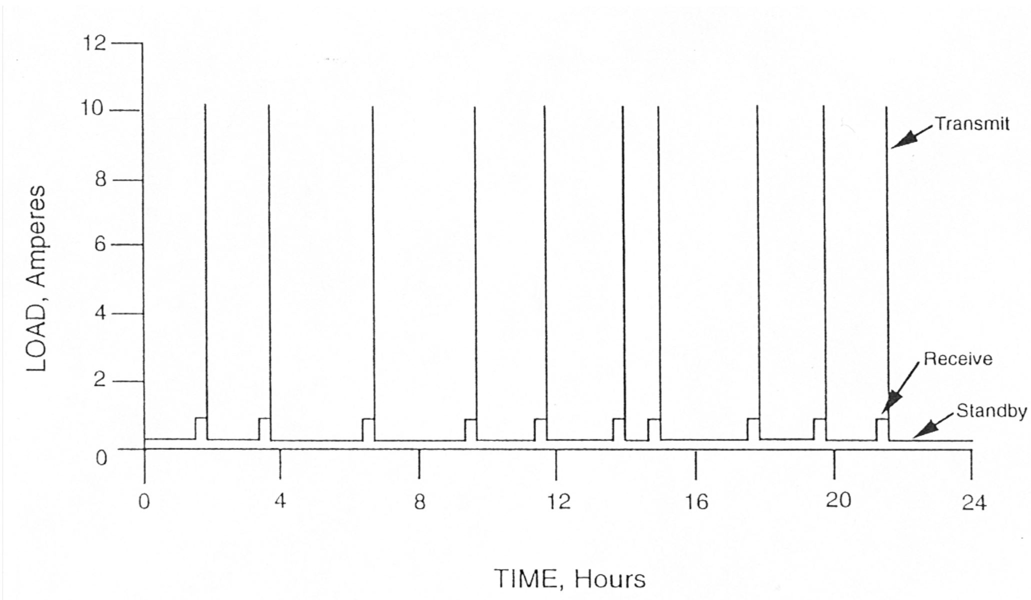

Figure B.2—Simulated load-profile diagram for remote communications repeater

Example B.2
Worksheet 1—Battery sizing

1) Project name and description:
   Communications system. High reliability required, 6 month interval between servicing, mountain top location, thermally insulated battery.
2) Nominal system voltage: ___*48*___V
3) Days of battery reserve:___15___ days
4) 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
Transmitter	*64*	*40*				*10*	√	[b]		*0.5*	*5*
Recover	*64*	*40*				*1*				*2.0*	*2*
Standby	*64*	*40*				*0.5*				*21.5*	*10.8*
Note—All loads include parasitics.											
										Total daily load *17.8* **Ah**

[a]Including parasitic currents.
[b]*Since individual durations depend on usage, columns 4f and 4g have not been used. The hours/day have been obtained from the customer's requirements.*

5) Load data summary
   a) Maximum momentary current I_{coin} from above table (or line 5a of Worksheet 3) (refer to load profile diagram):___*0*___A
   b) Maximum running current I_{coin} from above table (or line 5b of Worksheet 3) (refer to load profile diagram): ___*0*___ A
   c) Total daily load from above table (or line 5c of Worksheet 3): ___*17.8*___ 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): ___*0*___A
   f) Maximum momentary current draw from battery (greater of line 5a or line 5e): ___*0*___ A
   g) Greatest value of $I_{noncoin}$ for running currents from above table (or line 5e of Worksheet 3): ___*10*___ A
   h) Maximum running current draw from battery (greater of line 5b or line 5g): ___*10*___ A
   i) Maximum current draw from battery (greater of line 5f or line 5h.): ___*10*___ A
   j) Lowest value of V_{max} from above table (or line 5f of Worksheet 3): ___*64*___ V
   k) Greatest value of V_{min} from above table (or line 5g of Worksheet 3): ___*40*___ V

6) Battery capacity
   a) Unadjusted battery capacity (line 3 × line 5c): ___*267*___ Ah
   b) Maximum allowable depth of discharge (MDOD): ___*80*___ %
   c) Capacity adjusted for MDOD (line 6a ÷ line 6b):___*334*___ 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]: ___*89*___ Ah
   f) Percent of capacity at end of life: ___*80*___ %
   g) Capacity adjusted for end of life (line 6a ÷ line 6f): ___*334*___ Ah
   h) Capacity adjusted for depths of discharge or end of life (greatest of line 6c, line 6e, or line 6g): ___*334*___Ah
   i) Minimum operating temperature: ___*7.2*___ °C
   j) Associated temperature correction factor: ___*1.2*___
   k) Capacity adjusted for temperature: ___*401*___ Ah
   l) Design margin factor (≥1): ___*1.1*___
   m) Capacity adjusted for design margin (line 6k × line 61): ___*441*___ Ah
7) Functional-hour rate (line 6m ÷ line 5h): ___*44*___ h
8) Voltage-window adjustment
   a) Controller low-voltage disconnect setpoint: ___*42*___ V
   b) Adjusted V_{min} (greater of line 5k or line 8a): ___*42*___ V
   c) Controller full-charge voltage setpoint: ___*58*___ 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): ___*58*___ V
9) Number of series-connected cells
   a) Recommended full-charge voltage for selected cell: (limited by line 8d): ___*2.40*___ V
   b) Maximum number of cells in series, round down (line 8d ÷ line 9a): ___*24*___
   c) Recommended EOD voltage for selected cell: ___*1.75*___V
   d) Calculated EOD voltage for cell (line 8b ÷ line 9b): ___*1.75*___ V

   NOTE —If 9d > 9c, proceed to 9g; otherwise continue with 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 9e and 9f); select different battery type, go to 6b; change controller full-charge voltage setpoint, go to 8c; select different controller, go to 8a.

   g) Enter the selected number of series cells (line 9b or line 9e, as appropriate): ___*24*___
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 less than line 6m, when discharged to the calculated EOD voltage (line 9d), at the functional-hour rate (line 7): ___*242*___ Ah
   b) Number of parallel strings, round up (line 6m ÷ line 10a): ___*2*___
   c) Final battery capacity (line 10a × line 10b): ___*484*___ Ah
11) Checks/considerations
   a) Maximum charge rate
      i) Recommended maximum charge current during recharge: ___*97*___ A

ii) Maximum available charging current during recharge: ___*40*___ A

NOTE—If line 11a, ii > line 11a, i, the battery may be damaged.

b) Excessive overcharging

i) Recommended maximum charge current after reaching regulation voltage at the battery's average temperature of ___*15.6*___°C: ___*2*___ A

ii) Maximum available charging current after reaching regulation voltage: ___*2*___ A

NOTE—If line 11b, ii > line 11b, i, the battery may be damaged.

c) Undercharging—Array/load ratio for the minimum design month: ___*1.5*___

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

d) High-rate discharge—Maximum discharge current: ___*10*___ 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: ___*–12.2*___ °C

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

f) Battery self discharge

i) Battery's self discharge: ___*1.0*___ Ah/day

ii) Battery's capacity for each day of battery reserve (line 10c ÷ line 3): ___*32*___Ah/day

NOTE—If 11f, i/11f, ii> 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: ___—___ days*

**Valve regulated battery selected*.

NOTE—If line 11g < 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: _*PDZ Inc.*__

Final battery is ___*24*___ cells in series by ___*2*___ strings in parallel.

Battery capacity is ___*484*___ Ah rated at the ___*44*___ h functional-hour rate.

Battery full-charge voltage is ___*58*___ V.

Battery end-of-discharge voltage is ___*42*___ V.

B.3 Remote residence

Example B.3 describe the battery sizing for a remote cabin, used only on the weekends. Seven days of battery reserve are sought. Although the major load is present on weekends only, the security system operates at all times. Figure B.3 is a typical load profile diagram.

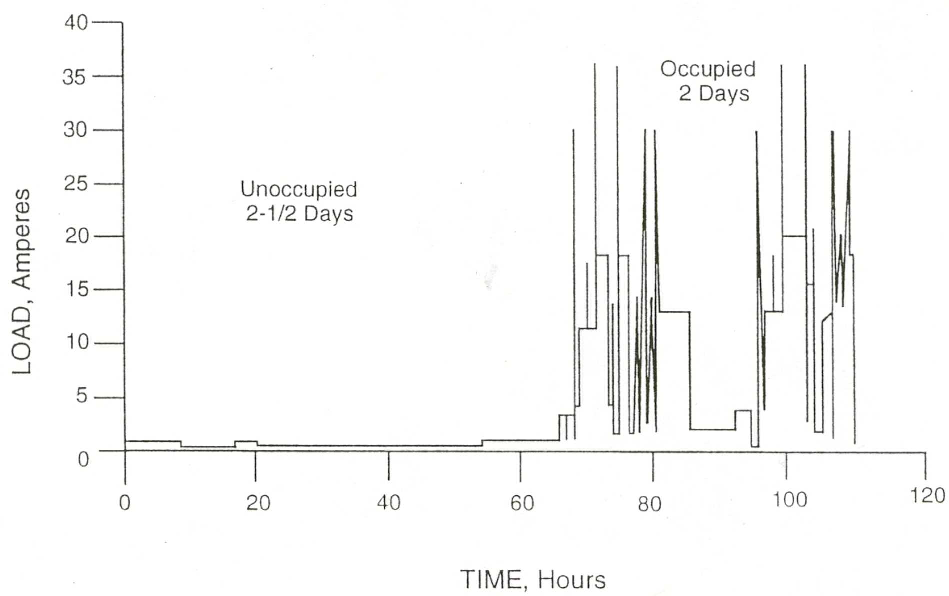

Figure B.3—Simulated partial load profile diagram for remote residence (4-1/2 days)

Example B.3
Worksheet 1—Battery sizing

1) Project name and description:
Weekend cabin on an island off the coast of Maine. Artist occupied—heavy loads are for equipment used in his work.

2) Nominal system voltage: *24* V

3) Days of battery reserve: *7* days

4) 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
SEE WORKSHEET 2											
						Total daily load					Ah

[a]Including parasitic currents.

5) Load data summary

a) Maximum momentary current I_{coin} from above table (or line 5a of Worksheet 3) (refer to load profile diagram): *36.1* A

b) Maximum running current I_{coin} from above table (or line 5b of Worksheet 3) (refer to load profile diagram): *35.15* A

c) Total daily load from above table (or line 5c of Worksheet 3): *54.1* Ah/day

d) Maximum daily load from Worksheets 2 if used: *153* Ah/day

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): *36.1* 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): *35.15* A

i) Maximum current draw from battery (greater of line 5f or line 5h.): *36.1* A

j) Lowest value of V_{max} from above table (or line 5f of Worksheet 3): *30* V

k) Greatest value of V_{min} from above table (or line 5g of Worksheet 3): *23*

6) Battery capacity
   a) Unadjusted battery capacity (line 3 × line 5c): ___*417*___ Ah
   b) Maximum allowable depth of discharge (MDOD): ___*50*___ %
   c) Capacity adjusted for MDOD (line 6a ÷ line 6b): ___*834*___ 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]: ___*772*___ Ah
   f) Percent of capacity at end of life: ___*80*___ %
   g) Capacity adjusted for end of life (line 6a ÷ line 6f): ___*521*___ Ah
   h) Capacity adjusted for depths of discharge or end of life (greatest of line 6c, line 6e, or line 6g): ___*834*___Ah
   i) Minimum operating temperature: ___*0*___ °C
   j) Associated temperature correction factor: ___*1.35*___
   k) Capacity adjusted for temperature: ___*1126*___ Ah
   l) Design margin factor (≥1): ___*1.1*___
   m) Capacity adjusted for design margin (line 6k × line 61): ___*1239*___ Ah
7) Functional-hour rate (line 6m ÷ line 5h): ___*35*___ h
8) Voltage-window adjustment
   a) Controller low-voltage disconnect setpoint: ___*24.5*___ V
   b) Adjusted V_{min} (greater of line 5k or line 8a): ___*24.5*___ V
   c) Controller full-charge voltage setpoint: ___*28.8*___ 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): ___*28.8*___ V
9) Number of series-connected cells
   a) Recommended full-charge voltage for selected cell: (limited by line 8d): ___*2.40*___ V
   b) Maximum number of cells in series, round down (line 8d ÷ line 9a): ___*12*___
   c) Recommended EOD voltage for selected cell: ___*2.0*___ V
   d) Calculated EOD voltage for cell (line 8b ÷ line 9b): ___*2.04*___ V

   NOTE —If 9d > 9c, proceed to 9g; otherwise continue with 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 9e and 9f); select different battery type, go to 6b; change controller full-charge voltage setpoint, go to 8c; select different controller, go to 8a.

   g) Enter the selected number of series cells (line 9b or line 9e, as appropriate): ___*12*___
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 less than line 6m, when discharged to the calculated EOD voltage (line 9d), at the functional-hour rate (line 7): ___*1240*___ Ah
   b) Number of parallel strings, round up (line 6m ÷ line 10a): ___*1*___
   c) Final battery capacity (line 10a × line 10b): ___*1240*___ Ah
11) Checks/considerations
   a) Maximum charge rate
      i) Recommended maximum charge current during recharge: ___*150*___ A

ii) Maximum available charging current during recharge: ___*12*___ A

NOTE—If line 11a, ii > line 11a, i, the battery may be damaged.

b) Excessive overcharging

i) Recommended maximum charge current after reaching regulation voltage at the battery's average temperature of ___*15*___ °C: ___*11*___ A

ii) Maximum available charging current after reaching regulation voltage: ___*2*___ A

NOTE—If line 11b, ii > line 11b, i, the battery may be damaged.

c) Undercharging—Array/load ratio for the minimum design month: ___*1.3*___

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

d) High-rate discharge—Maximum discharge current: ___*36.1*___ 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: ___*–20*___ °C

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

f) Battery self discharge

i) Battery's self discharge: ___*1.5*___ Ah/day

ii) Battery's capacity for each day of battery reserve (line 10c ÷ line 3): ___*177*___ Ah/day

NOTE—If 11f, i/11f, ii> 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: ___*30*___ days

NOTE—If line 11g < 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: ___*ABC Batteries*___.

Final battery is ___*12*___ cells in series by ___*1*___ strings in parallel.

Battery capacity is ___*1240*___ Ah rated at the ___*35*___ h functional-hour rate.

Battery full-charge voltage is ___*28.8*___ V.

Battery end-of-discharge voltage is ___*24.5*___ V.

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 load exists. Summarize the data in Worksheet 3 and transfer to Worksheet 1:

Load data

Day: *unoccupied days*

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
Security											
Lights	*30*	*21*			*1.0*		√		*12*	*12*	*12.0*
Security Systems	*30*	*21*			*0.3*		√			*24*	*7.2*
Parasitics					*0.1*		√			*24*	*2.4*
										Total daily load	*21.6* **Ah**

[a]Including parasitic currents.

Maximum momentary current I_{coin} (refer to load profile diagram): *0* A

Maximum running current I_{coin} (refer to load profile diagram): *1.4* A

Number of repetitions: *5*

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

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

Load data

Day: *occupied days*

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**
Security Lights	*30*	*21*			*1.0*		√		*12*	*12*	*12.0*
Security System	*30*	*21*			*0.3*		√			*24*	*7.2*
Lights am	*30*	*23*			*1.5*				*1*	*1*	*1.5*
Lights pm 1	*30*	*23*			*10.0*					*2*	*20.0*
Lights pm 2	*30*	*23*			*3.0*		√			*2*	*6.0*
Water pump	*30*	*15*	*15*		*10.0*			*4*	*0.0675*	*0.27*	*3.7*
TV	*30*	*23*			*0.75*		√			*2*	*1.5*
Projector	*30*	*22*	*36*		*18.0*					*5*	*90.6*
Appliance 1	*30*	*22*			*30*			*4*	*0.0175*	*0.07*	*2.1*
Appliance 2	*30*	*22*			*30*		√			*0.25*	*7.5*
Parasitics					*0.1*					*24*	*2.4*
										Total daily load	*154.5* **Ah**

[a]Including parasitic currents.

Maximum momentary current I_{coin} (refer to load profile diagram): *36.1* A

Maximum running current I_{coin} (refer to load profile diagram): *35.15* A

Number of repetitions: *2*

Worksheet 3—Summary

5) Load data summary

   a) Greatest value of the maximum momentary I_{coin} currents: ___*36.1*___ A

   b) Greatest value of the maximum running I_{coin} currents:___*35.15*___ A

   c) Average daily load:

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

      ii) Total the load over the period of days of battery reserve and divide by the number of days of battery reserve:___*59.6*___ Ah/day

   d) Greatest value of $I_{noncoin}$ for momentary currents for any of the above load devices:___*0*___ A

   e) Greatest value of $I_{noncoin}$ for running current for any of the above load devices:___*0*___ A

   f) Lowest value of V_{max} for any of the above load devices:___*30*___ V

   g) Greatest value of V_{min} for any of the above load devices:___*23*___ V

Annex C

(informative)

Bibliography

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[B3] IEEE Std 929-2000, IEEE Recommended Practice for Utility Interface of Residential and Intermediate Photovoltaic (PV) Systems.