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

IEEE Standards Board

Developed by the
IEEE Standards Coordinating Committee 21
on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage

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Developed by the

IEEE Standards Coordinating Committees/SCC21—Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage (SASB/SCC21)

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Abstract: A method for determining the energy-capacity requirements (sizing) of both vented and valve-regulated lead-acid batteries used in terrestrial stand-alone photovoltaic (PV) systems is described in this recommended practice. Sizing batteries for hybrid or grid-connected PV systems is beyond the scope of this recommended practice. Installation, maintenance, safety, testing procedures, and consideration of battery types other than lead-acid are beyond the scope of this recommended practice. Recommended practices for the remainder of the electrical systems associated with PV installations are also beyond the scope of this recommended practice.

Keywords: battery capacity, battery requirements, IEEE 1013™, lead-acid batteries, photovoltaic (PV), photovoltaic power systems, sizing, sizing lead-acid batteries, solar, stand-alone

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Introduction

This introduction is not part of IEEE Std 1013-2019, IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stand-Alone Photovoltaic (PV) Systems.

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

Contents

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

1. Overview

This recommended practice provides a systematic approach for determining the appropriate energy capacity of a lead-acid battery to satisfy the energy requirements of the electrical loads of a stand-alone photovoltaic (PV) system. Since this capacity determination (sizing) assumes that no power is available from the array, the resulting battery capacity should be more than adequate to meet the PV system's load requirements during its normal operation.

1.1 Scope

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

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 recommended practice.

1.2 Purpose

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

2. Definitions, acronyms, and abbreviations

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[1]

2.1 Definitions

regulation voltage: The maximum voltage that a charge controller allows the battery to reach under charging conditions.

solar radiation: The time integral of solar irradiance.

NOTE—Solar radiation data for a geographic location is generally reported for each month as the average daily radiation for a specific array tilt angle. A typical range for daily solar radiation is 2 kWh/m^2 to 7 kWh/m^2.

2.2 Acronyms and abbreviations

DOD	depth of discharge
EOD	end of discharge
EOL	end of life
I_{coin}	coincident current
I_{mp}	maximum power point current
I_{noncoin}	non-coincident current
MDDOD	maximum daily depth of discharge
MDOD	maximum depth of discharge
PV	photovoltaic
V_{max}	Maximum voltage limit
V_{min}	Minimum voltage limit

3. Outline of sizing methodology

The functional description of a standalone system is depicted in the following diagram:

[1]*IEEE Standards Dictionary Online* is available at: http://dictionary.ieee.org.

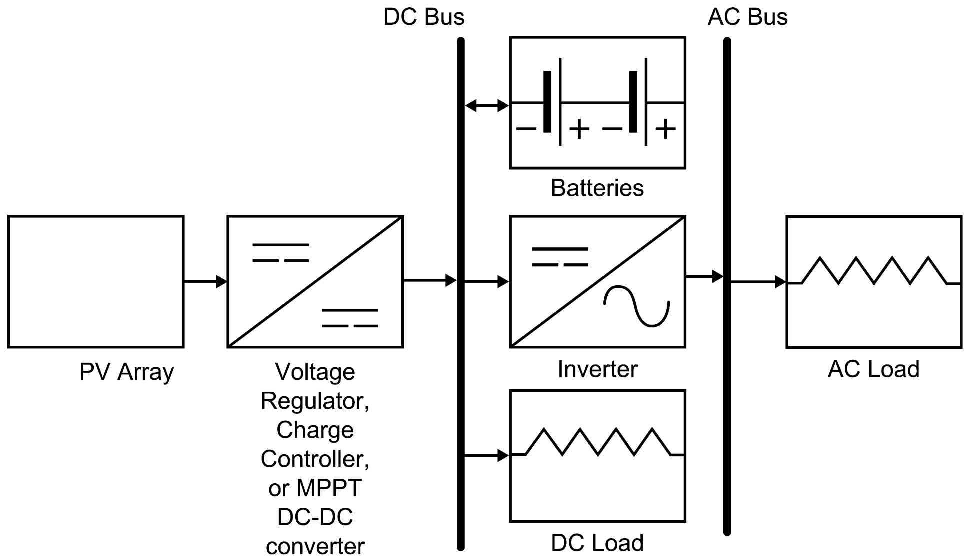

Figure 1—Description of a stand-alone PV system

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, are discussed in subsequent clauses:

— *Autonomy* (Clause 4). The length of time that the stand-alone PV system's load should be supported solely by its fully charged battery is established by system design requirements.

— *Load determination* (Clause 5). 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 allowable voltage limitsare determined by the system's load devices.

— *Battery capacity and functional-hour rate determination* (Clause 5). The battery capacity and its discharge functional-hour rate are determined by the specific application's load(s), autonomy, and battery characteristics (see Annex A).

— *Determining number of series-connected cells* (Clause 7). 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 8). 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 9). Worksheets that provide a systematic approach to the sizing of a battery for a stand-alone PV system are 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 the PV application. Information regarding lead-acid battery characteristics is presented.

— *Examples* (Annex B). Examples demonstrating various aspects of battery sizing are presented.

4. Autonomy considerations

PV 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 autonomy 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 autonomy than non-critical applications.

b) *System availability*. System availability is the minimum percentage of the time that the PV system should be able to satisfy the system's specified design loads.

c) *Solar irradiance variability*. Daily and seasonal variations in solar irradiance affect the required autonomy.

d) *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.

e) *Recharge capability*. If the array is insufficiently sized or if the available recharge time is too short, then the battery may not be fully recharged between discharges.

f) *Accessibility of site*. The worst-case time required for reaching the site and for correcting any problem should be considered.

5. Load determination

A description of the system's electrical load, within the autonomy period, is needed for the sizing of the battery. The validity of the battery sizing depends on the accuracy and completeness of this information.

5.1 General considerations

The overall duty cycle imposed on the battery is the description of the dc load current and its duration within the autonomy period during which it is assumed that no power is provided by the PV array. 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 9 provides a convenient method of tabulating load data in accordance with the sizing method of this recommended practice.

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. Worksheet 2 and Worksheet 3 in Clause 9 provide convenient methods 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.

For applications where the load varies significantly on a monthly basis, the average daily load for each month should be determined. The battery sizing should be based on the resulting maximum average daily load.

A load-profile diagram is a helpful 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 autonomy period, the individual daily load-profile diagrams, plotted in sequence, constitute the system's load-profile diagram. See Annex B for examples.

5.2 Load data

The systematic identification and characterization of the system's individual loads are fundamental to defining the battery's duty cycle. The information in 5.2.1 through 5.2.6 is provided to assist in gathering and characterizing the system's loads.

5.2.1 Momentary current

Loads lasting 1 min 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:

a) Motor starting currents

b) High inverter surge currents

5.2.2 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 required current rises as the battery voltage falls. For the typically long-rate discharges of PV applications, the battery's voltage remains relatively constant until near the end of discharge (EOD); therefore, 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.

5.2.3 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, which is a parasitic current that depends on the battery type and capacity, is recommended as a check (see 8.5) after the battery is selected.

5.2.4 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 autonomy. If the inception time of a load is known, but the shutdown time is indefinite, it should be assumed that the load continues through the remainder of the autonomy period.

5.2.5 Load coincidence

Each load current (momentary or running) is classified as to whether or not it is coincident with any other loads and is 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 5.3).

5.2.6 Maximum and minimum load voltage

The maximum and minimum voltage at which each load device operates properly should be determined and tabulated (see Clause 9, Worksheet 3). 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 help ensure that the required minimum voltage is present at the load.

5.3 Data analysis

After the loads have been defined, the sizing and selection of an appropriate battery can begin. As the final capacity of the battery depends on the commercially available cell capacities in the desired lead-acid battery type, the final selection of battery and its capacity may be an iterative process.

5.3.1 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 autonomy period. Worksheet 2 in Clause 9 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.

5.3.2 Currents

The maximum momentary and the 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™ [B1] may result in a less conservatively sized battery.

6. Battery capacity and functional-hour rate determination

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

6.1 Unadjusted capacity

The unadjusted capacity, in ampere hours, is calculated by multiplying the days of autonomy by the average daily load (in ampere hours/day as determined in Clause 5). This capacity is adjusted in 6.3 for battery characteristics and operating conditions. See IEEE Std 1361™ [B3] for additional information on these subjects.

6.2 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 (DOD) and cycle life, are different for the various battery types. See IEEE Std 1361 [B3].

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.

If a valve-regulated battery is used, it should be selected for the intended application by considering the effect that charging current has on recombination and thus cell dryout, thermal runaway, and the consequences of hydrogen and oxygen evolution (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.

6.3 Capacity adjustment

After initial battery selection and sizing, the final battery's capacity is determined by making adjustments for various battery, operational, and PV system factors.

6.3.1 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 EOL capacity expressed in percent of the rated capacity. While 80% is often used as the EOL capacity in float-service applications, this value may mean earlier replacement than necessary for PV applications. This is due to a number of factors including the incomplete charging that can occur in PV applications. The resulting apparent loss in capacity results in a reduction of the autonomy period. If a fixed period is necessary, a larger EOL battery capacity should be used. Using an EOL percentage less than 80% in sizing the battery is one method of achieving this additional capacity. In most cases, an EOL percentage less than 50% is not recommended.

d) The largest of these three capacities satisfies the MDOD, MDDOD, and EOL adjustments.

6.3.2 Temperature adjustment

The available capacity of a battery is affected by its operating temperature. Cell capacity ratings are generally standardized at 25 °C in the United States. Other countries may use other temperatures when rating their battery capacities. The battery's capacity increases for temperatures above and decreases for temperatures below that used for the battery's capacity rating. When sizing a battery, its capacity is rarely adjusted for warm-temperature operation, but adjustments should be made for cold-temperature applications. Refer to the battery manufacturer's literature for temperature correction factors. The discharge-adjusted capacity determined in 6.3.1 should be further adjusted by this factor to yield a temperature-adjusted capacity.

6.3.3 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 load-operating conditions and load growth. A common practice to provide this design margin is to add 10% to 25% to the capacity as determined in 6.3.2.

6.4 Functional-hour rate

In order to select an appropriate battery, the battery's ampere-hour capacity and its discharge rate should be considered together. In continuous-load applications, the battery should have sufficient capacity to supply the constant-discharge rate over the autonomy period. However, in noncontinuous load applications, the discharge rate varies and could include high rates of discharge periodically throughout the autonomy period. Using an average discharge rate when selecting a battery could result in insufficient capacity to supply high currents above the minimum voltage late in the battery's discharge. The functional-hour rate, expressed in hours, 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 8.1, for cell selection, may be greater than the autonomy period.

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 as the maximum running current.

b) Divide the adjusted capacity as determined in 6.3.3 by the maximum running current selected in step a) above.

Example 1:

The adjusted battery capacity in a system with 5 days autonomy is 150 Ah, with a maximum current drain of 5 A. The functional-hour rate is 150 Ah divided by 5 A, or 30 h.

Example 2:

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

7. 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, along with the selected cell's allowable charging and discharging voltage limits, determine the number of series-connected cells of the battery.

7.1 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 two. 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.

7.2 Voltage window

Each piece of the application's electrical equipment has a voltage range within which it operates at its performance ratings. If the equipment is exposed to higher or lower-than-specified voltages, it may be damaged or operate improperly. An upper and lower voltage can be selected which mutually accommodates the voltage limits of the individual equipment. This high (V_{max}) and low (V_{min}) limit of system voltage is called the voltage window. Since the voltage of a lead-acid cell drops as energy is withdrawn from it, the magnitude of this voltage window has a direct effect on the number and capacity of cells selected for the application's battery. The narrower the voltage window, the larger the cell's capacity needs to be in order meet the application's energy demands; the wider the window, the smaller the cell's capacity may be.

From the tabulated maximum and minimum voltages in 5.2.6, the lowest maximum voltage (V_{max}) and the highest minimum voltage (V_{min}) define the voltage window within which all loads in the system operate properly [see item 4)b) of Clause 9]. If a charge controller is used, its set points should be within this voltage window.

When a temperature-compensated charge controller is used, the set points 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 is 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 8.5.

7.3 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.

7.3.1 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:

$$\text{Maximum number of cells (rounded down)} = \frac{V_{\max}}{\text{cell recharge voltage}} \tag{1}$$

When the system has capability for cell equalization or temperature-compensated charging, the maximum associated voltage should be used for Equation (1) provided it does not exceed the manufacturer's recommendations.

Example:

Assume 2.4 V per cell is the maximum recommended voltage for recharging and 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.

7.3.2 Minimum system voltage versus end-of-discharge (EOD) voltage

To help ensure that the battery is not operated below the manufacturer's recommended 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:

$$\text{Calculated EOD cell voltage} = \frac{V_{\min}}{\text{number of cells calculated from 7.3.1}} \tag{2}$$

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. It is also possible to reduce the number of cells to satisfy this condition, although this is not normal practice.

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, supplies less capacity than if it were discharged to the recommended EOD cell voltage. This lower capacity should be used as the cell's capacity for all sizing determinations.

7.3.3 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:

$$\text{Total number of multicell units} = \frac{V_{\max}}{\text{maximum multicell recharge voltage}} \qquad (3)$$

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.

7.3.4 Optimization

The calculation in 7.3.1 provides 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 8.3 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 8.5].

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

8. Battery size determination

Battery size is determined by using the results of Clause 6 and Clause 7 to select an appropriate battery that meets the load and site requirements.

8.1 Cell size selection

The cell size is selected by using the same manufacturer's data that was used in 6.2. Choose a cell that meets the capacity requirements of 6.3.3 when discharged at the functional-hour rate determined by 6.4 to an EOD voltage that is greater than or equal to the EOD voltage determined by 7.3. 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 8.2.

A manufacturer may list available capacities by either the capacity of the cell itself or the capacity of a cell's 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 6.3.3 by the positive plate capacity. Fractional results are to be rounded up to the next higher whole number.

8.2 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 series-connected cells, may (consistent with the manufacturer's recommendations) be connected in parallel to obtain the necessary capacity. It is recommended that these strings be as a close as practical in capacity.

The number of parallel strings is calculated by dividing the capacity found in 6.3.3 by the selected cell capacity determined by 8.1 (rounded up).

8.3 Final number of cells

The total number of cells can then be calculated by multiplying the number of series cells determined by 7.3 by the number of parallel strings.

8.4 Final battery capacity

The final battery capacity is calculated by multiplying the single-cell capacity at the functional-hour rate by the number of parallel strings.

8.5 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 results in the release of potentially flammable quantities of hydrogen gas, and accelerates water loss and positive plate deterioration. For valve-regulated batteries, overcharging will also result in premature dryout. The quantity and composition depends on the rate and duration of the overcharge, the battery and its valve design, oxygen recombination rate (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, versus valve-regulated batteries, where the water lost generally cannot be replaced and, therefore, life is typically shortened. Overcharging valve-regulated batteries can also cause a potentially hazardous condition known as thermal runaway. Overcharging can result in excess heat that lowers the cell's resistance, thereby enabling 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 increases the rate of positive grid corrosion and shortens the battery's life. If any of the conditions that may lead to overcharging exist, discussions between the PV system designer and the battery manufacturer are necessary to determine the preventive and corrective actions.

b) *Undercharging.* Too small an array, too little solar radiation, or too low a charging voltage results in an undercharged battery. If either of these conditions exist, discussions between the PV system designer and the battery manufacturer are necessary to determine the corrective action.

c) *High-discharge rate.* A momentary load, particularly one occurring at or near the end of the autonomy 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 [B1] (considering the required autonomy period for the load profile diagram), or a reexamination of the worst caseloads be made and discussed with the PV system designer. If the method of IEEE Std 485 is used, the resulting battery should be reevaluated according to the criteria given in this recommended practice. In most cases, the battery voltage should not drop below the minimum system voltage if the momentary load is less than the 20 h discharge rate.

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. Batteries with higher density electrolytes may be considered for extended low-temperature applications.

e) *Self-discharge as a battery load.* All batteries undergo 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 more than 5% of the adjusted capacity from 6.3.3.

9. 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 autonomy.* Enter the number of days of autonomy.

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 h).

   The following is an explanation of the terms used:

   a) *DC load device.* The identification of the dc loads.

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

   NOTE 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 for all loads. (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 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 item 4) above, 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 is 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 value is 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 autonomy 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 6h) 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 autonomy.

8) *Voltage window adjustment.* This section provides for any adjustment that may be necessary as a result of controller set points. The controller set points 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 7.2). When temperature-compensated charge controllers are used, the voltage window should correspond to the anticipated maximum and minimum battery temperature extremes.

a) Enter the set point of the low-voltage 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 set point 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 9c, 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 set point 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 11ai). (This current is the maximum charging current per cell times the number of parallel strings.)

   — Maximum available charging current within the voltage window (line 11aii).

   — Maximum recommended charging current for the battery after reaching the regulation voltage (line 11bi). (This current is highly dependent on the battery's operating temperature.)

   — Maximum available charging current at battery's regulation voltage (line 11bii).

   — 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:

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

e) *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 5a) in Clause 9].

f) *Array-to-load ratio.* The average daily ampere hour output of the array divided by the load's daily ampere hours for the minimum design month. The minimum design month's array-to-load ratio value should be above 1.3 to recharge the battery while the daily load is supplied.

NOTE—The value 1.3 includes typical systems losses. If the actual losses are known, this value should be changed accordingly. See IEEE Std 1562™ [B4] for a discussion of these losses and how to adjust for them.

g) *High-rate discharge.* Momentary or short-duration loads occurring near the end of the autonomy period could cause voltage decay [refer to item 5c in Clause 9 if (line 10c divided by line 5i) < 20 h].

h) *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).

i) *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 autonomy, 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.)

j) *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.

k) *Battery size and weight.* The battery's physical size and weight should be compatible with the application requirements and transportation modes.

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

9.1 Worksheet 1—Battery sizing

1) Project name and description:

2) Nominal system voltage: _________ V

3) Days of autonomy: _________ 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
   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 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.

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

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: _________

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

Annex A

(informative)

Battery characteristics

This annex summarizes some factors that should be considered in selecting a battery design for a terrestrial stand-alone photovoltaic (PV) application. For more complete information concerning some of these factors refer to Annex A and Annex B of IEEE Std 1361 [B3].

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 (EOD) voltages reduce capacity

d) Limitations on the depth of discharge (DOD) 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 water from the electrolyte, premature aging, 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 lead-acid batteries (VRLA) are characterized by plates in contact with an 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) 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 with shorter autonomy periods.

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 autonomy (MDOD). Manufacturers can supply the maximum number of permissible 80% discharges per year. Typical shallow-cycle-battery PV applications are those with longer autonomy periods.

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 battery operation 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) DOD
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 service 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 DOD, 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. The possibility of thermal runaway can be reduced 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 optimal-economic battery is the one with lowest lifecycle cost. The lifecycle 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:
f) Charge controller
g) Structural design including battery support structure and enclosure
h) Heating, ventilation, and cooling
i) Replacement costs
j) Salvage value/disposal costs
k) Energy efficiency
l) Accessory systems such as those for electrolyte agitation and water addition

A.6 Physical characteristics

Physical characteristics that may be important are as follows:

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™ [B2] for information on PV system maintenance.

A.8 Handling precautions

Batteries are potentially hazardous for a number of reasons, including generation and release of explosive gasses [see item a) of 8.5], stored electrical energy, and presence of corrosive liquids. Installation and maintenance personnel should be qualified in battery operating and handling procedures. Refer to IEEE Std 937 [B2] for additional information.

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.

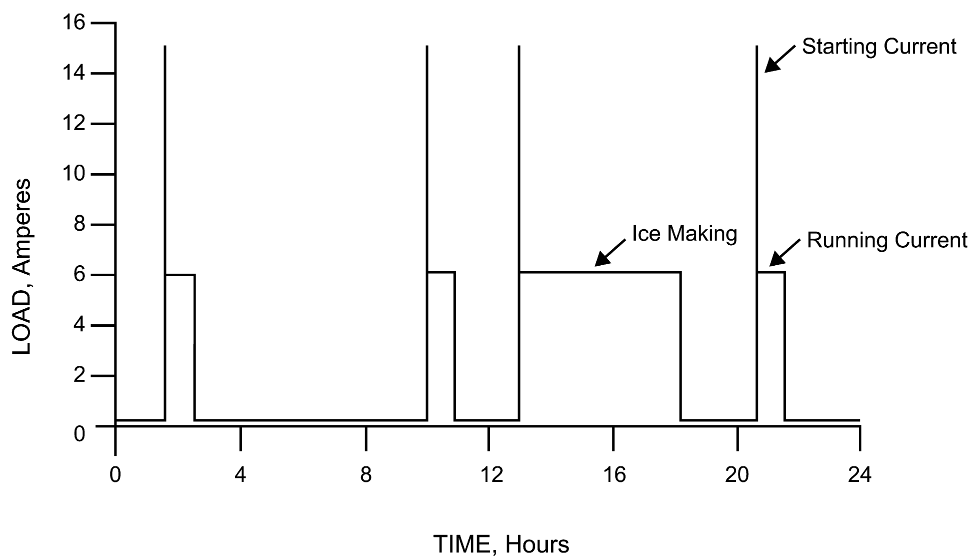

Figure B.1—Simulated load-profile diagram for vaccine storage refrigerator/freezer

B.1.1 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 autonomy: *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		X	3	1	3	18
							or				
Run 2 compressor[b]	15.0	10.5	15		6		X	1	5	5	30
Start Compressor	15.0	10.5						4	0.0167		1
Parasitics					0.1		X			24	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: — 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*__

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*__

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*__

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*__

NOTE—If line 11c < 1.3, there may be insufficient array energy to recharge the 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 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 days*__
*Cells with extra headspace selected.

NOTE—If line 11g < 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.*__

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). An autonomy period of 15 days was selected to help ensure high system reliability. The system is not accessible during six months of the year. There is a weight limitation on battery transportation as the site is only accessible by helicopter. Figure B.2 shows a simulated load-profile diagram for this application.

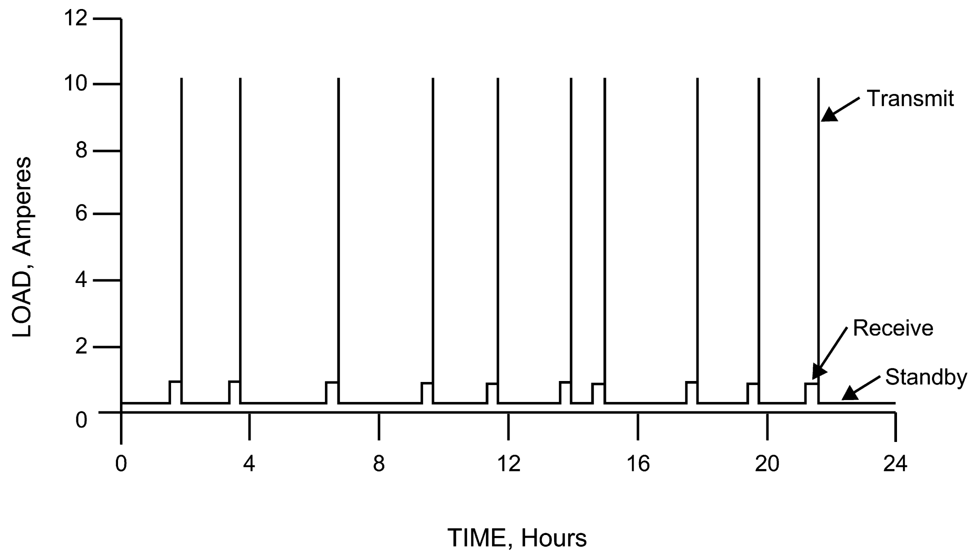

Figure B.2—Simulated load-profile diagram for remote communications system

B.2.1 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 autonomy: *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[b]	4f Number of occurrences[b]	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	X			0.5	5
2Receive	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, column 4f and column 4g have not been used. The hours/days 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 (EOL): ___*60*___%
   g) Capacity adjusted for EOL (line 6a ÷ line 6f): ___*445*___Ah
   h) Capacity adjusted for depths of discharge or end of life (greatest of line 6c, line 6e, or line 6g): *445*___Ah
   i) Minimum operating temperature: ___*7.2*___°C
   j) Associated temperature correction factor: ___*1.2*___
   k) Capacity adjusted for temperature: ___*534*___Ah
   l) Design margin factor (≥ 1): ___*1.1*___
   m) Capacity adjusted for design margin (line 6k × 6l): ___*587*___Ah
7) Functional-hour rate (line 6m ÷ line 5h):___*59*___h
8) Voltage-window adjustment
   a) Controller low-voltage disconnect set point: ___*42*___V
   b) Adjusted V_{min} (greater of line 5k or line 8a): ___*42*___V
   c) Controller full-charge voltage set point: ___*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 end of discharge (EOD) voltage for selected cell: *1.75* V

d) Calculated EOD voltage for cell (line 8b ÷ line 9b): *1.75* 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): *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 capacity less than line 6m, when discharged to the calculated EOD voltage (line 9d), at the functional-hour rate (line 7): *220* Ah

b) Number of parallel strings, round up (line 6m ÷ line 10a): *3*

c) Final battery capacity (line 10a × line 10b): *660* Ah

11) Checks/considerations

a) Maximum charge rate

i) Recommended maximum charge current during recharge: *88* A

ii) Maximum available charging current during recharge: *40* 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 *15.6* °C: *2* A

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

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

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

NOTE—If line 11c < 1.3, there may be insufficient array energy to recharge the 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: *1.5* Ah/day

ii) Battery's capacity for each day of autonomy (line 10c ÷ line 3): *44* 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: — days*
*Valve regulated battery selected.

NOTE—If line 11g < 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: *PDZ Inc.*

Final battery is *24* cells in series by *3* strings in parallel.

Battery capacity is *660* Ah rated at the *59* 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 describes the battery sizing for a remote cabin, used only on the weekends. Seven days of autonomy 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.

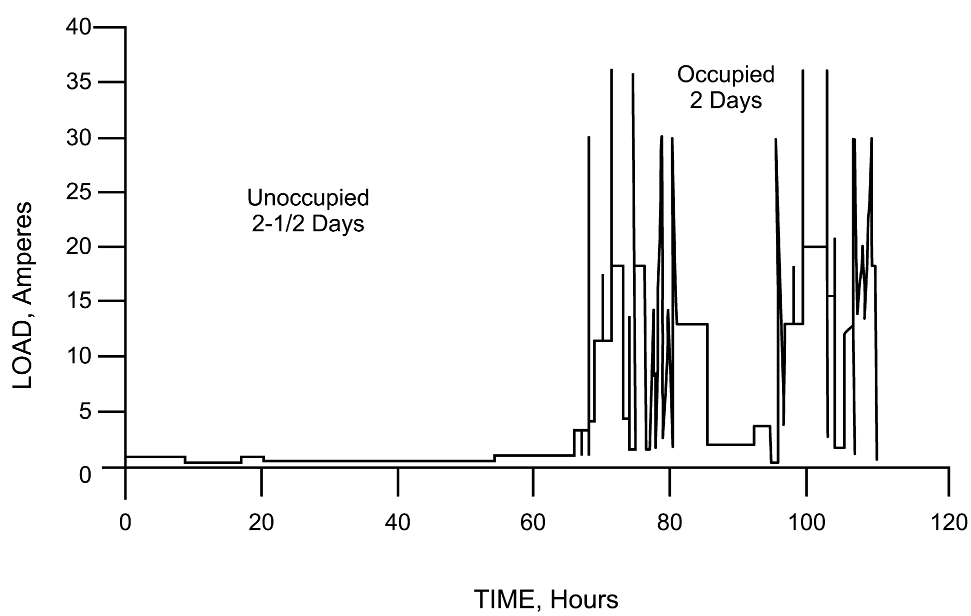

Figure B.3—Simulated partial-load profile diagram for remote residence (4-½ days)

B.3.1 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 autonomy: *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): *59.6* Ah/day

   d) Maximum daily load from Worksheets 2 if used: *154.5* 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* V

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 (EOL): *80* %

g) Capacity adjusted for EOL (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 × 6l): *1239* Ah

7) Functional-hour rate (line 6m ÷ line 5h): *35* h

8) Voltage-window adjustment

a) Controller low-voltage disconnect set point: *24.5* V

b) Adjusted V_{min} (greater of line 5k or line 8a): *24.5* V

c) Controller full-charge voltage set point: *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 end of discharge (EOD) voltage for selected cell: *2.0* V

d) Calculated EOD voltage for cell (line 8b ÷ line 9b): *2.04* 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): *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 capacity 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 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 ___*15*___ °C: ___*11*___ A

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

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

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

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

ii) Battery's capacity for each day of autonomy (line 10c ÷ line 3): ___*177*___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: ___*30*___days

NOTE—If line 11g < 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]

13) 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

B.3.2 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 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 system	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*

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

Number of repetitions: *5*

B.3.3 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: *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			X		12	12	12.0
Security system	30	21		0.3			X			24	7.2
Lights am	30	23		0.1						1	1.5
Lights pm 1	30	23								2	20.0
Lights pm 2	30	23					X			2	6.0
Water pump	30	15	15					4	0.0675	0.27	3.7
TV	30	23					X			2	1.5
Projector	30	22	36	18.0						5	90.6
Appliance 1	30	22						4	0.0175	0.07	2.1
Appliance 2	30	22					X			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

B.3.4 Worksheet 3—Load-data 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 autonomy period
      ii) Total load over autonomy period and divide by number of days of autonomy: *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

Bibliographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

The applicability of the following standards is determined by the specific requirements stated in this recommended practice, such as requiring certain clauses.

[B1] IEEE Std 485™, IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications.[2,3]

[B2] IEEE Std 937™, IEEE Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic (PV) Systems.

[B3] IEEE Std 1361™, IEEE Guide for Selection, Charging, Test and Evaluation of Lead-Acid Batteries Used in Stand-Alone Photovoltaic (PV) Systems.

[B4] IEEE Std 1562™, IEEE Guide for Array and Battery Sizing in Stand-Alone Photovoltaic (PV) Systems.

[2] The IEEE standards or products referred to in this annex are trademarks owned by The Institute of Electrical and Electronics Engineers, Incorporated.
[3] The IEEE publications listed in this annex are available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

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