



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

IEEE Standards Coordinating Committee 21

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



IEEE
3 Park Avenue
New York, NY 10016-5997, USA
20 July 2007

IEEE Std 1013™-2007
(Revision of
IEEE Std 1013-2000)

This is a Redline Document produced by Techstreet, a business of Thomson Reuters.

This document is intended to provide users with an indication of changes from one edition to the next. It includes a full-text version of the new document, plus an indication of changes from the previous version.

Redlines are designed to save time and improve efficiencies by using the latest software technology to find and highlight document changes. More professionals are using valuable new technologies like redlines, to help improve outcomes in a fastpaced global business world.

Because it may not be technically possible to capture all changes accurately, it is recommended that users consult previous editions as appropriate. In all cases, only the current base version of this publication is to be considered the official document.

Redline Processing Notes:

1. ~~Red Text~~ - Red strikethrough text denotes deletions.
2. Blue Text - Blue underlined text denotes modifications and additions.

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

Sponsored by the

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

Approved 22 March 2007

IEEE-SA Standards Board

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. 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, lead-acid batteries, photovoltaic (PV), photovoltaic power systems, sizing, sizing lead-acid batteries, solar, stand-alone

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2007 by the Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 20 July 2007. Printed in the United States of America.

IEEE is a registered trademark in the U.S. Patent & Trademark Office, owned by the Institute of Electrical and Electronics Engineers, Incorporated.

Print: ISBN 0-7381-5593-4 SH95682
PDF: ISBN 0-7381-5594-2 SS95682

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board. The IEEE develops its standards through a consensus development process, approved by the American National Standards Institute, which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and serve without compensation. While the IEEE administers the process and establishes rules to promote fairness in the consensus development process, the IEEE does not independently evaluate, test, or verify the accuracy of any of the information contained in its standards.

Use of an IEEE Standard is wholly voluntary. The IEEE disclaims liability for any personal injury, property or other damage, of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance upon this, or any other IEEE Standard document.

The IEEE does not warrant or represent the accuracy or content of the material contained herein, and expressly disclaims any express or implied warranty, including any implied warranty of merchantability or fitness for a specific purpose, or that the use of the material contained herein is free from patent infringement. IEEE Standards documents are supplied “**AS IS**.”

The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

In publishing and making this document available, the IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity. Nor is the IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing this, and any other IEEE Standards document, should rely upon the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position, explanation, or interpretation of the IEEE.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE-SA Standards Board
445 Hoes Lane
Piscataway, NJ 08854
USA

Authorization to photocopy portions of any individual standard for internal or personal use is granted by the Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Introduction

This introduction is not part of IEEE Std 1013-2007, 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.

Notice to users

Errata

Errata, if any, for this and all other standards can be accessed at the following URL: <http://standards.ieee.org/reading/ieee/updates/errata/index.html>. Users are encouraged to check this URL for errata periodically.

Interpretations

Current interpretations can be accessed at the following URL: <http://standards.ieee.org/reading/ieee/interp/index.html>.

Patents

Attention is called to the possibility that implementation of this recommended practice may require use of subject matter covered by patent rights. By publication of this recommended practice, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents or patent applications for which a license may be required to implement an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

Participants

At the time this recommended practice was completed, the Energy Storage Subsystems Working Group had the following membership:

Jay L. Chamberlin, *Chair*
Kenneth S. Sanders, *Secretary*

Howard Barikmo
Rob Cary
Garth P. Corey
James Dunlop
Lauren Giles

Robert Hammond
Thomas D. Hund
Liang Ji
Peter F. McNutt
Haissam Nasrat

Michael T. Nispel
Carl Parker
Robert F. Rallo
Stephen Vechy
John Wiles

The following members of the individual balloting committee voted on this recommended practice. Balloters may have voted for approval, disapproval, or abstention.

William J. Ackerman
Munnu Bajpai
Thomas S. Basso
Richard T. Bolgeo
Steven R. Brockschink
William A. Byrd
Thomas Carpenter
Jay L. Chamberlin
Weijen Chen
Keith Chow
Stephen P. Conrad
Tommy P. Cooper
Garth P. Corey
C. G. Currin
Stephen Dare
Randall L. Dotson
Gary R. Engmann

Randall C. Groves
David A. Horvath
Thomas D. Hund
Jim Kulchisky
Saumen K. Kundu
William G. Lowe
G. L. Luri
Keith N. Malmedal
James A. McDowall
Mark F. McGranaghan
Peter F. McNutt
Gary L. Michel
Haissam Nasrat
Michael S. Newman
Michael T. Nispel
Chris L. Osterloh

Donald M. Parker
Percy E. Pool
Robert F. Rallo
Charles W. Rogers
Joseph R. Rostron
Randall M. Safier
Kenneth S. Sanders
Steven Sano
Bartien Sayogo
Stephen C. Schwarm
Tarkeshwar Singh
Herbert J. Sinnock
David R. Smith
S. Thamilarasan
Joe D. Watson
James W. Wilson, Jr.
Oren Yuen

At the time this recommended practice was approved, the IEEE Standards Coordinating Committee 21 on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage had the following membership:

Richard DeBlasio, *Chair*
Stephen Chalmers, *Vice-Chair*
Thomas S. Basso, *Secretary*
Bill Ash, *IEEE SCC21 Liaison*

David L. Bassett
John J. Bzura
Jay L. Chamberlin
James M. Daley

Douglas C. Dawson
Frank Goodman
Kelvin Hecht
Joseph Koepfinger

Benjamin Kroposki
Robert Saint
Mallur N. Satyanarayan
Timothy P. Zgonena

When the IEEE-SA Standards Board approved this recommended practice on 22 March 2007, it had the following membership:

Steve M. Mills, *Chair*
Robert M. Grow, *Vice-Chair*
Donald F. Wright, *Past Chair*
Judith Gorman, *Secretary*

Richard DeBlasio
Alexander D. Gelman
William R. Goldbach
Arnold M. Greenspan
Joanna N. Guenin
Julian Forster*
Kenneth S. Hanus
William B. Hopf

Richard H. Hulett
Hermann Koch
Joseph L. Koepfinger*
John D. Kulick
David J. Law
Glenn Parsons
Ronald C. Petersen
Tom A. Prevost

Narayanan Ramachandran
Greg Ratta
Robby Robson
Anne-Marie Sahazizian
Virginia Sulzberger
Malcolm V. Thaden
Richard L. Townsend
Howard L. Wolfman

*Member Emeritus

Also included are the following nonvoting IEEE-SA Standards Board liaisons:

Satish K. Aggarwal, *NRC Representative*
Alan H. Cookson, *NIST Representative*

Jennie Steinhagen
IEEE Standards Program Manager, Document Development

Bill Ash
IEEE Standards Program Manager, Technical Program Development

Contents

1. Overview	1
1.1 Scope	1
1.2 Purpose	1
2. Definitions, acronyms, and abbreviations	2
2.1 Definitions	2
2.2 Acronyms and abbreviations	2
3. Outline of sizing methodology	3
4. Autonomy considerations	3
5. Load determination.....	4
5.1 General considerations.....	4
5.2 Load data	5
5.3 Data analysis.....	6
6. Battery capacity and functional-hour rate determination.....	6
6.1 Unadjusted capacity.....	6
6.2 Battery type selection	6
6.3 Capacity adjustment	7
6.4 Functional-hour rate	8
7. Determining number of series-connected cells.....	8
7.1 Nominal system voltage	8
7.2 Voltage window.....	8
7.3 Calculating the number of series-connected cells.....	9
8. Battery size determination	10
8.1 Cell size selection	11
8.2 Number of parallel strings	11
8.3 Final number of cells	11
8.4 Final battery capacity.....	11
8.5 Checks and considerations.....	11
9. Battery sizing worksheets.....	12
Annex A (informative) Battery characteristics	23
A.1 Capacity	23
A.2 Type.....	23

A.3 Cyclability	23
A.4 Cycle life.....	24
A.5 Economic considerations	25
A.6 Physical characteristics.....	25
A.7 Maintenance.....	26
A.8 Handling Precautions.....	26
Annex B (informative) Examples.....	27
Annex C (informative) Bibliography.....	44

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 ~~photovoltaic~~ stand-alone PV systems. Installation, maintenance, safety, testing procedures, and consideration of battery types other than lead-acid are beyond the scope of this ~~document~~ 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 ~~document~~ 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 recommended practice,, the following terms and definitions apply. The Authoritative Dictionary of IEEE Standards Terms [B1]¹ should be referenced for terms not defined in this clause.

~~This shall be used in conjunction with 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~~

¹IEEE 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 Systems.~~

2.1 Definitions

2.1.1 array-to-load ratio: Average daily photovoltaic ampere hours (Ah) available divided by the average daily load in ampere hours.

NOTE—The average daily photovoltaic (PV) ampere hours is calculated by taking the average daily solar resource for the month of interest in kilowatt hours per square meter (kW/m^2) times the array current at its maximum power point (I_{mp}) under standard test conditions (STC).²

2.1.2 autonomy: The length of time that a photovoltaic (PV) system can provide energy to the load without energy from the PV array.

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

2.1.4 solar irradiance: Instantaneous power density of sunlight measured in watts per meter squared (W/m^2).

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 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 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.**~~

2.1.5 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 kW/m^2 to 7 kW/m^2 .

2.1.6 standard test conditions (STC): The accepted conditions under which photovoltaic devices are commonly rated: 1000 W/m^2 irradiance at a spectral distribution air mass (AM) of 1.5 and a 25°C PV cell temperature.

2.1.7 sun hours: Length of time in hours at a solar irradiance level of 1 kW/m^2 needed to produce the daily solar radiation obtained from the integration of solar irradiance over all daylight hours. Sun hours

is sometimes referred to as peak sun hours.

2.2 Acronyms and abbreviations

<u>AM</u>	<u>air mass</u>
<u>DOD</u>	<u>depth of discharge</u>
<u>EOD</u>	<u>end of discharge</u>
<u>EOL</u>	<u>end of life</u>
<u>I_{coin}</u>	<u>coincident current</u>
<u>I_{mp}</u>	<u>maximum power point current</u>
<u>I_{noncoin}</u>	<u>non-coincident current</u>
<u>MDDOD</u>	<u>maximum daily depth of discharge</u>
<u>MDOD</u>	<u>maximum depth of discharge</u>
<u>PV</u>	<u>photovoltaic</u>
<u>STC</u>	<u>standard test conditions</u>
<u>V_{max}</u>	<u>Maximum voltage limit</u>
<u>V_{min}</u>	<u>Minimum voltage limit</u>

¹ The numbers in brackets correspond to those of the bibliography in Annex C.

² Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

3. 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, 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 operational voltage window are 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 load, days of battery reserve~~ 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 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:

- System application.* Critical load applications generally require more ~~days of battery reserve~~autonomy than non-critical applications.
- System availability.* System availability is the minimum percentage of the time that the PV system should be able to satisfy the ~~system~~system's specified design loads.
- Solar irradiance variability.* Daily and seasonal variations in solar irradiance affect the required autonomy.
- 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.
- 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.
- Accessibility of site.* The worst-case time required for reaching the site and for correcting any problem should be considered.

~~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.~~

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 ~~days of battery reserve, autonomy period~~ 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 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 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 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 ~~that should be gathered for each load is discussed 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 ~~as follows~~:

- 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. ~~Since the battery voltage~~ [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. 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 autonomy period.

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 6.2). 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 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 485-1997³ [\[B2\]](#) may