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(Revision of
IEEE Std 1115-1992)

IEEE Recommended Practice for Sizing Nickel-Cadmium Batteries for Stationary Applications

Sponsor

IEEE Standards Coordinating Committee 29
on
Stationary Batteries

Approved 30 March 2000

IEEE-SA Standards Board

Abstract: The sizing of nickel-cadmium batteries used in full float operation for stationary applications is covered in this recommended practice.
Keywords: nickel-cadmium batteries, stationary applications

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Introduction

(This introduction is not part of IEEE 1115-2000, IEEE Recommended Practice for Sizing Nickel-Cadmium Batteries for Stationary Applications.)

The storage battery is of primary importance in ensuring the satisfactory operation of generating stations, substations, and other stationary applications. This recommended practice is based on commonly accepted methods used to define the load and to ensure adequate battery capacity. The method described is applicable to all installations and battery sizes.

The installations considered herein are designed for operation with a battery charger serving to maintain the battery in a charged condition as well as to supply the normal dc load. Alternate energy systems (e.g., windmills and photovoltaic systems) may provide only partial or intermittent charging, and are beyond the scope of this document. See IEEE Std 1144-1996 [B6][1] for details.

This recommended practice was prepared by the Nickel-Cadmium Sizing Working Group of IEEE Standards Coordinating Committee 29 (SCC29). It may be used separately, but when combined with IEEE Std 1106-1995, it will provide the user with a general guide to designing, placing in service, and maintaining a nickel-cadmium battery installation. At the time this standard was approved the members of the Nickel-Cadmium Sizing Working Group were as follows:

James A. McDowall, *Chair*

Richard T. Bolgeo
Jay L. Chamberlin
Anthony Green
José Marrero
Leif Olsson
Lesley Varga
Graham Walker

The following persons were on the balloting committee:

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Jay L. Chamberlin
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Lesley Varga

When the IEEE-SA Standards Board approved this standard on 30 March 2000, it had the following membership:

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[1] The numbers in brackets correspond to those of the bibliography in Annex D.

Also included is the following nonvoting IEEE-SA Standards Board liaison:

Alan Cookson, *NIST Representative*
Donald R. Volzka, *TAB Representative*

Andrew D. Ickowicz
IEEE Standards Project Editor

Contents

IEEE Recommended Practice for Sizing Nickel-Cadmium Batteries for Stationary Applications

1. Overview

This recommended practice describes methods for defining the dc load and for sizing a nickel-cadmium battery to supply that load. Some factors relating to cell selection are provided for consideration.

1.1 Scope

This recommended practice covers the sizing of nickel-cadmium batteries used in full float operation for stationary applications. Installation, maintenance, qualification, testing procedures, and consideration of battery types other than nickel-cadmium batteries are beyond the scope of this recommended practice.

Design of the dc system and sizing of the battery charger(s) are also beyond the scope of this recommended practice.

1.2 Purpose

The purpose of this recommended practice is to provide a proven and standardized sizing technique for nickel-cadmium batteries. This sizing method takes normal usage factors into account, and forms the basis for reliable battery operation.

2. References

This standard shall be used in conjunction with the following publications:

IEEE Std 1106-1995, IEEE Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications.[1]

IEEE Std 1184-1994, IEEE Guide for the Selection and Sizing of Batteries for Uninterruptible Power Systems.

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

3. Definitions

The following definitions apply specifically to this recommended practice. For terms not defined in this clause, please refer to the documents listed in Clause 2.[2]

3.1 available capacity: The capacity for a given discharge time and end-of-discharge voltage that can be withdrawn from a cell under the specific conditions of operation.

3.2 battery duty cycle: The loads a battery is expected to supply for specified time periods.

3.3 full float (constant potential) operation: Operation of a dc system with the battery, battery charger, and load all connected in parallel and with the battery charger supplying the normal dc load plus any self-discharge or charging current required by the battery. (The battery will deliver current only when the load exceeds the charger output.)

3.4 period: An interval of time in the battery duty cycle during which the load is assumed to be constant for purposes of cell sizing calculations.

3.5 rated capacity (nickel-cadmium cell): The capacity assigned to a nickel-cadmium cell by its manufacturer for a specific constant current discharge, with a given discharge time, at a specified electrolyte temperature, to a given end-of-discharge voltage. The conditions used to establish rated capacity are based on a constant current charge, in accordance with IEC 60623 (1990-03) [B2][3].

4. Defining loads

4.1 General considerations

The duty cycle imposed on the battery by any of the conditions described here will depend on the dc system design and the requirements of the installation. The battery must supply the dc power requirement when the following conditions occur:

a) The load on the dc system exceeds the maximum output of the battery charger.
b) The output of the battery charger is interrupted.
c) The ac power is lost [may result in a greater dc power demand than in item b) above].

The most severe of these conditions, in terms of battery load and duration, should be used to determine the battery size for the installation.

4.2 Load classifications

The individual dc loads supplied by the battery during the duty cycle may be classified as continuous or noncontinuous.

4.2.1 Continuous loads

Continuous loads are energized throughout the duty cycle. These loads are those normally carried by the battery charger and those initiated at the inception of the duty cycle. Typical continuous loads are

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

[3] The numbers in brackets correspond to those of the bibliography in Annex D.

a) Lighting
b) Continuously operating motors
c) Converters (e.g., inverters)
d) Indicating lights
e) Continuously energized coils
f) Annunciator loads
g) Communication systems

4.2.2 Noncontinuous loads

Noncontinuous loads are energized only during a portion of the duty cycle. These loads may switch on at any time within the duty cycle and may be on for a set length of time, be removed automatically or by operator action, or continue to the end of the duty cycle. When several loads occur simultaneously within the same short period of time and a discrete sequence cannot be established, the load should be assumed to be the sum of all loads occurring within that period. If a discrete sequence can be established, the load for the period should be assumed to be the maximum load at any instant. If a load lasts for less than one second, it is normally considered to last for a full second. Typical noncontinuous loads are

a) Emergency pump motors
b) Critical ventilation system motors
c) Fire protection systems
d) Switchgear operations
e) Motor-driven valve operations
f) Isolating switch operations
g) Field flashing of generators
h) Motor starting currents
i) Inrush currents

4.2.3 Other considerations

The lists of typical loads appearing in 4.2.1 and 4.2.2 are not a full catalog of the dc loads at any particular installation. Loads applied to the battery are normally typed as constant power, constant resistance, or constant current. However, for sizing purposes, loads are treated as constant power or constant current. The designer should review each system carefully to be sure all possible loads and their variations are included (see Annex B).

4.3 Duty cycle diagram

A duty cycle diagram showing total load at any time during the cycle is an aid in the analysis of the duty cycle. To prepare such a diagram, all loads, expressed as either power or current expected during the cycle, are tabulated along with their anticipated inception and shutdown times. The total time span of the duty cycle is determined by the requirements of the installation.

4.3.1 Known loads

Loads that have inception and shutdown times that are known are plotted on the duty cycle diagram as they would occur. If the inception time is known, but the shutdown time is indefinite, it should be assumed that the load will continue through the remainder of the duty cycle.

4.3.2 Random loads

Noncontinuous loads that occur at random should be shown at the most critical time of the duty cycle in order to simulate the worst case load on the battery. To determine the most critical time, it is necessary to size the battery without the random load(s) and to identify the section of the duty cycle that controls battery size. Then the random load(s) should be superimposed on the end of that controlling section as shown in Figure 1 (see also 6.4.4).

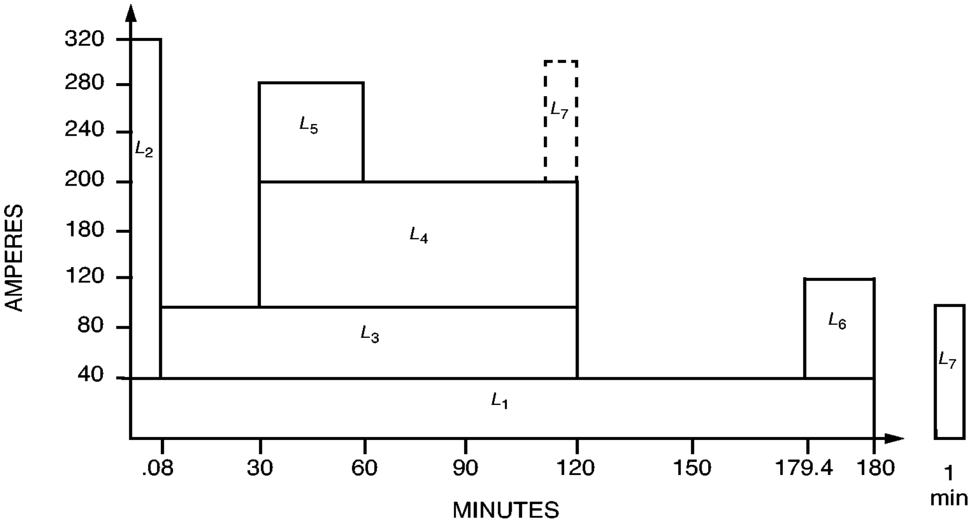

Figure 1—Diagram of a duty cycle

4.3.3 Duty cycle example

Figure 1 is a diagram of a duty cycle made up of the following hypothetical loads expressed in amperes. When the duty cycle includes both constant power and constant current loads, it is usually more convenient to convert the power loads to current loads (see Annex B).

L_1	40 A for 3 h—continuous load
L_2	280 A for 5 s—starting current to load L_3
L_3	60 A from 5 s through the 120th minute
L_4	100 A from the 30th min through the 120th minute
L_5	80 A from the 30th min through the 60th minute
L_6	load at the end of the duty cycle, with known sequence of: 40 A for the first 5 s 80 A for the next 10 s 30 A for the next 20 s For simplicity, this can be *conservatively* considered to be an 80 A load for 35 s.
L_7	100 A for 1 min—random load. This consists of four 25 A loads for 1 min that can occur at any time within the duty cycle. Therefore, the assumption is that they all occur simultaneously.

This example is worked out in detail in Annex A. There it will be found that the first 120 min is the controlling section of the duty cycle. Therefore, the random load is located on the duty cycle so that the random load ends at the end of the 120th minute. This is indicated by dashes.

5. Cell selection

This section summarizes some factors that should be considered in selecting a cell type for a particular application. Various cell designs have different charge, discharge, and aging characteristics. Refer to IEEE Std 1184-1994 or vendor literature for a discussion of cell characteristics.

5.1 Cell designs

All nickel-cadmium cells used in applications covered by this recommended practice are categorized by the different plate thicknesses. Generally, cells with thin plates are used for loads requiring high-discharge currents of short duration. Cells with thick plates are used for loads of long duration. Cells with medium plate thickness are used for loads requiring combined performance. Any plate thickness can be utilized for any of these load requirements, but generally the economics will determine the correct plate thickness to be used.

Cells designed for use in full float operation are either vented or fitted with low-pressure valves. Hermetically sealed cells of the type used in portable appliances are not suitable for operation with constant potential chargers (see 6.3).

5.2 Selection Factors

The following factors should be considered in the selection of the cell type:

a) Physical characteristics such as dimension and weight of the cells, container material, intercell connectors, and terminals
b) Planned life of the installation and expected life of the cell
c) Frequency and depth of discharge
d) Ambient temperature
e) Charging characteristics
f) Maintenance requirements
g) Ventilation requirements
h) Shock and vibration

The battery manufacturers should be contacted for detailed cell design and performance characteristics to allow proper selection and sizing of a battery for a specific application.

6. Determining battery size

Several basic factors govern the size (number of cells and rated capacity) of the battery. Included are the maximum system voltage, the minimum system voltage, the duty cycle, correction factors, and design margin. Since a battery string is usually composed of a number of identical cells connected in series, the voltage of the battery is the voltage of a cell multiplied by the number of cells in series. The ampere-hour capacity of a battery string is the same as the ampere-hour capacity of a single cell.

If cells of sufficiently large capacity are not available, then two or more strings, of equal number of series-connected cells, may be connected in parallel to obtain the necessary capacity. The ampere hour capacity of such a battery is the sum of the ampere-hour capacities of the strings. The manufacturer should be consulted for any limitation on paralleling.

Operating conditions can change the available capacity of the battery. For example:

a) The available capacity decreases as its temperature decreases.
b) The available capacity decreases as the discharge rate increases.
c) The minimum specified cell voltage at any time during the battery discharge cycle limits the available capacity.
d) The charging method can affect the available capacity.

6.1 Number of cells

The maximum and minimum allowable system voltages determine the number of cells in the battery. It has been common practice to use 9–10, 18–20, 36–40, 92–100, or 184–200 cells for system voltages of 12, 24, 48, 125, or 250 V, respectively. In some cases, it may be desirable to vary from this practice to match the battery more closely to system voltage limitations. It should be noted that the use of the widest possible voltage window, within the confines of individual load requirements, will result in the most economical battery. Furthermore, the use of the largest number of cells allows the lowest minimum cell voltage and, therefore, the smallest size cell for the duty cycle. Subclause A.1 illustrates the application of the following techniques.

6.1.1 Calculation of number of cells and minimum cell voltage

When the battery voltage is not allowed to exceed a given maximum system voltage, the number of cells will be limited by the manufacturer's recommended cell voltage required for satisfactory charging. That is,

$$\frac{\text{Maximum allowable system voltage}}{\text{Cell voltage required for satisfactory charging}} = \text{Number of cells}$$

The minimum battery voltage equals the minimum system voltage plus any voltage drop between the battery terminals and the load. The minimum battery voltage is then used to calculate the allowable minimum cell voltage

$$\frac{\text{Minimum battery voltage}}{\text{Number of cells}} = \text{Minimum cell voltage}$$

6.1.2 Charging time as limiting factor

The time available to charge the battery can affect both the number of cells and the cell size. The time required for a charge decreases as the charging voltage per cell increases, assuming that the charging equipment can supply the high current necessary early in the recharge cycle. If the maximum charging voltage is limited, it is necessary to select the number of cells that can be charged in the time available. This, in turn, may require using a larger cell than would otherwise have been necessary. Limits are supplied by the battery manufacturer for charging current and voltage.

6.1.3 Rounding off

If the results of calculations shown in 6.1.1 indicate a need for a fractional cell, round that result off to the nearest whole number of cells. The minimum cell voltage and charge voltage should then be recalculated and verified for adequacy of operation.

6.2 Additional considerations

Before proceeding to calculate the cell size required for a particular installation, the designer should consider the following factors that will influence cell size.

6.2.1 Temperature derating factor (T_t)

The available capacity of a cell is affected by its operating temperature. The standard temperature for stating cell capacity is 25 °C. If the lowest expected electrolyte temperature is below standard, select a cell large enough to have the required capacity available at the lowest expected temperature. The battery manufacturer should be consulted for capacity derating factors for various discharge times and temperatures. If the lowest expected electrolyte temperature is above 25 °C, generally there is no noticeable increase in the available capacity.

6.2.2 Design margin

It is prudent design practice to provide a capacity margin to allow for unforeseen additions to the dc system, and less-than-optimum operating conditions of the battery due to improper maintenance, recent discharge, ambient temperatures lower than anticipated, or a combination of these factors. A method of providing this design margin is to add a percentage factor to the cell size determined by calculations. If the various loads are expected to grow at different rates, it may be more accurate to apply the expected growth rate to each load for a given time and to develop a duty cycle from the results.

Note that the "margins" required by 6.3.1.5 and 6.3.3 of IEEE Std 323-1983 are to be applied during "qualification" and are not related to "design margin."

The cell size calculated for a specific application will seldom match a commercially available cell exactly, and it is normal procedure to select the next higher cell size. The additional capacity obtained can be considered part of the design margin.

6.2.3 Aging factor

Capacity decreases gradually during the life of the battery, with no sudden capacity loss being encountered under normal operating conditions. Since the rate of capacity loss is dependent upon such factors as operating temperature, electrolyte-specific gravity, and depth and frequency of discharge, an aging factor should be chosen based on the required service life (see IEEE Std 1106-1995). The choice of aging factor is, therefore, essentially an economic consideration. In the sizing calculation shown in Figure A.1, an aging factor of 1.25 is used, meaning that the battery is sized to carry the loads until its capacity has decreased to 80% of its rated capacity. For an application involving continuous high temperatures and/or frequent deep discharges, it may be desirable to use a factor of, say, 1.43, and replace the battery when its capacity falls to 70% of rated capacity. For applications involving short, high-rate discharges such as engine starting, the rate of fall-off in short-rate performance is slower and a lower aging factor may be used. For example, in an uninterruptible power supply (UPS) application with a 15 min discharge time and a 15 year desired service life, it may be appropriate to use a 1.11 aging factor, so that the battery would be replaced when its performance falls to 90% of the published value. The battery manufacturer should be consulted for additional information on aging factors.

6.3 Effects of constant potential charging

Prolonged float charging of a nickel-cadmium battery will cause a lowering of the average voltage on discharge. Depending on the discharge rate and minimum battery voltage, the available capacity may be affected.

The designer should make sure that capacity rating factors, K_t (see 6.4.3) obtained from the manufacturer are based on constant potential operation.

CAUTION

Hermetically-sealed nickel-cadmium batteries should not be used in constant potential charging applications (see 5.1).

6.4 Cell size

This section describes and explains a proven method of calculating the cell capacity necessary for satisfactory performance on a given duty cycle. Annex A demonstrates the use of this method for a specific duty cycle in a stationary float application. An optional preprinted worksheet (Figure 3) is used to simplify the calculations. Instructions for the proper use of the worksheet are given in 6.5.

6.4.1 Initial cell size

Equation (1) (see 6.4.2) requires the use of a capacity rating factor K_t (see 6.4.3) that is based on the discharge characteristics of a particular range of cell types. Thus, the initial calculation must be based on a trial selection of cell range. Depending on the results of this initial calculation, it may be desirable to repeat the calculation for other cell ranges to obtain the optimum cell type and size for the particular application. Use the capacity from the first calculation as a guide for selecting additional ranges to size.

6.4.2 Sizing methodology

The cell selected for a specific duty cycle must have enough capacity to carry the combined loads during the duty cycle. To determine the required cell size, it is necessary to calculate, from an analysis of each section of the duty cycle (see Figure 2), the maximum capacity required by the combined load demands (current versus time) of the various sections. The first section analyzed is the first period of the duty cycle.

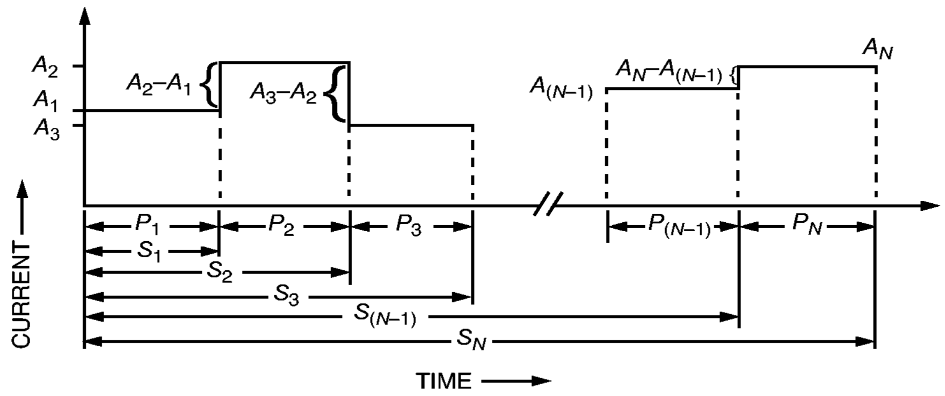

Figure 2—Generalized duty cycle diagram

Using the capacity rating factor (see 6.4.3) for the given cell range and the applicable temperature derating factor T_t, a cell size is calculated that will supply the required current for the duration of the first period. For the second section, the capacity is calculated assuming that the current A_1 required for the first period is continued through the second period; this capacity is then adjusted for the change in current (A_2 - A_1) during the second period. In the same manner, the capacity is calculated for each subsequent section of the duty cycle. This iterative process is continued until all sections of the duty cycle have been considered. The calculation of the capacity F_S required by each section S, where S can be any integer from 1 to N, can be expressed mathematically as follows:

$$F_S = \sum_{P=1}^{P=S} [A_P - A_{(P-1)}]K_t T_t \tag{1}$$

The maximum capacity (max F_S) calculated determines the cell size that can be expressed by the following general equation:

$$\text{cell size} = \max_{S=1}^{S=N} F_S \tag{2}$$

where

S is the section of the duty cycle being analyzed. Section S contains the first S periods of the duty cycle (for example, section S_5 contains periods 1 through 5). See Figure 2 for a graphical representation of "section."
N is the number of periods in the duty cycle
P is the period being analyzed
A_P is the amperes required for period P
t is the time in minutes from the beginning of period P through the end of section S
K_t is the capacity rating factor (see 6.4.3) for a given cell type, at the t minute discharge rate, at 25 °C, to a definite end-of-discharge voltage
T_t is the temperature derating factor at t minutes, based on electrolyte temperature at the start of the duty cycle
F_S is the capacity required by each section S

If the current for period $P + 1$ is greater than the current for period P, then section $S = P + 1$ will require a larger cell than section $S = P$. Consequently, the calculations for section $S = P$ can be omitted.

6.4.3 Capacity rating factor, K_t

The capacity rating factor, K_t, is the ratio of rated ampere-hour capacity (at a standard time rate, at 25 °C, and to a standard end-of-discharge voltage) of a cell, to the amperes that can be supplied by that cell for t minutes at 25 °C and to a given end-of-discharge voltage. K_t factors are available from the battery manufacturer, or may be calculated from other published data (see Annex C). Equation (1) and Equation (2) can be combined as follows:

$$\text{cell size} = \max_{S=1}^{S=N} F_S = \max_{S=1}^{S=N} \sum_{P=1}^{P=S} [A_P - A_{(P-1)}]K_t T_t$$

6.4.4 Random load calculations

When equipment loads that occur at random are included as part of the battery duty cycle, it is necessary to calculate the cell size required for the duty cycle without the random load(s) and then add this to the cell size required for the random load(s) only.

6.5 Cell sizing worksheet

A worksheet, Figure 3, has been designed, and may be used to simplify the manual application of the procedure described in 6.4. Examples of its use will be found in Annex A, specifically in Figure A.3. Instructions for proper use of the worksheet areas are as follows:

a) Fill in necessary information in the heading of the worksheet. The temperature and voltage recorded are those used in the calculations. The voltage used is the minimum battery voltage divided by the number of cells in the battery.

b) Fill in the amperes and the minutes in columns (2) and (4) as indicated by the section heading notations. See Annex B for the method of converting power loads to current loads.

c) Calculate and record the changes in amperes as indicated in column (3). Record whether the changes are positive or negative.

d) Calculate and record the amount of time in minutes from the start of each period to the end of the section as indicated in column (5).

e) Record in column (6) the capacity rating factors K_t, and in column (7) the temperature derating factors T_t, for each discharge time calculated in column (5).

f) Calculate and record the cell size for each period as indicated in column (8). Note the separate subcolumns for positive and negative values.

g) Calculate and record in column (8) the subtotals and totals for each section as indicated.

h) Record the maximum section size [the largest total from column (8)] in item (9), the random section size in item (10), and the uncorrected size (US) in items (11) and (12).

i) Enter the design margin ($\geq$1.0) in item (13) and the aging factor ($\geq$1.0) in item (14). Combine items (12), (13), and (14) as indicated and record the result in item (15).

j) When item (15) does not match the capacity of a commercially available cell, the next larger cell is required. Show the result in item (16).

k) From the value in item (16) and the manufacturer's literature, determine the commercial designation of the required cell and record it in item (17).

Project: Date: Page:

Lowest Expected Electrolyte Temp: °F/°C Minimum Cell Voltage: Cell Mfg: Cell Type: Sized By:

(1) Period	(2) Load (amperes)	(3) Change in Load (amperes)	(4) Duration or Period (minutes)	(5) Time to End of Section (minutes)	(6) Capacity Rating Factor at t Min Rate (K_t)	(7) Temperature Derating Factor for t Min (T_t)	(8) Required Section Size (3) x (6) x (7) = Rated Amp Hrs	
							Pos. Values	Neg. Values
Section 1 - First Period Only - if A2 is greater than A1, go to Section 2								
1	A1=	A1-0=	M1=	t=M1=				* * *
					Sec 1	Total		* * *
Section 2 - First Two Periods Only - if A3 is greater than A2, go to Section 3								
1	A1=	A1-0=	M1=	t=M1+M2=				
2	A2=	A2-A1=	M2=	t=M2=				
					Sec	Sub Total		
					2	Total		* * *
Section 3 - First Three Periods Only - if A4 is greater than A3, go to Section 4								
1	A1=	A1-0=	M1=	t=M1+M2+M3=				
2	A2=	A2-A1=	M2=	t=M2+M3=				
3	A3=	A3-A2=	M3=	t=M3=				
					Sec	Sub Total		
					3	Total		* * *
Section 4 - First Four Periods Only - if A5 is greater than A4, go to Section 5								
1	A1=	A1-0=	M1=	t=M1+...M4=				
2	A2=	A2-A1=	M2=	t=M2+M3+M4=				
3	A3=	A3-A2=	M3=	t=M3+M4=				
4	A4=	A4-A3=	M4=	t=M4=				
					Sec	Sub Total		
					4	Total		* * *
Section 5 - First Five Periods Only - if A6 is greater than A5, go to Section 6								
1	A1=	A1-0=	M1=	t=M1+...M5=				
2	A2=	A2-A1=	M2=	t=M2+...M5=				
3	A3=	A3-A2=	M3=	t=M3+M4+M5=				
4	A4=	A4-A3=	M4=	t=M4+M5=				
5	A5=	A5-A4=	M5=	t=M5=				
					Sec	Sub Total		
					5	Total		* * *
Section 6 - First Six Periods Only - if A7 is greater than A6, go to Section 7								
1	A1=	A1-0=	M1=	t=M1+...M6=				
2	A2=	A2-A1=	M2=	t=M2+...M6=				
3	A3=	A3-A2=	M3=	t=M3+...M6=				
4	A4=	A4-A3=	M4=	t=M4+M5+M6=				
5	A5=	A5-A4=	M5=	t=M5+M6=				
6	A6=	A6-A5=	M6=	t=M6=				
					Sec	Sub Total		
					6	Total		* * *
Section 7 - First Seven Periods Only - if A8 is greater than A7, go to Section 8								
1	A1=	A1-0=	M1=	t=M1+...M7=				
2	A2=	A2-A1=	M2=	t=M2+...M7=				
3	A3=	A3-A2=	M3=	t=M3+...M7=				
4	A4=	A4-A3=	M4=	t=M4+...M7=				
5	A5=	A5-A4=	M5=	t=M5+M6+M7=				
6	A6=	A6-A5=	M6=	t=M6+M7=				
7	A7=	A7-A6=	M7=	t=M7=				
					Sec	Sub Total		
					7	Total		* * *
Random Equipment Load Only (if needed)								
R	AR=	AR-0=	MR=	t=MR=				* * *

Maximum Section Size (9) ________ + Random Section Size (10) ________ = Uncorrected Size (US) (11) ________

US (12) ________ x Design Margin (13) 1.____ x Aging Factor (14) 1.____ = (15) ________

When the cell size (15) is greater than a standard cell size, the next larger cell is required.

Required cell size (16) ________ Ampere Hours. Therefore cell (17) ________ is required.

Figure 3—Cell sizing worksheet

Annex A

(informative)

Duty cycle

In the following example, the duty cycle used is that of Figure A.1 and the lowest expected electrolyte temperature is 0 °C. Subclause A.1 provides an example of a calculation selecting the number of cells to be used in the battery. Subclause A.2 shows how the cell sizing worksheet can be used to calculate the required cell size.

A.1 Required number of cells

Example: The dc system voltage limits are from 105 V to 140 V; for the particular cell type being considered (see subclause A.2), the manufacturer recommends a cell voltage of 1.47 V for satisfactory charging. The battery and charger must remain directly connected to the dc system at all times.

Number of cells = 140 V / 1.47 V per cell = 95.2, therefore 95 cells

End-of-discharge voltage = 105 V / 95 cells = 1.10 V per cell

A.2 Required cell capacity

From the battery duty cycle diagram, Figure A.1, we can construct Table A.1, which will be of value in filling in the cell sizing worksheet. The last column of Table A.1 shows the capacity removed for each period. The total ampere-hour capacity removed may be used to determine the initial cell size (see 6.4.1) for the calculation. Table A.2 shows hypothetical tabular discharge data for the KM medium performance cell range manufactured by the ABC Company. The table gives current values for discharges started at 25 °C and terminated when the average cell voltage reaches 1.10 V. In this example, the total capacity removed is 433 Ah and the next larger cell size is KM438P. Therefore, the capacity rating factors (K_t) for the initial calculation are derived from the data for this cell type. These factors are shown in Table A.3.

Figure A.2 shows hypothetical temperature derating factors (T_t) for KM cells over a wide range of temperatures.

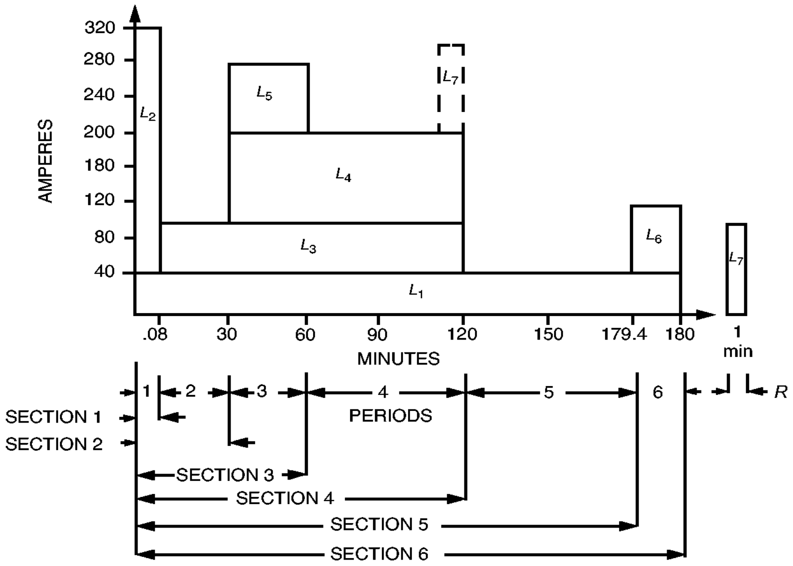

Figure A.1—Battery duty cycle diagram

Table A.1—Sample cell sizing data

Period	Loads	Total amperes	Duration (min)	Capacity removed (Ah)
1	$L_1 + L_2$	320	0.08 (5 s)	0.43
2	$L_1 + L_3$	100	29.92	49.87
3	$L_1 + L_3 + L_4 + L_5$	280	30	140.00
4	$L_1 + L_3 + L_4$	200	60	200.00
5	L_1	40	59.42	39.61
6	$L_1 + L_6$	120	0.58 (35 s)	1.16
7	L_7	100	1	1.67
			Total	**432.74**

Table A.2—Hypothetical discharge currents for KM cell range manufactured by ABC Company (Discharge amperes to 1.10 V/cell after prolonged float charging)

Cell type	Rated Ah	1 s	60 s	15 min	30 min	60 min	90 min	120 min	180 min	300 min	480 min
KM369P	369	878	627	334	266	207	166	138	107	72.0	45.4
KM392P	392	927	666	355	282	220	177	147	113	76.4	48.2
KM415P	415	984	705	375	299	233	187	155	120	80.9	51.0
KM438P	*438*	*1041*	*743*	*396*	*315*	*246*	*198*	*164*	*127*	*85.4*	*53.9*
KM461P	461	1090	786	417	332	258	208	173	133	89.9	56.7
KM505P	505	1197	857	457	364	283	228	189	146	98.5	62.1
KM555P	555	1317	942	502	400	311	250	208	161	108	68.3
KM625P	625	1480	1062	565	450	350	282	234	181	122	76.9
KM690P	690	1635	1175	624	497	387	311	258	200	135	84.9
KM740P	740	1756	1260	669	533	415	334	277	214	144	91.0
KM830P	830	1968	1409	754	598	465	374	311	240	162	102
KM920P	920	2181	1565	833	663	516	415	345	266	179	113
KM965P	965	2287	1643	876	695	541	435	361	279	188	119
KM1040P	1040	2464	1770	941	750	583	469	390	301	203	128
KM1150P	1150	2726	1954	1041	831	645	519	431	333	224	141
KM1220P	1220	2896	2074	1106	882	684	550	457	353	238	150
KM1390P	1390	3299	2365	1257	1000	776	627	521	402	271	171

The K_t factor for time t is calculated in the following table by interpolation using the formula

$$K_t = K_{t_2} - \frac{(K_{t_2} - K_{t_1}) \times (t_2 - t)}{(t_2 - t_1)}$$

Note that interpolation must be performed only on the K_t factors. Interpolation of current values will yield incorrect results.

Table A.3—Calculation of capacity rating factors (K_t) for KM438P Cell Type

Discharge time t (min)	Time t_1 from data (min)	Time t_2 from data (min)	(1) Amperes for time t_1 (A)	(2) Amperes for time t_2 (A)	Factor K_{t_1} for time t_1 438 ÷ (1)	Factor K_{t_2} for time t_2 438 ÷ (2)	Factor K_t for time t
0.083	0.017	1	1041	743	0.421	0.590	0.432
0.583	0.017	1	1041	743	0.421	0.590	0.518
30	30	—	315	—	1.390	—	1.390
59.92	30	60	315	246	1.390	1.780	1.779
60	60	—	246	—	1.780	—	1.780
90	90	—	198	—	2.212	—	2.212
119.92	90	120	198	164	2.212	2.671	2.670
120	120	—	164	—	2.671	—	2.671
150	120	180	164	127	2.671	3.449	3.060
179.92	120	180	164	127	2.671	3.449	3.448
180	180	—	127	—	3.449	—	3.449

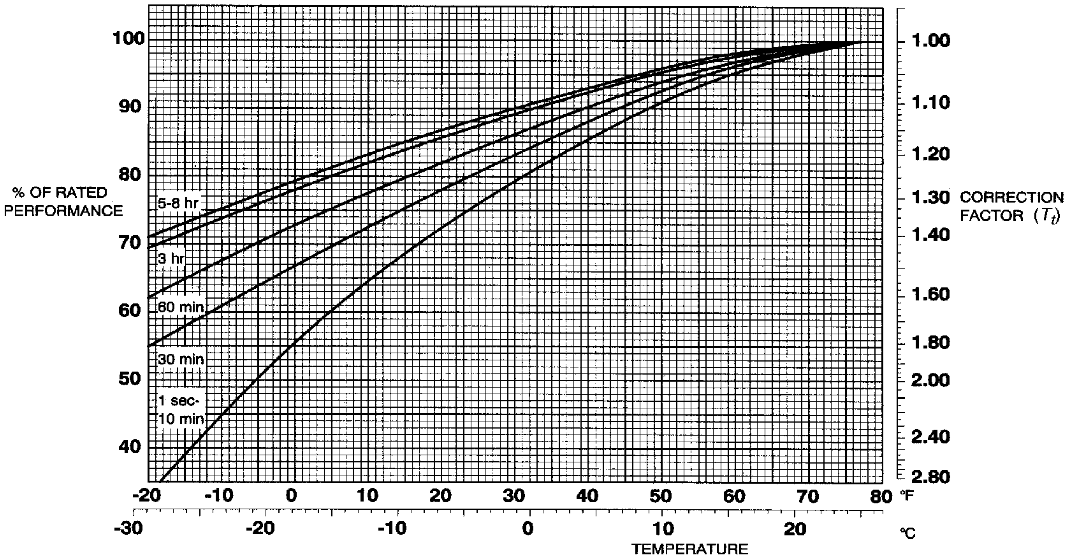

Figure A.2—Hypothetical temperature derating curves for KM cell manufactured by ABC Company

The data in Table A.3 and Figure A.2 are entered in Figure A.3. In this case, the calculation yields a required cell size of 905 Ah. Since the original K_t factors were derived for a cell with a rated capacity of 438 Ah, it is necessary to check that these are compatible with the K_t factors for the larger cell. In this case, an examination of the data in Table A.2 shows that the K_t factors for the KM920P are essentially the same as for the KM438P, so no further work is necessary. If the K_t factors are different, the calculation should be repeated with the new values. This iterative process should be continued until the K_t factors for the calculated cell type are compatible with those used in the sizing worksheet.

Project: Example Duty Cycle Date: 2/2/98 Page: 1
Lowest Expected Electrolyte Temp: 0 °C Minimum Cell Voltage: 1.10 V Cell Mfg: ABC Co. Cell Type: M Sized By: J.McD

(1) Period	(2) Load (amperes)	(3) Change in Load (amperes)	(4) Duration or Period (minutes)	(5) Time to End of Section (minutes)	(6) Capacity Rating Factor at t Min Rate (K_t)	(7) Temperature Derating Factor for t Min (T_t)	(8) Required Section Size (3) x (6) x (7) = Rated Amp Hrs	
							Pos. Values	Neg. Values
Section 1 - First Period Only - if A2 is greater than A1, go to Section 2								
1	A1= 320	A1-0= 320	M1= 0.08	t=M1= 0.08	0.432	1.23	170.0	* * *
					Sec 1	Total	170.0	* * *
Section 2 - First Two Periods Only - if A3 is greater than A2, go to Section 3								
1	A1=	A1-0=	M1=	t=M1+M2=				
2	A2=	A2-A1=	M2=	t=M2=				
					Sec	Sub Total		
					2	Total		* * *
Section 3 - First Three Periods Only - if A4 is greater than A3, go to Section 4								
1	A1= 320	A1-0= 320	M1= 0.08	t=M1+M2+M3= 60	1.780	1.15	655.0	
2	A2= 100	A2-A1= -220	M2= 29.92	t=M2+M3= 59.92	1.779	1.15		450.1
3	A3= 280	A3-A2= 180	M3= 30	t=M3= 30				
					Sec	Sub Total	655.0	450.1
					3	Total	205.0	* * *
Section 4 - First Four Periods Only - if A5 is greater than A4, go to Section 5								
1	A1= 320	A1-0= 320	M1= 0.08	t=M1+...M4= 120	2.671	1.12	957.3	
2	A2= 100	A2-A1= -220	M2= 29.92	t=M2+M3+M4= 119.92	2.670	1.12		657.9
3	A3= 280	A3-A2= 180	M3= 30	t=M3+M4= 90	2.212	1.13	449.9	
4	A4= 200	A4-A3= -80	M4= 60	t=M4= 60	1.780	1.15		163.8
					Sec	Sub Total	1407.2	821.6
					4	Total	585.6	* * *
Section 5 - First Five Periods Only - if A6 is greater than A5, go to Section 6								
1	A1=	A1-0=	M1=	t=M1+...M5=				
2	A2=	A2-A1=	M2=	t=M2+...M5=				
3	A3=	A3-A2=	M3=	t=M3+M4+M5=				
4	A4=	A4-A3=	M4=	t=M4+M5=				
5	A5=	A5-A4=	M5=	t=M5=				
					Sec	Sub Total		
					5	Total		* * *
Section 6 - First Six Periods Only - if A7 is greater than A6, go to Section 7								
1	A1= 320	A1-0= 320	M1= 0.08	t=M1+...M6= 180	3.449	1.11	1225.1	
2	A2= 100	A2-A1= -220	M2= 29.92	t=M2+...M6= 179.92	3.448	1.11		842.0
3	A3= 280	A3-A2= 180	M3= 30	t=M3+...M6= 150	3.060	1.12	616.9	
4	A4= 200	A4-A3= -80	M4= 60	t=M4+M5+M6= 120	2.671	1.12		239.3
5	A5= 40	A5-A4= -160	M5= 59.42	t=M5+M6= 60	1.780	1.15		327.5
6	A6= 120	A6-A5= 80	M6= 0.58	t=M6= 0.58	0.518	1.23	51.0	
					Sec	Sub Total	1893.0	1408.8
					6	Total	484.1	* * *
Section 7 - First Seven Periods Only - if A8 is greater than A7, go to Section 8								
1	A1=	A1-0=	M1=	t=M1+...M7=				
2	A2=	A2-A1=	M2=	t=M2+...M7=				
3	A3=	A3-A2=	M3=	t=M3+...M7=				
4	A4=	A4-A3=	M4=	t=M4+...M7=				
5	A5=	A5-A4=	M5=	t=M5+M6+M7=				
6	A6=	A6-A5=	M6=	t=M6+M7=				
7	A7=	A7-A6=	M7=	t=M7=				
					Sec	Sub Total		
					7	Total		* * *
Random Equipment Load Only (if needed)								
R	AR= 100	AR-0= 100	MR= 1	t=MR= 1	0.590	1.23	72.6	* * *

Maximum Section Size (9) 585.6 + Random Section Size (10) 72.6 = Uncorrected Size (US) (11) 658.2
US (12) 658.2 x Design Margin (13) 1.10 x Aging Factor (14) 1.25 = (15) 905.0
When the cell size (15) is greater than a standard cell size, the next larger cell is required.
Required cell size (16) 905 Ampere Hours. Therefore cell (17) M920 is required.

Figure A.3—Sample worksheet

Annex B

(informative)

Converting constant power loads to constant current loads

Loads applied to the battery are normally typed as constant power, constant resistance, or constant current. The designer should review each system carefully to ensure all possible loads and their variations have been included.

Battery voltage decreases as the battery discharges. The amount by which the battery voltage decreases depends on the internal battery resistance and the load placed on the battery.

Inverters and dc/dc power supplies are usually constant power loads. For constant power loads, the battery's discharge current increases as its voltage decreases. The voltage drop may be increased by the cable resistance and the resulting discharge current will be higher. It is desirable to consider the increase in discharge current as battery voltage declines. This can be calculated as follows:

$$I_{av} = \frac{P}{E_{av}}$$

where

I_{av} is the average discharge current in amperes for the discharge period
P is the discharge load, in W
E_{av} is the average discharge voltage for the discharge period

Since the average battery voltage is dependent on a number of factors, information is not readily available from the battery manufacturer. A conservative method of converting watts to amperes assumes a constant current for the entire load duration which is equal to the current being supplied by the battery at the end of the discharge period (minimum volts, maximum amperes). Thus,

$$I_{max} = \frac{P}{E_{min}}$$

where

I_{max} is the discharge current at the end of the discharge period
P is the discharge load, in W
E_{min} is the minimum permissible battery voltage

Example: For a nominal 48 V system with a minimum battery voltage of 42 V and a voltage drop from the battery to the load of 2 V, a constant power load of 5000 W will discharge the battery at a current no greater than

$$I_{max} = \frac{5000\ \text{W}}{40\ \text{V}} = 125\ \text{A}$$

For constant resistance loads, current decreases as the voltage decreases. Dc motor starting, emergency lighting, relays, contactors, and indicating lights are usually constant resistance. A constant resistance load may be conservatively estimated as a constant current load with the following formula:

$$I_{max} = \frac{E_{nom}}{R_{av}}$$

or

$$I_{max} = \frac{W_R}{E_{nom}}$$

where

I_{max} is the maximum discharge current
E_{nom} is the nominal system voltage
R_{av} is the resistance of the load(s)
W_R is the discharge power at the nominal system voltage

Similarly, as for power loads, the load current can be calculated using the average battery voltage. System voltage drop to the loads can also be considered.

For constant current loads, current is approximately constant as the voltage decreases. Running dc motors can be approximated as constant current. Within the normal battery voltage range, the flux is fairly constant in the motor. Modeling a dc motor as a constant current is conservative if the voltage maintains the motor in saturation.

Annex C

(informative)

Calculating capacity rating factors

Under certain circumstances, it may be necessary to calculate capacity rating (K_t) factors from other data published by the manufacturer. For example, K_t factors may not be available for a specific end-of-discharge voltage and/or for a particular discharge time.

Published discharge data for nickel-cadmium cells are most commonly available in tabular form, in which the current available from each cell type is stated for a given discharge time and end-of-discharge voltage. For intermediate times and voltages, it is necessary to interpolate between the known values.

The charging method used as a basis for the published data is an important factor. For a stationary float application, data based on prolonged constant potential charging should be used. If constant current charging has been used to establish the discharge data, appropriate float correction factors should be obtained from the manufacturer. These float charging correction factors, which express the proportion of the constant-current-charging-based performance that is available after prolonged operation on float charging, are published for specific discharge times and end-of-discharge voltages.

To calculate a K_t factor from discharge data for prolonged float charging, the rated capacity of the cell is divided by the discharge current for the specified time and end-of-discharge voltage:

$$K_t = \frac{\text{Rated capacity in ampere hours}}{\text{Discharge current in amperes}}$$

Using discharge data derived from constant current charging, the formula becomes

$$K_t = \frac{\text{Rated capacity in ampere hours}}{\text{Discharge current in amperes} \times \text{Float correction factor}}$$

It is important to note that K_t factors calculated by this method are specific to the cell type in question and may not be applicable for all cell types in a particular range. If the calculated cell type from item (17) of the cell sizing worksheet (Figure 3) is not the same as the cell type used for K_t factors, it may be necessary to calculate new K_t factors for a more appropriate cell type (see 6.4.1).

Annex D

(informative)

Bibliography

[B1] Hoxie, E.A., “Some discharge characteristics of lead-acid batteries,” *AIEE Transactions* (Applications and Industry), vol. 73, pp. 17–2, 1954.

[B2] IEC 60623 (1990-03), Vented nickel-cadmium prismatic rechargeable single cells.

[B3] IEEE Std 323-1983 (Reaff 1990), IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations.

[B4] IEEE Std 627-1980 (Reaff 1996), IEEE Standard for Design Qualification of Safety System Equipment Used in Nuclear Power Generating Stations.

[B5] IEEE Std 946-1992, IEEE Recommended Practice for the Design of DC Auxiliary Power Systems for Generating Stations.

[B6] IEEE Std 1144-1996, IEEE Recommended Practice for Sizing Nickel-Cadmium Batteries for Photovoltaic (PV) Systems.

[B7] *The IEEE Standard Dictionary of Electrical and Electronics Terms*, Sixth Edition.