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IEEE Recommended Practice for Electrical Sizing of Nickel-Cadmium Batteries for Rail Passenger Vehicles

IEEE Vehicular Technology Society

Sponsored by the
Rail Transit Vehicle Interface Standards Committee

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Approved 12 June 2003

IEEE-SA Standards Board

Abstract: A method for defining the electrical load supplied by a nickel-cadmium battery and for sizing the battery to supply that load is described in this recommended practice.

Keywords: ampere hours, available capacity, constant current load, constant power load, fully-charged capacity, nickel-cadmium battery, period, rated capacity, resistive load, state of charge

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Introduction

[This introduction is not part of IEEE Std 1568-2003, IEEE Recommended Practice for Electrical Sizing of Nickel-Cadmium Batteries for Rail Passenger Vehicles.]

The storage battery is of primary importance in ensuring the satisfactory operation of rail passenger vehicles. This recommended practice provides methods for electrical sizing of nickel-cadmium batteries for use aboard rail passenger vehicles. It is based on commonly accepted methods used to define the load and to ensure adequate battery capacity. The method described is applicable to all battery sizes.

This recommended practice was prepared by the Electrical Sizing of Nickel-Cadmium Batteries Working Group of Rail Transit Vehicle Interface Standards Committee of the IEEE Vehicular Technology Society. When combined with IEEE Std 1476™-2000, it will provide the user with a general guide to defining the loads and electrical sizing of nickel-cadmium batteries for rail passenger vehicles.

Participants

At the time this recommended practice was completed, the Working Group on the Electrical Sizing of Nickel-Cadmium Batteries for Rail Passenger Vehicles had the following membership:

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IEEE Recommended Practice for Electrical Sizing of Nickel-Cadmium Batteries for Rail Passenger Vehicles

1. Overview

This recommended practice describes a method for defining the electrical load supplied by a nickel-cadmium battery and for sizing the battery to supply that load. Necessary factors relating to cell selection are provided for consideration. In order to utilize the methodology embodied in this recommended practice, it is necessary it be used in conjunction with IEEE Std 1476™ -2000[1].

1.1 Scope

This recommended practice prescribes a method for electrical sizing of nickel-cadmium batteries for use on passenger rail cars used for battery back up of low voltage dc auxiliary power systems. It encompasses all factors that influence the electrical battery capacity requirements including loads, temperature, cycling, charging and discharging profiles. It does not address physical sizing, qualification or testing of the batteries, and it does not apply to batteries used for motive power or engine starting.

1.2 Purpose

This recommended practice provides a standardized method for electrical sizing of nickel-cadmium batteries for application and use aboard rail passenger vehicles.

2. References

This recommended practice should be used in conjunction with the following publications.

IEC 60623 (2001-09), Secondary Cells and Batteries Containing Alkaline or Other Non-Acid Electrolytes—Vented Nickel-Cadmium Prismatic Rechargeable Single Cells.[2]

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

[2] IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

IEEE Std 1476-2000, IEEE Standard for Passenger Train Auxiliary Power Systems Interfaces.[3,4]

IEEE Std 1536™-2002, IEEE Standard for Rail Transit Vehicle Battery Physical Interface.

3. Definitions, abbreviations, and acronyms

3.1 Definitions

For the purposes of this recommended practice, the following terms and definitions apply. IEEE 100™, *The Authoritative Dictionary of IEEE Standards Terms* [B3], should be referenced for terms not defined in this subclause.

3.1.1 aging factor: A quantitative factor expressing the degradation in the ability of the battery, due to usage, to deliver electrical energy under specified operating conditions such as, but not limited to, operating ambient temperature, cycling, depth of discharge, and maintenance practices.

NOTE—This is based on experience, application (cycling/float service), and charging parameters.

3.1.2 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.

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

3.1.4 constant current loads: A load that demands constant current even when the input voltage varies.

NOTE—Typical of such loads is lighting when driven from an inverter ballast configuration.

3.1.5 constant power load: A load that demands constant power from the source even when the voltage value drops such as when switching from the low-voltage power supply to the battery.

NOTE—Typical of such loads are those that have their own built-in regulator such as propulsion control power supplies.

3.1.6 fully charged capacity: state of the battery charge following a constant current charge. Considered to be 100% state of charge of the new battery.

NOTE—Constant current charge in accordance with IEC 60623.

3.1.7 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.

3.1.8 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.

NOTE—Constant current charge in accordance with IEC 60623.

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[3] The IEEE standards or products referred to in Clause 2 are trademarks owned by the Institute of Electrical and Electronics Engineers, Incorporated.

[4] 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/).

3.1.9 resistive loads: Loads for which the current supplied by the low-voltage power supply/battery varies proportionally with the source voltage.

NOTE—These loads will demand less current when the source voltage is switched from the low-voltage power supply to the battery. Typically, relays fall into this category.

3.2 Abbreviations and acronyms

Ah	ampere hours
APTA	American Public Transportation Association
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
LVPS	low voltage power supply
SOC	state of charge

4. Defining loads

The battery loads should be compiled in accordance with the requirements prescribed in 4.2.2 (Low-voltage dc loads) of IEEE Std 1476-2000. The loads should be expressed in watts at nominal LVPS output voltage as defined in Table 4 of IEEE Std 1476-2000. Constant power, constant current and resistive loads should be given along with anticipated application time. If the authority having jurisdiction desires additional capacity to allow for expected additions to the low voltage dc system, those loads should be specified by the authority having jurisdiction either in watts or as a percentage of a total load and added to the total load.

Each time period when such power loads are unchanged is called a discharge period. The battery capacity calculation using methodology described in 6.3.2 of this recommended practice requires current loads for each discharge period.

The following equation may be used to derive the battery current from the power loads for each instant of the battery discharge:

$$A = \frac{P_P}{V_B - V_D} + \frac{P_I}{V_N} + \frac{P_R}{V_N^2}(V_B - V_D) \tag{1}$$

where

A is the battery discharge current in amps
P_P is the constant power load in watts
P_I is the constant current load in watts at nominal LVPS output voltage
P_R is the resistive load in watts at nominal LVPS output voltage
V_D is voltage drop from the battery to the load
V_B is the voltage at the battery
V_N is the nominal LVPS output voltage

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. The internal battery resistance in turn is dependent on the electrolyte temperature. Though this method will produce the most accurate result, to perform such analyses requires information that may not be readily available from the battery manufacturer.

To simplify calculation of the battery current, the battery voltage is assumed constant for the entire period and equal to the average discharge voltage for that period. The information required to determine average discharge voltage should be provided by the battery manufacturer.

NOTE—Discharge curves (cell voltage versus percent of rated capacity) may provide the basis for determining average discharge voltage.

Voltage drop in the wiring, provided by the car builder or the authority having jurisdiction, is assumed constant to simplify the calculations.

The following equation should be used to derive the average battery discharge current for each discharge period, A_{Pav}:

$$A_{Pav} = \frac{P_P}{V_{Pav} - V_D} + \frac{P_I}{V_N} + \frac{P_R}{V_N^{\,2}}(V_{Pav} - V_D) \tag{2}$$

where

A_{Pav} is the average discharge current for the discharge period
V_{Pav} is the average battery discharge voltage for the discharge period

An example in A.2 demonstrates this method of deriving the battery current from the power loads.

5. Cell type selection

This clause describes factors that should be considered in selecting a cell type for a particular application. Various cell designs have different charge, discharge, and aging characteristics under specific operating conditions.

5.1 Cell performance

All nickel-cadmium cells used in applications covered by this recommended practice are categorized by the cell performance, as defined in IEC 60623. Generally, cells with plates designated as H or X are used for loads requiring high discharge currents of short duration. Cells with L-plates are used for loads of long duration. Cells with M-plates are used for loads requiring combined performance.

5.2 Selection consideration

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

a) Physical characteristics such as dimensions and weight of the cells as described in IEEE Std 1536-2002, container material, inter-cell connectors, and terminals;
b) Expected service life of the cells (aging)
c) Frequency and depth of discharge;
d) Discharge characteristics;
e) Ambient battery temperature;
f) Charging characteristics;
g) Maintenance requirements;
h) Ventilation requirements;
i) Shock and vibration requirements;
j) Flammability / Smoke emission / Toxicity requirements.

The battery manufacturer should provide detailed cell performance characteristics to allow proper selection and sizing of a battery for the specific application.

6. Determining battery size

Several basic factors govern the size (number of cells and rated capacity) of the battery. Included are the minimum and maximum operating voltages, the duty cycle, design margin, and correction and derating factors. Tray configurations may also be a consideration in selecting the number of cells. Since a battery 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 in this case is the same as the ampere-hour capacity of a single cell.

If cells of sufficiently large capacity are not available, the battery 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 battery voltage at any time during the discharge cycle limits the available capacity;
d) The charging method affects the available capacity;
e) The frequency, depth of discharge and time available for recharge affects the available capacity;
f) The battery temperature during charge affects the available capacity.

6.1 Calculation of number of cells

The battery charging voltage, as well as maximum and minimum allowable system voltages, determine the number of cells in the battery. It has been common practice to use 18–20, 24-26, 36–40,48–52 or 75–90 cells for the nominal system voltages of 24, 32, 48, 64 or 110 V, respectively (IEEE Std 1476-2000 outlines the voltage ranges for 24, 32, 48 and 64 V nominal voltages).

NOTE—The use of a larger number of cells allows lower minimum cell voltage and, therefore, smaller cell capacity for the duty cycle.

Initially the number of cells should be determined by dividing the nominal LVPS output voltage (see Table 4 of IEEE Std 1476-2000) by the battery manufacturer's recommended cell voltage required for satisfactory charging at 20°C. When temperature compensation is used to control the LVPS output voltage, and battery voltage is not allowed to exceed a given maximum system voltage, the number of cells will be limited by the battery manufacturer's recommended cell voltage required for satisfactory charging at low temperature. In this case, the initially calculated number of cells may be reexamined or compromise temperature compensation requirements may be adopted.

NOTE—For dedicated off-line battery chargers the recommended battery supplier's charging voltage can be used without limiting number of cells or temperature compensation.

The time required to recharge a discharged battery decreases as the charging voltage per cell increases, assuming that the charging equipment can supply the high current necessary early in the recharge cycle. Therefore, it is necessary to select the number of cells that can be adequately recharged in the time available.

If the results of calculations to determine the initial number of cells indicate a need for a fractional cell, round that result off to the whole number of cells that satisfies the battery requirements. If desired, a number of cells that results in a standardized tray configuration may be considered. The minimum cell voltage and charging voltage should then be recalculated and verified for adequacy of operation as follows:

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 minimum allowable cell voltage:

$$\frac{\text{Minimum battery voltage}}{\text{number of cells}} = \text{Minimum cell voltage} \tag{3}$$

Annex subclause A.1 illustrates the application of the aforementioned techniques.

6.2 Additional considerations

Before proceeding to calculate the cell capacity required for a particular application, the following factors that influence cell capacity should be considered.

6.2.1 Temperature derating factor (T_t)

The available capacity of a cell is affected by the operating temperature of the electrolyte. The electrolyte temperature for stating cell capacity is typically 20°C. At temperatures below 20°C the available capacity of a cell is reduced. At temperatures higher than 20°C there is no meaningful increase in capacity. The degradation in the ability of the battery to deliver electrical energy under operating temperatures below 20°C is expressed by the temperature derating factor T_t. ($T_t \leq 1.0$).

Since the temperature derating factor T_t varies based on the cell design, discharge time and end-of-discharge voltage, the temperature derating factors should be obtained from the battery manufacturer .

The time of discharge has significant effect on the temperature derating factor. Therefore, the battery manufacturers should make temperature derating information available for at least the following discharge times: 1 sec, 1 min, 5 min, 30 min, 1 hour, 2 hours, 5 hours, and 8 hours. For other discharge times the T_t factor may be calculated by interpolation.

Since the available capacity on discharge always depends on the final discharge voltage, it is important that the battery manufacturers, as a minimum, make available temperature derating factors for 1.0, 1.05 and 1.1 volts per cell at the end of discharge.

Table A.4 provides a sample of the hypothetical temperature derating factors for various discharge times and temperatures at a minimum discharge voltage of 1.0 volt per cell.

Weather of U.S. Cities [B5] summarizes in convenient form local climatic characteristics, including Normal Daily Maximum and Normal Daily Minimum values of temperature and Extreme Record High and Extreme Record Low values of temperature in the major U.S. metropolitan areas.

NOTE—The Normal Daily Maximum and Normal Daily Minimum for each month is the average over 30 years of the highest or lowest temperature respectively in that month.

Although the battery may be required to operate over a wider temperature range, it is sufficiently prudent to calculate the vehicle battery capacity based on the Normal Daily Maximum and Normal Daily Minimum values of temperature for the warmest and the coldest month of the year respectively, not on the Extreme Record High and Extreme Record Low values.

NOTE—The design margin (see 6.2.4) provides for ambient temperatures lower than normal.

Where the proposed site is located in an area not covered by the above reference, data from other comparable sources should be used.

For purposes of sizing the batteries, the vehicle operating temperature range is not necessarily the operating range of the batteries. The environment and temperature of the battery when called upon to perform its backup function should be considered. For example, the battery may be warmed by charging or discharging it, the battery compartment may have heaters to elevate its temperature or be located in a place where it is influenced by or affected by the temperature of surrounding equipment.

It may be necessary to calculate battery capacity for both low and high temperature conditions and select the larger cell. For additional information on the effect of high temperature on the battery sizing, refer to Annex B.

6.2.2 State-of-charge (SOC) factor

The responsibility to determine the state-of-charge factor is with the battery manufacturer as outlined in IEEE Std 1476-2000. The state of charge is the initial available capacity prior to a discharge, expressed as a percentage of a fully charged capacity. The state of charge depends on the cell type, charging method, voltage, current, temperature, the depth, time and the frequency of discharge and/or recharge.

NOTE—Typically SOC may range from 0.80 to 0.95.

Time required to recharge the battery to the SOC used should be specified by the authority having jurisdiction.

Annex B provides additional information on the parameters that can affect the state-of-charge factor, and how the SOC may be improved. Instructions for use of the state-of-charge factor for the battery capacity calculation are given in 6.4. Annex A demonstrates the application of the state-of-charge factor.

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, maintenance practices, electrolyte specific gravity, the depth and frequency of discharge and recharge, an aging factor, if required by the authority having jurisdiction, should be chosen by the battery manufacturer based on the operating environment and service life specified by the authority having jurisdiction (refer to IEEE Std 1476-2000). An aging factor value should be chosen such that the battery performs the required duty cycle throughout the specified service life.

NOTE—Typically an aging factor may range from 1 to 1.1.

6.2.4 Design margin

It is prudent for the authority having jurisdiction to specify additional capacity to allow for uncertainties of the load determination, unforeseen growth of the low voltage dc system, less-than-optimum operating conditions of the battery due to improper maintenance, ambient temperatures or state of charge lower than specified, or a combination of these factors. A method of providing this design margin is to apply a factor to the cell capacity determined by calculations.

NOTES:

1—Typically design margin may range from 1.05 to 1.25.

2—If the battery box is designed for the battery trays in compliance with IEEE Std 1536-2002, it may provide space for the larger battery that is required to accommodate the growth of the low voltage dc system in the future. This may be considered as an alternative to an increase of the battery capacity initially.

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

6.3 Cell capacity calculation

This subclause describes and explains a method of calculating the cell capacity necessary for satisfactory performance for a given duty cycle. Annex A demonstrates the use of this method for a sample rail passenger vehicle duty cycle. A worksheet (Figure 2) is used to simplify the calculations. Instructions for the proper use of the worksheet are given in 6.4.

6.3.1 Capacity rating factor (K_t)

The cell capacity calculation method described herein (see 6.3.2) requires the use of a capacity rating factor K_t. The capacity rating factor K_t, is the ratio of rated ampere-hour capacity of a cell at a 5-hour rate of discharge, at 20°C to a 1 volt/cell end-of-discharge voltage (in accordance with IEC 60623), to the current that can be supplied by that cell for t minutes at 20°C to the minimum cell voltage (see 6.1). K_t factors should be available from the battery manufacturer, or may be calculated from other published data (see Annex C).

6.3.2 Methodology

The method of calculating the required cell capacity is based on the Hoxie method for sizing lead-acid batteries (see [B2]) and modified in IEEE Std 1115™-2000 [B4].

The cell selected for a specific duty cycle must have enough capacity to carry the loads during the duty cycle. The duty cycle of required amperes and the load time sequence is assembled by combining the various loads in superposition fashion (see Figure 1). The duty cycle is then separated into periods that commence each time the load changes. The periods are then combined into sections. Each section contains the first S periods of the duty cycle (for example, section S2 contains periods 1 through 2). See Figure 1 for a graphical representation of “section.”

To determine the required cell capacity, it is necessary to calculate, from an analysis of each section of the duty cycle 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.

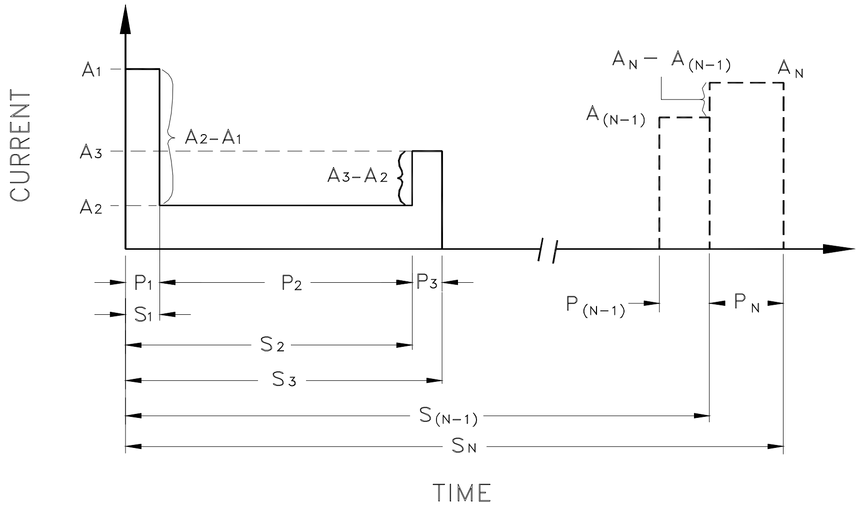

Figure 1—Generalized duty cycle diagram

Using the capacity rating factor K_t (see 6.3.1) for a given cell type range and the applicable temperature derating factor T_t, a cell capacity 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 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:

$$F_S = \sum_{P=1}^{P=S} \left[A_P - A_{(P-1)} \right] K_t / T_t \tag{4}$$

The maximum calculated value of F_S (max F_S) determines the cell capacity, expressed by the following general equation:

$$\text{cell capacity } = \max F_S \; (S = 1, 2, \ldots, N) \tag{5}$$

where

S is the section of the duty cycle being analyzed.
N is the number of periods in the duty cycle
P is the period being analyzed
A_P is the current in 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 6.3.1)
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 in Ah required by each section S

NOTE—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.

Equations (4) and (5) can be combined as follows:

$$\text{cell capacity} = \max F_S (S = 1,2,...,N) = \max \left\{ \sum_{P=1}^{P=S} \left[A_P - A_{(P-1)} \right] K_t / T_t \right\} (S = 1,2,...,N) \tag{6}$$

6.3.3 Preliminary cell capacity

The capacity rating factor K_t 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 type range. Depending on the results of this initial calculation, it may be desirable to repeat the calculation for other cell type ranges to obtain the optimum cell type and capacity for the particular application. Use the capacity from the first calculation as a guide for selecting additional cell type ranges.

6.3.4 Random load calculations

When significant equipment loads, such as track brake application, occur at random they should be considered in the battery duty cycle at the most critical time that controls the battery capacity. The random load(s) should be superimposed on the end of that controlling section. To determine the most critical time, it is necessary to calculate the battery capacity without the random load(s) and to identify the section of the duty cycle that controls battery capacity. The capacity required to support random load(s) should be calculated separately and then added to the capacity of the controlling section. A cell capacity calculation worksheet described in 6.4 has been designed to add the random section capacity to the capacity of the controlling section. The sample worksheet in Annex A provides an example of the battery capacity calculation for the duty cycle with a random load.

6.4 Cell capacity calculation worksheet

The worksheet shown in Figure 2 may be used to simplify the manual application of the procedure described in 6.3. Examples of its use will be found in Annex A, specifically in the sample cell capacity calculation worksheet (see Figure A.1). Instructions for proper use of the worksheet follow.

Fill in necessary information in the heading of the worksheet. The temperature and voltages recorded are those used in the calculations.

Part I: Required Section Size Calculation.

a) Fill in the amperes and the minutes in columns (2) and (4), as indicated by the column heading notations. See Clause 4 for the method of deriving the current loads from the power loads.
b) Calculate and record the changes in amperes as indicated in column (3). Record whether the changes are positive or negative.
c) 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).
d) 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).
e) Calculate and record the cell capacity for each period as indicated in column (8). Record positive and negative values.
f) Calculate and record in column (8) the totals for each section as indicated.

Part II: Required Cell Capacity Calculation.

a) Record the maximum section capacity [the largest total from column (8)] on line 1, and the random section capacity on line 2.
b) Calculate, as indicated, and record the uncorrected capacity on line 3.
c) Enter the state-of-charge factor (≤1.0) on line 4, the design margin (>1.0) on line 5, and the aging factor (≥1.0) on line 6.
d) Combine lines 3, 4, 5, and 6, as indicated, and record the result on line 7.
e) When line 7 does not match the capacity of a commercially available cell, the next larger cell is required. Show the result on line 8.
f) From the value on line 8 and the battery manufacturer's literature, determine the commercial designation of the required cell and record it on line 9.

Project:			Date:	Sized By:			Page:
Lowest Expected Electrolyte Temp:		Minimum Cell Voltage:	Nominal LVPS Output Voltage:		Max. Volt. Drop: No. of Cells:		Cell Mfg: Cell Type:
PART I. Required Section Size Calculation.							
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Period	Load (amperes)	Change in Load (amperes)	Duration of Period (minutes)	Time to End of Section (minutes)	Capacity Rating Factor at *t* Min Rate (K_t)	Temperature Derating Factor for *t* Min (T_t)	Required Section Size (3) x (6) / (7) = Rated Amp Hrs
Section 1 - First Period Only - if A2 is greater than A1, go to Section 2							
1	A1=	A1-0=	P1=	t=P1=			
						Section 1 total	
Section 2 - First Two Periods Only - if A3 is greater than A2, go to Section 3							
1	A1=	A1-0=	P1=	t=P1+P2=			
2	A2=	A2-A1=	P2=	t=P2=			
						Section 2 total	
Section 3 - First Three Periods Only - if A4 is greater than A3, go to Section 4							
1	A1=	A1-0=	P1=	t=P1+P2+P3=			
2	A2=	A2-A1=	P2=	t=P2+P3=			
3	A3=	A3-A2=	P3=	t=P3=			
						Section 3 total	
Section 4 - First Four Periods Only - if A5 is greater than A4, go to Section 5							
1	A1=	A1-0=	P1=	t=P1+...P4=			
2	A2=	A2-A1=	P2=	t=P2+P3+P4=			
3	A3=	A3-A2=	P3=	t=P3+P4=			
4	A4=	A4-A3=	P4=	t=P4=			
						Section 4 total	
Random Load Only (if needed)							
R	AR=	AR-0=	PR=	t=PR=			
PART II. Required Cell Capacity Calculation.							
1	Maximum Section Capacity, Ah						
2	Random Section Capacity, Ah						
3	Uncorrected cell capacity, Ah. Add lines 1 and 2						
4	SOC factor						
5	Design Margin						
6	Aging Factor						
7	Cell capacity, Ah = (line 3 / line 4) x line 5 x line 6						
8	Required cell capacity, Ah						
9	Required cell type						

Figure 2—Cell capacity calculation worksheet

Annex A

(informative)

Sample calculations

Sample low voltage system requirements:

1) The nominal voltage is 32 V.

2) The system voltage limits are 23 V to 42.5 V at the load.

3) For the particular cell being considered, type KM, the battery manufacturer recommends a cell charging voltage of 1.47 V at 20°C.

4) Maximum voltage drop in the wiring is 2 Volts.

5) The electrolyte temperature operating range is –10°C to 40°C.

6) The battery is float charged by the LVPS with nominal 37.5 V output voltage. Below 20°C the temperature compensation is provided at the rate of –3mV per cell for every °C of the difference between the lowest electrolyte temperature and 20°C. For the purpose of this calculation, the effect of the temperature above 20°C is ignored.

7) The battery is required to maintain minimum permissible voltage at the load (23 V) over the following 1 hour duty cycle:

- Load 1 (L1): 2000 W constant power plus 3400 W resistive plus 2500 W constant current for 3 sec, followed by
- Load 2 (L2): 900 W constant power plus 1800 W resistive plus 750 W constant current for 59 min 57 sec.
- Load 3 (L3): 200 W resistive plus 300 W constant current random load. It may occur at any time within the duty cycle for 3 sec.

The above power loads are given at a nominal LVPS output voltage of 37.5 Vdc

8) The battery manufacturer recommends a state-of-charge factor of 0.8.

9) The authority having jurisdiction requires 10% (1.1) design margin to allow for combination of the uncertainties of the load determination, unforeseen growth of the low voltage dc system, less-than-optimum operating conditions of the battery due to improper maintenance, ambient temperatures or state of charge lower than anticipated.

10) The authority having jurisdiction specifies 10 years service life. Based on the operating environment and service life specified by the authority having jurisdiction the battery manufacturer recommends the aging factor of 1.1.

A.1 provides an example of a calculation selecting the number of cells to be used in the battery. A.2 shows how the cell capacity calculation worksheet can be used to calculate the required cell capacity.

A.1 Required number of cells

1) Determine initial number of cells

— Initial number of cells = 37.5 V/1.47 V per cell = 25.5, rounded off to 25 cells (refer to 6.1).

2) Low temperature check

— At –10°C LVPS output voltage will be [1.47 + (–0.003V × (–10°C –20°C))] × 25 = 39V, this is acceptable since it is less than the upper system voltage limit of 42.5 V.

3) Minimum voltage at the battery terminals

— End-of-discharge voltage = (23 + 2) V/25 cells = 1.0 V per cell, minimum allowable voltage per cell to meet minimum voltage requirement at the battery terminals.

A.2 Required cell capacity

The cell capacity calculation worksheet (see Figure A.1) is being used to simplify the manual application of the procedure described in 6.3.

Fill in information in the heading of the worksheet, –10°C temperature, 1.0 V/cell minimum cell voltage, and 37.5 V nominal LVPS output voltage.

Complete Figure A.1, Part I. Required Section Size Calculation.

From the battery duty cycle, construct Table A.1, which will be of value in filling in the sample cell capacity calculation worksheet, Figure A.1, Part I. Since the sample duty cycle includes the random load, it is necessary to calculate the battery capacity without the random load to identify the section of the duty cycle that controls battery capacity. Therefore, first calculate the preliminary battery capacity based on continuous loads L1 and L2 only. The battery manufacturer estimates that the average voltage V_{Pav} for the period P1 is 31.25 V, for the period P2 is 29.25 V and for the period R is 26.25 V. Average load for each period is calculated using Equation (2) (refer to Clause 4). The last column of Table A.1 shows the capacity removed for each period. It is calculated as a product of discharge current A_{Pav} for that period and period duration t. The 2 V voltage drop is used in these calculations.

The total ampere-hour capacity removed will be used to determine the preliminary cell capacity (see 6.3.3) for the initial calculation.

Table A.1—Sample cell capacity calculation data

Period	Load	Duration, t (min)	Constant power load, P_P (W)	Resistive load, P_R (W)	Constant current load, P_I (W)	Average voltage, V_{Pav} (V)	Average load, A_{Pav} (A)	Capacity removed (Ah)
P1	L1	0.05	2000	3400	2500	31.25	205.76	0.17
P2	L2	59.95	900	1800	750	29.25	87.91	87.83
							Total	88.00
R	L3	0.05		200	300	26.25	11.45	0.01

a) Table A.1 provides the information necessary to fill in the amperes and the time (minutes) in columns (2) and (4) of the cell capacity calculation worksheet, Figure A.1, Part I, as indicated by the column heading notations.
b) The changes in amperes are calculated and recorded in column (3) of the worksheet.
c) The amount of time in minutes from the start of each period to the end of the section is calculated and entered in column (5).

In this example the capacity rating factors K_t, (see 6.3.1) are not available from the battery manufacturer, therefore, it is necessary to calculate these factors from other published data.

Table A.2 shows hypothetical tabular discharge data for the KM medium performance cell range manufactured by the XYZ Company. This table gives current values for discharges started at 20°C and terminated when the average cell voltage reaches 1.0 V. In this example, the total capacity removed is 88 Ah (the preliminary battery capacity based on continuous loads L1 and L2 only) and the next larger cell is KM112. Therefore, the capacity rating factors (K_t) for the initial calculation are derived from the data for this cell type, as explained in 6.3.3. These factors are shown in Table A.3.

Table A.2—Hypothetical discharge currents for KM cell range manufactured by XYZ Company. Discharge currents in amperes to 1.0 V/cell at 20°C after constant current charging

Cell type	Rated C5Ah	1 sec	1 min	5 min	30 min	1 hr	2 hr	5 hr	8 hr
KM 86	86	424	288	167	112	74	41	17	7.1
KM 112	112	508	361	214	144	96	54	22	9
KM 138	138	627	444	264	178	119	66	28	10.4
KM 161	161	731	518	308	208	138	77	32	11.9
KM 184	184	835	592	351	237	158	88	37	13.4
KM 208	208	944	670	397	268	179	99	42	14.0

NOTE—the data presented in Tables A.2 and A.4 are hypothetical. They are not to be used for specific application.

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

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

NOTE—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 KM 112 Cell Type

Discharge Time t (minutes)	Time t_1 From Data (minutes)	Time t_2 From Data (minutes)	Amperes for Time t_1 (A)	Amperes for Time t_2 (A)	Factor K_{t1} for Time t_1	Factor K_{t2} for Time t_2	Factor K_t for Time t
0.05	0.017	1	508	361	0.220	0.310	0.224
59.95	30	60	144	96	0.778	1.167	1.166
60	60		96		1.167		1.167

d) The capacity rating factors K_t from Table A.3 are entered in column (6) and the temperature derating factors T_t, (from Table A.4) in column (7) for each discharge time calculated in column (5).

Table A.4 shows hypothetical tabular temperature derating factors (T_t) for KM cells over a wide range of temperatures.

Table 1—Hypothetical temperature derating factors for KM cell manufactured by XYZ Company (1.0 v/cell end discharge voltage)

	1 sec	1 min	5 min	30 min	1 hr	2 hr	5 hr	8 hr
20°C	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10°C	0.89	0.9	0.91	0.927	0.94	0.945	0.955	0.965
0°C	0.78	0.795	0.81	0.84	0.87	0.88	0.905	0.91
–10°C	**0.63**	0.65	0.68	0.75	**0.79**	0.82	0.84	0.86
–20°C	0.45	0.48	0.51	0.59	0.71	0.74	0.77	0.79
–30°C	0.23	0.3	0.33	0.55	0.62	0.66	0.7	0.72

e) The cell capacity for periods P1 and P2 is calculated and entered in column (8).

f) The totals for section 1 (73.16 Ah) and for section 2 (130.01 Ah) are calculated and recorded in column (8).

It can be seen now that the section 2 (first 60 minutes) is the largest section of the duty cycle. Therefore, the random load is located on the duty cycle so that it ends at the end of the 60th minute because this is the most critical time that controls the battery capacity (refer to 6.3.4). The battery manufacturer estimates that the average discharge voltage V_{Pav} for the duration of the random load is 26.25 V. Record this voltage in Table A.1, calculate the average current for the duration of the random load using Equation (2), enter the result (11.45 A) in the worksheet, Figure A.1, calculate the cell capacity for the random load (4.07 Ah), and then enter it in column (8).

Complete Figure A.1, Part II. Required Cell Capacity Calculation.

a) The maximum section capacity [the largest section total from column (8)] is entered on line 1 (130.01 Ah) and the random section capacity on line 2 (4.07 Ah).

b) The uncorrected capacity is calculated (134.08 Ah) and recorded on line 3.

c) The state-of-charge of charge factor (0.8) is entered on line 4, the design margin (1.1) is entered on line 5 and the aging factor (1.1) on line 6.

d) Line 3 is divided by line 4, the result is multiplied by lines 5 and 6, as indicated, and the result of multiplication (202.8 Ah) is recorded on line 7.
e) Since line 7 does not match the capacity of any cell listed in Table A.2, the next larger cell: 208 Ah is selected. The result is shown on line 8.
f) From the value on line 8 and Table A.2, the commercial designation of the required cell (KM 208) is determined and recorded on line 9.

The calculation yields a required cell capacity of 202.8 Ah. Since the original K_t factors were derived for a cell with a rated capacity of 112 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 KM 208 are essentially the same as for the KM 112, so no further work is necessary. If the K_t factors were 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 cell capacity calculation worksheet.

Calculations may be repeated for other than 25 cells for economical or physical considerations.

Project:	Sample Duty Cycle					Date:	1/12/00	Sized By:	AS		Page:1
Lowest Expected			Minimum			Nominal LVPS Output			Max. Volt. Drop:	2 V	Cell Mfg:XYZ Co.
Electrolyte Temp:		-10 °C	Cell Voltage:		1.0 V	Voltage:		37.5 V	No. of Cells:	25	Cell Type: M
PART I. Required Section Size Calculation.											
(1)	(2)		(3)		(4)		(5)		(6)	(7)	(8)
Period	Load (amperes)		Change in Load (amperes)		Duration of Period (minutes)		Time to End of Section (minutes)		Capacity Rating Factor at t Min Rate (K_t)	Temperature Derating Factor for t Min (T_t)	Required Section Size (3) x (6) / (7) = Rated Amp Hrs
Section 1 - First Period Only - if A2 is greater than A1, go to Section 2											
1	A1=	205.76	A1-0=	205.76	P1=	0.05	t=P1=	0.05	0.224	0.63	73.16
										Section 1 total	73.16
Section 2 - First Two Periods Only - if A3 is greater than A2, go to Section 3											
1	A1=	205.76	A1-0=	205.76	P1=	0.05	t=P1+P2=	60	1.167	0.79	303.95
2	A2=	87.91	A2-A1=	-117.85	P2=	59.95	t=P2=	59.95	1.166	0.79	-173.94
										Section 2 total	130.01
Section 3 - First Three Periods Only - if A4 is greater than A3, go to Section 4											
1	A1=		A1-0=		P1=		t=P1+P2+P3=				
2	A2=		A2-A1=		P2=		t=P2+P3=				
3	A3=		A3-A2=		P3=		t=P3=				
										Section 3 total	
Section 4 - First Four Periods Only - if A5 is greater than A4, go to Section 5											
1	A1=		A1-0=		P1=		t=P1+...P4=				
2	A2=		A2-A1=		P2=		t=P2+P3+P4=				
3	A3=		A3-A2=		P3=		t=P3+P4=				
4	A4=		A4-A3=		P4=		t=P4=				
										Section 4 total	
Random Load Only (if needed)											
R	AR=	11.45	AR-0=	11.45	PR=	0.05	t=PR=	0.05	0.224	0.63	4.07
PART II. Required Cell Capacity Calculation.											
1	Maximum Section Capacity, Ah										130.01
2	Random Section Capacity, Ah										4.07
3	Uncorrected cell capacity, Ah. Add lines 1 and 2										134.08
4	SOC factor										0.8
5	Design Margin										1.1
6	Aging Factor										1.1
7	Cell capacity, Ah = (line 3 / line 4) x line 5 x line 6										202.80
8	Required cell capacity, Ah										208
9	Required cell type										KM 208

Figure A.1—Sample cell capacity calculation worksheet

Annex B

(informative)

State-of-charge factor

The state-of-charge factor is determined by the battery manufacturer (see 6.2.2), based on the specified operating conditions. This annex provides additional information on the parameters that can affect this factor, and how the SOC may be improved. Battery charging system design and capacity also affect the state of charge, but are beyond the scope of this recommended practice. For more information refer to IEEE Std 1476-2000.

B.1 Recharge time, voltage and current

Batteries in rail transit applications are most commonly charged by a constant voltage system with a current limited output. Such charging systems have two main operating modes:

a) Current-limited mode.
During the initial recharge of a discharged battery, the battery voltage is below the preset level and charging is at the current limit of the charging system.

b) Voltage-limited mode.
After the battery voltage reaches the preset charging voltage, the charge current is limited to what the battery can accept, depending on its state of charge, the charging voltage, electrolyte temperature and plate technology.

There is a transition phase between these two modes, during which the preset charging voltage is reached and the charge current tapers down to a lower value. During prolonged charging, the system stabilizes in voltage-limited mode at a very low current.

In rail transit operation, recharge time is generally limited by operational considerations. If the minimum required time to recharge a fully discharged battery is not specified by the authority having jurisdiction, assumptions should be made by the car builder or battery manufacturer regarding the minimum available recharge time.

If at the end of the recharge time, the system is still in current-limited mode, then it should be possible to increase the SOC by increasing the current limit of the charging source. Increasing the current limit above about $1.0C_5$ amperes (where C_5 is a constant that is numerically equal to the five-hour discharge rated battery capacity) will have very little effect, since the battery voltage would rise very rapidly to the preset charging voltage and put the system into voltage-limited mode.

If the system is in voltage-limited mode at the end of the recharge time, the best way to increase the SOC is by using a higher preset charging voltage. However, if this higher voltage is applied on an ongoing basis, it will result in increased water consumption and maintenance requirements.

B.2 Charging method

Many constant voltage charging systems operate at a single voltage level, typically 1.45 to 1.55 volts per cell at 20°C. The voltage setting is a compromise that allows the battery to be brought to an acceptable SOC without resulting in excessive water consumption.

The temperature compensation technique, described in B.3.1 allows the single level battery chargers to achieve a higher SOC using a higher voltage at lower temperatures at the expense of more sophisticated charger.

A two level constant voltage charging system allows the battery to be charged to a higher SOC using a higher voltage. It can then be maintained at that level using a lower voltage. The potential disadvantage of such systems is that they are more complicated, and the switching point between the two levels must be carefully chosen to avoid undercharging or overcharging.

B.3 Charging temperature

The battery electrolyte temperature during charging can affect the SOC, either by limiting the level of current that can be accepted or by reducing the efficiency with which the charge supplied to the battery is stored.

Because of the different processes involved, the SOC factor for low temperature operation may not be the same as at higher temperature. It may be necessary to calculate battery capacity for both conditions and select the larger cell. Note that battery loads may not be the same for low and high temperature operation.

B.3.1 Low temperature charging

When recharging a fully discharged battery at low temperature, the preset charging voltage may be reached very quickly, thus limiting the time spent in the current-limited mode and limiting the amount of charge returned to the battery within the available recharge time. One method of compensating for this effect is to increase the charge voltage. This allows more charging time in current-limited mode, and a higher charge current in voltage-limited mode, thus achieving a higher state of charge than with a system without temperature compensation.

B.3.2 High temperature charging

As the electrolyte temperature is increased, the charge current that the battery can accept at a particular voltage and state of charge is also increased. Above 25°C, however, the efficiency of converting and storing this charging energy is reduced. This will generally result in a lower SOC being attained. Note that temperature compensation will not improve the charge efficiency at high temperatures.

B.4 Cycling service

Frequent discharges due to rail gaps, section isolators or intermittent primary power supply, such as may exist with ice on the third rail or catenary wire, may affect the state of charge. Repeated discharges with insufficient recharge will result in progressive reduction of SOC. Additional analyses should be performed to determine the SOC factor.

If operators routinely leave their vehicles without charging power but with battery loads connected, this may result in the batteries being deeply discharged, sometimes more than once a day. Such frequent cycling service may further lower the SOC, and should be taken into account in the capacity calculation.

Annex C

(informative)

Calculating capacity rating factors

Under certain circumstances it may be necessary to calculate capacity rating (K_t) factors from other data provided by the battery 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.

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

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

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 line 9 of the worksheet (Figure 2) 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 6.3.3).

Annex D

(informative)

Bibliography

[B1] APTA RP–E-007-98R1, Recommended Practice for Storage Batteries and Battery Compartments.

[B2] HOXIE, E. A., “Some Discharge Characteristics of Lead-Acid Batteries,” *AIEE Transactions (Applications and Industry)*, vol. 73, pp. 17–20, 1954.

[B3] IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition.

[B4] IEEE Std 1115-2000, IEEE Recommended Practice for Sizing Nickel-Cadmium Batteries for Stationary Applications.

[B5] Weather of U.S. Cities, Fifth Edition, Volumes 1 and 2, James A. Ruffner and Frank E. Bair, Gale Research Company, Detroit, Michigan, 1996; Library of Congress Card Number 87-11869, ISBN 0-8103-5525-6.