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IEEE Guide for Selection, Charging, Test, and Evaluation of Lead-Acid Batteries Used in Stand-Alone Photovoltaic (PV) Systems

IEEE Standards Coordinating Committee 21

Sponsored by the
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Fuel Cell Photovoltaics, Dispersed Generation, and Energy Storage



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Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage

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Abstract: This guide is applicable to all stand-alone photovoltaic (PV) systems where PV is the only charging source. Stand-alone photovoltaic (PV) system parameters and operating conditions are discussed in relation to battery characteristics and expected system performance. Charging parameters for PV systems are suggested to help in the selection of a battery for a specific application. Finally, a performance test to verify the battery selection and system parameters is provided, including discussions on how to interpret test results. Test results only provide information on initial battery performance. No cycle-life predictions are made.

Keywords: lead-acid battery test procedure, lead-acid battery tutorial, photovoltaic (PV) battery characteristics, PV battery selection, PV systems, PV battery test procedure

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Introduction

(This introduction is not part of IEEE Std 1361-2003, IEEE Guide for Selection, Charging, Test, and Evaluation of Lead-Acid Batteries Used in Stand-Alone Photovoltaic (PV) Systems.)

The PV system designer depends on the capacity of a storage battery for reliable extended operation of the system load during hours of darkness and below-average solar resource. Photovoltaic systems can subject batteries to harsh operational environments with minimal control of recharge profiles. The economics of photovoltaic modules limit the ability to charge the battery at more traditional motive power deep-cycle charge rates and times. Typical charge rates for small stand-alone PV systems are less than 6.5 amperes and may be less than 2.0 amperes per 100 ampere-hours of battery capacity. Relatively low rates, coupled with the unpredictability of the solar resource, results in limited recharge capabilities.

Stand-alone PV systems are typically used in remote locations with minimal power resources, which limits the amount of initial battery boost charging possible. In daily operation, the limited available PV charging source combined with relatively low-charge regulation voltages may be insufficient to provide a full charge to the battery. In an effort to identify appropriate stand-alone PV system parameters together with appropriate battery technology, a repeatable test procedure is provided to verify PV system parameters based on laboratory battery performance testing. This test procedure is designed to be characteristic of the low-charge/discharge rates, shallow cycle operation, and various charging methods used in PV systems.

This guide contains relevant information on PV system design considerations as related to lead-acid batteries and a recommended test plan for evaluating battery performance in a particular system design. Specific lead-acid battery topics include the following:

- PV battery selection
- PV battery characteristics
- PV battery testing and evaluation

The recommended test plan for evaluating PV batteries includes the following:

- Limitations and expectations
- System parameter selection
- PV battery cycle test
- Interpretation of test results

This guide may be used separately, or in combination with IEEE Std 937™-2000, IEEE Recommended Practice for the Installation and Maintenance of Lead-acid Batteries for Photovoltaic (PV) Systems, and IEEE Std 1013™-2000, IEEE Recommended Practice for Sizing Lead-acid Batteries for Photovoltaic (PV) Systems. Together, these documents will provide the user with a general guide to sizing, designing, placing in service, maintaining, and testing lead-acid storage batteries for PV systems.

Interpretations and errata

Interpretations and errata associated with this amendment may be found at one of the following Internet locations:

- <http://standards.ieee.org/reading/ieee/interp/>
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Contents

1. Overview.....	1
1.1 Scope.....	1
1.2 Purpose.....	1
2. References.....	2
3. Definitions	2
4. Safety	3
4.1 Arc hazard.....	4
4.2 Hydrogen venting	4
4.3 Secondary containment.....	4
5. Lead-acid battery selection and use	5
5.1 Battery characteristics	5
5.2 PV system parameters.....	5
6. Recommended test plan	5
6.1 Limitations and expectations	5
6.2 Objectives	6
6.3 Parameter selection.....	6
6.4 PV battery test procedure.....	6
6.5 Evaluation of test results.....	11
Annex A (informative) Lead-acid battery technologies.....	13
Annex B (informative) Lead-acid battery characteristics	16
Annex C (informative) PV system operational parameters	21
Annex D (informative) Bibliography.....	26

IEEE Guide for Selection, Charging, Test, and Evaluation of Lead-Acid Batteries Used in Stand-Alone Photovoltaic (PV) Systems

1. Overview

This guide was written to provide a relevant photovoltaic (PV) battery test procedure that can be used to evaluate battery performance and identify appropriate PV battery charging requirements. Use of this document by funding organizations, battery manufacturers, PV system integrators, and consumers should provide the means for improved battery selection and its subsequent charging specifications. It is intended that this document provide a means to identify more cost-effective and reliable PV batteries.

1.1 Scope

This guide contains a tutorial on lead-acid battery technology, battery charging characteristics, and a laboratory test procedure to evaluate charge parameters and battery performance. The information on lead-acid battery designs and environmental characteristics is provided to help the PV system designer make appropriate battery decisions. PV system parameters and operating conditions are discussed. Charging parameters related to PV systems are also suggested to help in the selection of appropriate test setpoints. Finally, a performance test to verify the battery's operating setpoints and performance is provided, including discussions on how to interpret test results.

This guide is applicable to all stand-alone PV systems where PV is the only charging source. This guide does not include PV hybrid systems.

1.2 Purpose

This document provides guidance in understanding lead-acid battery charging requirements in relation to the operational parameters that affect overall PV system design and battery performance. This document will aid in battery selection, evaluation, and PV system design, and it does provide a test plan for evaluating the selected battery.

2. References

This guide shall be used in conjunction with the following publications. When the following specifications are superseded by an approved revision, the revision shall apply.

IEEE Std 937TM-2000, IEEE Recommended Practice for the Installation and Maintenance of Lead-acid Batteries for Photovoltaic (PV) Systems.^{1, 2}

IEEE Std 1013TM-2000, IEEE Recommended Practice for Sizing Lead-acid Batteries for Photovoltaic (PV) Systems.

3. Definitions

For the purposes of this guide, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition [B4] should be referenced for terms not defined in this clause.³

3.1 ampere-hours (Ah) charge efficiency: This is calculated by dividing the Ah discharged by the required Ah charged to maintain battery capacity under specific cycle and charging conditions.

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

3.3 battery conditioning: It charges a battery to its full capacity after performing multiple cycles. Battery conditioning is designed specifically for obtaining maximum new battery capacity.

3.4 calculated photovoltaic (PV) array ampere-hours (Ah) to load Ah ratio (A:L): The monthly daily average PV ampere-hours available divided by the monthly daily average load ampere-hours. Average daily PV ampere-hours are calculated by taking the daily average solar resource for each month in kWh/m² times the PV array current at its maximum power point (Imp) at standard test conditions (STC). Array to load ratios can also be calculated in terms of their respective Watt-hour parameters.

3.5 charge ampere-hours (Ah) to load Ah ratio (C:L): The total available charge ampere-hours (Ah) divided by the load Ah. Charge Ah are calculated by integrating the set charge current over the total charge time. The actual charge Ah is not necessarily the calculated charge Ah because of charge current tapering at regulation voltage.

3.6 charge controller: An electrical control device that regulates battery charging by voltage control and/or other means. It may also incorporate one or more of the following functions: discharge termination, regulation voltage temperature compensation, load control, and status indication.

3.7 c/x charge/discharge rate: The manufacturer's rated battery capacity in ampere-hours usually at the 20 h rate divided by the discharge time in hours. A 100 Ah battery discharged/charged at the 35 h rate would result in a discharge/charge current of 2.86 ampere (100/35 = 2.86 ampere).

3.8 deficit charge: Charging a battery with less ampere-hours (Ah) than is required to return the battery to its initial state-of-charge. This results in a reduction in the battery state-of-charge.

3.9 end-of-discharge voltage (EODV): The battery voltage just prior to load termination. It will be the minimum voltage for the given discharge cycle.

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

3.10 low-voltage disconnect (LVD): The battery voltage at which the load is disconnected to prevent over-discharge. This is the determining factor for the actual maximum allowable depth of discharge and available battery capacity in a photovoltaic (PV) system.

3.11 low-voltage reconnect (LVR): The battery voltage at which the load is reconnected after a low-voltage disconnect.

3.12 opportunity charging: Partial or complete charging of the battery whenever the opportunity arises.

3.13 overcharge: The number of ampere-hours (Ah) charged divided by the number of Ah discharged times 100. Typical overcharge values are between 105% and 130%.

3.14 premature capacity loss: Significant lead-acid battery capacity loss, usually greater than 10%, that occurs during cycling even though the battery receives adequate charge to recover the discharged capacity. The decline in capacity occurs early in the projected cycle-life of the battery without any of the traditional capacity loss or wearout mechanisms.

3.15 regulation reconnect voltage (V_{rr}): The battery voltage at which the charge controller reconnects the charging source to the battery.

3.16 solar insolation: The total daily solar irradiance in kWh/m². Most data for a geographic location are reported for each month as the average daily irradiance for a specific array tilt angle. Typical daily values are between 2 and 7 kWh/m².

3.17 standard test conditions (STC): The accepted conditions under which photovoltaic (PV) devices are commonly rated: 1000 W/m² irradiance at a spectral distribution of airmass (AM) 1.5 and a 25 °C PV cell temperature.

3.18 sulfation, excessive or “hard”: The growth of lead sulfate (PbSO₄) crystals on the positive and negative plates of a lead-acid battery after an extended time in a discharged condition. “Hard” can be identified by an abnormal drop in electrolyte specific gravity after an equalization charge and by a gritty texture on the plates.

3.19 sustaining charge: The battery will be restored to the same state-of-charge it was prior to the discharge.

3.20 termination voltage: The battery voltage at which discharge is terminated.

4. Safety

CAUTION

Whenever batteries are used, certain safety concerns need to be considered. Installation of batteries under test should be in accordance with procedures outlined in IEEE Std 937-2000.⁴ Goggles for eye protection, acid-resistant gloves, eyewash stations (portable or stationary), electrolyte neutralizing solutions, protective clothing, and a class C fire extinguisher should be considered mandatory for personnel safety.

Select a solution (or powder) that will neutralize the 20% to 30% sulfuric-acid solution (standard electrolyte). Sodium bicarbonate (baking soda) works well to neutralize electrolyte spills. Neutralizing electrolyte spills may subject the users to hazardous waste regulations. Contact the local hazardous waste office for guidance.

⁴For information on references, see Clause 2.