OVERVIEW AND PURPOSE OF IEEE STD 937—
RECOMMENDED PRACTICE FOR INSTALLATION AND MAINTENANCE OF LEAD-ACID BATTERIES FOR PHOTOVOLTAIC (PV) SYSTEMS

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ABSTRACT

This paper gives an overview of the 2007 revision of IEEE Std 937-2000 – *IEEE Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic (PV) Systems*, and its purpose. It discusses some of the basic differences between photovoltaic-system battery requirements and those of traditional stationary standby battery systems. Of particular interest to the audience is how a battery's application and environment affect the recommended practices. Photovoltaic (PV) installations differ from industrial standby installations—such as telecommunications, uninterruptible power supplies, and utilities—in several key areas, including charge and discharge rates, depth of discharge, state of charge, and application temperature. Despite using the same lead-acid battery types, such conditions require changes in how the batteries should be installed and maintained. IEEE Std 937 can assist in maximizing battery life for those with atypical industrial applications that may have some of the same characteristics as a pure PV installation.

INTRODUCTION

IEEE Std 937-2000 – *IEEE Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic (PV) Systems* (Ref. 1) provides installation design considerations and procedures for storage, location, mounting, ventilation, assembly, and maintenance of vented and valve-regulated lead-acid batteries for PV systems. Although there are other IEEE standards that deal with lead-acid battery installation and maintenance, they are generally intended for other types of applications, such as utility grid-tied float-service applications. IEEE Std 937 provides information for installation and maintenance of lead-acid batteries in PV applications, generally characterized by non-grid-connected, cycling service. It also reflects the typically remote nature of PV applications.

IEEE Std 937 was originally written in the early 1980s because of the differences between battery usage in PV systems and traditional standby battery systems. It was developed by IEEE Standards Coordinating Committee 21 (SCC21), a committee that develops standards specifically for fuel cells, photovoltaics, dispersed generation, and energy storage.

Other battery standards dealing with installation and maintenance of lead-acid batteries were written primarily for large utility-interconnected standby applications by the IEEE Power Engineering Society (PES) Stationary Battery (StatBatt) Committee. Some of these standards include IEEE Std 450, IEEE Std 484, IEEE Std 1187, and IEEE Std 1188 (Refs. 2–5). The StatBatt Committee deals with the design, manufacturing, sizing, selection, installation, maintenance, testing, and operation of storage batteries and associated DC systems used in standby applications, such as those commonly found in generating stations, substations, energy storage, industrial control, emergency/standby generator sets, emergency lighting, telecommunications, and uninterruptible power supplies (UPS).

OVERVIEW OF IEEE STD 937

As its title implies, IEEE Std 937 covers both the installation and maintenance issues associated with lead-acid batteries in PV systems. It also covers both vented and valve-regulated types of lead-acid batteries. (StatBat has developed separate standards for installation and maintenance for each battery type.) The first part of IEEE Std 937 briefly discusses safety equipment and procedures. Next, IEEE Std 937 covers installation design criteria: enclosure location, mechanical and environmental considerations, the battery support structure, electrical aspects, and seismic considerations. The next section covers installation procedures: receiving inspection, unpacking and storing batteries, assembling the support structure, mounting and connecting the battery, and performing preoperational checks. Up to this point, IEEE Std 937 is similar to other battery installation design standards, IEEE Std 484 and IEEE Std 1187.

The next section discusses initial charging procedures. Many PV systems are not grid-tied, and may have no other source of power in addition to the PV array. This section discusses the preferred method for battery charging, with the caveat that field conditions may prevent strict adherence to the battery-charging procedure.

The maintenance section of IEEE Std 937 discusses the importance of regular inspections and good record keeping. Because PV systems are often remote and small, it was felt that the minimum maintenance interval should be quarterly, as opposed to monthly. After this, IEEE Std 937 once again closely follows IEEE Std 450, with a section on corrective actions to be taken if abnormal battery conditions are found.

Probably the most significant difference between IEEE Std 937 and the other battery documents is the absence of a section on battery testing and procedures. IEEE 937 recommends using the test schedule and battery test procedures from IEEE Std 450 and IEEE Std 1188 **only if** the PV system design allows their use.

The main technical body of IEEE Std 937 finishes with a discussion of battery-replacement criteria. Unlike IEEE Std 450 and IEEE Std 1188, which recommend replacing the battery when its capacity falls below 80% of the manufacturer’s rating, IEEE Std 937 recommends replacement when the battery is unable to support the load for a user-specified length of time due to a low-voltage disconnect not as the result of extended periods without sunshine. In other words, the user may determine the battery-replacement criteria and this could be user specific.

STATUS OF IEEE STD 937

Late in 2006, the revision of IEEE Std 937-2000—the revision is referred to as IEEE P937—was thoroughly reviewed by a group of people with various battery backgrounds, including users, producers, consultants, those with a general interest, as well as battery specialists in government and from academia. This paper was prompted, in part, because some of the reviewers felt that IEEE P937 did not differentiate itself from those standards aimed specifically at stationary batteries, especially IEEE Std 450 and IEEE Std 1188. The major difference between IEEE P937 and these other standards is the absence of a battery-testing procedure. IEEE Std 450 has an entire section plus an annex devoted to procedures for testing vented lead-acid batteries (IEEE Std 1188 is its valve-regulated lead-acid [VRLA] counterpart).

DIFFERENT BATTERIES AND PROCEDURES FOR DIFFERENT APPLICATIONS

Batteries used for energy storage within PV installations see a very different usage profile than batteries used in typical standby installations. This usage profile changes the common modes of failure. Therefore, a different set of battery features is required for a long and robust service life. The maintenance and installation procedures also change to preserve and extend the service life of a PV battery. The discussion below summarizes these major differences and their effects on the batteries.

General Comparison

In a typical standby installation, the load is powered by the electric grid. When the grid fails unexpectedly, the battery on standby is ready to immediately provide emergency power to the equipment. The battery provides power until depleted, or until the electric power is restored. The battery is then recharged and awaits the next power interruption.

This is quite different from battery use in conventional, stand-alone PV applications. Although the PV array generates electricity from the sun, the sun neither shines consistently nor at night when energy may be required. The battery in a PV installation serves two main purposes. The obvious main purpose of the battery in a PV installation is to provide power when the sun is not shining. Another purpose is to supply any power demands greater than the existing array output can fulfill. It can perform these functions by storing the excess energy created by the PV array during the day that is not being immediately consumed. However, because the cost of generating electricity through PV arrays is high, typically little excess energy is generated.

With these two general scenarios, there are four major areas of difference in battery use between a PV and standby application:

- Charge and discharge (current) rates
- Depth of discharge (DOD)
- State of charge (SOC)
- Application temperature

Discharge and Charge Rates

The battery is sized to provide full power for a certain number of days—known as days of autonomy—when almost no electricity is generated by the PV array. Although many PV designs are possible, as an example and simplified analysis, 5 days of autonomy means the battery will be discharged at the 120-hour rate (5 days x 24 hours = 120 hours), assuming a constant load. For non-constant loads, the discharge rate could be substantially greater, even exceeding the 20-hour rate.

The battery also stores excess energy generated by the PV array that is not immediately consumed by the load. PV arrays are designed to provide slightly more energy than the application's average load consumes, commonly 110%–140% of the load during peak sun. Although the load may discharge the battery at the 120-hour rate, the excess current from the PV array available to charge the battery might vary from less than half this rate to that represented by the full array output current, which could exceed the 20-hour rate. Ideally the array should replace the energy used in the same 5-day autonomy period. As the sun shines for a shorter period than a day, the average charge rate could be much larger than the average discharge rate. If all of the array power were to go to the load, 5 days x 6 sun hours = 30-hour rate. As some of the power goes to the load, the rate could be even greater.

These generally low charge and discharge rates mean that the battery's internal efficiency is much less of a factor for a PV application. Standby batteries must have a lower internal resistance for the high rates, and they must be closely matched within the string to avoid a single cell's voltage dropping too low during a discharge, or rising too high while charging. The importance and effect of external connector resistances also rises with the applied currents.

Conversely, PV batteries can have thicker plates, with a lower porosity, and not suffer from recharge or discharge inefficiency. Because internal energy loss is a factor of the square of the current, the lower currents in a PV application mean that internal resistance variations are usually negligible. Although capacity matching for UPS and float matching for telecom batteries are important, these items are much less critical for PV batteries. Also, a battery that has aged and is no longer able to provide the higher rates of a standby installation may be able to provide the lower rates required for a PV system, which is why discarded standby batteries often find a second home in PV installations.

Table 1. Battery differences in discharge and charge rates

PV Application	Standby Application	Difference
Generally low, but varying charge and discharge currents, often 100- to 200-h rate	Much higher rates of discharge: 15 min (UPS), 5–8 h (telecom), 10 h (switchgear) Recharge: 8–24 h rate	PV batteries can have much thicker plates with a lower porosity. Standby batteries require lower internal resistance and matched internal resistance within a string. Connector resistances are much more important in standby installations.

State of Charge (SOC)

Standby batteries are kept at a 100% SOC until a power outage. The battery is then discharged for the duration of the outage, and then immediately recharged back to a full SOC.

In contrast, with the exception of some PV/hybrid systems, PV installations are typically designed so the batteries are rarely or never at a full SOC. This is because PV systems are designed so that there is little excess energy generated by the PV array, and that excess energy which is generated is usually stored by the battery and not wasted. Also, because the batteries are charged at varying rates and times depending on the intensity and duration of the sun, the batteries can be at any SOC at any time.

Therefore, PV batteries must be able to tolerate and recover from remaining at a low SOC for extended periods. Because lead-acid batteries have a tendency to form large sulfate crystals while at a low SOC, it is desirable that PV batteries be fully charged periodically as part of their routine maintenance. The charge current in PV systems can vary constantly. Because of this, electrolyte checks in vented batteries are usually more accurate than voltage measurements to determine the battery SOC. On the plus side, the battery cells within a PV system are usually more closely matched because variations in internal resistance are negligible at lower currents. This means testing a smaller number of pilot cells may be sufficient as compared to a standby battery string.

Because PV batteries are rarely at a full SOC, and the recharge currents are relatively low, there is also minimal gassing of these batteries. This reduces, but does not eliminate, the need for ventilation, and also reduces the urgency of water replenishment compared to vented standby batteries.

Table 2. Battery differences in state of charge

PV Application	Standby Application	Difference
Often in a state of deficit charging; can be at any SOC at any time Rarely at 100% SOC	Always kept at 100% SOC, always recharged immediately	PV batteries must tolerate and recover from extended stand time at low SOC. Periodic full recharges or equalization may be beneficial Electrolyte readings more accurate than voltage to determine SOC in PV strings, needing fewer pilot cells Standby batteries have higher gassing rates and higher water loss

Depth of Discharge (DOD)

Standby batteries are at a full SOC until needed during a power outage. Thus, DOD depends on the length of time the power is interrupted. Standby batteries are rarely fully discharged, because most power outages are only seconds in duration.

In contrast, as summarized earlier, PV batteries may be at any SOC. If the sun is not shining, the battery will continue to be used and further discharged. Because of this, PV batteries are commonly discharged very deeply (>80%), and individual cell reversal, while not advisable nor desirable, is quite possible. Batteries designed or suitable for PV service are often manufactured with high-density plates to tolerate higher numbers of deep discharges. Higher-density plates reduce the high-rate capability, but the increased life is usually the better side of the trade-off.

For this type of duty cycle, PV batteries are often manufactured with excess electrolyte or with proprietary additives to prevent the specific gravity of the electrolyte from dropping too low during these deep discharges. If a battery design does not have excess electrolyte, or the battery is reduced in capacity for cost or space reasons (i.e., the days of autonomy are reduced), then increased monitoring of the SOC would be prudent. As stated earlier, specific gravity measurements are generally more accurate than voltage readings for PV batteries for determining SOC. A gravity reading that varies greatly from the average could be an indication that a battery cell is failing.

Table 3. Battery differences in depth of discharge

PV Application	Standby Application	Difference
Very deep discharges are common (>80%) Individual cell reversal may occur	Discharges only occur periodically Deep discharges (>50%) are uncommon, Very deep discharges (>80%) are rare	Excess electrolyte is necessary for PV batteries; plates must tolerate repeated full discharges (high-density plates) For PV installations, increased SOC monitoring is required if small or non-PV batteries are used

Application Temperature

Temperature extremes are not exclusive to PV installations. Although batteries for standby applications can be well controlled and indoors, many batteries are installed outside in cabinets, unprotected from temperature extremes. However, because of the way batteries are operated in PV applications, the performance and lifetimes vary somewhat in both cold and hot environments.

As reviewed in earlier sections, PV batteries remain more often at a lower SOC during their normal operation than do standby batteries. In the lead-acid battery, this lower SOC equates to a lower specific gravity, which raises its freezing point. Therefore, it is especially important to protect PV batteries from freezing in very cold environments. Because standby batteries are kept at a full SOC and are typically recharged immediately after discharging, this is a lesser concern for standby applications.

Conversely, this lower SOC assists the PV battery somewhat at higher temperatures. Because PV batteries are frequently not at a 100% SOC, they often do not reach the voltage necessary to electrolyze the water in the electrolyte. Not only does this reduce the evolved gasses, but it also reduces the battery temperature because the extra charge current that goes into a fully charged battery will either electrolyze the water or is converted into heat.

Table 4. Battery differences in temperature

PV Application	Standby Application	Difference
Commonly experience high and low temperature extremes	Many installations are environmentally controlled Heaters are common for cold installations High temperatures may be seen in outdoor cabinets	Due to lower SOC, the chance of freezing at cold temperatures is more severe with PV batteries At 100% SOC, temperature compensation at high temperatures is more of an issue with standby batteries

SUMMARY

IEEE Std 937 – *IEEE Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic (PV) System* was developed because batteries used in PV systems have different operational requirements compared to those in standby applications, specifically in the areas of charge and discharge rates, depth of discharge, state of charge, and application temperature. These factors, in addition to generally being deployed in remote locations, means that their maintenance and testing needs are also different. Although other battery standards are excellent resources for PV-system battery users, their application needs to be tempered by the PV system's operational factors. Work still remains to be done on this document, particularly in the area of battery testing of PV systems. Please contact the authors if you would like to participate in future revisions of IEEE Std 937.

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