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Technical Report

Validation Testing of Procedures for Determining the Performance of Stand-Alone Photovoltaic Systems

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Prepared under Task No. PVP1.7301

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1 INTRODUCTION

Standard test procedures, “IEEE P1526/D1 Draft Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems,” [1] have been developed to assess the performance of stand-alone PV systems tested outdoors under prevailing conditions. A copy of the procedures is included in Appendix E. This report presents an overview of the procedures and results from three validation tests conducted between January 1999 and September 2000 at one European and four U.S. test sites. There was good measurement agreement between the results measured at different test sites on similar systems.

To date, most PV system performance test procedures have looked at the performance of the individual components and have not addressed how the integrated system works as a whole. The performance test procedures described in this report verify that the system and load operate as expected, ensure that the PV array and system are capable of recharging the battery, determine the usable battery capacity (UBC), and determine if there is any significant change in the UBC measured three different times during the procedures.

The procedures described in this report establish the technical foundation needed to reduce the uncertainty that a system’s performance will be what its designers and builders claim. The need for these procedures was recently made more apparent with the initiation of a PV Global Approval Program at the international level. These procedures will serve as the basis for national and international stand-alone photovoltaic (SAPV) system test standards. The procedures consist of a short-term (about 1 month) procedure that can assess the performance of a SAPV system. The majority of PV systems being installed around the world are small lighting systems that usually consist of an array, lighting load, controller, and battery. These systems are essentially PV-powered battery chargers with a small load. The main focus of the procedures is to indicate how well the PV system can charge the battery.

The procedures have been submitted to both IEEE SCC21 and IEC TC82 for use in developing standards. The IEEE SCC21 has initiated P1526, “Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems,” [1] and the IEC TC82 has initiated Standard 62124, “Photovoltaic Stand-Alone Systems Design Qualification and Type Approval” [2]. The IEC document also addresses indoor testing.

2 GLOSSARY

Ah	Ampere hours
A:L	Array-to-load ratio
a-Si	Amorphous silicon
CB	Charge Battery sequence
DAS	Data acquisition system
FSEC	Florida Solar Energy Center
FT	Functional Test
FT_{avg}	Functional Test with an average A:L ratio
FT_{low}	Functional Test with a low A:L ratio
GENEC	Groupement Energetique de Cadarache
I	Current
IEC TC82	International Electrotechnical Commission Technical Committee 82
IEEE SCC21	Institute of Electrical and Electronic Engineers Standards Coordinating Committee 21
Irrpoa	Plane-of-array irradiance
LA	Lead acid
LVD	Low-voltage disconnect
NREL	National Renewable Energy Laboratory
P-Chart	Performance Chart
PV	Photovoltaic
PVUSA	Photovoltaics for Utility Scale Applications
PWM	Pulse-width modulation
RT	Recovery Test
SAPV	Stand-alone photovoltaic
Sh	Sun-hour
SWTDI	Southwest Technology Development Institute
T_{batt} avg	Average battery temperature
T_{bt}	Battery temperature
UBC	Usable battery capacity
UBC_0	Initial UBC
UBC_1	Second UBC
UBC_2	Final UBC
V	Voltage
V_r	Regulation voltage
VRLA	Valve-regulated lead-acid
x-Si	Crystalline silicon

3 OVERVIEW OF THE PERFORMANCE PROCEDURES

Figure 1 is a graphical representation of the battery voltage during the procedures. During the test period, the average battery temperature is held at 30° ± 5°C to better simulate the temperature in a tropical climate where many SAPV systems are being installed.

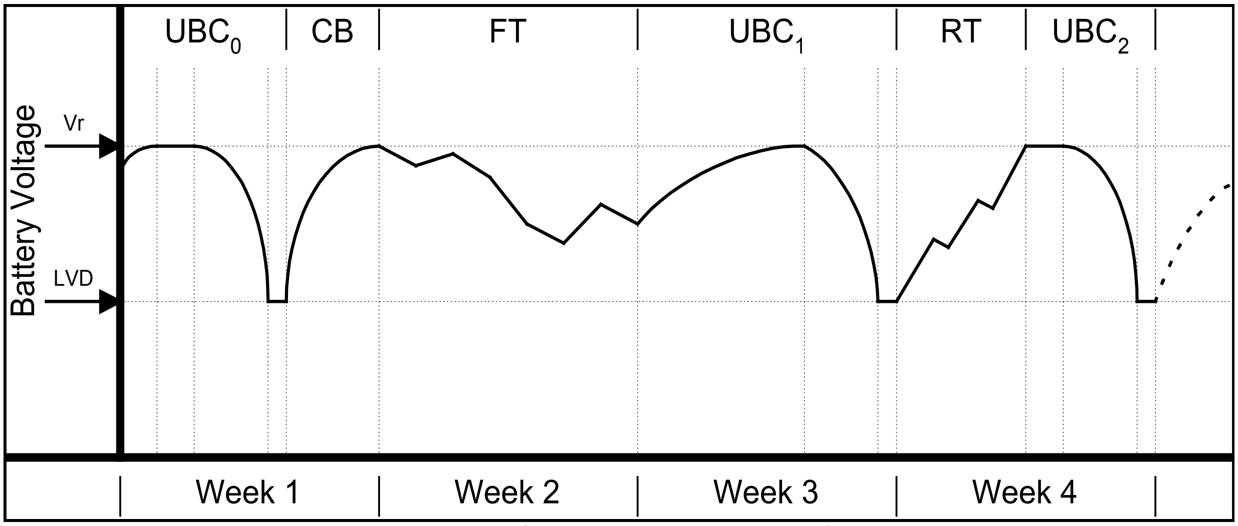

Figure 1. Sample test procedure profile.

3.1 UBC_0 – Initial Usable Battery Capacity Test

The UBC_0 test establishes a baseline battery capacity. With the load disconnected, the battery is charged up to regulation voltage (V_r) by the array and held there for at least an accumulated 12 hours. Next, with the array disconnected, the battery is discharged by operating the load continuously until the system reaches low-voltage disconnect (LVD). UBC_0 will be used as the baseline battery capacity to determine if the battery capacity has changed significantly after running the procedures.

3.2 CB – Charge Battery

With the load disconnected, the battery is charged up to V_r by the array and held there for at least 12 hours before beginning the Functional Test.

3.3 FT – Functional Test

The FT is run for at least 7 days to determine if the system and load work properly under normal system operation. Initially, the load is disconnected and the battery is charged up to V_r by the array and held there for at least 12 hours. The load is then set to operate 4 hours per night. For at least 2 consecutive days, the array should receive "low" solar insolation, $\leq$ 2 sun-hours (Sh) per day, to verify that the load can operate from the battery with minimal array contribution. For at least 2 (not necessarily consecutive) days, the array should receive "high" solar insolation, $\geq$ 5 Sh per day, to verify that the controller properly regulates the battery charge.

Some notes about sun-hours (Sh): Sh are used to simplify the explanation of amp-hour (Ah) production of the array. One Sh is defined to be 1 kWh/m^2. The units of Sh are hours. As an example, suppose the daily insolation is 5 kWh/m^2 on an array with a rated current of 3 A. An estimate of the array's production would be 5 h x 3 A, or 15 Ah. In using Sh, it is assumed that the array voltage is high enough to charge the battery. This is confirmed while conducting the procedures.

3.4 UBC_1 – Second Usable Battery Capacity Test

The second battery capacity test, UBC_1, is conducted the same way as UBC_0. The purpose of UBC_1 is to determine if the battery capacity has changed significantly after the FT.

3.5 RT – Recovery Test

The purpose of the RT is to determine how many Sh are required for the array to charge the battery from LVD to V_r with the load enabled. After reaching LVD in the UBC_1 test, the system is set for normal operation with the load set to operate 4 hours per night. The system should operate until the battery reaches V_r and then for at least another 3 days.

The Performance Chart, or P-Chart [3-5], in Figure 2 is generated by plotting the battery Ah versus Sh data from the FT and RT. It displays at what point the charge controller begins regulating the array output. The data tend to fall along three line segments. Data points fall on Segment A when there is incomplete battery recharge on days with low solar insolation. Data points fall on Segment B when the battery is at a low state of charge (SOC) and recharge is not yet limited by the charge controller. This occurs during the first sunny days after inclement weather. Data points fall on Segment C when the battery is at a high SOC and recharge is limited by the charge controller. This occurs after several days of high solar insolation. The intersection of segments A, B, and C indicates the minimum number of Sh required to recharge the battery for the number of Ah consumed by the load on a daily basis. If the array is to successfully recharge the battery, the expected average number of Sh for the location where the system is to be deployed must be greater than this value.

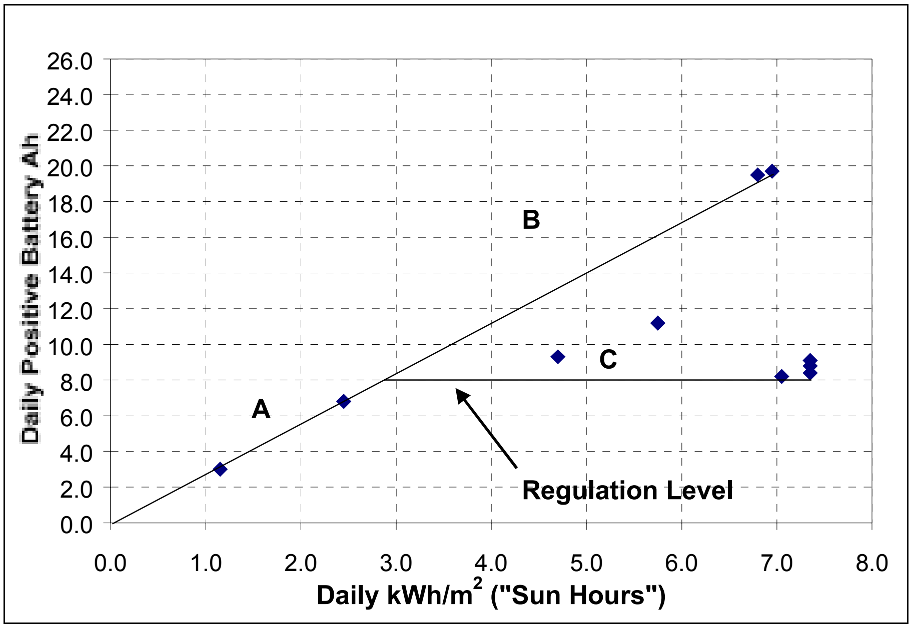

Figure 2. Sample P-Chart taken from System 1-2 at NREL, April 29 – May 11, 2000 (4-hour load run-time).

3.6 UBC_2 – Final Usable Battery Capacity Test

The final battery capacity test, UBC_2, is conducted the same way as UBC_0. The purpose of UBC_2 is to determine if the battery capacity has changed significantly after running the entire test sequence and to determine the hours of autonomy for the system. If the load size or run time changes, knowing the UBC simplifies predicting the system's hours of autonomy.

4 CHANGES FROM PREVIOUS PROCEDURES

The procedures are currently on their third revision. After validating each revision, shortcomings were noted and the procedures were modified to improve their ability to accurately predict the performance of SAPV systems. The original procedures, "Interim Test Methods and Procedures for Determining the Performance of Small PV Systems," [6] were published in July 1998. The tests were designed to last about 3 weeks (Figure 3). The load was set to run as prescribed by the system manufacturer in the FT. The UBC test was conducted at the conclusion of the procedures.

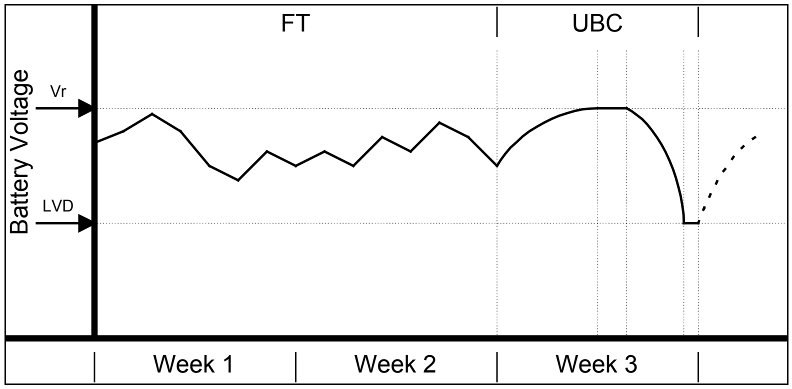

Figure 3. Sample test procedure profile from the original procedures, published July 1998.

After conducting Validation 1, the procedures were updated and re-published in September 1999 as the "Procedures for Determining the Performance of Stand-Alone PV Systems" [7]. Major changes included adding the FT_{low} and the RT (Figure 4). In the FT_{avg} test, the load was run as prescribed by the system manufacturer for the test location. During the FT_{low} test, the system was operated at its expected worse-case array-to-load ratio (A:L). To achieve the lower A:L, the load could be increased or the solar resource could be decreased. The RT was added.

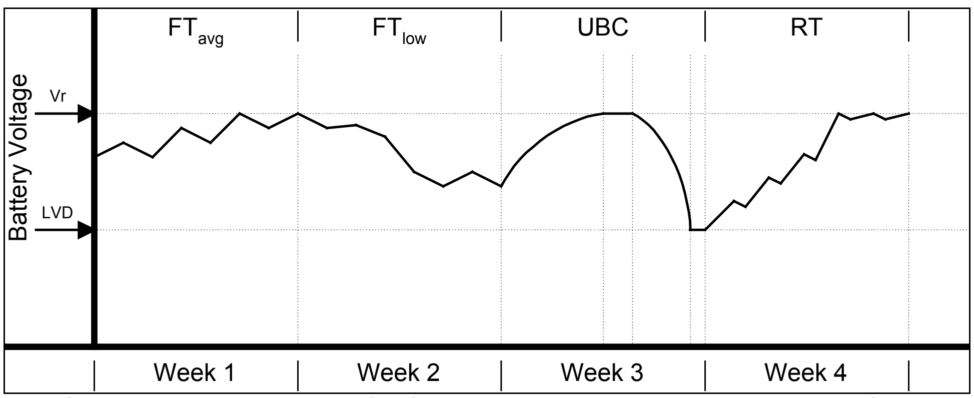

Figure 4. Sample test procedure profile from the second procedures, published September 1999.

Based on the findings of Validation 2, the procedures were revised into their present form, with two major changes (Figure 1). Two UBC tests, one at the beginning and one in the middle of the procedures, were added to monitor how the UBC changes over time. The FT was returned to a single test.

5 THE SYSTEMS AND TEST SITES

Table 1 describes the systems that were used for the validations. The left column contains the system designation and the test site. The table contains specified or rated values. Systems 1-1, 1-3, 1-4, 2-1, and 2-3 were also used in the first two validations. The systems are small SAPV home-lighting systems with one module, one 12-V lead-acid battery, a controller, and fluorescent lamps. The systems from Manufacturers 1 and 3 came as complete systems. The system from Manufacturer 2 was shipped without a battery. Upon asking the system supplier (not the manufacturer) what battery should be purchased, we were only told it could be **any** 12-V lead-acid (LA) battery with a capacity of 60 Ah. The only battery that met this criteria was a sealed gelled VRLA battery. As will be explained later, this turned out to be a poor choice for this system. Prior to Validation 3, we replaced this battery with a 12-V, 85-Ah flooded LA battery in Systems 2-2 and 2-3.

Table 1. System descriptions.

		PV		LOAD		CONTROLLER					12-V LA BATTERY	
	Manufacturer & Origin	**Type**	**Pmax (W)**	**Type**	**Power (W)**	**Type**	**Vr (V)**	**Battery Type Selectability?**	**LVD (V)**	**Temperature Compensation Sensor on Battery?**	**Type**	**Capacity (Ah)**
System 1-1 NREL	**1 US**	x-Si	50	1 fluorescent lamp	15	constant-voltage, solid-state PWM	14.4	yes	11.5	no	flooded LA (antimony)	105
System 1-2 NREL	"	"	"	"	"	"	"	"	"	"	"	"
System 1-3 SWTDI	"	"	"	"	"	"	"	"	"	"	"	"
System 1-4 FSEC	"	"	"	"	"	"	"	"	"	"	"	"
System 2-1 NREL	**2 US**	a-Si	32	2 fluorescent lamps	16	on/off shunt	n/a	no	n/a	no	gelled VRLA	60
System 2-2 NREL	"	"	"	"	"	"	"	"	"	"	flooded LA (antimony)	85
System 2-3 SWTDI	"	"	"	"	"	"	"	"	"	"	"	"
System 2-4 PVUSA	"	"	"	"	"	"	"	"	"	"	gelled VRLA	60
System 3-1 NREL	**3 Europe**	x-Si	70	4 fluorescent lamps	42	on/off shunt	n/a	no	n/a	no	tubular flooded LA (antimony)	140
System 3-2 NREL	"	"	"	"	"	"	"	"	"	"	"	"
System 3-3 GENEC	"	"	"	"	"	"	"	"	"	"	"	"

Validation testing of the latest procedures was conducted outdoors under prevailing condition at three U.S. laboratories: NREL in Golden, Colorado; FSEC in Cocoa, Florida; and SWTDI in Las Cruces, New Mexico; as well as at GENEC, in Provence, France. Another U.S. test site, PVUSA in Davis, California, participated in the first two validations.

Conducting the validation at various test sites gave us experience running the procedures under a variety of conditions. The following are some generalizations about the climates at the test sites. NREL is typically sunny, with a wide temperature range and low humidity. FSEC is typically hot, cloudy, and humid. SWTDI is typically hot, sunny, and dry. GENEC is typically sunny, with a comfortable temperature range and moderately humid.

Each test site used a computerized DAS to gather data. Table 2 gives an overview of the DASs and their accuracy. The logger accuracy is percentage of full-scale reading. Differences may exist between the test sites' sensors because each site may have used sensors from different manufacturers.

Table 2. DAS specifications.

Test Site	Data Logger	Logger Accuracy	Voltage Sensor Accuracy	Current Sensor Accuracy	Temperature Sensor Accuracy	Irradiance Sensor Accuracy
NREL	Campbell Scientific CR10	0.2%	0.1%	1%	1 deg C	5%
FSEC	Campbell Scientific CR10X	0.2%	0.1%	1%	1 deg C	5%
SWTDI	Campbell Scientific CR10	0.2%	0.25%	0.25%	1 deg C	5%
GENEC	Hewlett Packard 34970	0.1%	0.002%	0.003%	1%	2%
PVUSA	Campbell Scientific CR23X	0.2%	n/a	n/a	n/a	n/a

6 RESULTS FROM THE VALIDATION TESTS

The purpose of validating the procedures was to establish that the procedures could be carried out at all, and also, to determine if the results obtained at different test sites using similar systems would be similar. Validation 1 was completed by January 1999, and Validation 2 was completed by April 1999. Validation 3 was completed by September 2000. The systems were allowed to operate normally between validations.

Batteries labeled as "tested" in Table 3 are batteries that were also used during the first two validations. Batteries labeled as "new" were purchased from local vendors just prior to starting Validation 3. The left column contains the system designation, the test site, whether the battery was new or used at the start of the validation, and the rated capacity of the battery.

Table 3. UBC results from Validation 3.

System	UBC0	UBC1	UBC2	UBC2 / UBC0	Vr	LVD	T_{batt} avg
Units	Ah	Ah	Ah		V	V	^{o}C
System 1-1 **NREL** tested battery - 105 Ah	64	51	54	84%	14.40 - 14.73	11.68	25
System 1-2 **NREL** new battery - 105 Ah	79	78	76	96%	14.46 - 14.86	11.43	25
System 1-3 **SWTDI** new battery - 105 Ah	74	n/a	77	104%	14.35	11.39	28
System 1-4 **FSEC** tested battery - 105 Ah	55	58	58	105%	14.23	11.59	24
System 2-1 **NREL** tested battery - 60 Ah	24	24	21	88%	14.97 - 15.09	11.24 - 11.37	25
System 2-2 **NREL** new battery - 85 Ah	71	62	60	85%	14.59 - 14.73	11.43	25
System 2-3 **SWTDI** new battery - 85 Ah	52	n/a	56	108%	14.15	11.55	28
System 3-1 **NREL** new battery - 140 Ah	39	49	44	113%	13.80 - 13.96	11.10 - 11.25	25
System 3-2 **NREL** new battery - 140 Ah	46	44	45	98%	13.86 - 13.99	11.11 - 11.16	25
System 3-3 **Genec** new battery - 140 Ah	54	n/a	56	104%	13.75	11.20	24

At NREL, the battery box heaters are being replaced with units that will better regulate the battery temperature to the specified 30°C.

The battery used in System 2-1 was a VRLA gelled battery originally purchased with the system in early 1999. From the earlier validations, it was determined that the controller setpoints were better suited (i.e., higher) to charge a flooded lead-acid battery. Its UBC dropped drastically between Validation 1 (UBC was 76 Ah and rated capacity was 60 Ah) and Validation 3 due constant overcharge. At NREL, we wanted to see how the system would perform with a battery that was known to be "bad."

From Table 3, the final UBC values for both systems from Manufacturer 1 with "tested" batteries (7% difference between 1-1 and 1-4), and also, for the two systems with "new" batteries (1% between 1-2 and 1-3), are close considering the measurements were carried out at different test sites. The same is true for the two systems from Manufacturer 2 with new batteries (7% between 2-2 and 2-3). The 20% difference in UBC values between the systems at NREL and GENEC is most likely attributed to inadequate information on how to properly condition the batteries prior to installation. At NREL, we began using the battery in the same way that we had used the batteries from the other systems. On noticing the very low UBC, we questioned the system manufacturer about this. The manufacturer then sent GENEC and us the instructions on how to properly condition their battery prior to installation. GENEC had these instructions before they installed and used the battery.

Normally, a new lead-acid battery will exhibit a slight capacity increase during its first few cycles of use. This is observed in three out of six of the systems with new batteries. The rated battery capacity, in the System column, is higher than the UBC, as manufacturers measure the battery capacity discharged down to 10.5 V, instead of to the higher LVD value.

Table 4 lists the expected and measured daily Ah loads for the systems that were tested with the lamps set to run 4 hours per night. In all but one case, the measured load is lower than its calculated value.

Table 4. Additional Validation 3 results.

System	Rated Daily Load	Measured Daily Load	Sh to Vr	Sh / Day to meet Load	Calculated A:L	Measured A:L
	Ah	Ah	kWh/m^2	kWh/m^2		
System 1-1 **NREL** tested battery - 105 Ah	5.2	4.8	34	3.5	3.0	2.1
System 1-2 **NREL** new battery - 105 Ah	5.2	5.2	38	3.0	3.0	2.0
System 1-3 **SWTDI** new battery - 105 Ah	5.2	4.9	n/a	n/a	4.3	1.7
System 1-4 **FSEC** tested battery - 105 Ah	5.2	4.7	54	3.3	3.1	2.2
System 2-1 **NREL** tested battery - 60 Ah	5.3	4.8	23	2.0	2.0	1.1
System 2-2 **NREL** new battery - 85 Ah	5.3	5	45	5.0	2.0	2.0
System 2-3 **SWTDI** new battery - 85 Ah	2.7	3.4	n/a	n/a	5.5	1.3
System 3-1 **NREL** new battery - 140 Ah	14	11.2	3	3.0	1.6	1.1
System 3-2 **NREL** new battery - 140 Ah	14	11.6	2	3.5	1.6	1.1
System 3-3 **Genec** new battery - 140 Ah	12.7	12.4	4	4.0	n/a	n/a

The “Sh to V_r” value indicates how many Sh are required to charge the battery from LVD up to V_r. This value is found during the RT by integrating the solar irradiance from the time the discharged battery begins charging until it reaches V_r. Knowing this value, we can calculate how many days of average solar insolation are required at a given location to recharge the discharged battery.

The "Sh / Day to meet Load" value is taken from the intersection of the lines on the P-Chart. The P-Chart data are taken from the FT and RT. This is the minimum number of Sh required for the array to recharge the battery each day after the load operated for 4 hours. Knowing this value, we can determine if the array and system can replenish the Ah lost each day to the load.

The calculated and measured A:L values are listed, illustrating that although a system array may be expected to produce a certain number of Ah, the actual amount may be substantially less due to weather patterns or the way the charge controller functions. The A:L ratio is the array Ah divided by the load Ah.

7 SYSTEM PERFORMANCE RESULTS

Figures 5 to 10, in Appendix A, graphically present some of the data collected from a system tested at NREL during Validation 3. The top plot in each figure is the solar irradiance (sampled every 5 seconds, averaged every 15 minutes). The next plot is the average battery voltage (sampled every 5 seconds, averaged every 15 minutes). The battery voltage increases when it is being charged by the array during the day and decreases when the load is operating. The three UBC tests can be seen where the battery is discharged down to LVD. The middle plot is the average battery current (sampled every 5 seconds, averaged every 15 minutes). Battery current is positive when the array is charging during the day and negative when the load is operating. The next plot is the cumulative battery Ah (sampled every 15 minutes), which was reset periodically. The Ah accumulate positively when the array charges the battery and negatively when the load is operating. The bottom plot is the average battery temperature (sampled every 5 seconds, averaged every 15 minutes).

The P-Charts for the systems tested at NREL are found in Figures 11 to 16, in Appendix A. Data and results from SWTDI, FSEC, and GENEC are in Appendices B, C, and D, respectively.

8 SYSTEM PROBLEMS ENCOUNTERED DURING VALIDATION TESTING

The objective of performing the validation testing was to see if the procedures could identify system problems. The results in this section indicate the procedures did identify problems and issues.

8.1 Systems 1-1, 1-2, 1-3, and 1-4:

- These systems ran problem free.
- One criticism of this system might be that although the charge controller does have temperature compensation, the sensor is built into the controller. Battery manufacturers specify a V_r at 25°C. In general, temperature compensation adjusts the V_r up or down, depending on the temperature of the battery. Above 25°C, V_r is adjusted down, and below this, V_r is adjusted up with lead-acid batteries. Without temperature compensation, a cold battery may not fully charge, and a hot battery may be charged excessively [8]. Temperature compensation is recommended by battery manufacturers. For temperature compensation to work properly, the temperature of the battery must be sensed. In this system, having the temperature compensation sensor built into the controller can lead to two problems: First, if the controller is not mounted adjacent to the battery, the controller may sense the wrong temperature and improperly compensate the V_r. Second, some controllers dissipate excess array power as heat. If the sensor is built into a controller that is heating up, the elevated sensor temperature could result in the battery being undercharged.

8.2 Systems 2-1, 2-2, and 2-3:

- High controller setpoints can cause early failure of VRLA batteries (VRLA batteries were used in these systems during Validations 1 and 2). The maximum measured V_r was 15.09 V in System 2-1. The recommended setpoint for a VRLA battery should not exceed 14.4 V [8]. For Validation 3, the VRLA batteries were replaced with flooded lead-acid batteries in Systems 2-2 and 2-3. Either the system manufacturer should specify the battery to be used in this system, or the controller should be field adjustable.

- The controller may cycle the lamps after reaching LVD due to inadequate hysteresis. Hysteresis is the voltage difference between LVD and reconnect. This can be seen in the battery voltage and current plots in Figure 6.
- Both lamp assemblies failed in 2-1 after Validations 2 and had to be replaced before starting Validation 3. (As of the publication of this report, both lamps have failed in 2-1, and one has failed in 2-2.)
- One lamp assembly failed in 2-3 during Validation 3.
- This charge controller does not have temperature compensation.

8.3 Systems 3-1, 3-2, and 3-3:

- Inadequate documentation contributed to the batteries being improperly conditioned, which may have led to reduced UBC in 3-1 and 3-2.
- Low V_r setpoints probably contributed to the very low UBC values in these flooded lead-antimony batteries. The recommended setpoint should be 15.3 [8].
- Battery polarity labels can be removed and are easily reversed.
- The controller may cycle the lamps after reaching LVD due to inadequate hysteresis. This can be seen in the battery voltage and current plots in Figure 7.
- The controller only allows one of the four lamps to turn on at a time.
- This charge controller does not have temperature compensation.

9 UBC RESULTS FROM EARLIER VALIDATIONS

The UBC results from the first two validations are found in Table 5. Validation 1 was completed by January 1999. Validation 2 was completed by April 1999. The systems were allowed to operate normally between validations. The UBC of the systems from Manufacturer 1 generally decreased slightly. The UBC of the three systems from Manufacturer 2 that were run in Validation 1 and 2 decreased drastically because the system's vendor incorrectly recommended the use of a gelled lead-acid battery, whereas the controller was set for a flooded battery. Constant overcharge eventually damaged the gelled batteries. The controller setpoints were set for a flooded LA battery and were not field adjustable.

Table 5. Results from first two validations.

	Validation 1		Validation 2			
System	**UBC**	**T_{batt} avg**	**UBC**	**T_{batt} avg**	**UBC V2 / UBC V1**	**LVD**
Units	Ah	°C	Ah	°C		V
System 1-1 NREL 105 Ah	65	8	55	5	85%	11.7
System 1-3 SWTDI 105 Ah	70	22	65	21	93%	11.5
System 1-4 FSEC 105 Ah	60	22	86	22	143%	11.6
System 1-5 PVUSA 105 Ah			74	6		11.4
System 2-1 NREL 60 Ah	76	7	19	3	25%	11.4
System 2-3 SWTDI 60 Ah	65	24	38	25	58%	11.6
System 2-4 FSEC 60 Ah	67	19				11.0
System 2-5 PVUSA 60 Ah	62	23	36	8	58%	11.3

10 FUTURE WORK

10.1 Proposed Changes to the Procedures

Based on the findings of Validation 3, some changes will appear in the next revision of the procedures. The load run-time may be specified by the system designer, instead of using the current 4-hour run time that "favors" systems with smaller loads. UBC_1 will be modified so that when the battery reaches V_r, the discharge will start immediately. This will quantify the UBC when the battery has only just reached V_r, instead of allowing the battery to continue charging after reaching V_r.

A number of questions were raised during Validation 3 that will need to be addressed:

- How do we limit solar insolation when we are testing outdoors? (Is disconnecting the array after reaching a certain number of sun-hours the same as collecting the same number of sun-hours under low-irradiance conditions?)
- When is a battery (fully) charged?
- How many days data are required before the P-chart yields meaningful results?
- What constitutes a "good" PV system?
- Must a "good" PV system have an LVD? Some researchers thought that a well-designed system would never allow a battery to drop so low; therefore, an LVD should not be necessary. If no LVD is employed, at what point would the tests terminate?

10.2 Development of a Qualification Test for SAPV Systems

A qualification test for pre-packaged, SAPV systems will be developed on completion of the performance test document, IEEE 1526. SAPV systems commonly contain PV modules, batteries, and charge controllers powering such loads as lighting, radios, and televisions. They are often installed in remote villages in developing countries. A qualification test will be developed that will include the performance test, in addition to other component tests, to determine the long-term reliability of SAPV systems.

As an example, the module qualification procedures evolved from module performance procedures, including IEEE 1262, "Recommended Practice for Qualification of PV Modules," [9] and IEC 61215, "Crystalline Silicon Terrestrial PV Modules - Design Qualification and Type Approval" [10]. The individual tests were developed based on failure mechanisms observed in the field. The module qualification test sequence includes:

- Thermal-Cycle Test
- Humidity Freeze Test
- Damp Heat Test
- High-Pot Test
- Mechanical Load
- Hail Test
- Hot Spot
- UV Exposure.

IEEE 1526 currently provides performance procedures for SAPV systems. Several steps need to be taken to develop it into qualification procedures:

- Identify failures in SAPV systems. This will involve corresponding with and visiting other laboratories, PV system integrators, and installers.
- Identify the mechanisms that lead to system failures.
- Find accelerated conditions that can duplicate failures in the field.
- Establish tentative test levels and compare to field results.
- Modify the qualification procedures as needed.

The following is a proposed timeline for developing SAPV system qualification procedures:

FY 2001 - Complete development of performance procedures for SAPV systems (IEEE 1526).
Identify failures and mechanisms leading to failures in fielded systems.
FY 2002 - Find accelerated conditions that duplicate failures in the field and establish tentative procedures.
FY 2003 - Start procedures and compare to field results. Modify as needed. Develop draft procedures.
FY 2004 - Publish NREL technical report detailing qualification procedures for small SAPV systems and submit to IEEE for developing a consensus standard.

11 CONCLUDING REMARKS

Validating the procedures at the various test sites did demonstrate their value. The procedures did verify that the systems and loads operated (or failed); but because they are of relatively short duration, they may not uncover unreliable components. Qualification procedures will be developed to address this problem. The performance procedures did measure the ability of the array and system to recharge the battery. The procedures did measure the system's UBC and how it changes over time. There was good measurement agreement between the UBC results measured at different test sites on similar systems. The performance procedures do provide valuable results, especially in terms of a system's design.

12 ACKNOWLEDGEMENTS

The authors would like to thank the many individuals that reviewed the test procedures, especially Mike Thomas and John Stevens (Sandia National Laboratories) for their detailed reviews and comments. We also thank Steve Durand for his contributions to the procedures in their early stages. This work was performed at NREL under Contract No. DE-AC36-99GO10337. At SWTDI, the work is funded under Contract No. DE-AC04-94AL85000. At FSEC, the work is funded under Contract No. DE-FC04-00AL66793. GENEC would also like to thank its partners in the EC's PLISE Project: JRC ESTI (Italy), TUV Rheinland (Germany), CIEMAT (Spain), BP Solarex (UK), and Transenergie (France).

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Appendix A: NREL Results

This appendix contains some of the data and results of the six SAPV systems tested at NREL.

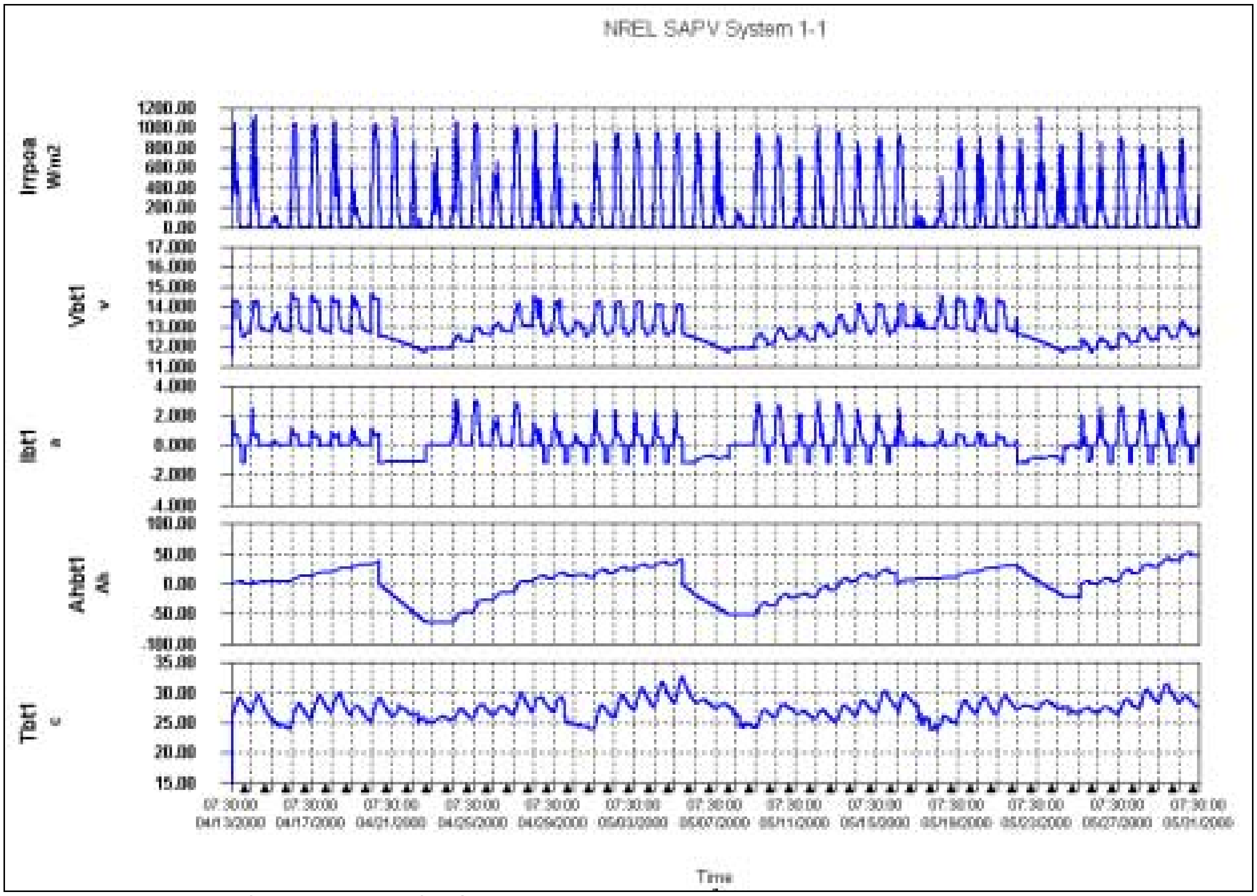

Figure 5. Performance data for System 1-1, at NREL during Validation 3, April 13 – May 31, 2000.

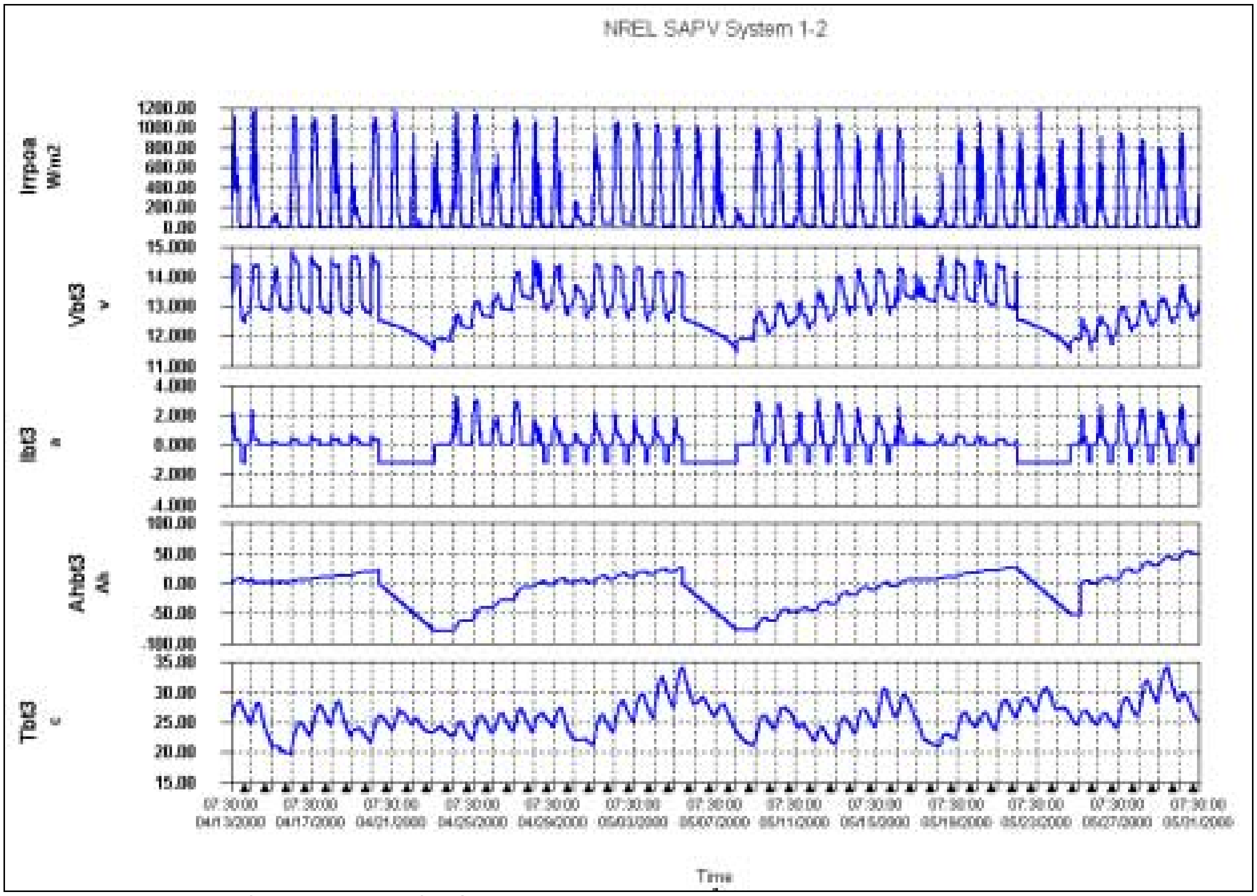

Figure 6. Performance data for System 1-2, at NREL during Validation 3, April 13 – May 31, 2000.

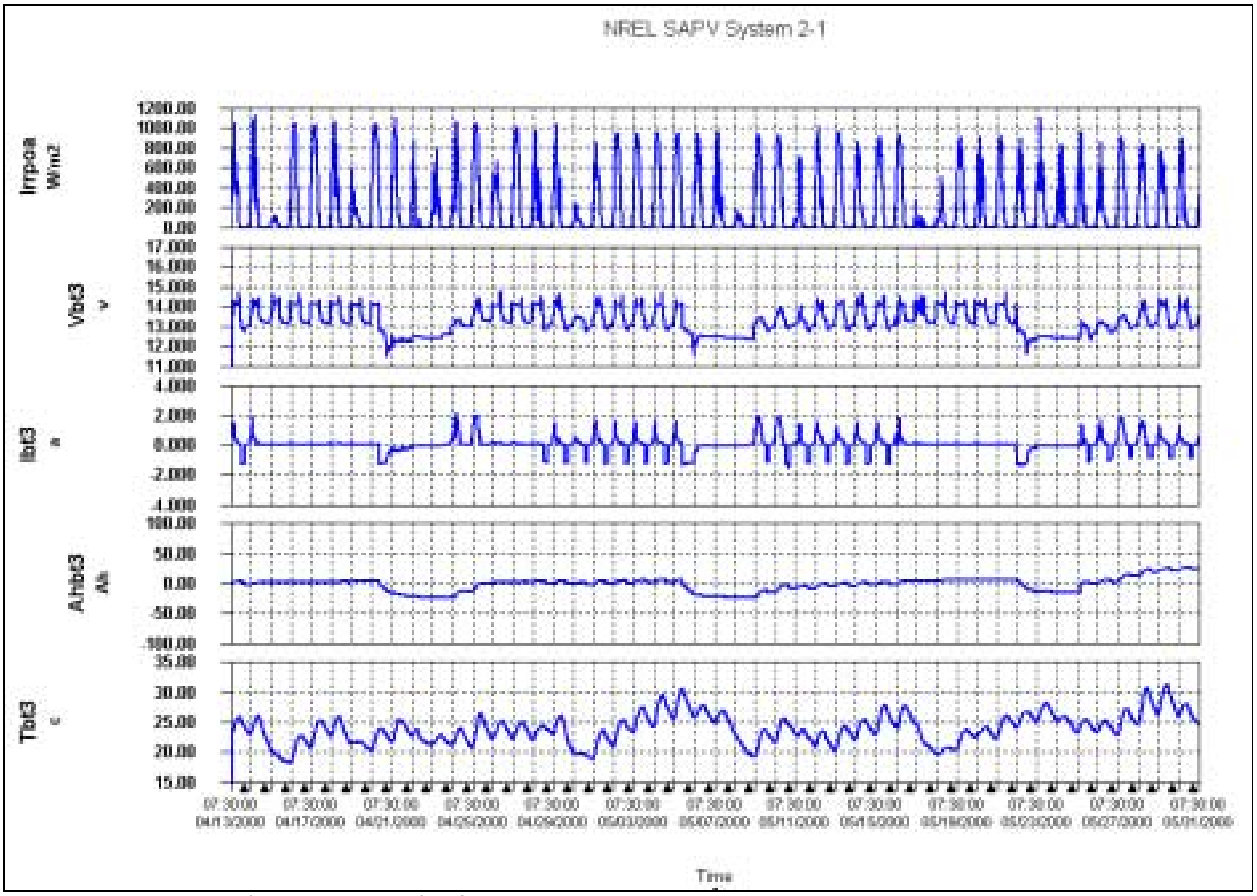

Figure 7. Performance data for System 2-1, at NREL during Validation 3, April 13 – May 31, 2000.

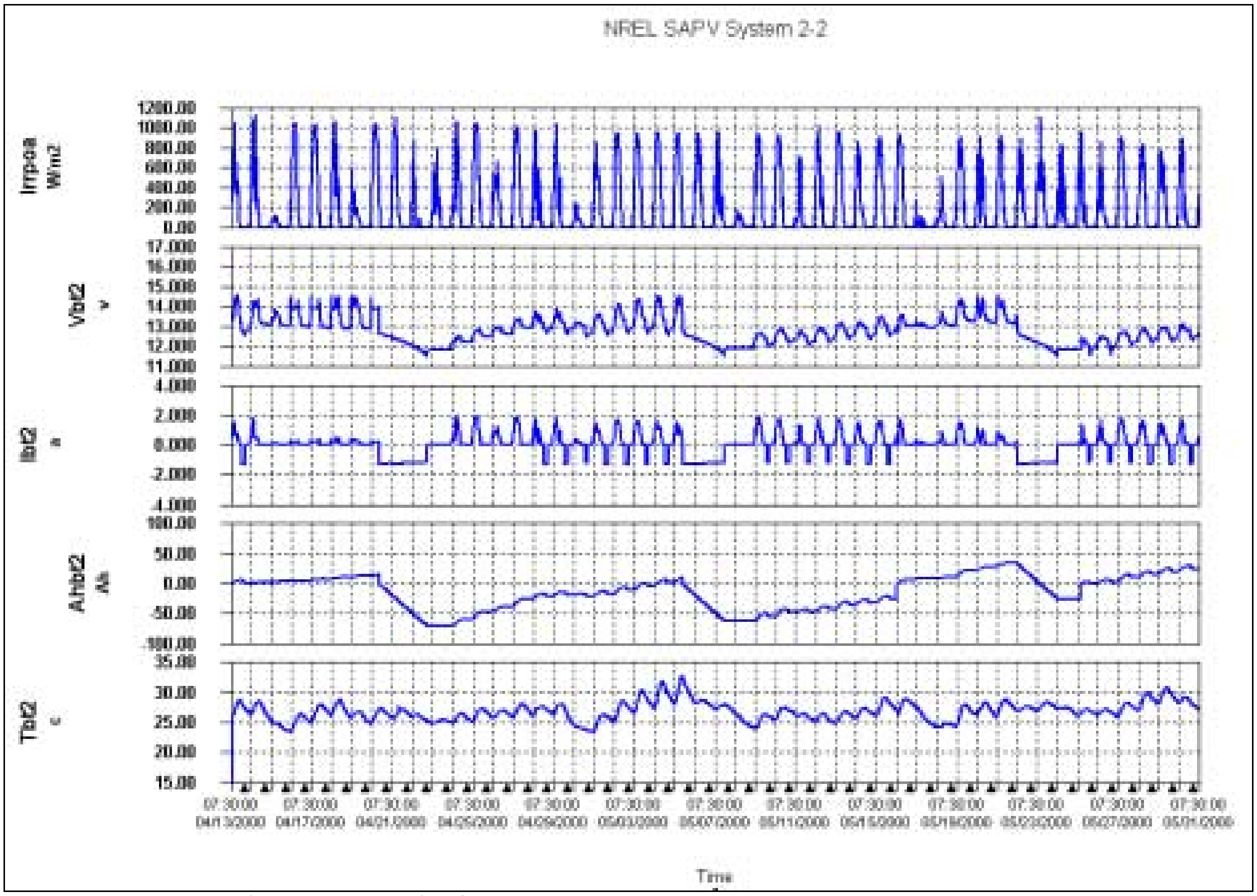

Figure 8. Performance data for System 2-2, at NREL during Validation 3, April 13 – May 31, 2000.

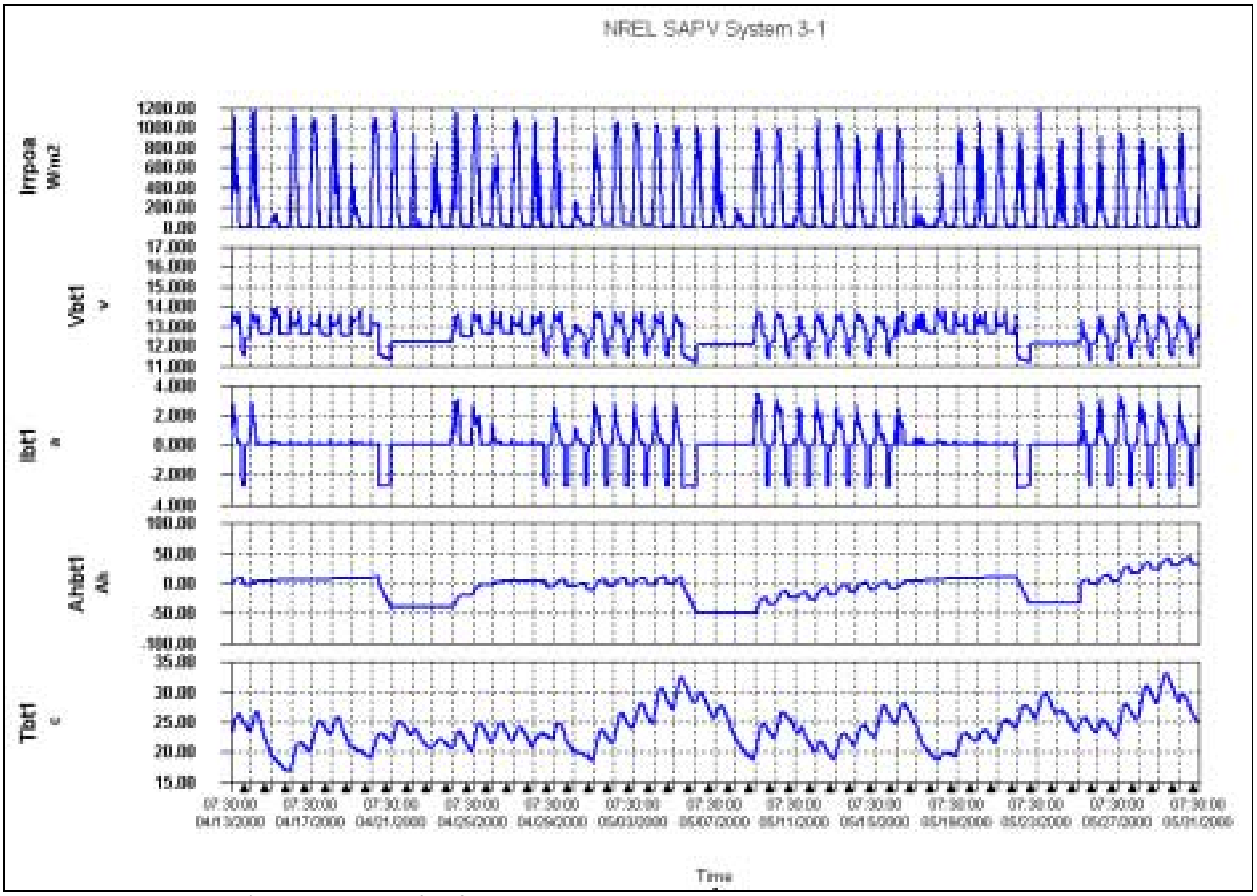

Figure 9. Performance data for System 3-1, at NREL during Validation 3, April 13 – May 31, 2000.

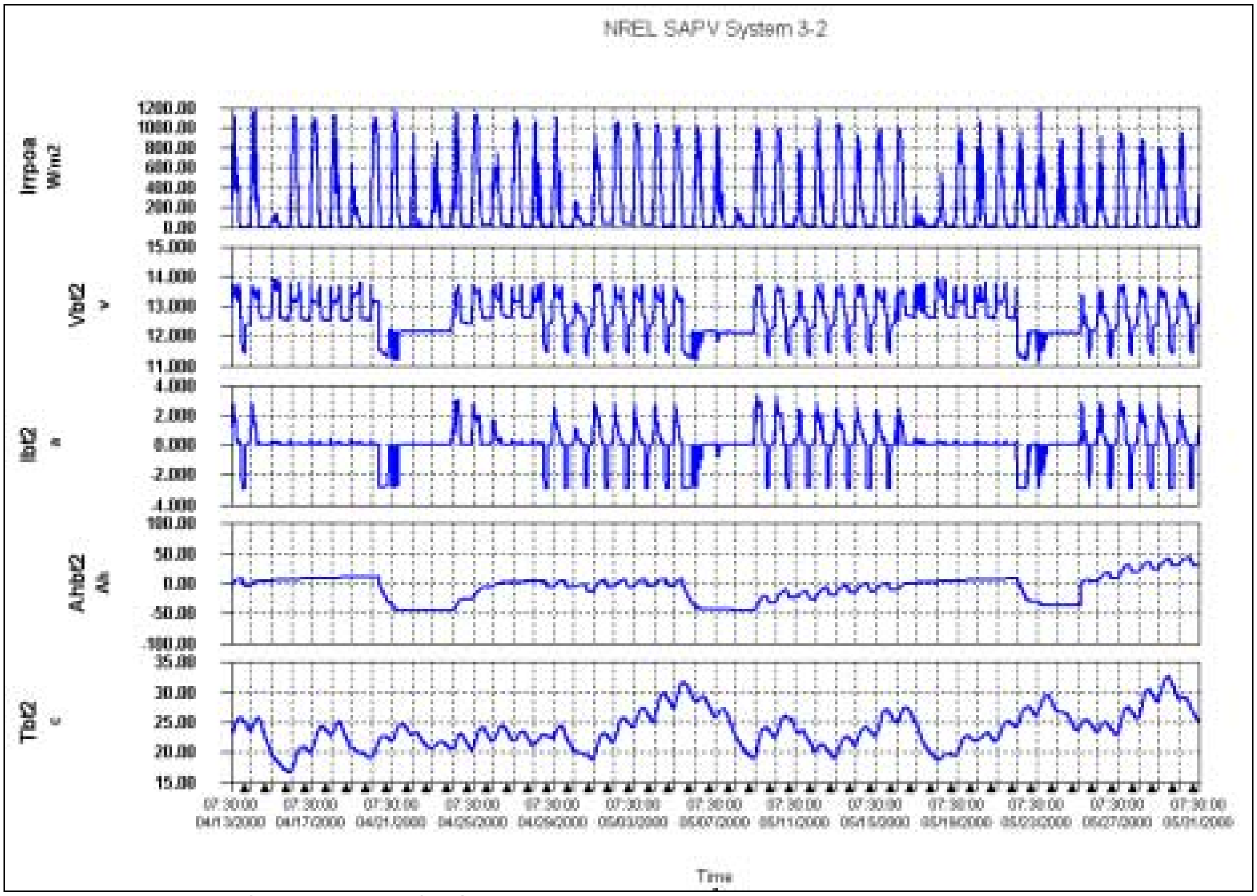

Figure 10. Performance data for System 3-2, at NREL during Validation 3, April 13 – May 31, 2000.

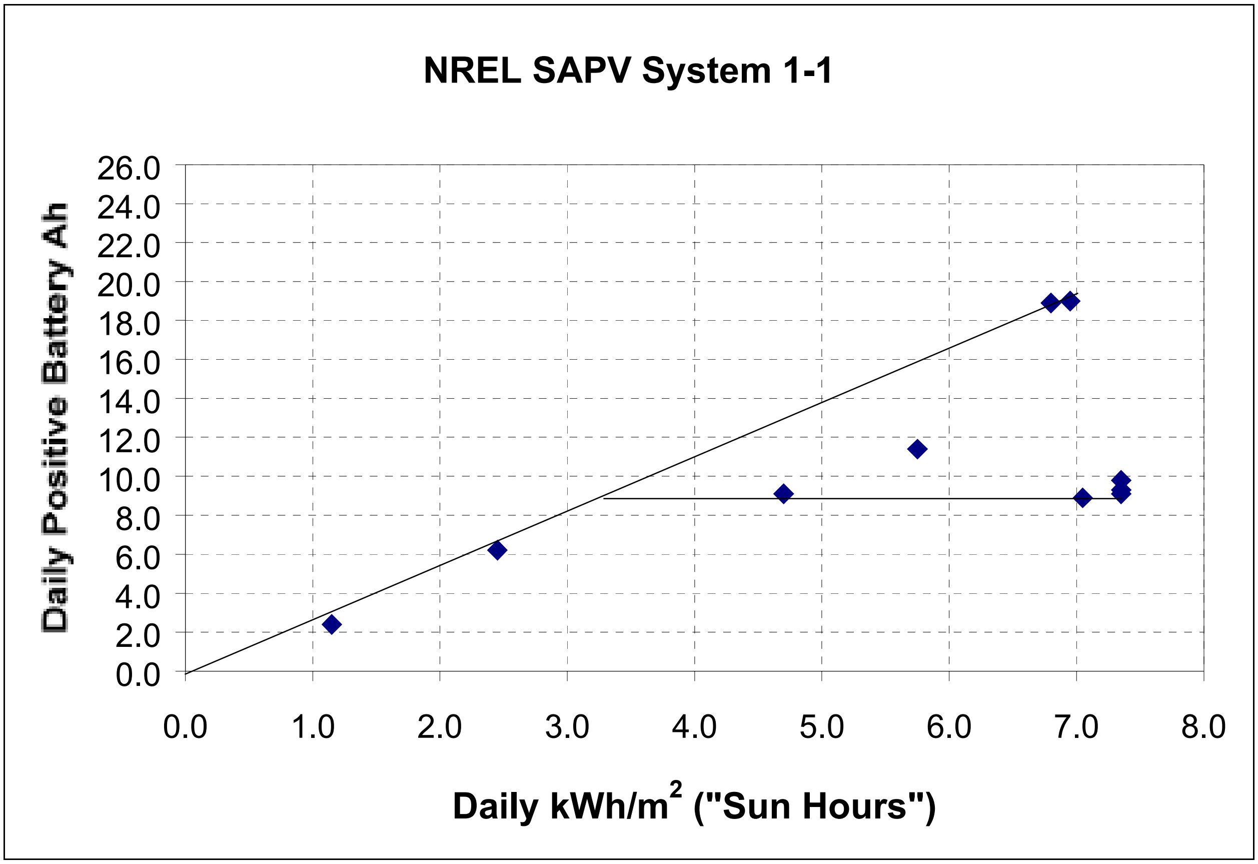

Figure 11. P-Chart for System 1-1 at NREL, April 29 – May 11, 2000 (4-hour load run-time).

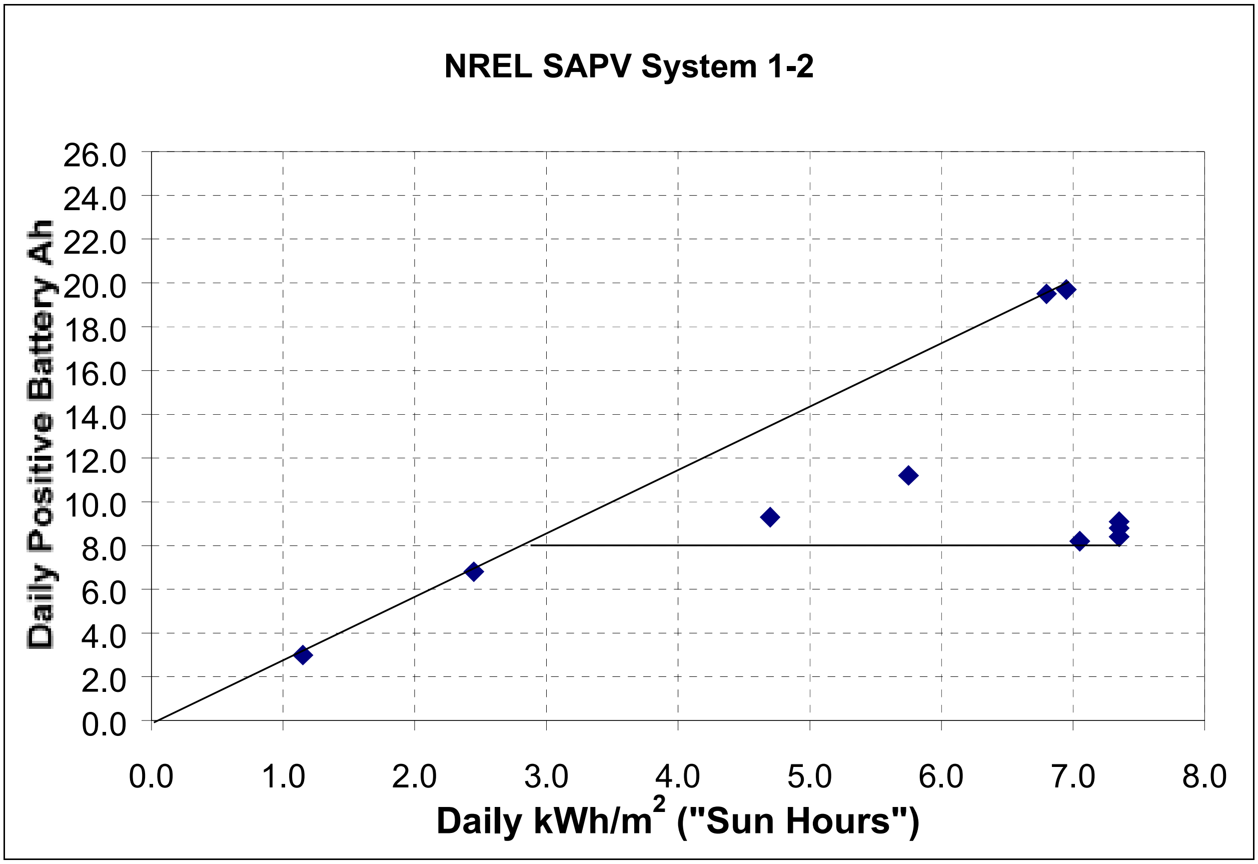

Figure 12. P-Chart for System 1-2 at NREL, April 29 – May 11, 2000 (4-hour load run-time).

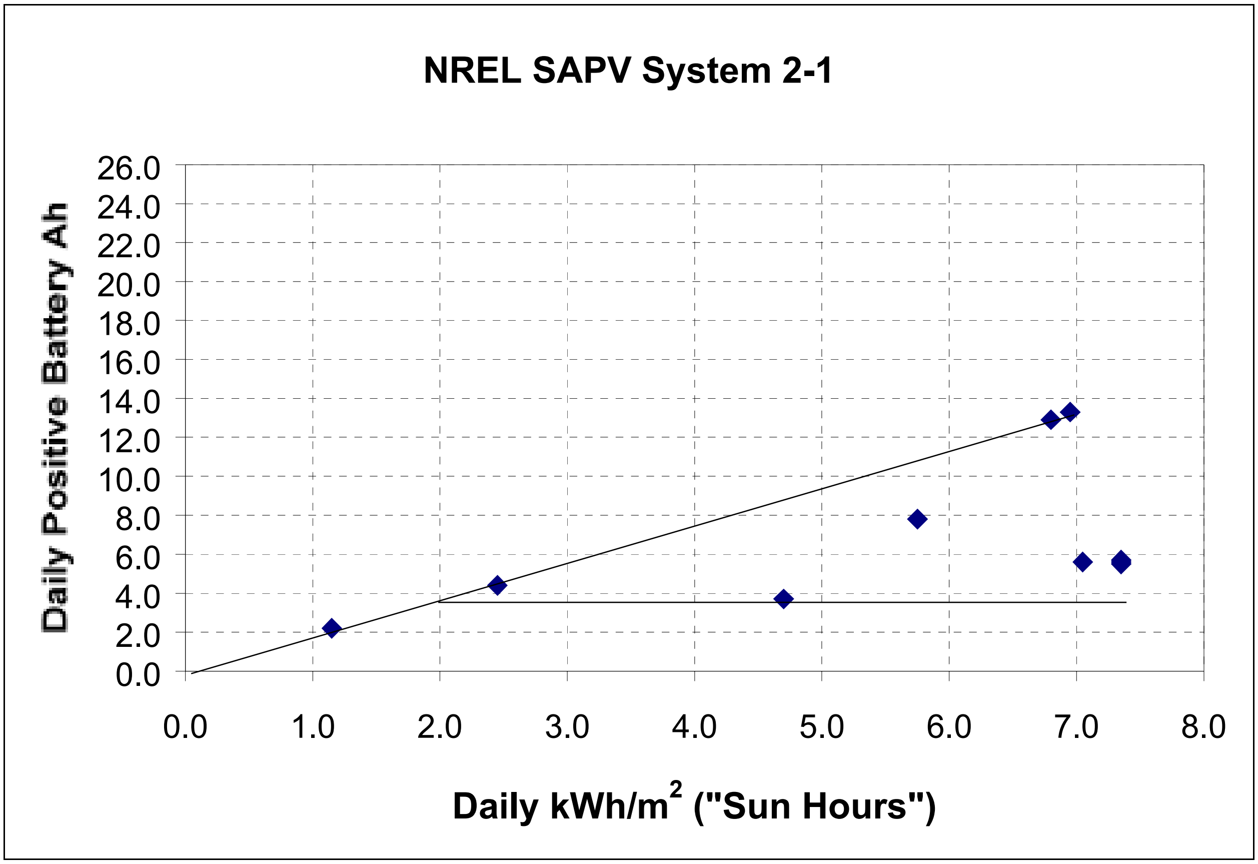

Figure 13. P-Chart for System 2-1 at NREL, April 29 – May 11, 2000 (4-hour load run-time).

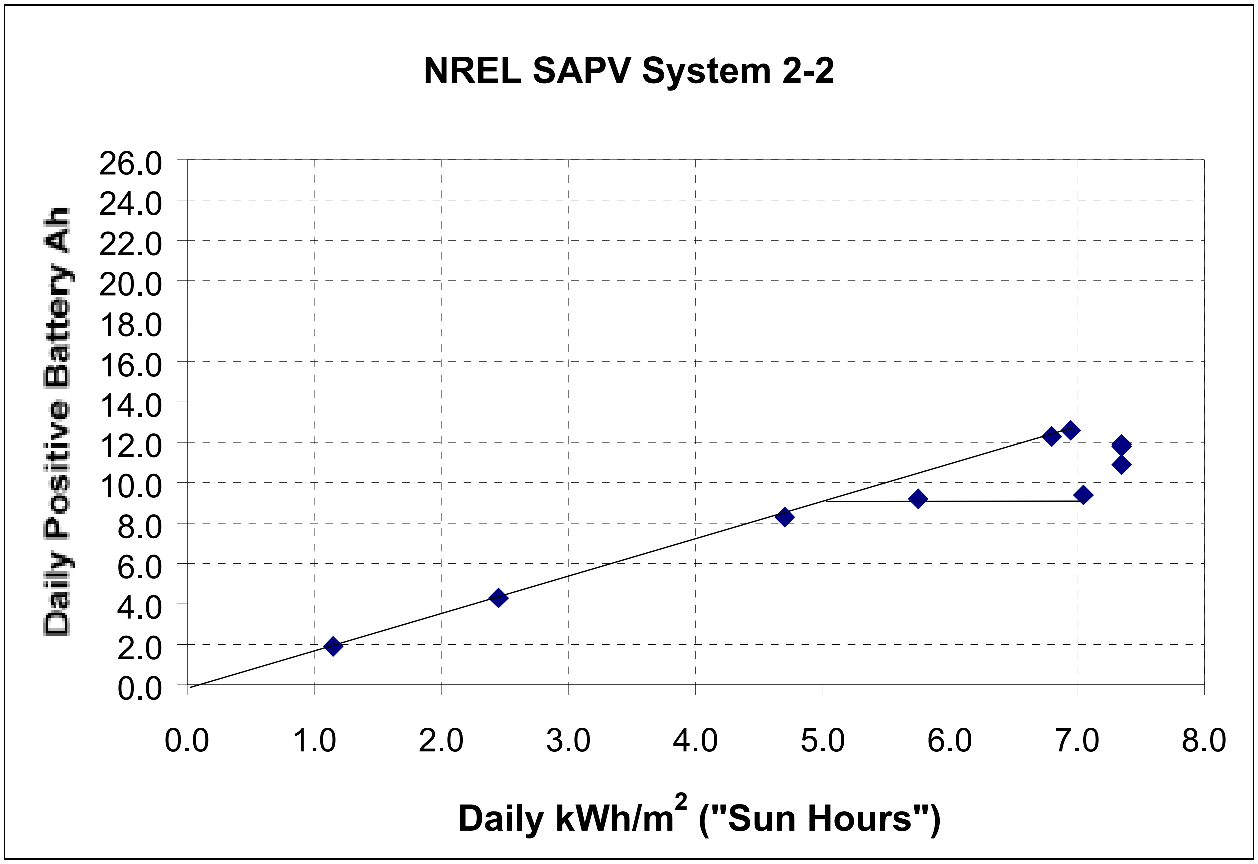

Figure 14. P-Chart for System 2-2 at NREL, April 29 – May 11, 2000 (4-hour load run-time).

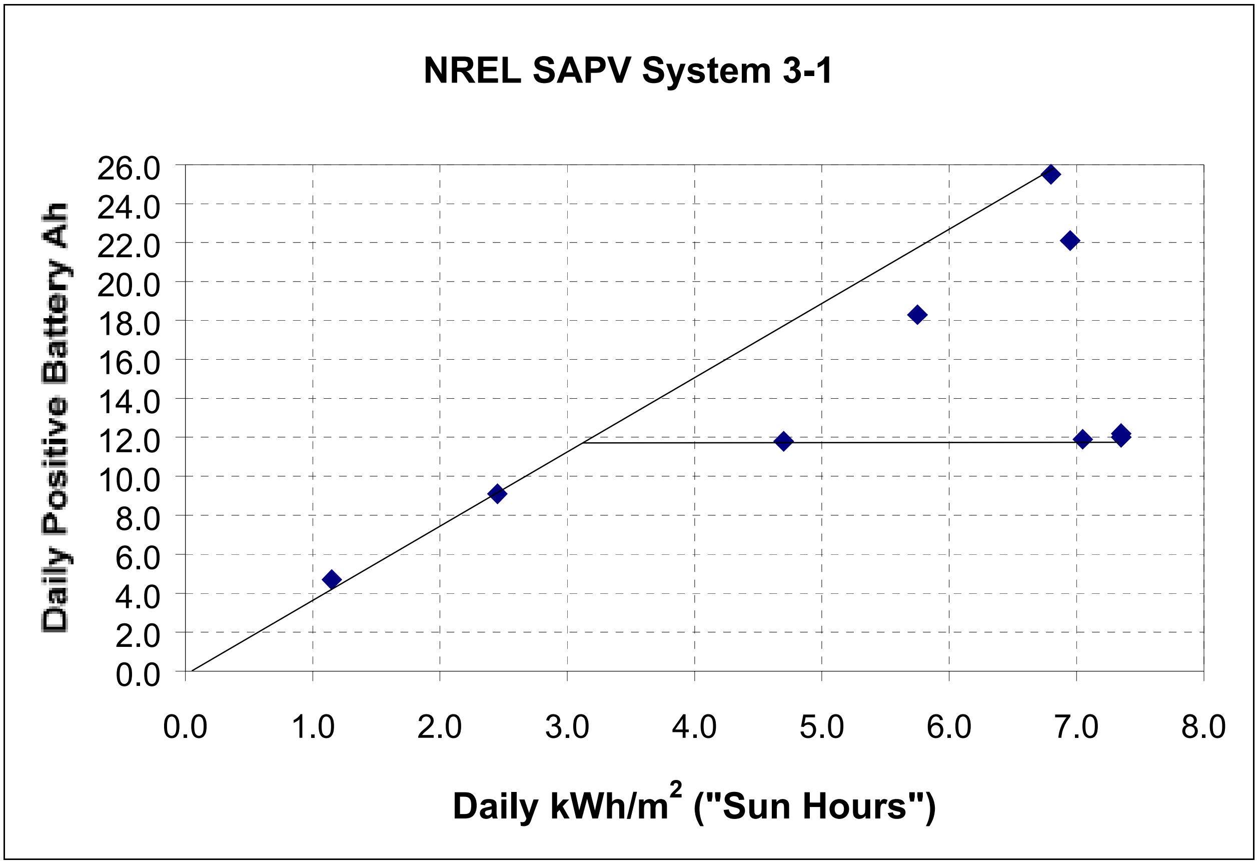

Figure 15. P-Chart for System 3-1 at NREL, April 29 – May 11, 2000 (4-hour load run-time).

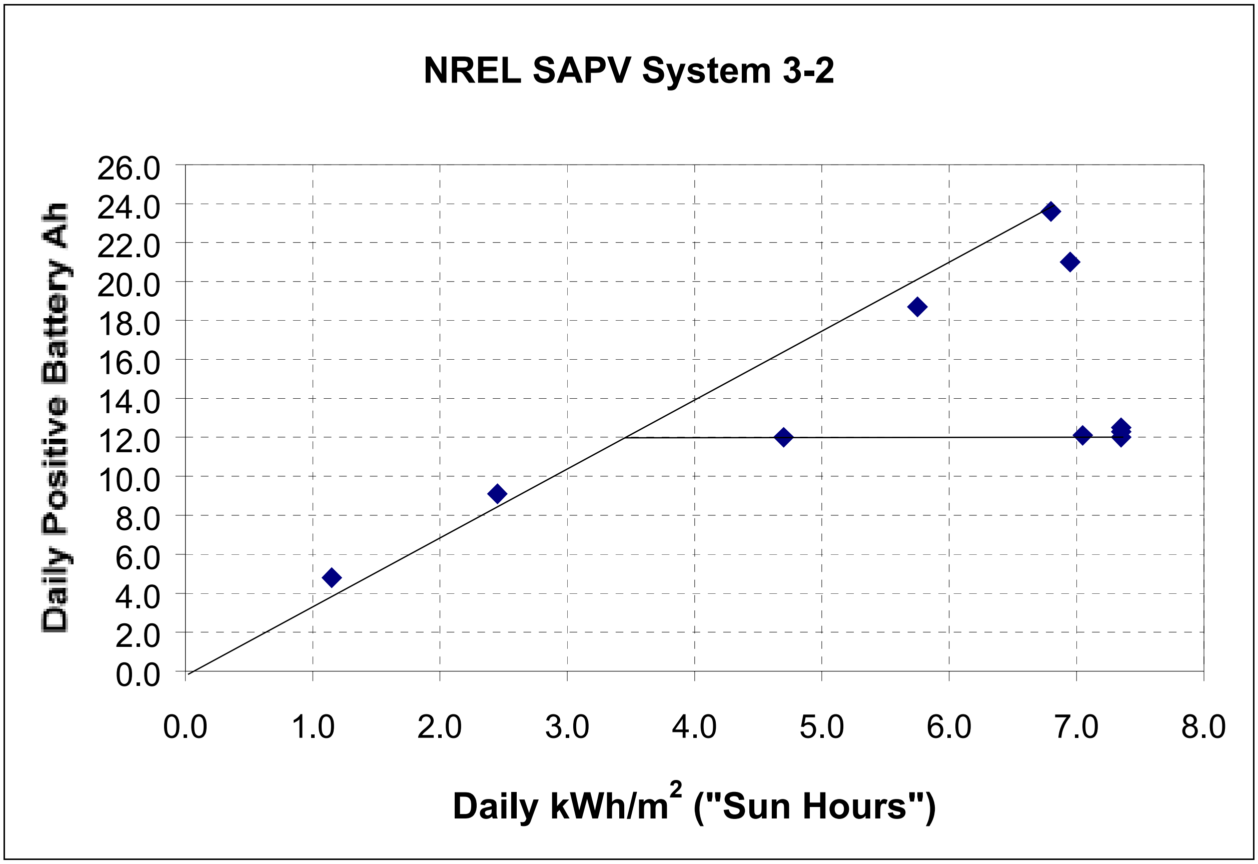

Figure 16. P-Chart for System 3-2 at NREL, April 29 – May 11, 2000 (4-hour load run-time).

NREL System 1-1

Stand-Alone PV System Summary - Page 1 of 2 - System Specifications and Information

System Information

Parameter		
System Manufacturer	5.1	#1
System Model	5.1	HLK-50
Vendor	5.1	#1

Array Information

Parameter		Specified		Measured/Observed
Module Manufacturer	5.1	Solec		
Module Model	5.1	S-050		
Active Material	5.1	x-Si		
Array Configuration	5.1	1 x 1		
Array P_{max} @ STC (W)	5.1	50	9	
Array V_{pp} (V)	5.1	17.1	9	
Array I_{pp} (A)	5.1	2.92	9	
Array V_{oc} (V)	5.1	21.3	9	
Array I_{sc} (A)	5.1	3.34	9	
Array Shield	5.1	none		

Load Information

Parameter		Specified		Measured/Observed
Description	5.1	fluorescent lamp		
Manufacturer	5.1	ThinLite		
Voltage (V)	5.1	12	7.3.1	
Current (A)	5.1	1.25	7.3.1	1.2
Power (W)	5.1	15 W		
Operating Temperature Range (^{o}C)	5.1			
Number of Loads	5.1	1		

Controller Information

Parameter		Specified		Measured/Observed
Manufacturer	5.1	MorningStar		
Model	5.1	SunSaver-6		
Type	5.1	constant voltage, solid state PWM		
Vr Set Point (V)	5.1	14.4 V flooded battery	7.6.1	14.40 - 14.73
Controller-Battery Compatibility	5.1	user settable		
Temperature Compensation Sensor Attaches to Battery?	5.1	no		
Reverse-Current Protection?	5.1	yes		
Load Timer Accuracy	5.1	n/a	7.3.1	n/a
LVD Set Point (V)	5.1	11.5	7.6.2	11.68

Battery Information

Parameter		Specified		Measured/Observed
Manufacturer	5.1	Trojan "old" spare from Manu #1		
Model	5.1	RE-4		
Type	5.1	flooded LA (antimony)		
Configuration	5.1	1 x 1		
Voltage (V)	5.1	12	7.3.1	
Capacity (Ah)	5.1	105 Ah	7.6.2	54

Documentation Checklist

Parameter		Included	Notes/Comments
Parts List	5.1	X	
Required-But-Not-Included-Parts List	5.1		
Recommended-Tool List	5.1	X	
Mechanical Drawings	5.1	X	
Electrical Schematic or Diagram	5.1	X	
Installation Procedures	5.1	X	
Spare Parts List	5.1		
Maintenance Procedures	5.1	X	

NREL System 1-1

Stand-Alone PV System Summary - Page 2 of 2 - Test Information and Results

Test Information

Parameter				
Test Facility	5.1	NREL		
Address	5.1	1617 Cole Blvd, Golden, CO 80215 USA		
Contact	5.1	Peter McNutt		
System Inspection				
System Arrival Date	5.1	1/26/1999		
(Attach copy of system documentation)	5.1			
Damaged parts?	5.2	(negative battery post bent slightly)		
All parts present?	5.2	yes		
Parts that need to be procured?	5.2			
System Installation & Instrumentation				
Battery preparation and boost charge documented?	6.1.1	no		
Average battery temperature & range (°C)	6.1.2			
CC temperature compensation senses T_bt?	6.1.3	no		
Load(s) start & operate	6.1.4	ok		
Load operation sensing method	6.2.5	photometers		
(Attach diagram with DAS sensor locations)	6.2.6			
System Operation				
Parameter		**Specified**		**Measured/Observed**
Run Time (Hrs)	5.1	4 hrs	7.3.1	4
Load Control Method	5.1	DAS		
System Intended Location	5.1	Golden CO		
Intended Location Design Month	5.1	December		
System Performance Results				
Parameter		**Specified/Calculated**		**Measured/Observed**
Hours of Autonomy (Hrs)	5.1	(105 Ah / 2) / 1.25 A = 42 h	7.6.4	54 Ah / 1.2 A = 45 h
Sun-Hours to Vr	5.1	n/a	7.5.1	34
A:L Ratio	7.3.2	(2.9 A x 4.5 h) / (1.3 A x 4 h) = 2.5	7.3.3	2.1

System Performance Tests

UBC_0		
Start date & time	7.1.1	4/14/00 (105) 0600 mst
Vr (V)	7.1.1	14.73 V
T_bt min/avg/max at Vr (°C)	7.1.1	24 / 27 / 30 deg C
LVD (V)	7.1.2	11.68 V
UBC_0 (Ah)	7.1.2	64 Ah (25 / 26 / 29 deg C)
End date & time	7.1.2	4/24/00 (115) 0500
FT		
Start date & time	7.3.1	4/28/00 (119) 05:15
V_ld min/avg/max (V)	7.3.1	12.29 / 12.40 / 12.48 V
I_ld min/avg/max (A)	7.3.1	1.11 / 1.18 / 1.20 A
Run time (Hrs/night)	7.3.1	4 h/night
V_bt min/max (V)	7.3.1	12.44 / 14.51 V
T_bt min/avg/max (°C)	7.3.1	24 / 28 / 33 deg C
End date & time	7.3.1	5/5/00 (126) 17:00
Expected A:L ratio	7.3.2	(5.4 h x 2.9 A) / (4 h x 1.3 A) = 3.0
Actual A:L ratio	7.3.3	70 Ah / 34 Ah = 2.1
UBC_1		
Start date & time	7.4.1	5/5/00 (126) 17:00
Vr (V)	7.4.1	14.40 V
T_bt min/avg/max at Vr (°C)	7.4.1	26 / 29 / 33 deg C
LVD (V)	7.4.2	11.68 V (24 / 28 / 33 deg C)
UBC_1 (Ah)	7.4.2	51 Ah
End date & time	7.4.2	5/9/00 (130) 06:00
RT		
Start date & time	7.5.1	5/9/00 (130) 06:30
End date & time	7.5.1	5/16/00 (137) 06:15
Sun Hours to Vr	7.5.1	34 Sh
Battery Ah to Vr	7.5.2	67 Ah
Battery Ah / Sun Hour	7.5.2	9.5 Ah / 3.5 Sh = 2.7 Ah / Sh
Sun Hours / Day required to meet load	7.5.2	3.5 Sh
(Attach Battery Ah vs. Sun-hours plot)	7.5.2	
UBC_2		
Vr (V)	7.6.1	14.62 V
T_bt min/avg/max at Vr (°C)	7.6.1	24 / 27 / 30 deg C
LVD (V)	7.6.2	11.68 V
UBC_2	7.6.2	54 Ah (26 / 28 / 29 deg C) (54 / 105 = 51%)
End date & time	7.6.2	5/25/00 (146) 12:00
UBC_0 - UBC_2 (Ah)	7.6.3	10 Ah decrease (-16%)
Hours of Autonomy (Hrs)	7.6.4	45 h

Final System Inspection

Maintenance procedures ok?	8.1	ok
System visual inspection ok?	8.2	ok
System wiring ok?	8.3	ok

NREL System 1-2

Stand-Alone PV System Summary - Page 1 of 2 - System Specifications and Information

System Information

Parameter			
System Manufacturer	5.1	#1	
System Model	5.1	HLK-50	
Vendor	5.1	#1	

Array Information

Parameter		Specified	Measured/Observed	
Module Manufacturer	5.1	Solec		
Module Model	5.1	S-050		
Active Material	5.1	x-Si		
Array Configuration	5.1	1 x 1		
Array P_{max} @ STC (W)	5.1	50	9	
Array V_{pp} (V)	5.1	17.1	9	
Array I_{pp} (A)	5.1	2.92	9	
Array V_{oc} (V)	5.1	21.3	9	
Array I_{sc} (A)	5.1	3.34	9	
Array Shield	5.1	none		

Load Information

Parameter		Specified	Measured/Observed	
Description	5.1	fluorescent lamp		
Manufacturer	5.1	ThinLite		
Voltage (V)	5.1	12V	7.3.1	
Current (A)	5.1	1.25A	7.3.1	1.3
Power (W)	5.1	15W		
Operating Temperature Range (^{o}C)	5.1			
Number of Loads	5.1	1		

Controller Information

Parameter		Specified	Measured/Observed	
Manufacturer	5.1	MorningStar		
Model	5.1	SunSaver-6		
Type	5.1	constant voltage, solid state PWM		
Vr Set Point (V)	5.1	14.4V flooded battery	7.6.1	14.46 - 14.86
Controller-Battery Compatibility	5.1	user settable		
Temperature Compensation Sensor Attaches to Battery?	5.1	no		
Reverse-Current Protection?	5.1	yes		
Load Timer Accuracy	5.1	n/a	7.3.1	
LVD Set Point (V)	5.1	11.5	7.6.2	11.43

Battery Information

Parameter		Specified	Measured/Observed	
Manufacturer	5.1	Trojan "new" from Hensley		
Model	5.1	27-EV		
Type	5.1	flooded LA (antimony)		
Configuration	5.1	1 x 1		
Voltage (V)	5.1	12V	7.3.1	
Capacity (Ah)	5.1	105Ah	7.6.2	76

Documentation Checklist

Parameter		Included	Notes/Comments
Parts List	5.1	X	
Required-But-Not-Included-Parts List	5.1		
Recommended-Tool List	5.1	X	
Mechanical Drawings	5.1	X	
Electrical Schematic or Diagram	5.1	X	
Installation Procedures	5.1	X	
Spare Parts List	5.1		
Maintenance Procedures	5.1	X	

NREL System 1-2

Stand-Alone PV System Summary - Page 2 of 2 - Test Information and Results

Test Information

Parameter				
Test Facility	5.1	NREL		
Address	5.1	1617 Cole Blvd, Golden, CO 80215 USA		
Contact	5.1	Peter McNutt		
System Inspection				
System Arrival Date	5.1	1/26/1999 (battery 2/10/00 - Hensley)		
(Attach copy of system documentation)	5.1			
Damaged parts?	5.2			
All parts present?	5.2	yes		
Parts that need to be procured?	5.2			
System Installation & Instrumentation				
Battery preparation and boost charge documented?	6.1.1	no		
Average battery temperature & range (^oC)	6.1.2			
CC temperature compensation senses T_bt?	6.1.3	no		
Load(s) start & operate	6.1.4	ok		
Load operation sensing method	6.2.5	photometers		
(Attach diagram with DAS sensor locations)	6.2.6			
System Operation				
Parameter		**Specified**		**Measured/Observed**
Run Time (Hrs)	5.1	4 hrs	7.3.1	
Load Control Method	5.1	DAS		
System Intended Location	5.1	Golden CO		
Intended Location Design Month	5.1	December		
System Performance Results				
Parameter		**Specified/Calculated**		**Measured/Observed**
Hours of Autonomy (Hrs)	5.1	(105Ah / 2) / 2.9A = 18h	7.6.4	60
Sun-Hours to Vr	5.1	n/a	7.5.1	38
A:L Ratio	7.3.2	(2.9A x 4.5h) / (1.3A x 4h) = 2.5	7.3.3	2
System Performance Tests				
UBC_0				
Start date & time	7.1.1	4/14/00 (105) 0600 mst		
Vr (V)	7.1.1	14.86V		
T_bt min/avg/max at Vr (^oC)	7.1.1	20 / 24 / 29 deg C		
LVD (V)	7.1.2	11.44V		
UBC_0 (Ah)	7.1.2	79Ah (23 / 25 / 28 deg C)		
End date & time	7.1.2	4/24/00 (115) 0500		
FT				
Start date & time	7.3.1	4/28/00 (119) 05:15		
V_ld min/avg/max (V)	7.3.1	11.78 / 12.56 / 12.90 V		
I_ld min/avg/max (A)	7.3.1	1.10 / 1.27 / 1.29 A		
Run time (Hrs/night)	7.3.1	4 h/night		
V_bt min/max (V)	7.3.1	12.48 / 14.57 V		
T_bt min/avg/max (^oC)	7.3.1	21 / 28 / 34 deg C		
End date & time	7.3.1	5/5/00 (126) 17:00		
Expected A:L ratio	7.3.2	(5.4 h x 2.9 A) / (4 h x 1.3 A) = 3.0		
Actual A:L ratio	7.3.3	69 Ah / 35 Ah = 2.0		
UBC_1				
Start date & time	7.4.1	5/5/00 (126) 17:00		
Vr (V)	7.4.1	14.46 V		
T_bt min/avg/max at Vr (^oC)	7.4.1	21 / 27 / 34 deg C		
LVD (V)	7.4.2	11.43 V		
UBC_1 (Ah)	7.4.2	78 Ah		
End date & time	7.4.2	5/9/00 (130) 06:00		
RT				
Start date & time	7.5.1	5/9/00 (130) 06:30		
End date & time	7.5.1	5/16/00 (137) 06:15		
Sun Hours to Vr	7.5.1	38 Sh		
Battery Ah to Vr	7.5.2	71 Ah		
Battery Ah / Sun Hour	7.5.2	8 Ah / 3 Sh		
Sun Hours / Day required to meet load	7.5.2	3.0 Sh		
(Attach Battery Ah vs. Sun-hours plot)	7.5.2			
UBC_2				
Vr (V)	7.6.1	14.73 V		
T_bt min/avg/max at Vr (^oC)	7.6.1	21 / 25 / 30 deg C		
LVD (V)	7.6.2	11.44 V		
UBC_2	7.6.2	76 Ah (25 / 28 / 31 deg C) (76 / 105 = 72%)		
End date & time	7.6.2	5/25/00 (146) 12:00		
UBC_0 - UBC_2 (Ah)	7.6.3	3 Ah decrease (-4%)		
Hours of Autonomy (Hrs)	7.6.4	60 h		
Final System Inspection				
Maintenance procedures ok?	8.1	ok		
System visual inspection ok?	8.2	ok		
System wiring ok?	8.3	ok		

NREL System 2-1

Stand-Alone PV System Summary - Page 1 of 2 - System Specifications and Information

System Information

Parameter		
System Manufacturer	5.1	#2
System Model	5.1	Lighting Kit
Vendor	5.1	

Array Information

Parameter		Specified		Measured/Observed
Module Manufacturer	5.1	#2		
Module Model	5.1			
Active Material	5.1	a-Si		
Array Configuration	5.1	1 x 1		
Array P_{max} @ STC (W)	5.1	32	9	
Array V_{pp} (V)	5.1	16.5	9	
Array I_{pp} (A)	5.1	1.94	9	
Array V_{oc} (V)	5.1	23.8	9	
Array I_{sc} (A)	5.1	2.4	9	
Array Shield	5.1	none		

Load Information

Parameter		Specified		Measured/Observed
Description	5.1	fluorescent lamps		
Manufacturer	5.1	n/a		
Voltage (V)	5.1	12V	7.3.1	
Current (A)	5.1	2 x 0.67A = 1.33A	7.3.1	1.2
Power (W)	5.1	2 x 8W = 16W		
Operating Temperature Range (^oC)	5.1			
Number of Loads	5.1	2		

Controller Information

Parameter		Specified		Measured/Observed
Manufacturer	5.1	#2		
Model	5.1	PCC		
Type	5.1	on/off shunt		
Vr Set Point (V)	5.1	?	7.6.1	14.97 - 15.09
Controller-Battery Compatibility	5.1	?		
Temperature Compensation Sensor Attaches to Battery?	5.1	none		
Reverse-Current Protection?	5.1	?		
Load Timer Accuracy	5.1	n/a	7.3.1	
LVD Set Point (V)	5.1	?	7.6.2	11.24 - 11.37

Battery Information

Parameter		Specified		Measured/Observed
Manufacturer	5.1	PowerSonic (known bad - using to validate procedures)		
Model	5.1	12600		
Type	5.1	gelled VRLA		
Configuration	5.1	1 x 1		
Voltage (V)	5.1	12V	7.3.1	
Capacity (Ah)	5.1	60Ah	7.6.2	21

Documentation Checklist

Parameter		Included	Notes/Comments
Parts List	5.1	X	
Required-But-Not-Included-Parts List	5.1		
Recommended-Tool List	5.1	X	
Mechanical Drawings	5.1	PV only	
Electrical Schematic or Diagram	5.1	X	
Installation Procedures	5.1	X	
Spare Parts List	5.1		
Maintenance Procedures	5.1	X	

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Stand-Alone PV System Summary - Page 2 of 2 - Test Information and Results

Test Information				
Parameter				
Test Facility	5.1	NREL		
Address	5.1	1617 Cole Blvd, Golden, CO 80215 USA		
Contact	5.1	Peter McNutt		
System Inspection				
System Arrival Date	5.1	12/1/1998	using known bad, original battery	
(Attach copy of system documentation)	5.1			
Damaged parts?	5.2	no		
All parts present?	5.2	yes		
Parts that need to be procured?	5.2			
System Installation & Instrumentation				
Battery preparation and boost charge documented?	6.1.1	no		
Average battery temperature & range (^oC)	6.1.2			
CC temperature compensation senses T_bt?	6.1.3	no		
Load(s) start & operate	6.1.4	yes		
Load operation sensing method	6.2.5	photometers		
(Attach diagram with DAS sensor locations)	6.2.6			
System Operation				
Parameter		**Specified**		**Measured/Observed**
Run Time (Hrs)	5.1	4 hrs	7.3.1	
Load Control Method	5.1	DAS		
System Intended Location	5.1	Golden CO		
Intended Location Design Month	5.1	December		
System Performance Results				
Parameter		**Specified/Calculated**		**Measured/Observed**
Hours of Autonomy (Hrs)	5.1	(60Ah / 2) / 1.9A = 16h	7.6.4	17
Sun-Hours to Vr	5.1	n/a	7.5.1	23
A:L Ratio	7.3.2	(1.9A x 4.5h) / (1.3A x 4h) = 1.6	7.3.3	1.1
System Performance Tests				
UBC_0				
Start date & time	7.1.1	4/14/00 (105) 0600 mst		
Vr (V)	7.1.1	15.09V		
T_bt min/avg/max at Vr (^oC)	7.1.1	18 / 22 / 26 deg C		
LVD (V)	7.1.2	11.24V		
UBC_0 (Ah)	7.1.2	24Ah (21 / 23 / 26 deg C)		
End date & time	7.1.2	4/24/00 (115) 0500		
FT				
Start date & time	7.3.1	4/28/00 (119) 05:15		
V_ld min/avg/max (V)	7.3.1	12.51 / 12.63 / 12.70 V		
I_ld min/avg/max (A)	7.3.1	1.11 / 1.21 / 1.27 A		
Run time (Hrs/night)	7.3.1	4 h/night		
V_bt min/max (V)	7.3.1	12.71 / 14.99 V		
T_bt min/avg/max (^oC)	7.3.1	19 / 24 / 30 deg C		
End date & time	7.3.1	5/5/00 (126) 17:00		
Expected A:L ratio	7.3.2	(5.4 h x 1.9 A) / (4 h x 1.3 A) = 2.0		
Actual A:L ratio	7.3.3	38 Ah / 34 Ah = 1.1		
UBC_1				
Start date & time	7.4.1	5/5/00 (126) 17:00		
Vr (V)	7.4.1	14.97 V		
T_bt min/avg/max at Vr (^oC)	7.4.1	22 / 24 / 31 deg C		
LVD (V)	7.4.2	11.35 V		
UBC_1 (Ah)	7.4.2	24 Ah		
End date & time	7.4.2	5/9/00 (130) 06:00		
RT				
Start date & time	7.5.1	5/9/00 (130) 06:30		
End date & time	7.5.1	5/16/00 (137) 06:15		
Sun Hours to Vr	7.5.1	23 Sh		
Battery Ah to Vr	7.5.2	22 Ah		
Battery Ah / Sun Hour	7.5.2	3.7 Ah / 2.0 Sh		
Sun Hours / Day required to meet load	7.5.2	3		
(Attach Battery Ah vs. Sun-hours plot)	7.5.2			
UBC_2				
Vr (V)	7.6.1	15.04 V		
T_bt min/avg/max at Vr (^oC)	7.6.1	20 / 23 / 28 deg C		
LVD (V)	7.6.2	11.37 V		
UBC_2	7.6.2	21 Ah (24/26/28 deg C) (21/60 = 35%)		
End date & time	7.6.2	5/25/00 (146) 12:00		
UBC_0 - UBC_2 (Ah)	7.6.3	3 Ah decrease (-12 %)		
Hours of Autonomy (Hrs)	7.6.4	17 h		
Final System Inspection				
Maintenance procedures ok?	8.1	check wiring & battery maintenance per battery manufacturer's recommendations		
System visual inspection ok?	8.2	ok		
System wiring ok?	8.3	ok		

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Stand-Alone PV System Summary - Page 1 of 2 - System Specifications and Information

System Information

Parameter		
System Manufacturer	5.1	#2
System Model	5.1	Lighting Kit
Vendor	5.1	

Array Information

Parameter		Specified		Measured/Observed
Module Manufacturer	5.1	#2		
Module Model	5.1			
Active Material	5.1	a-Si		
Array Configuration	5.1	1 x 1		
Array P_{max} @ STC (W)	5.1	32	9	
Array V_{pp} (V)	5.1	16.5	9	
Array I_{pp} (A)	5.1	1.94	9	
Array V_{oc} (V)	5.1	23.8	9	
Array I_{sc} (A)	5.1	2.4	9	
Array Shield	5.1	none		

Load Information

Parameter		Specified		Measured/Observed
Description	5.1	fluorescent lamps		
Manufacturer	5.1	n/a		
Voltage (V)	5.1	12V	7.3.1	
Current (A)	5.1	2 x 0.67A = 1.33A	7.3.1	1.25
Power (W)	5.1	2 x 8W = 16W		
Operating Temperature Range (^{o}C)	5.1			
Number of Loads	5.1	2		

Controller Information

Parameter		Specified		Measured/Observed
Manufacturer	5.1	#2		
Model	5.1	PCC		
Type	5.1	on/off shunt		
Vr Set Point (V)	5.1	?	7.6.1	14.59 - 14.73
Controller-Battery Compatibility	5.1	?		
Temperature Compensation Sensor Attaches to Battery?	5.1	none		
Reverse-Current Protection?	5.1	?		
Load Timer Accuracy	5.1	n/a	7.3.1	
LVD Set Point (V)	5.1	?	7.6.2	11.43

Battery Information

Parameter		Specified		Measured/Observed
Manufacturer	5.1	Trojan		
Model	5.1	24-EV		
Type	5.1	flooded LA (antimony)		
Configuration	5.1	1 x 1		
Voltage (V)	5.1	12V	7.3.1	
Capacity (Ah)	5.1	85Ah	7.6.2	60

Documentation Checklist

Parameter		Included	Notes/Comments
Parts List	5.1	X	
Required-But-Not-Included-Parts List	5.1		
Recommended-Tool List	5.1	X	
Mechanical Drawings	5.1	PV only	
Electrical Schematic or Diagram	5.1	X	
Installation Procedures	5.1	X	
Spare Parts List	5.1		
Maintenance Procedures	5.1	X	

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Stand-Alone PV System Summary - Page 2 of 2 - Test Information and Results

Test Information

Parameter				
Test Facility	5.1	NREL		
Address	5.1	1617 Cole Blvd, Golden, CO 80215 USA		
Contact	5.1	Peter McNutt		

System Inspection

System Arrival Date	5.1	system 12/1/98, battery 2/10/00	installed "new" flooded LA battery
(Attach copy of system documentation)	5.1		
Damaged parts?	5.2	no	
All parts present?	5.2	yes	
Parts that need to be procured?	5.2		

System Installation & Instrumentation

Battery preparation and boost charge documented?	6.1.1	no
Average battery temperature & range (°C)	6.1.2	
CC temperature compensation senses T_bt?	6.1.3	no
Load(s) start & operate	6.1.4	yes
Load operation sensing method	6.2.5	photometers
(Attach diagram with DAS sensor locations)	6.2.6	

System Operation

Parameter		Specified		Measured/Observed
Run Time (Hrs)	5.1	4 hrs	7.3.1	
Load Control Method	5.1	DAS		
System Intended Location	5.1	Golden CO		
Intended Location Design Month	5.1	December		

System Performance Results

Parameter		Specified/Calculated		Measured/Observed
Hours of Autonomy (Hrs)	5.1	(85Ah / 2) / 1.9A = 22h	7.6.4	48
Sun-Hours to Vr	5.1	n/a	7.5.1	45 +
A:L Ratio	7.3.2	(1.9A x 4.5h) / (1.3A x 4h) = 1.6	7.3.3	2

System Performance Tests

UBC_0		
Start date & time	7.1.1	4/14/00 (105) 0600 mst
Vr (V)	7.1.1	14.73V
T_bt min/avg/max at Vr (°C)	7.1.1	23 / 26 / 29 deg C
LVD (V)	7.1.2	11.43V
UBC_0 (Ah)	7.1.2	71Ah (25 / 26 / 28 deg C)
End date & time	7.1.2	4/24/00 (115) 0500
FT		
Start date & time	7.3.1	4/28/00 (119) 05:15
V_ld min/avg/max (V)	7.3.1	12.16 / 12.46 / 12.79 V
I_ld min/avg/max (A)	7.3.1	1.20 / 1.26 / 1.29 A
Run time (Hrs/night)	7.3.1	4 h/night
V_bt min/max (V)	7.3.1	12.41 / 14.59 V
T_bt min/avg/max (°C)	7.3.1	23 / 27 / 32 deg C
End date & time	7.3.1	5/5/00 (126) 17:00
Expected A:L ratio	7.3.2	(5.4 h x 1.9 A) / (4 h x 1.3 A) = 2.0
Actual A:L ratio	7.3.3	72 Ah / 36 Ah = 2.0
UBC_1		
Start date & time	7.4.1	5/5/00 (126) 17:00
Vr (V)	7.4.1	14.59 V
T_bt min/avg/max at Vr (°C)	7.4.1	29 / 30 / 32 deg C
LVD (V)	7.4.2	11.42 V
UBC_1 (Ah)	7.4.2	62 Ah
End date & time	7.4.2	5/9/00 (130) 06:00
RT		
Start date & time	7.5.1	5/9/00 (130) 06:30
End date & time	7.5.1	5/16/00 (137) 06:15
Sun Hours to Vr	7.5.1	45 Sh - not yet regulating
Battery Ah to Vr	7.5.2	45 Ah - not yet regulating
Battery Ah / Sun Hour	7.5.2	9 Ah / 5 Sh
Sun Hours / Day required to meet load	7.5.2	5
(Attach Battery Ah vs. Sun-hours plot)	7.5.2	
UBC_2		
Vr (V)	7.6.1	14.65 V
T_bt min/avg/max at Vr (°C)	7.6.1	24 / 27 / 29 deg C
LVD (V)	7.6.2	11.43 V
UBC_2	7.6.2	60 Ah (27 / 28 / 28 deg C) (60 / 85 = 71%)
End date & time	7.6.2	5/25/00 (146) 12:00
UBC_0 - UBC_2 (Ah)	7.6.3	11 Ah decrease (-15%)
Hours of Autonomy (Hrs)	7.6.4	48 h

Final System Inspection

Maintenance procedures ok?	8.1	check wiring & battery maintenance per battery manufacturer's recommendations
System visual inspection ok?	8.2	ok
System wiring ok?	8.3	ok

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Stand-Alone PV System Summary - Page 1 of 2 - System Specifications and Information

System Information

Parameter		
System Manufacturer	5.1	#3
System Model	5.1	LK4 Lighting Kit
Vendor	5.1	#3

Array Information

Parameter		Specified		Measured/Observed
Module Manufacturer	5.1	#3		
Module Model	5.1			
Active Material	5.1	m-Si		
Array Configuration	5.1	1 x 1		
Array P_{max} @ STC (W)	5.1	70	9	
Array V_{pp} (V)	5.1	17	9	
Array I_{pp} (A)	5.1	4.1	9	
Array V_{oc} (V)	5.1	21	9	
Array I_{sc} (A)	5.1	4.5	9	
Array Shield	5.1	none		

Load Information

Parameter		Specified		Measured/Observed
Description	5.1	fluorescent lamps		
Manufacturer	5.1	LabCraft (UK), BL8 & BL13, Sylvania F8W & F13W		
Voltage (V)	5.1	12V	7.3.1	
Current (A)	5.1	2 x 1.1 + 2 * 0.7 = 3.5A	7.3.1	2.8
Power (W)	5.1	2 x 13W + 2 x 8W = 42W		
Operating Temperature Range (^{o}C)	5.1			
Number of Loads	5.1	4		

Controller Information

Parameter		Specified		Measured/Observed
Manufacturer	5.1	#3		
Model	5.1	LK4		
Type	5.1	on/off shunt(?)		
Vr Set Point (V)	5.1	?	7.6.1	13.80 - 13.96
Controller-Battery Compatibility	5.1	no		
Temperature Compensation Sensor Attaches to Battery?	5.1	no		
Reverse-Current Protection?	5.1	?		
Load Timer Accuracy	5.1	n/a	7.3.1	
LVD Set Point (V)	5.1	?	7.6.2	11.10 - 12.15

Battery Information

Parameter		Specified		Measured/Observed
Manufacturer	5.1	#3		
Model	5.1	12P 140		
Type	5.1	flooded LA, tubular (antimony)		
Configuration	5.1	1 x 1		
Voltage (V)	5.1	12V	7.3.1	
Capacity (Ah)	5.1	140	7.6.2	44

Documentation Checklist

Parameter		Included	Notes/Comments
Parts List	5.1	X	for lighting kit only
Required-But-Not-Included-Parts List	5.1		
Recommended-Tool List	5.1	X	
Mechanical Drawings	5.1		
Electrical Schematic or Diagram	5.1		not in one place
Installation Procedures	5.1	X	
Spare Parts List	5.1		
Maintenance Procedures	5.1	X	

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Stand-Alone PV System Summary - Page 2 of 2 - Test Information and Results

Test Information

Parameter				
Test Facility	5.1	NREL		
Address	5.1	1617 Cole Blvd, Golden, CO 80215 USA		
Contact	5.1	Peter McNutt		
System Inspection				
System Arrival Date	5.1	2/28/00 - shipped from Europe		
(Attach copy of system documentation)	5.1			
Damaged parts?	5.2			
All parts present?	5.2	yes		
Parts that need to be procured?	5.2			
System Installation & Instrumentation				
Battery preparation and boost charge documented?	6.1.1	no		
Average battery temperature & range (°C)	6.1.2			
CC temperature compensation senses T_bt?	6.1.3	no		
Load(s) start & operate	6.1.4	only 1 lamp can start at a time		
Load operation sensing method	6.2.5	photometers		
(Attach diagram with DAS sensor locations)	6.2.6			
System Operation				
Parameter		**Specified**		**Measured/Observed**
Run Time (Hrs)	5.1	4 hrs	7.3.1	
Load Control Method	5.1	DAS		
System Intended Location	5.1	Golden CO		
Intended Location Design Month	5.1	December		
System Performance Results				
Parameter		**Specified/Calculated**		**Measured/Observed**
Hours of Autonomy (Hrs)	5.1	(140Ah / 2) / 3.5A = 20h	7.6.4	16
Sun-Hours to Vr	5.1	n/a	7.5.1	3
A:L Ratio	7.3.2	1.6	7.3.3	1.1
System Performance Tests				
UBC_0				
Start date & time	7.1.1	4/14/00 (105) 0600 mst		
Vr (V)	7.1.1	13.96V		
T_bt min/avg/max at Vr (°C)	7.1.1	17 / 21 / 26 deg C		
LVD (V)	7.1.2	11.25V		
UBC_0 (Ah)	7.1.2	39Ah (21 / 22 / 25 deg C)		
End date & time	7.1.2	4/24/00 (115) 0500		
FT				
Start date & time	7.3.1	4/28/00 (119) 05:15		
V_ld min/avg/max (V)	7.3.1	11.09 / 11.23 / 11.58 V		
I_ld min/avg/max (A)	7.3.1	2.26 / 2.82 / 2.86 A		
Run time (Hrs/night)	7.3.1	4 h/night		
V_bt min/max (V)	7.3.1	11.39 / 13.92 V		
T_bt min/avg/max (°C)	7.3.1	19 / 26 / 33 deg C		
End date & time	7.3.1	5/5/00 (126) 17:00		
Expected A:L ratio	7.3.2	(5.4 h x 4.1 A) / (4 h x 3.5 A) = 1.6		
Actual A:L ratio	7.3.3	84 Ah / 78 Ah = 1.1		
UBC_1				
Start date & time	7.4.1	5/5/00 (126) 17:00		
Vr (V)	7.4.1	13.80 V		
T_bt min/avg/max at Vr (°C)	7.4.1	22 / 27 / 33 deg C		
LVD (V)	7.4.2	11.10 V		
UBC_1 (Ah)	7.4.2	49 Ah		
End date & time	7.4.2	5/9/00 (130) 06:00		
RT				
Start date & time	7.5.1	5/9/00 (130) 06:30		
End date & time	7.5.1	5/16/00 (137) 06:15		
Sun Hours to Vr	7.5.1	3 Sh		
Battery Ah to Vr	7.5.2	11 Ah		
Battery Ah / Sun Hour	7.5.2	12 Ah / 3.3 Sh		
Sun Hours / Day required to meet load	7.5.2	3		
(Attach Battery Ah vs. Sun-hours plot)	7.5.2			
UBC_2				
Vr (V)	7.6.1	13.93 V		
T_bt min/avg/max at Vr (°C)	7.6.1	19 / 23 / 28 deg C		
LVD (V)	7.6.2	11.14 V		
UBC_2	7.6.2	44 Ah (25 / 27 / 28 deg C) (44 / 140 = 31%)		
End date & time	7.6.2	5/25/00 (146) 12:00		
UBC_0 - UBC_2 (Ah)	7.6.3	5 Ah increase (+13 %)		
Hours of Autonomy (Hrs)	7.6.4	16 h		
Final System Inspection				
Maintenance procedures ok?	8.1	ok		
System visual inspection ok?	8.2	ok		
System wiring ok?	8.3	ok		

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Stand-Alone PV System Summary - Page 1 of 2 - System Specifications and Information

System Information

Parameter		
System Manufacturer	5.1	#3
System Model	5.1	LK4 Lighting Kit
Vendor	5.1	#3

Array Information

Parameter		Specified		Measured/Observed
Module Manufacturer	5.1	#3		
Module Model	5.1			
Active Material	5.1	m-Si		
Array Configuration	5.1	1 x 1		
Array P_{max} @ STC (W)	5.1	70	9	
Array V_{pp} (V)	5.1	17	9	
Array I_{pp} (A)	5.1	4.1	9	
Array V_{oc} (V)	5.1	21	9	
Array I_{sc} (A)	5.1	4.5	9	
Array Shield	5.1	none		

Load Information

Parameter		Specified		Measured/Observed
Description	5.1	fluorescent lamps		
Manufacturer	5.1	LabCraft (UK), BL8 & BL13, Sylvania F8W & F13W		
Voltage (V)	5.1	12V	7.3.1	
Current (A)	5.1	2 x 1.1 + 2 * 0.7 = 3.5A	7.3.1	2.9
Power (W)	5.1	2 x 13W + 2 x 8W = 42W		
Operating Temperature Range (^{o}C)	5.1			
Number of Loads	5.1	4		

Controller Information

Parameter		Specified		Measured/Observed
Manufacturer	5.1	#3		
Model	5.1	LK4		
Type	5.1	on/off shunt(?)		
Vr Set Point (V)	5.1		7.6.1	13.86 - 13.99
Controller-Battery Compatibility	5.1			
Temperature Compensation Sensor Attaches to Battery?	5.1			
Reverse-Current Protection?	5.1			
Load Timer Accuracy	5.1		7.3.1	
LVD Set Point (V)	5.1		7.6.2	11.11 - 11.16

Battery Information

Parameter		Specified		Measured/Observed
Manufacturer	5.1	#3		
Model	5.1	12P 140		
Type	5.1	flooded LA, tubular (antimony)		
Configuration	5.1	1 x 1		
Voltage (V)	5.1	12V	7.3.1	
Capacity (Ah)	5.1	140Ah	7.6.2	45

Documentation Checklist

Parameter		Included	Notes/Comments
Parts List	5.1	X	for lighting kit only
Required-But-Not-Included-Parts List	5.1		
Recommended-Tool List	5.1	X	
Mechanical Drawings	5.1		
Electrical Schematic or Diagram	5.1		not in one place
Installation Procedures	5.1	X	
Spare Parts List	5.1		
Maintenance Procedures	5.1	X	

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Stand-Alone PV System Summary - Page 2 of 2 - Test Information and Results

Test Information

Parameter		
Test Facility	5.1	NREL
Address	5.1	1617 Cole Blvd, Golden, CO 80215 USA
Contact	5.1	Peter McNutt

System Inspection

System Arrival Date	5.1	2/28/00 - shipped from Europe
(Attach copy of system documentation)	5.1	
Damaged parts?	5.2	
All parts present?	5.2	yes
Parts that need to be procured?	5.2	

System Installation & Instrumentation

Battery preparation and boost charge documented?	6.1.1	no
Average battery temperature & range (°C)	6.1.2	
CC temperature compensation senses T_bt?	6.1.3	no
Load(s) start & operate	6.1.4	only 1 lamp can start at a time
Load operation sensing method	6.2.5	photometers
(Attach diagram with DAS sensor locations)	6.2.6	

System Operation

Parameter		Specified		Measured/Observed
Run Time (Hrs)	5.1	4 hrs	7.3.1	
Load Control Method	5.1	DAS		
System Intended Location	5.1	Golden CO		
Intended Location Design Month	5.1	December		

System Performance Results

Parameter		Specified/Calculated		Measured/Observed
Hours of Autonomy (Hrs)	5.1	(140Ah / 2) / 3.5A = 20h	7.6.4	16
Sun-Hours to Vr	5.1	n/a	7.5.1	2
A:L Ratio	7.3.2	1.6	7.3.3	1.1

System Performance Tests

UBC_0		
Start date & time	7.1.1	4/14/00 (105) 0600 mst
Vr (V)	7.1.1	13.99V
T_bt min/avg/max at Vr (°C)	7.1.1	17 / 21 / 26 deg C
LVD (V)	7.1.2	11.16V
UBC_0 (Ah)	7.1.2	46Ah (21 / 22 / 25 deg C)
End date & time	7.1.2	4/24/00 (115) 0500
FT		
Start date & time	7.3.1	4/28/00 (119) 05:15
V_ld min/avg/max (V)	7.3.1	10.99 / 11.15 / 11.52 V
I_ld min/avg/max (A)	7.3.1	2.31 / 2.86 / 2.88 A
Run time (Hrs/night)	7.3.1	4 h/night
V_bt min/max (V)	7.3.1	11.30 / 13.95 V
T_bt min/avg/max (°C)	7.3.1	19 / 26 / 32 deg C
End date & time	7.3.1	5/5/00 (126) 17:00
Expected A:L ratio	7.3.2	(5.4 h x 4.1 A) / (4 h x 3.5 A) = 1.6
Actual A:L ratio	7.3.3	86 Ah / 81 Ah = 1.1
UBC_1		
Start date & time	7.4.1	5/5/00 (126) 17:00
Vr (V)	7.4.1	13.86 V
T_bt min/avg/max at Vr (°C)	7.4.1	22 / 26 / 31 deg C
LVD (V)	7.4.2	11.14 V
UBC_1 (Ah)	7.4.2	44 Ah
End date & time	7.4.2	5/9/00 (130) 06:00
RT		
Start date & time	7.5.1	5/9/00 (130) 06:30
End date & time	7.5.1	5/16/00 (137) 06:15
Sun Hours to Vr	7.5.1	2 Sh
Battery Ah to Vr	7.5.2	7 Ah
Battery Ah / Sun Hour	7.5.2	12 Ah / 3.3 Sh
Sun Hours / Day required to meet load	7.5.2	3
(Attach Battery Ah vs. Sun-hours plot)	7.5.2	
UBC_2		
Vr (V)	7.6.1	13.97
T_bt min/avg/max at Vr (°C)	7.6.1	19 / 23 / 28 deg C
LVD (V)	7.6.2	11.11 V
UBC_2	7.6.2	45 Ah (24 / 27 / 28 deg C) (45 / 140 = 32%)
End date & time	7.6.2	5/25/00 (146) 12:00
UBC_0 - UBC_2 (Ah)	7.6.3	1 Ah decrease (-2 %)
Hours of Autonomy (Hrs)	7.6.4	16 h

Final System Inspection

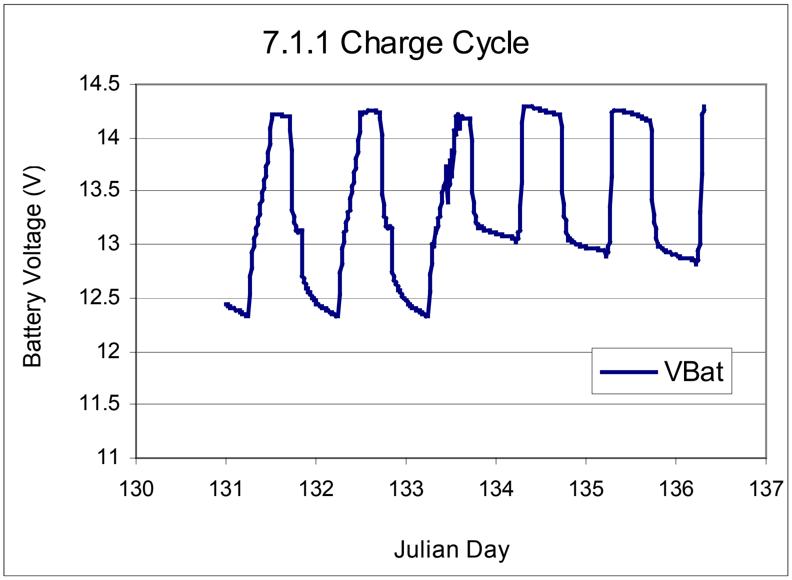
Maintenance procedures ok?	8.1	ok
System visual inspection ok?	8.2	ok
System wiring ok?	8.3	ok

Appendix B: SWTDI Results

SWTDI System 1-3 Results

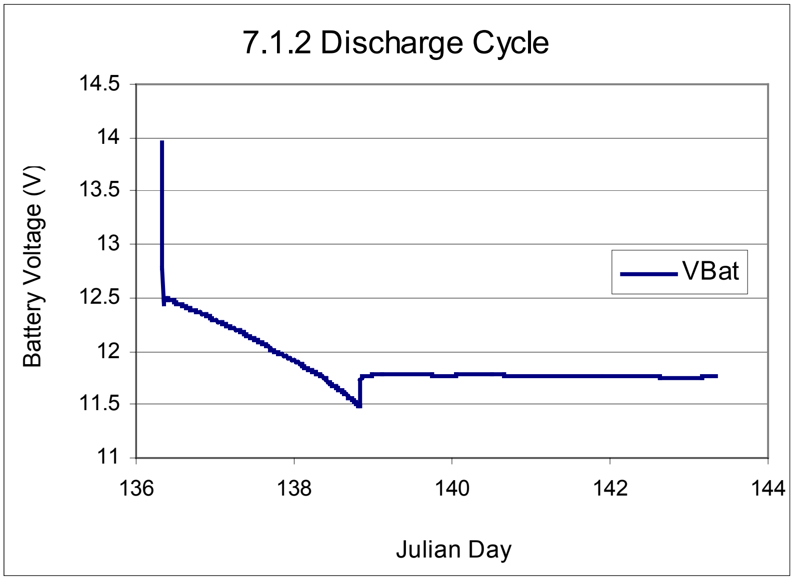
This appendix contains the some of the data and results obtained at SWTDI testing two SAPV Systems, 1-3 followed by 2-3. The section numbers correspond to those in the test procedures.

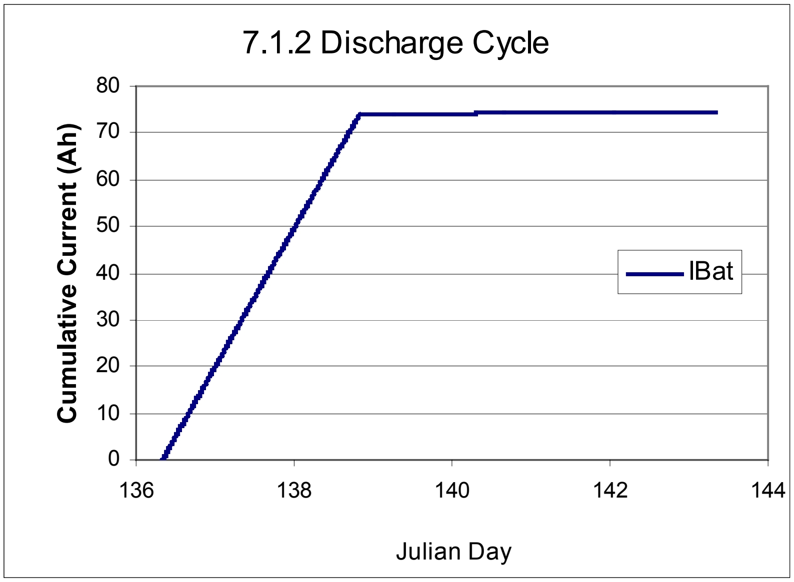
7.1.1 Battery Charge Cycle Vr 14.29 (V)



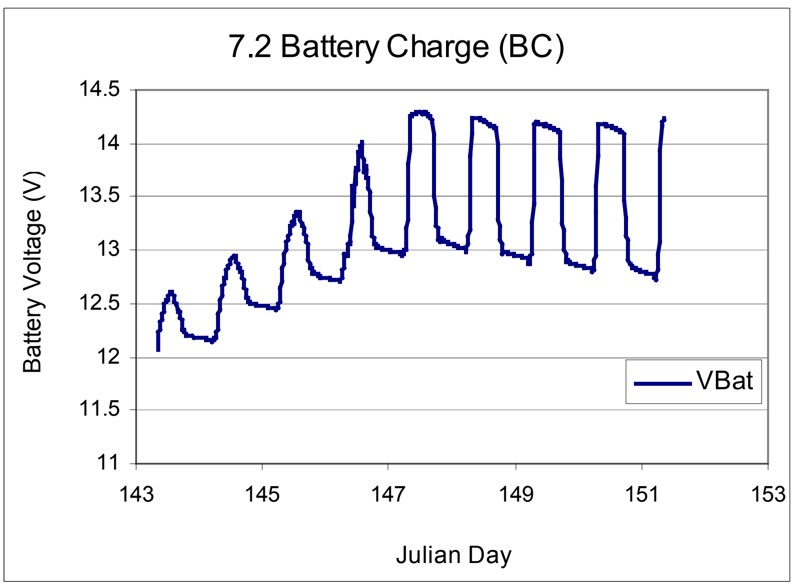
7.1.2 Battery Discharge Cycle

LVD 11.49 (V)
UBC_0 74.4 (Ah)





7.2 Battery Charge (BC)

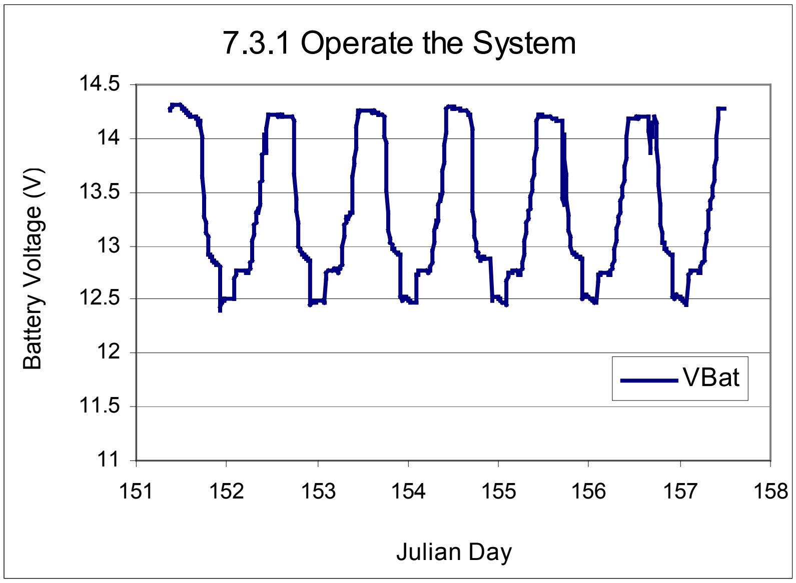


7.3.1 Operate the System

Vmax	12.54	(V)
Vmin	12.39	(V)
Vavg	12.50	(V)
Imax	1.24	(A)
Imin	1.20	(A)
Iavg	1.22	(A)

Cum Load Time	24	(hours)
Daily POA	6.8	(kWh/m^2)

Vbmax	14.32	(V)
Vbmin	12.39	(V)
Tmax	31.55	(C)
Tmin	27.14	(C)
Tavg	27.47	(C)



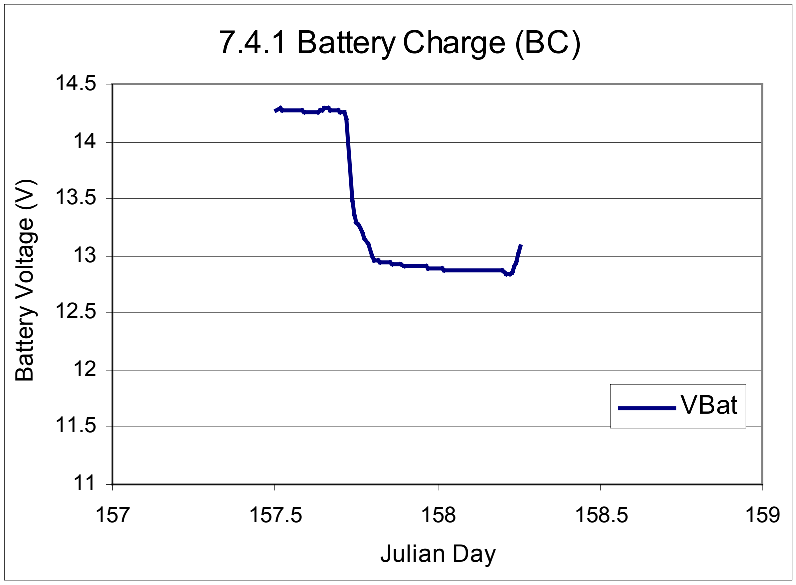
7.3.2 Expected A:L Ratio

STC-Array Current	2.92	(A)	Expected
SunHrs/Day	7.30	(hours)	A:L Ratio 4.2632
Load Current	1.25	(A)	
Run Hrs/Day	4.00	(hours)	

7.3.3 Actual A:L ratio

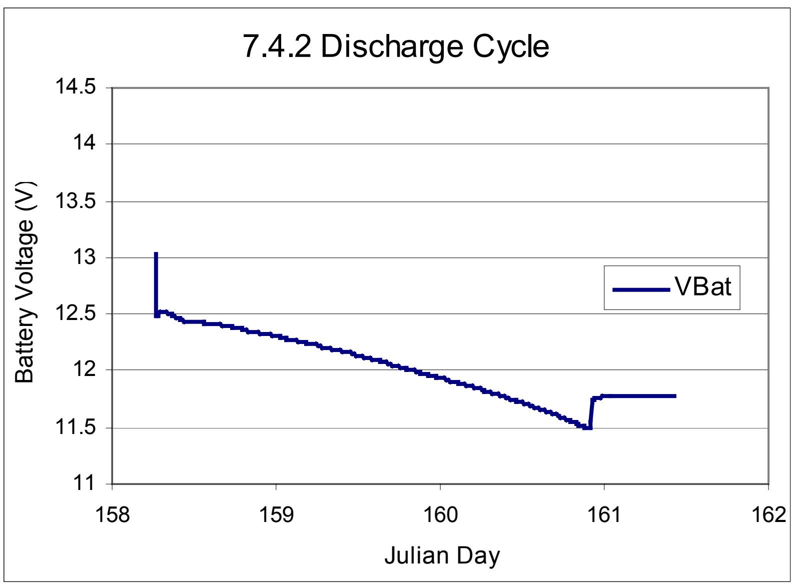
Load Energy	369.98	(Wh)	Actual
Array Energy	620.00	(Wh)	A:L Ratio 1.675766258

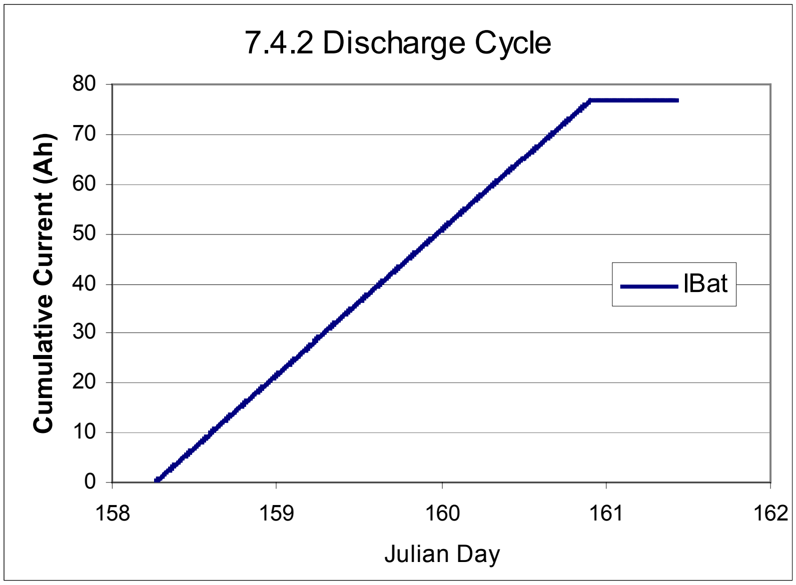
7.4.1 Battery Charge (BC)



7.4.2 Battery Discharge Cycle

LVD	11.39	(V)
UBC_1	76.95	(Ah)



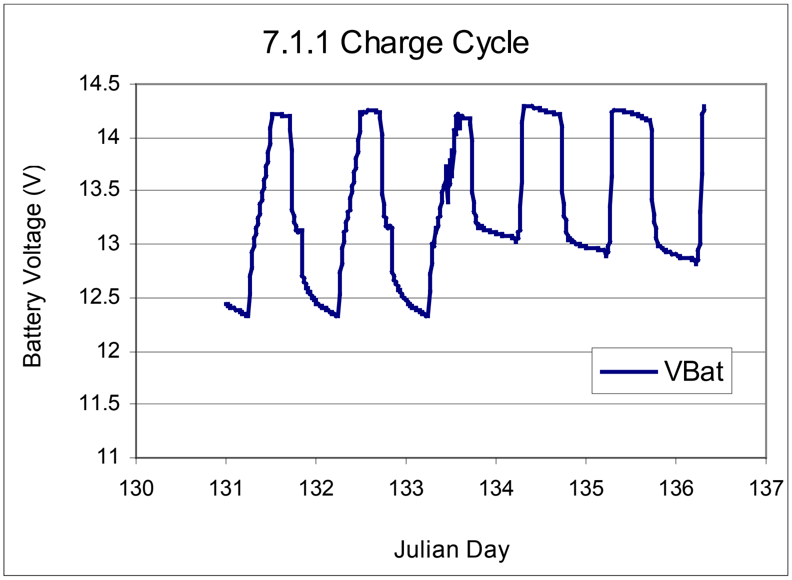

7.4.2 Discharge Cycle
Cumulative Current (Ah)
80
70
60
50
40
30
20
10
0
158
159
160
161
162
Julian Day
IBat

SWTDI System 2-3 Results

This section contains the results obtained at SWTDI testing SAPV System 2-3. The section numbers correspond to those of the procedures.

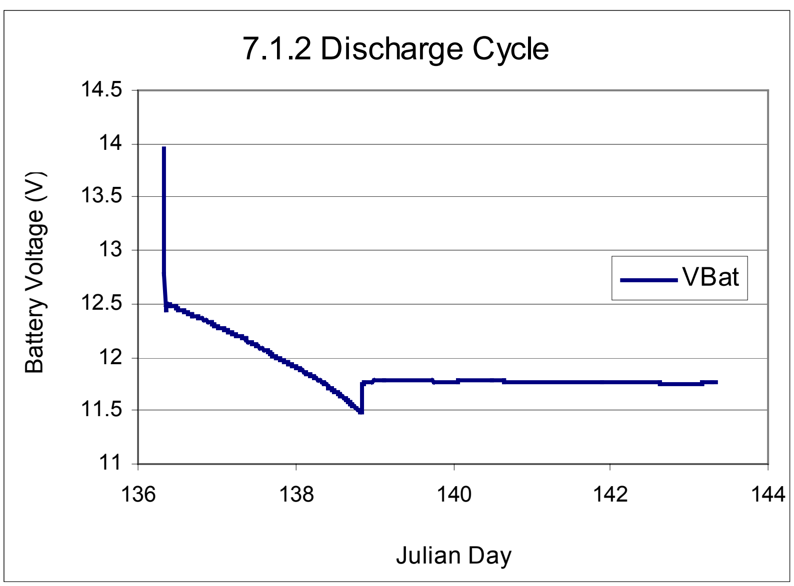
7.1.1 Battery Charge Cycle

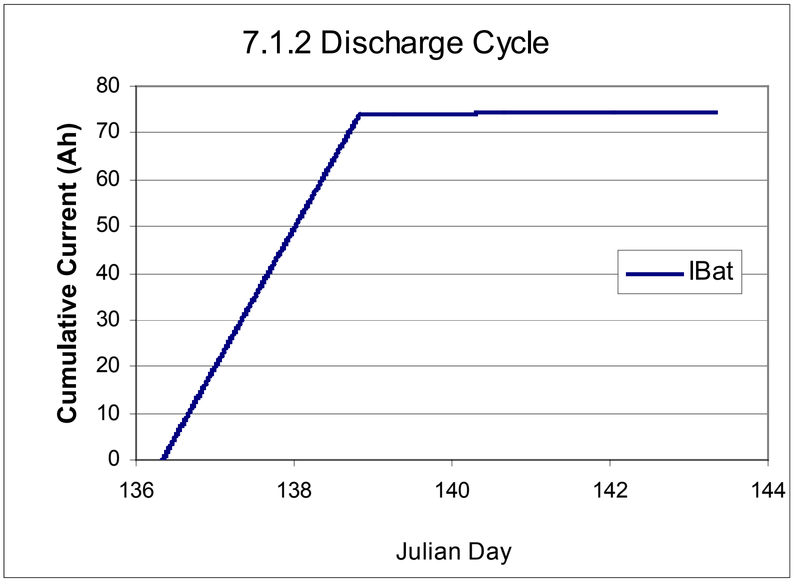
Vr 14.29 (V)



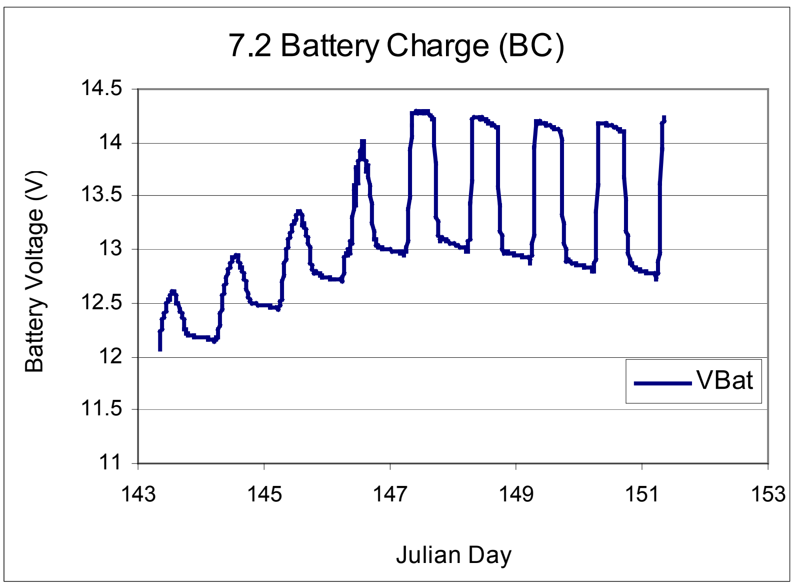
7.1.2 Battery Discharge Cycle

LVD 11.49 (V)
UBC_0 74.4 (Ah)





7.2 Battery Charge (BC)

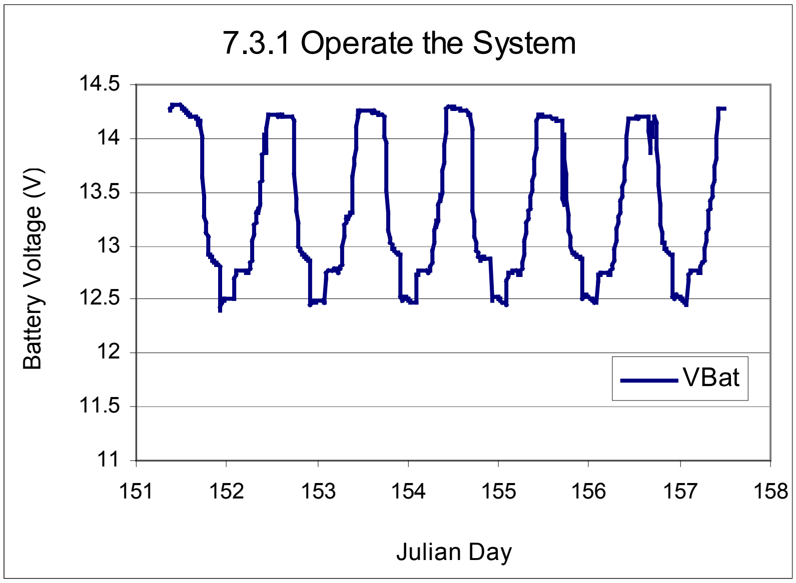


7.3.1 Operate the System

Vmax	12.54	(V)
Vmin	12.39	(V)
Vavg	12.50	(V)
Imax	1.24	(A)
Imin	1.20	(A)
Iavg	1.22	(A)

Cum Load Time	24	(hours)
Daily POA	6.8	(kWh/m^2)

Vbmax	14.32	(V)
Vbmin	12.39	(V)
Tmax	31.55	(C)
Tmin	27.14	(C)
Tavg	27.47	(C)



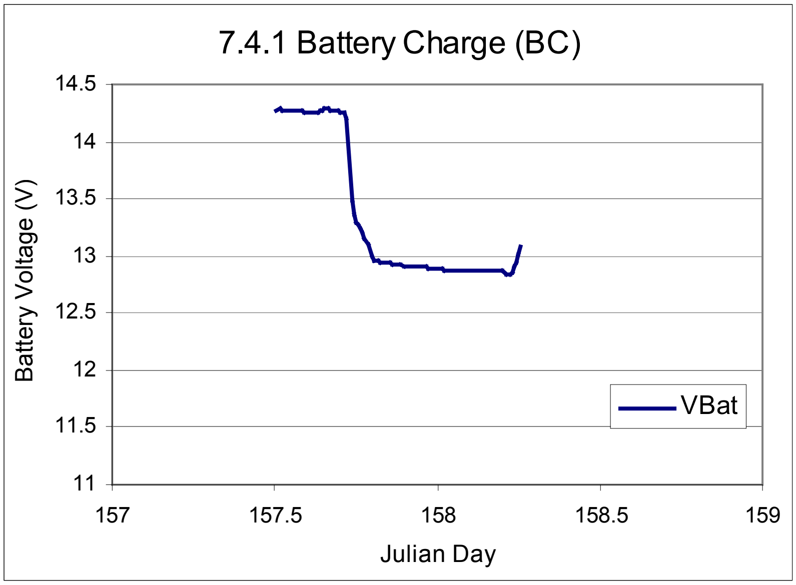
7.3.2   Expected A:L Ratio   Note: only one lamp still working

STC-Array Current	2.92	(A)	Expected	
SunHrs/Day	7.30	(hours)	A:L Ratio	4.2632
Load Current	1.25	(A)		
Run Hrs/Day	4.00	(hours)		

7.3.3   Actual A:L Ratio   Note: only one lamp still working

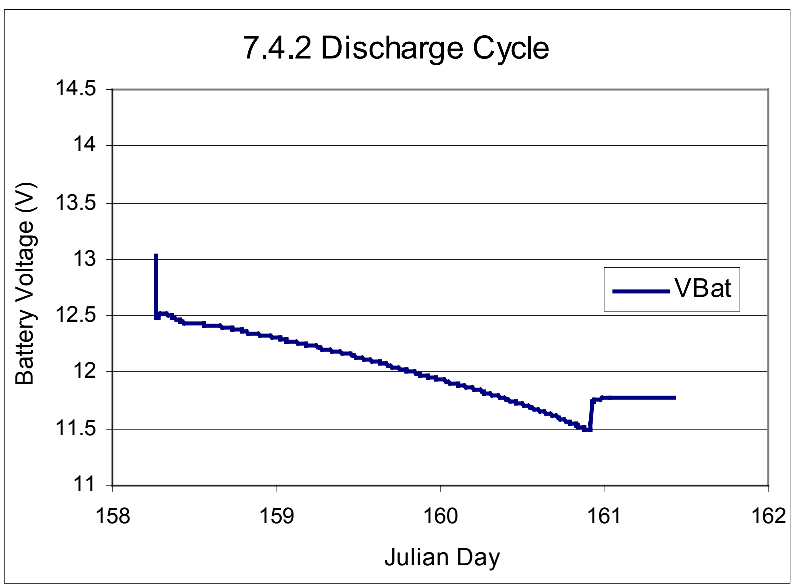
Load Energy	369.98	(Wh)	Actual	
Array Energy	620.00	(Wh)	A:L Ratio	1.675766258

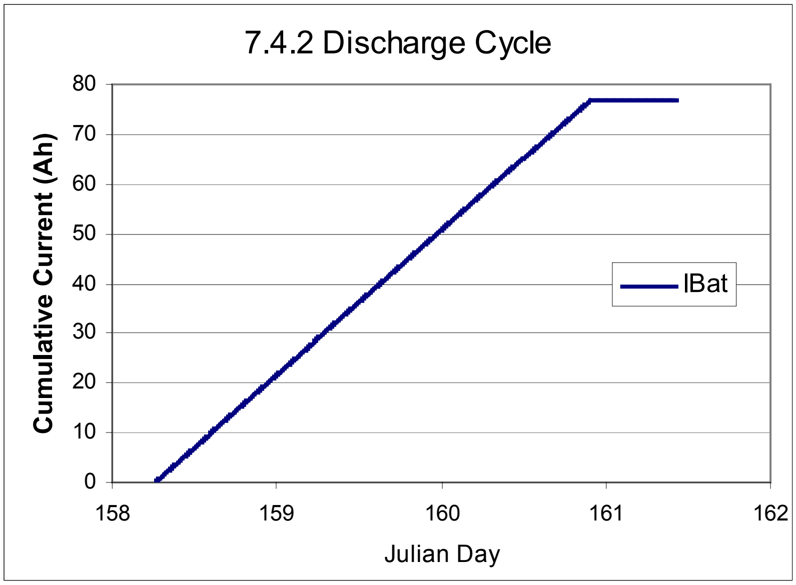
7.4.1 Battery Charge (BC)



7.4.2 Battery Discharge Cycle

LVD	11.39	(V)
UBC_1	76.95	(Ah)




7.4.2 Discharge Cycle
Cumulative Current (Ah)
80
70
60
50
40
30
20
10
0
158
159
160
161
162
Julian Day
IBat

Appendix C: FSEC Results – System 1-4

This appendix contains some of the data and results obtained at FSEC testing SAPV System 1-4. The section numbers correspond to those of the test procedures.

7.1 Initial Capacity Test (UBCo)

7.1.1 Battery Charge Cycle		Date	Campbell Time
Start		5/31/2000	2:30 PM
Finish		6/4/2000	11:45 AM
Vr 14.2	Actual Max: 14.27 V		
Battery Temp at Vr	(°C)		
Minimum	22.86		
Average	24.76		
Maximum	26.91		

7.1.2 Battery Discharge Cycle		Date	Campbell Time
Start		6/4/2000	11:45 AM
Finish		6/6/2000	10:00 AM
LVD 11.59			
UBCo (amp-hours)	54.98		

7.2 Battery Charge (BC)	Date	Campbell Time
Start	6/6/2000	1:45 PM
Finish	6/13/2000	2:00 PM

7.3 Functional Test (FT)

7.3.1 Field Test Daily Record

			Battery Voltages		Battery Temperatures		
Day	Date	POA Insolation	Max Voltage	Min Voltage	Min °C	Ave °C	Max °C
165	6/13/1900	6.76	14.20	12.07	22.08	28.63	35.45
166	6/14/1900	6.41	14.14	12.13	21.46	28.55	34.83
167	6/15/1900	6.71	14.10	12.13	21.36	28.17	34.32
168	6/16/1900	7.09	14.10	12.14	19.14	28.24	34.98
169	6/17/1900	4.71	14.13	12.12	22.64	27.58	33.36
170	6/18/1900	6.88	14.07	12.13	21.96	28.83	35.26
171	6/19/1900	6.95	14.07	12.13	21.09	28.71	35.40
172	6/20/1900	6.86	14.06	12.13	20.82	28.55	35.54
173	6/21/1900	6.96	14.06	12.13	20.55	28.20	35.46
174	6/22/1900	6.18	14.06	12.13	20.31	28.23	35.93
175	6/23/1900	1.93	13.58	12.14	21.90	25.30	30.42
176	6/24/1900	2.43	14.00	12.11	18.82	23.01	28.43
177	6/25/1900	4.30	14.13	12.14	17.93	24.32	30.59
178	6/26/1900	3.69	14.16	12.14	21.52	26.22	31.01
179	6/27/1900	2.49	14.13	12.14	20.41	25.39	29.19
			Max	Min	Min	Ave	Max
			14.20	12.07	17.93	27.20	35.93

7.3.1 Operate the System		Date	Campbell Time
Start		6/13/2000	2:00 PM
Finish		6/27/2000	2:15 PM
Load Voltages (V)			
Minimum	12.07		
Average	12.20		
Maximum	12.60		

Load Currents (A)	
Minimum	-1.038
Average	-1.170285714
Maximum	-1.194
Load Run Time (hours)	4

7.3.2 Compute Expected A:L Ratio
Expected A:L Ratio 3.09

7.3.3 Compute Actual A:L Ratio
Actual A:L Ratio 2.15
See 'FT Actual AL Ratio'

7.4 Second Capacity Test (UBC1)

7.4.1 Battery Charge Cycle		Date	Campbell Time
Start		6/27/2000	2:15 PM
Finish		6/30/2000	3:00 PM
Battery Temp at Vr	(°C)		
Minimum	21.10		
Average	24.10		
Maximum	31.20		

7.4.2 Battery Discharge Cycle		Date	Campbell Time
Start		6/30/2000	3:00 PM
Finish		7/2/2000	4:00 PM
LVD (Volts)	11.58		
UBC1 (amp-hours)	58.43		

7.5 Recovery Test (RT)

7.5.1 Operate the System		Date	Campbell Time
Start		7/13/2000	11:00 AM
Finish		7/23/2000	2:30 PM
Sun-hours to Vr	53.6		

7.5.2 Plot Battery Ah vs. Sun-Hours
See Worksheet 'Ah vs. Sun-hours'

7.6 Final Capacity Test (UBC2)

7.6.1 Battery Charge Cycle		Date	Campbell Time
Start		7/24/2000	7:00 AM
Finish		7/26/2000	1:45 PM
Battery Temp at Vr	(°C)		
Minimum	20.67		
Average	21.82		
Maximum	22.33		

7.6.2 Battery Discharge Cycle		Date	Campbell Time
Start		7/26/2000	1:45 PM
Finish		7/28/2000	2:30 PM
LVD (volts)	11.58		
UBC2 (amp-hours)	58.30		

7.6.3 Compare UBC
Change in Capacity (Ah) -3.32

7.6.4 Compute Hours of Autonomy Hours of Autonomy 49.8

Appendix D: GENEC Results – System 3-3

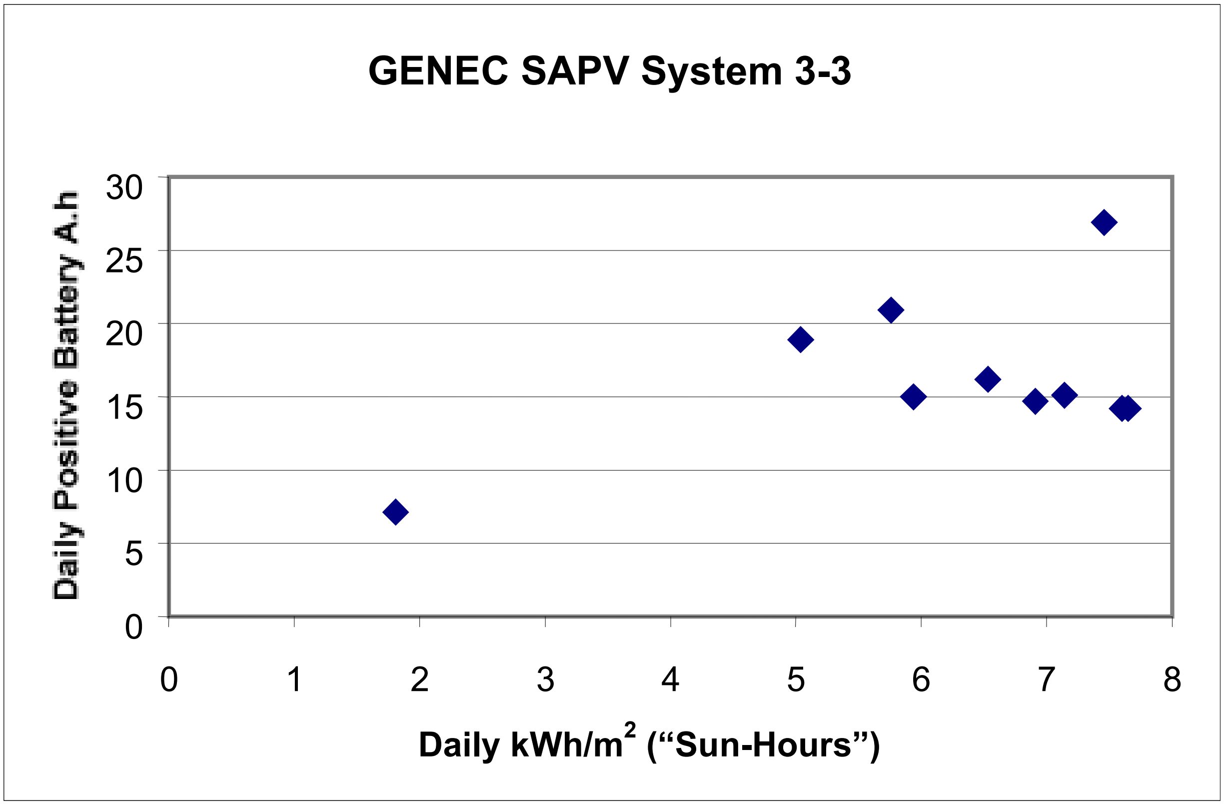


Figure 17. P-Chart for System 3-3 at GENEC, July 2000 (4-hour load run-time).

IEEE P1526/D1
Draft Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems

1. OVERVIEW

These procedures approach the testing of stand-alone PV systems from the point of view that they are PV powered battery chargers. The system performance is based upon how well it can charge the battery. The usable battery capacity is measured by charging and discharging the battery three separate times. The tests are designed to test the overall system performance in the span of about one month.

1.1 Scope

The test methods and procedures included in this document cover stand-alone PV systems. Procedures provided are for conducting performance testing of individual components and complete systems. The methodology includes testing the system outdoors in prevailing conditions and indoors under simulated conditions.

1.2 Purpose

This recommended practice provides test methods and procedures for determining stand-alone photovoltaic system performance and conducting design verification. Test procedures provided in this document are intended to assist designers, manufacturers, system integrators, users, and laboratories in conducting these performance tests.

1.3 Limitations

These procedures do not address component or system reliability, quality issues, safety, or compliance to a regional or national mechanical or electrical code (e.g., NEC). These procedures do not cover grid-tied or PV-hybrid systems.

2. REFERENCES

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

IEEE Std 100-1996, IEEE Standard Dictionary of Electrical and Electronic Terms

3. DEFINITIONS

For purposes of this recommended practice, the following terms and definitions apply. IEEE Std 100-1996 should be referenced for terms not defined in this clause.

3.1 array to load (A:L) ratio – The ratio of the ampere-hours (Ah) produced by the PV array to the Ah consumed by the load.

3.2 charge controller – An electrical device that protects the battery from overcharge. The charge controller may also indicate system status and provide system protection, such as protecting the battery from over discharge.

3.3 design month – The month in which the daily A:L ratio is minimum. This may not necessarily be the month with the minimum number of sun hours.

3.4 hours of autonomy – The number of hours that the battery can provide power to the load with no contribution from the PV array.

3.5 load – A device connected to an electrical system that consumes electrical power. Systems may have multiple loads. Some loads may have built-in battery low-voltage disconnect protection.

3.6 low-voltage disconnect (LVD) – The battery voltage at which the load is disconnected to prevent over discharge. The LVD is a determining factor for the usable battery capacity in the PV system.

3.7 plane-of-array (POA) irradiance – The solar power measured in the same plane as the PV array.

3.8 rated battery capacity – The Ah a fully charged battery is specified to deliver at a specified battery temperature and discharge rate, to a specified cutoff voltage.

3.9 regulation voltage (Vr) – The maximum voltage that the charge controller will allow the battery to reach under charging conditions. At this point, the charge controller will reduce or remove the array energy from the battery.

3.10 solar insolation – The cumulative solar irradiance over a giver period of time in kWh/m^2.

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

3.12 sun hours - The equivalent number of hours of peak (kW/m^2) sunlight received per day at a particular location in the plane of the array. Sources of values for various locations and months can be found in the bibliography.

3.13 usable battery capacity (UBC) – The measured Ah, before temperature-correction, that a fully charged battery will deliver to the system load before reaching the LVD cutoff voltage.

4. TESTING METHODOLOGY

4.1 Testing overview

These procedures are intended to test PV systems for overall system functionality. The required test specimens are described in Clause 4.2. Clause 4.3 describes the documentation that will be generated by the testing. Clause 4 covers the system inspection, examining the documentation delivered with the PV systems as well as the system hardware. Clause 5 covers the installation and instrumentation of the PV systems. The PV system performance tests are found in Clause 6, preceded by a chart summarizing the test sequence. The specific sequence of tests to be run will be determined based on the specific system to be tested and its loads. Examples of different types of PV systems are described in sources found in the bibliography. Clause 7 is a final system inspection, examining the system maintenance procedures and looking for visible hardware problems. Clause 8 is an optional I-V curve test that should be conducted if the array has an array shield. A sample System Summary is provided in Annex B. The person conducting the tests should fill in as much of the System Summary data as possible.

4.2 PV system and test requirements

At least three complete systems representative of the systems to be deployed in the field are required to conduct the tests in this document. A complete system includes documentation and all related parts for installation. Spare parts may be included in the event parts are damaged in shipment or during testing. The intended location where the system will be installed and operated (not necessarily the test location) should be specified. If optional meters or indicators are available for the system being tested, these should also be procured and evaluated with the system. If the battery charge and discharge set points are adjustable, use the set points recommended by the system manufacturer, or if this information is not provided, use the set points as received, including any recommended adjustments. If the set points seem inappropriate, consult the system manufacturer.

4.3 Test report and documentation

In addition to completing the System Summary, the person conducting the tests should collect all relevant test data, calculations, and appropriate comments. An electronic copy of the system data should be kept for future reference.

5. SYSTEM INSPECTION

5.1 System documentation review

Record the date that the system arrived at the test facility. Copy all documentation received with the system and include it with the System Summary. Check off all documentation included with the system. Read through the documentation. Fill in as much data as possible in the System Summary. Record how the load is controlled. Record the location for which the system is intended (not necessarily the test location). Record the Hours of Autonomy, and Sun Hours to Battery Recovery if provided by the system manufacturer. Record the system and component specifications. If the system includes an inverter, it will be considered part of the DC load.

Note: underlined items are to be filled in the system summary.

5.2 Initial system hardware inspection

Visually inspect system parts and components and verify that they arrived undamaged. Note any damage that could affect the performance of the system. Replace any damaged items. Verify that all parts listed in the Parts List are present. Note any missing system parts that should have been included but were not. Any parts that are required, but not supplied with the system, should be procured at this point. These should be listed in a required-but-not-included parts list. The person conducting the tests may refuse to test a system that could be dangerous to operate.

6. SYSTEM INSTALLATION AND INSTRUMENTATION

6.1 System installation

Install the system according to the manufacturer's instructions. (It may be easier to install the DAS during the system assembly.) The PV system installation instructions should cover all steps of the system assembly. The person conducting the tests should not modify or add to the system. The system should only be installed and tested as it is received and as specified in the documentation. Minor system modifications may be unavoidable to install the DAS. Any system modifications should be noted in the system schematic or diagram. If cabling is precut with terminations for system installation, the full length of cable should be used. Caution should be used in installing the charge controller, as some need to be connected in a specified sequence to avoid damage. Consult the manufacturer's instructions.

6.1.1 Battery preparation and boost charge

If the battery is dry charged, follow the manufacturer's instructions for adding electrolyte and preconditioning the battery for system operation. If the battery is not installed into the system within 3 months of being received, the battery should be boost charged before it is installed. Note if the system documentation instructs the user when and how to boost charge the battery.

6.1.2 Battery temperature

The battery should be installed in a temperature controlled enclosure. The average battery temperature should be 30°C, ±5°C, with a maximum range of 20° to 40°C. This temperature corresponds to those found in tropical climates where PV systems are often installed. If the average temperature at the intended location will be significantly different from these recommended parameters, the person conducting the tests and the test requester may adjust the average temperature and range to suit their needs. Record the selected average battery temperature and temperature range.

6.1.3 Controller installation

If a charge controller has a temperature compensation sensor, the sensor should be mounted to the battery according to the manufacturer's instructions. If the temperature compensation sensor is built into the controller, the controller should be mounted in the same enclosure as the battery. Note if the charge controller has temperature compensation that senses the battery temperature. The controller should never be mounted with the battery if there is any potential danger for an explosion, or where it might be subjected to the spray of battery electrolyte.

6.1.4 Verify load operation

After installing the PV system, verify that the load starts and operates properly. In systems with multiple loads, verify that all loads can operate simultaneously, and that each individual load can start and run while all other loads are operating. For this test, it is only necessary to operate the loads long enough to determine that they function correctly. Turn off all loads after verifying they operate.

6.2 DAS specifications and installation

The datalogger should use at least a 12-bit analog-to-digital converter and have an input range that exceeds the expected positive and negative maximum voltages for each input sensor. An appropriate voltage divider using precision resistors may be used. The DAS must be reliable: if any critical data is lost due to a power failure during any test, then that test should be restarted. Any DAS power failures should be noted. Table 1 and the following paragraphs summarize the system parameters to be measured.

DAS parameters

Measured Parameter	Symbol	Comments	Other Recorded Parameters
Array Voltage	V_pv		
Load Voltage	V_ld		minimum, average, and maximum
Battery Voltage	V_bt	measured at the battery	minimum, average, and maximum
DAS Voltage	V_das	collected for data integrity purposes	
Array Current	I_pv		
Load Current	I_ld		minimum, average, and maximum
Battery Current	I_bt		battery amp-hours
Air Temperature	T_amb		
Module Temperature	T_pv		
Battery Temperature	T_bt	at temperature compensation sensor or negative battery post	minimum, average, and maximum
DAS Temperature	T_das	collected for data integrity purposes	
Solar Irradiance	Irrad		solar insolation
Load Operating			load run time

6.2.1 Voltage measurements

The voltage sensor should have a range exceeding the maximum expected voltage and a resolution of at least 0.01V. The voltage measurement accuracy should be within ±1%. Install voltage sensors for the PV array and loads. Install the voltage sensor for the battery at the battery terminals. The DAS voltage should be monitored for the purpose of data integrity.

6.2.2 Current measurements

The current sensor should have a range exceeding the expected maximum positive and negative current and a resolution of at least 0.01A. The current measurement accuracy should be within ±1%. Install current sensors for the PV array, battery, and loads. In systems where the load runs only at night (for example, lighting) monitoring the array and load currents is optional. The DAS should monitor the current into and out of the battery. Current into the battery (from the PV array) will be considered positive, and current out of the battery (to the load) will be considered negative. Ampere-hours may be computed by integrating the DC current.

Because of the importance of accurately measuring the battery Ah, it may be necessary to adjust the DAS sample rate or install an integrator/filter. The type of charge controller will dictate the sample rate of the datalogger. For ON-OFF controllers, the datalogger sample rate should be at least two times faster than the switching period of the controller. For charge controllers using constant-voltage or pulse-width-modulation circuitry, the switching period may be milliseconds, not seconds. If the datalogger sample rate is not fast enough, then one method is to sample with an integrator/filter circuit added to the DAS input. The time constant of the integrator/filter will need to be at least two times the controller switching period. An oscilloscope may be required to determine the controller type and its switching frequency. Data should be stored as 15 minute averages with minimums and maximums as specified in Clause 6.

6.2.3 Temperature measurements

The temperature sensors should have a range exceeding the expected maximum positive and negative temperatures and a resolution of at least 1°C. The temperature measurement accuracy should be within ±2%. The ambient air temperature should be measured. The temperature sensor on the back of the module should be mounted near the middle of a solar cell near the center of a module. The battery temperature sensor should be mounted as close as possible to the temperature compensation sensor or on the negative battery terminal if there is no temperature compensation sensor. The DAS temperature should be monitored for the purpose of data integrity.

6.2.4 Irradiance measurements

The irradiance sensor should have a range of at least 1500W/m^2 and a resolution better than 1.0W/m^2. The irradiance measurement accuracy should be within ±5%. The irradiance sensor should be as close as possible without shading the array. The irradiance sensor should be mounted in the same plane and within +/- 5° of the array tilt angle.

6.2.5 Load operation sensor

Install a sensor to detect proper load operation, for example, a light sensor mounted in front of a lamp. In the example of a fluorescent lamp, it would not be adequate to only look at the load current as an indicator of load operation as the bulb could malfunction yet the ballast may continue to draw current. Note the load operation method.

6.2.6 DAS calibration and diagram

After the DAS installation, verify each sensor is calibrated. Note the type and accuracy of each sensor. Note the calibration factor and the date of the last calibration of each sensor, if applicable. Modify a copy of the PV system schematic or diagram to show all DAS sensor locations and include it with the System Summary.

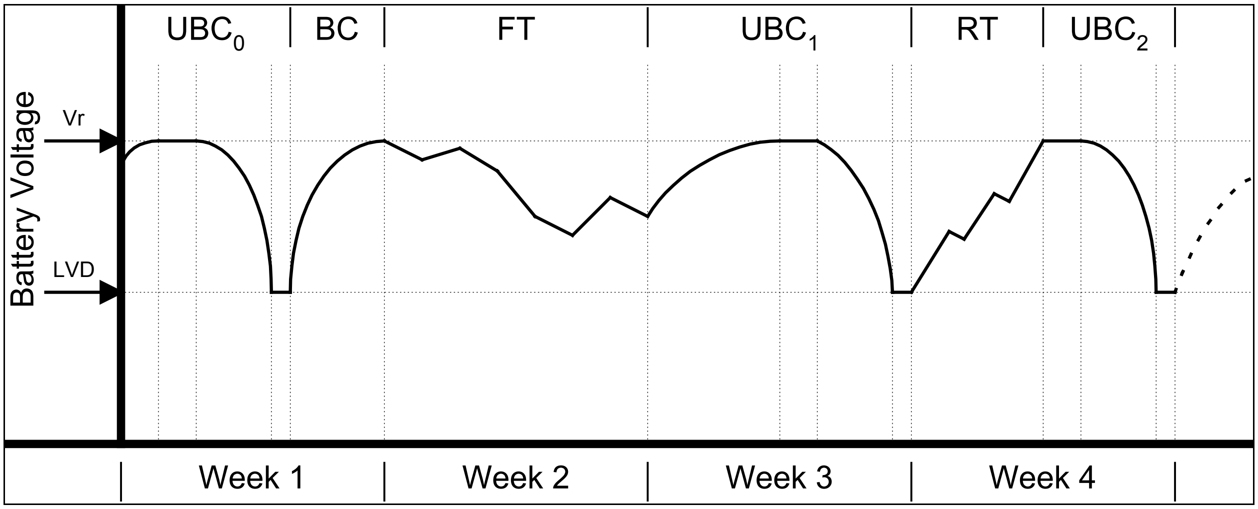
7. SYSTEM PERFORMANCE TESTS

The purpose of the system performance tests is to

1. Ensure the system and load operate as expected.
2. Ensure the PV array is capable of recharging the battery.
3. Determine if there is any significant change in the usable battery capacity during the short-term performance tests.

Figure 1 is a graphical representation of the testing in terms of battery voltage and time. The time periods shown are only approximates. Each period, briefly described below, is fully described in the section in parentheses.

UBC_0 (7.1): Initial capacity test – After installing the system, charge and discharge the battery. Measure the usable battery capacity.
CB (7.2): Recharge the battery before running the functional test.
FT (7.3): Run the functional test to verify the system and load operate properly.
UBC_1 (7.4): Second capacity test – Charge and discharge the battery. Measure the usable battery capacity.
RT (7.5): Recovery test – Determine the ability of the PV system to recharge the discharged battery.
UBC_2 (7.6): Final capacity test – Charge and discharge the battery. Measure the usable battery capacity.



Sample test profile for the stand-alone PV system performance test.

7.1 Initial capacity test (UBC_0)

This test will establish a baseline Usable Battery Capacity (UBC_0). The capacity test determines how many hours the charged battery can satisfy the load with no contribution from the PV array. This test is not appropriate for systems in which the battery is not protected by LVD circuitry.

7.1.1 Battery charge cycle

Charge the battery as follows: Disconnect the load. Allow the PV array to charge the battery until the charge controller reaches Vr and remains at Vr for at least an accumulated 12 hours. Reconnect the load. Verify that all meters and indicators function correctly. Record the start date and time. Record the maximum battery voltage as the Vr. Record the minimum, average, and maximum battery temperatures while the battery is at Vr.

7.1.2 Battery discharge cycle

Disconnect the array and connect the load. Operate the full load continuously, 24 hours per day, until it discharges the battery to the LVD voltage level. Some systems may require special measures in order to run the load continuously down to LVD. Verify that all meters and indicators function correctly. Allow the system to remain in this LVD state for a minimum of 5 hours and up to a maximum of 72 hours. Record the minimum measured battery voltage as the LVD. Record the Ah withdrawn from the battery as the UBC_0. Record the end date and time.

7.2 Battery charge (BC)

Prior to performing the functional test, charge the battery as follows: Disconnect the load. Allow the PV array to charge the battery until the charge controller reaches Vr and remains at Vr for at least an accumulated 12 hours. Reconnect the load.

7.3 Functional test (FT)

This test verifies the system and load can operate as intended. The test period should be at least 7 days.

7.3.1 Operate the system

Connect the array. Connect the load and set it to operate 4 hours per day. If the load is lighting, it should operate only during the night. Operate the system and load for 7 days. At least 2 consecutive days should be “low” insolation, less than 2 kWh/m^2 per day. At least 2 days, not necessarily consecutive days, should be “high” insolation, greater than 5 kWh/m^2 per day. Note if the system and load are operating properly by reviewing the system data each day.

Record the start date and time. For only that time when the load is operating during the functional test record: the minimum, average, and maximum load voltages; the minimum, average, and maximum load currents; the load run time. Verify that all meters and indicators function correctly. For the entire Functional Test record: the daily POA insolation; the maximum and minimum battery voltages; the minimum, average, and maximum battery temperatures. Record the end date and time.

7.3.2 Compute expected A:L ratio

The A:L ratio is an indicator of the ability of the system to supply power to the load. The expected A:L ratio is computed from manufacturers' ratings and historical insolation data for the test site. Compute and record:

$$\textbf{Expected A:L Ratio} = \frac{\textbf{Array Current x Sun Hours}}{\textbf{Load Current x Daily Run Time}},$$

where

Array Current (A) is the STC-rated array current at maximum power.
Sun Hours (Hrs) is the estimated average daily insolation received in the plane of the array during the month the test is conducted. This information may be found in sources listed in the bibliography.
Load Current (A) is the name-plate rated current of the load.
Daily Run Time (Hrs) is the number of hours the load is set to operate each day.

7.3.3 Compute actual A:L ratio

The actual A:L ratio is computed using the values measured during the entire functional test. Compute and record:

$$\textbf{Actual A:L Ratio} = \frac{\textbf{Array Ah that Charged the Battery}}{\textbf{Ah Withdrawn from the Battery}},$$

where

Array Energy that Charged the Battery (Ah) is the Ah the battery accepted from the array during the functional test.
Energy Consumed by the Load (Ah) is the Ah withdrawn from the battery, or consumed by the load, during the entire functional test.

7.4 Second capacity test (UBC_1)

This test will determine the UBC_1. This test is not appropriate for systems in which the battery is not protected by LVD circuitry.

7.4.1 Battery charge cycle

Charge the battery as follows: Disconnect the load. Allow the PV array to charge the battery until the charge controller reaches Vr and remains at Vr for at least an accumulated 12 hours. Reconnect the load. Verify that all meters and indicators function correctly. Record the start date and time. Record the maximum battery voltage as Vr. Note the minimum, average, and maximum battery temperatures while the battery is at Vr.

7.4.2 Battery discharge cycle

Disconnect the array. Connect the load. Operate the full load continuously, 24 hours per day, until it discharges the battery to the LVD voltage level. Some systems may require special measures in order to run the load continuously down to LVD. Verify that all meters and indicators function correctly. Allow the system to remain in this LVD state for a minimum of 5 hours and up to a maximum of 72 hours. Note if the controller attempts to reconnect the load to the battery during this time. Record the minimum measured battery voltage as the LVD. Record the Ah withdrawn from the battery as the UBC_1. Record the end date and time.

7.5 Recovery test (RT)

The purpose of the recovery test is to determine how many sun hours are required for the array to bring the discharged battery to Vr with the load configured for normal operation. This test should only be run after the system has reached LVD. In order to generate the data points for the following plot, this test should run for at least 7 days: at least three or four days should be of the array charging the battery, and three or four days should be when the battery has reached Vr.

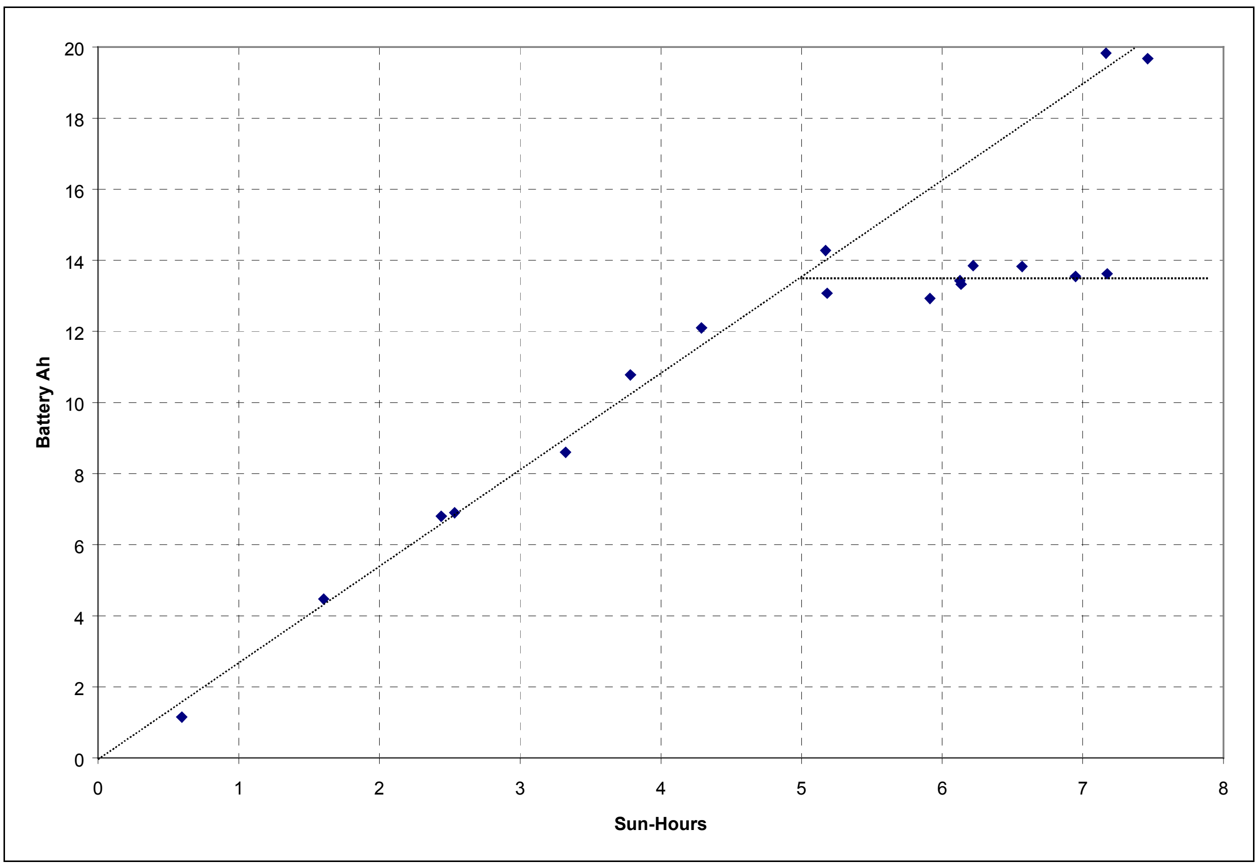
7.5.1 Operate the system

The battery must be at LVD before starting this test. Record the start date and time. Connect the array and connect the load. Set the load to operate 4 hours per day. Operate the system and load normally. This test should run until the controller reaches Vr and then for at least another 3 days. The load may not turn on the first few days until the battery voltage rises above the low-voltage reconnect voltage set point. Record the Sun Hours to Vr. Record the end date and time.

7.5.2 Plot battery Ah vs. sun hours

This plot gives a graphical representation of how many Ah the array can deliver to the battery for a given number of sun hours. It also displays at what point the charge controller begins regulating the array output.

Sum the Ah into the battery and the sun hours for each day during the functional and recovery tests. Plot the battery Ah along the Y axis vs. the sun hours along the X axis. The data should tend to fall along two lines similar to those shown in example in Figure 2. In this example it takes approximately 5 sun hours for the battery to reach regulation voltage after the load operated 4 hours. The steeper the diagonal line, the quicker the array will charge the battery. The level of the horizontal line indicates at what point the charge controller will begin regulating the array current. It is dependent upon the array size and load run time. Record the battery Ah at 1 sun-hour. Record the battery Ah regulation level.



Sample daily battery Ah vs. sun hours plot.

7.6 Final capacity test (UBC_2)

This test will determine the UBC_2. This test is not appropriate for systems in which the battery is not protected by LVD circuitry.

7.6.1 Battery charge cycle

Charge the battery as follows: Disconnect the load. Allow the PV array to charge the battery until the charge controller reaches Vr and remains at Vr for at least an accumulated 12 hours. Reconnect the load. Verify that all meters and indicators function correctly. Record the start date and time. Record the maximum battery voltage as Vr. Note the minimum, average, and maximum battery temperatures while the battery remains at Vr.

7.6.2 Battery discharge cycle

Disconnect the array. Connect the load. Operate the full load continuously, 24 hours per day, until it discharges the battery to the LVD voltage level. Some systems may require special measures in order to run the load continuously down to LVD. Verify that all meters and indicators function correctly. Allow the system to remain in this LVD state for a minimum of 5 hours and up to a maximum of 72 hours. Record the minimum measured battery voltage as the LVD. Record the Ah withdrawn from the battery as the UBC_2. Record the end date and time.

7.6.3 Compare UBC

Compute and record the difference between the initial and final measured capacities:

$$\text{Change in Capacity} = UBC_0 - UBC_2.$$

7.6.4 Compute hours of autonomy

Compute and record the Hours of Autonomy. The Hours of Autonomy value indicates how long the system may operate the load during periods of low irradiance. Compute and record:

$$\textbf{Hours of Autonomy} = \frac{\textbf{UBC2}}{\textbf{Load Current}},$$

where

UBC_2 (Ah) is the Ah capacity of the battery measured in 7.6.2.
Load Current (A) is the average load current measured in 7.3.1.

7.7 Final battery charge

Charge the battery after the final capacity test to ensure the battery is not left in a discharged state at the termination of the performance tests. Charge the battery as follows: Disconnect the load. Allow the PV array to charge the battery until the charge controller reaches Vr and remains at Vr for at least an accumulated 12 hours. The performance tests are complete.

8. FINAL SYSTEM INSPECTION

8.1 System maintenance procedure review

Read through and perform the manufacturer's recommended maintenance procedures. Note if the maintenance procedures are clear and report any difficulties that occur in performing the maintenance, for example, having to disconnect and remove the battery in order to check the battery electrolyte level).

8.2 Visual inspection

Record the date testing ends. Visually inspect the system, noting any problems or damage. The inspection should include all major system components: the PV array; the load; the mounting structure; wiring and cable; fuses, disconnects, protection devices; the controller; and the battery.

8.3 Wiring inspection

Flex all conductors along their entire length, noting any discoloration or brittleness of the insulation. Undersized conductors and poor connections will tend to overheat, leading to brittle and discolored insulation.

9. ARRAY I-V CURVE (OPTIONAL)

After the system has been operating outdoors for several weeks, an I-V curve of the array may be swept. An I-V curve should be swept if the array has a front shield. Disconnect the array from the system. Attach an I-V curve tracer or variable resistor to the DC terminals of the array. Clean the array and then sweep a curve on a clear, sunny day, and when the POA irradiance is between 800 and 1100W/m^2. Record the following measured array information, normalized to STC (1000W/m^2 and a PV cell temperature of 25°C): P_{max}, I_{sc}, V_{oc}, V_{pp}, and I_{pp}.

10. LOAD PERFORMANCE TEST (OPTIONAL)

It may be desired to run performance tests on the load(s). Such tests may be found in other documents. Sources listed in the bibliography describe in detail how to test a lamp in a PV lighting system. However, such tests are beyond the scope of this document, and may require specialized test equipment and procedures.

11. ANNEX A

Sample System Summary

For each PV system tested, a system summary should be completed by the person conducting the tests and submitted to the requestor. In general information entered in the “Specified” column is information provided by the system or component manufacturers and information in the “Measured/Observed” column is information gathered, or calculated, during the system tests. Depending upon the specific system to be tested, not all items in the summary will have entries. The corresponding test procedure section number is listed in each entry box. In addition to the completed system summary, the following items should also be provided to the requestor: copies of all documentation provided with the system and a modified copy of the system schematic or diagram to show the DAS sensor locations. Supporting test data, along with appropriate comments, may also be attached and submitted as necessary or requested as part of the system summary.

Stand-Alone PV System Summary - Page 1 of 2 - System Specifications and Information

System Information

Parameter	
System Manufacturer	4.1
System Model	4.1
Vendor	4.1

Array Information

Parameter	Specified	Measured/Observed
Module Manufacturer	4.1	
Module Model	4.1	
Active Material	4.1	
Array Configuration	4.1	
Array P_{max} @ STC	4.1	8
Array V_{pp}	4.1	8
Array I_{pp}	4.1	8
Array V_{oc}	4.1	8
Array I_{sc}	4.1	8
Array Shield	4.1	

Load Information

Parameter	Specified	Measured/Observed
Description	4.1	
Manufacturer	4.1	
Voltage	4.1	6.3.1
Current	4.1	6.3.1
Power	4.1	
Operating Temperature Range	4.1	
Number of Loads	4.1	

Controller Information

Parameter	Specified	Measured/Observed
Manufacturer	4.1	
Model	4.1	
Type	4.1	
Vr Set Point	4.1	6.6.1
Controller-Battery Compatibility	4.1	
Temperature Compensation Sensor Attaches to Battery	4.1	
Reverse-Current Protection	4.1	
Load Timer Accuracy	4.1	6.3.1
LVD Set Point	4.1	6.6.2

Battery Information

Parameter	Specified	Measured/Observed
Manufacturer	4.1	
Model	4.1	
Type	4.1	
Configuration	4.1	
Voltage	4.1	6.3.1
Capacity	4.1	6.6.2

Documentation Checklist

Parameter		Included	Notes/Comments
Parts List	4.1		
Required-But-Not-Included-Parts List	4.1		
Recommended-Tool List	4.1		
Mechanical Drawings	4.1		
Electrical Schematic or Diagram	4.1		
Installation Procedures	4.1		
Spare Parts List	4.1		
Maintenance Procedures	4.1		
Troubleshooting Guide	4.1		

Stand-Alone PV System Summary - Page 2 of 2 - Test Information and Results

Test Information

Parameter	
Test Facility	4.1
Address	4.1
Contact	4.1

System Inspection

System Arrival Date	4.1
(Attach copy of system documentation)	4.1
Damaged parts?	4.2
All parts present?	4.2
Parts that need to be procured?	4.2

5) System Installation & Instrumentation

Battery preparation and boost charge documented?	5.1.1
Average battery temperature & range	5.1.2
CC temperature compensation senses T_bt?	5.1.3
Load(s) start & operate	5.1.4
Load operation sensing method	5.2.5
(Attach diagram with DAS sensor locations)	5.2.6

System Operation

Parameter	Specified	Measured/Observed
Run Time	4.1	6.3.1
Load Control Method	4.1	
System Intended Location	4.1	
Intended Location Design Month	4.1	

System Performance Results

Parameter	Specified/Calculated	Measured/Observed
Hours of Autonomy	4.1	6.6.4
Sun-Hours to Vr	4.1	6.5.1
A:L Ratio	6.3.2	6.3.3

6) System Performance Tests

UBC_0	
Start date & time	6.1.1
Vr	6.1.1
T_bt min/avg/max at Vr	6.1.1
LVD	6.1.2
UBC_0	6.1.2
End date & time	6.1.2
FT	
Start date & time	6.3.1
V_ld min/avg/max	6.3.1
I_ld min/avg/max	6.3.1
Run time	6.3.1
V_bt min/max	6.3.1
T_bt min/avg/max	6.3.1
End date & time	6.3.1
Expected A:L ratio	6.3.2
Actual A:L ratio	6.3.3
UBC_1	
Start date & time	6.4.1
Vr	6.4.1
T_bt min/avg/max at Vr	6.4.1
LVD	6.4.2
UBC_1	6.4.2
End date & time	6.4.2
RT	
Start date & time	6.5.1
End date & time	6.5.1
Sun-hours to Vr	6.5.1
Battery Ah @ 1 sun-hour	6.5.2
Battery Ah regulation level	6.5.2
(Attach Battery Ah vs. Sun-hours plot)	6.5.2
UBC_2	
Vr	6.6.1
T_bt min/avg/max at Vr	6.6.1
LVD	6.6.2
UBC_2	6.6.2
End date & time	6.6.2
UBC_0 - UBC_2	6.6.3
Hours of Autonomy	6.6.4

7) Final System Inspection

Maintenance procedures ok?	7.1
System visual inspection ok?	7.2
System wiring ok?	7.3

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13. ABSTRACT *(Maximum 200 words)*
Standard test procedures, "IEEE P1526/D1 Draft Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems," [1] have been developed to assess the performance of stand-alone PV systems tested outdoors under prevailing conditions. A copy of the procedures is included in Appendix E. This report presents an overview of the procedures and results from three validation tests conducted between January 1999 and September 2000 at one European and four U.S. test sites. There was good measurement agreement between the results measured at different test sites on similar systems.

To date, most PV system performance test procedures have looked at the performance of the individual components and have not addressed how the integrated system works as a whole. The performance test procedures described in this report verify that the system and load operate as expected, ensure that the PV array and system are capable of recharging the battery, determine the usable battery capacity (UBC), and determine if there is any significant change in the UBC measured three different times during the procedures.

The procedures have been submitted to both IEEE SCC21 and IEC TC82 for use in developing standards. The IEEE SCC21 has initiated P1526, "Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems," [1] and the IEC TC82 has initiated Standard 62124, "Photovoltaic Stand-Alone Systems Design Qualification and Type Approval" [2]. The IEC document also addresses indoor testing.

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