PV Lighting Systems for BCC - Evaluation of VRLA Batteries and PWM Controls

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PHOTOVOLTAIC LIGHTING SYSTEMS FOR THE BREVARD COMMUNITY COLLEGE COMET WALKWAY

EVALUATION OF VRLA BATTERIES WITH PWM CONTROLLERS

SEVEN-MONTH PERFORMANCE SUMMARY

February 13 – September 15, 1997

Revision 2: April 1999

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Executive Summary

This report summarizes the seven-month performance of fifteen PV lighting systems operating with VRLA batteries and PWM charge control.

The testing and monitoring performed for this report were quite extensive. Every effort was made to have each of the systems components operate identically, excepting the batteries which were from three different battery manufacturers, Concorde, Deka, and GNB. It is unfortunate that the lighting systems power draw and light output varied during the testing. This caused the load on the battery systems to vary and made and ABC comparison of the three batteries questionable.

Three type of VRLA batteries are used, including the Concorde PVC 1295H (absorbed-glass-mat), GNB 12/5000X (absorbed-glass-mat) and Deka DF30H (gelled) batteries. Extensive initial baseline data is compared to similar data collected after seven months of operation, and analyzed with respect to the continuous data collected on three of the systems with data acquisition units.

Following are noteworthy events from the first seven-months of operation:

1. One of the two GNB 12-5000X AGM batteries in System 10 failed during the last month of operation, possibly from a shorted cell. The pair of batteries from this system delivered only a fraction of their initial measured capacity on tests conducted after seven months of operation, and no capacity increase was achieved after two additional charge/discharge cycles. This set of batteries was condemned and replaced with a spare set of GNB 12-5000X batteries. A post-mortem inspection of this battery identified the specific cell failure and potential causes for the failure.

2. As can be seen in the report the systems were sized for a load of 27 A.H./day with a minimum December PV to load ratio of 1.25 to 1.0. The Concorde PVC-1295H AGM batteries in system B15 were subjected to a load of almost 32 A.H./day. That represents a December PV to load ratio of about 1.06 to 1.0. Because of the increased load, new PV to load ratios for the February through September test period were calculated using the PVCAD system design program. This program uses published TMY solar resource data from Orlando, PV module data with an Imp of 8.3-amps, and Concorde battery data for a 200 Ah battery. The PVCAD results indicate that although the new December and January PV to load ratio was 0.99 to 1.10, the new February through September PV to load ratio was 1.21 to 1.54 with September being the lowest month. This is down from the original system design of about 1.43 to 1.82 PV to load ratio for the same time interval. The significance of this PVCAD calculation is that the batteries had available to them less excess PV charge from the original design of 11.6 to 22.1 Ah per day down to the new lower values of 6.7 to 17.2 Ah per day. Even with less finish charge available, the B15 system with the Concorde batteries did not fail or cause the system to have the LVD disconnect from the load. The Concorde batteries performed well under these adverse conditions.

3. The Deka DF30H gelled batteries in System 1-5 had a battery size consistent with design and, consequently, performed well. The batteries from System 5 delivered 94 percent of their initial measured capacity, and recovered 100 percent their initial capacity after a complete recharge during the seven-month cycle tests.

4. With the exception of Systems 1, 3, 7 and 10, all other systems operated the lighting load for the intended 9 hours per night.

- The loss of load in System 1 was attributed to an array problem discovered by IV measurements. This array will need to be replaced or repaired.

- The problem with System 3 was found to be a blown load fuse. The fuse was replaced and the system has operated fine over the last two months.

- The loss of load in System 7 was due to a failure of the load time clock resulting from a loose internal connection. The time clock was replaced and the system has operated fine ever since.

- The problem with System 10 was found to be a failure of one of the GNB 12-5000X AGM batteries. These batteries were replaced with a spare set.

5. No problems or other operational concerns were experienced with the PWM battery charge controllers.

6. The load currents for the low-pressure sodium light fixtures have increased by as much as 40 percent over the first seven months of operation. In addition, there has been up to a 20 percent decrease in illumination output.

7. Problems were found with two of the arrays, one having a one-third reduction in the maximum power current output. These arrays will be repaired or replaced.

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1 Introduction and Background

In January 1997, Florida Solar Energy Center (FSEC) staff completed the installation of fifteen (15) photovoltaic (PV) powered lighting systems on the Brevard Community College (BCC) campus in Cocoa, Florida. The PV lighting systems are located around BCC's Circle of Man, Environment and Technology (COMET) walkway, a one-mile path encircling Clearlake and connecting FSEC, the Brevard Museum, the BCC Planetarium and the joint University of Central Florida-BCC library (Figures 1-2).

Figure 1. PV lighting system in front of FSEC building.

Funded by the Brevard County Tourism Development Council and by cost-share commitments from Sandia National Laboratories (SNL) and FSEC, the objectives of this project are to:

- provide security lighting in remote, dark areas along the COMET walkway;
- create a highly visible demonstration of PV/solar systems technology for BCC students, staff and visitors; and
- operate a test bed for the experimental evaluation of batteries, charge controllers, lamps and ballasts used in PV lighting systems.

Figure 2. PV lighting system at night under full moon.

This report presents the initial seven-month performance summary for these 15 PV lighting systems, for the period February 13 through September 15, 1997. During this time, the systems were configured with three types of valve-regulated lead-acid (VRLA) batteries (five systems using each type of battery), all operating with pulse-width-modulated (PWM) battery charge controllers. Details of the system configurations are presented in following sections.

Prior to initial operation, extensive baseline data was collected on the individual components installed in each system. This data included battery capacity and high-rate load measurements, battery weights, charge controller set points, PV array I-V characteristics, load currents and illuminance levels. Three of the systems (one using each of the three battery types) were instrumented and outfitted with data acquisition units, for which extensive operational data were collected. Elapsed time meters were also installed in each system to record lighting load operational hours.

In this report, the initial baseline data is compared to similar data collected after seven months of operation, and analyzed with respect to the continuous data collected on three of the systems. The objectives of this evaluation are to investigate the cause and effect issues of system performance, primarily those involving the performance of the VRLA batteries operating with the PWM-type battery charge controllers.

2 System Components

Each of the fifteen PV lighting systems are fully self-contained, independently-operating power systems, each consisting of a photovoltaic (PV) array, battery bank, lighting fixture and system control board. The components for each system are integrated on a 35 foot Type III concrete utility pole as shown in Figures 1 and 2. Table 1 lists the specifications for the major components in each system.

Table 1. System Component Specifications

		Manufacturer	Model	Type	Ratings (avg.)
PV Array		Solarex	Georgetown	polycrystalline	125 Wp, Imp 8.29 A @ STC (2 in parallel)
Light Fixture		C-Ran	LPS-35	low pressure sodium	35 watt, 12 volt, 3 amp
Charge Controller		Morningstar	SunSaver10	series PWM	10 amp, inc LVD
Battery	**(3 types, 2 in parallel each system)**				
	Systems 1-5	East Penn	Deka DF30H	gelled VRLA	200 Ah at 3 amp rate
	Systems 6-10	GNB	12-5000X	AGM VRLA	200 Ah at 3 amp rate
	Systems 11-15	Concorde	PVC 1295H	AGM VRLA	200 Ah at 3 amp rate

2.1 Photovoltaic Array

The photovoltaic arrays for each system consist of two nominal 12-volt Solarex polycrystalline modules connected electrically in parallel. Based on tests conducted prior to installation, the nominal array maximum power rating at Standards Test Conditions is 125 watts and maximum power current of 8.3 amps at 15.1 volts. The total array surface area is approximately 1.5 square meters (Figure 3).

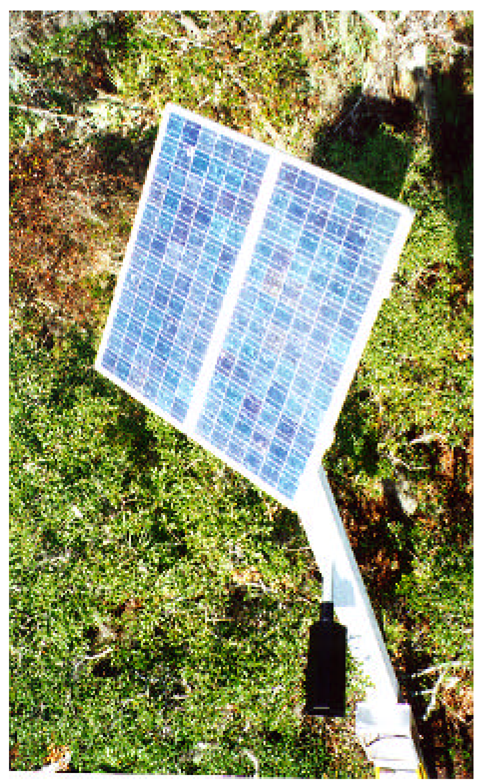

Figure 3. Installed PV array.

2.2 Lighting Fixture

Figure 4. Low pressure sodium lighting fixture.

The lighting fixtures are manufactured by C-Ran Corp. of Largo, Florida, and use a 35 watt low pressure sodium (LPS) lamp powered by a 12-volt dc ballast with a nominal rated load current of 3 amps. The fixture includes a specially designed reflector, a Lexan lens, and has a characteristic "cut-off" lighting illumination pattern. The choice of the LPS lamp and specific distribution were intended to reduce the potential glare and other problems associated with nighttime observations at the BCC Planetarium (Figure 4).

2.3 System Control

The system control board includes a battery charge controller, load timer, overcurrent protection, disconnect devices and grounding provisions (Figure 5). Three of the systems (one with each battery type) include a data acquisition system to monitor operational performance.

The charge controller used in the systems is the Morningstar SunSaver10 pulse-width-modulated controller (PWM), including two user selectable regulation voltages (via terminal jumper), on board battery temperature compensation, and low voltage load disconnect/reconnect circuit. The load is controlled using a programmable weekly time clock, which remotely switches the 3 amp lighting load for a 9 hour operational period each night.

Overcurrent and disconnect means are provided on the control board for the positive legs of the PV, battery and load circuits. The fused disconnects include 15 amp KLM dc-rated fuses for the PV and battery legs, and a 5 amp KLM fuse for the load.

Current shunts were also installed in the negative battery leg of each system for evaluation and data acquisition purposes. The current shunt is tied to a ground terminal on the control board, which is connected to the battery box, array support structure and terminated at a 10 foot copper-clad steel ground rod at the base of the pole.

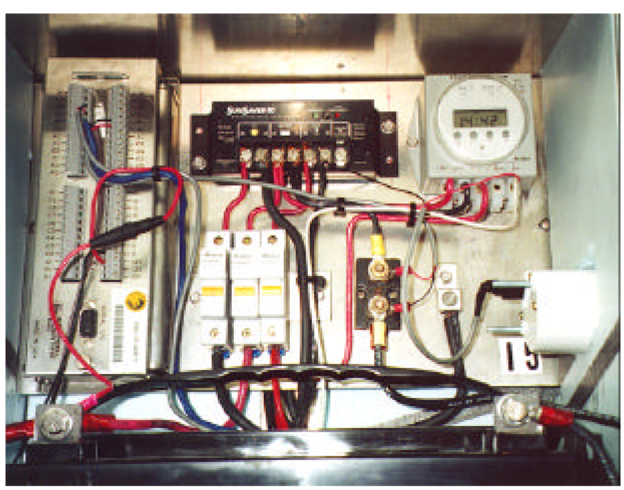

Figure 5. System control board with data acquisition unit.

2.4 Battery Bank

Three types of valve-regulated lead-acid (VRLA) batteries commonly used in PV lighting applications are being evaluated in these systems, with five (5) systems using each type of battery. These batteries include the Concorde PVC 1295H (absorbed-glass-mat), GNB 12/5000X (absorbed-glass-mat) and Deka DF30H (gelled), shown left to right in Figure 6. Each system uses two of the nominal 100 amp-hour batteries connected in parallel, for a total rated capacity of 200 amp-hours at 12 volts dc for each system.

Figure 6. VRLA batteries used in systems (L-R: Concorde PVC 1295H, GNB 12-5000X and Deka DF30H).

2.5 System Sizing and Design

The configurations for each of the fifteen PV lighting systems were designed to be as identical as possible, including the PV array, charge controller, light timer, wiring and light fixture. The primary difference is that three different battery types are used, one battery type for each group of five systems.

For the purposes of our experimental evaluation, the system sizing parameters were adjusted to achieve a minimum PV energy to electrical load ratio of 1.25 to for the worst insolation month of the year (January) in Central Florida. This minimum sizing criteria was selected to ensure adequate overcharge would be provided, and represents typical system designs supplied by the PV lighting industry.

To meet the desired 1.25 to 1 PV to load energy ratio, the rating for the PV array were first determined by current-voltage (I-V) curve measurements. Results of these measurements indicated an average array maximum power current of 8.3 amps at STC.

Using a wintertime design insolation level of 4 kWh/m^2-day (Central Florida, January, 45 degree tilt, south-facing surfaces), the predicted PV array output on an average daily basis for this design period was determined to be 33.2 amp-hours. To meet the minimum PV to load criteria of 1.25 to 1, the nightly load was limited to 26.5 amp-hours. Based on the nominal 3 amp load current for the low pressure sodium light fixtures, the programmable time clock was adjusted to operate the lighting load for nine (9) hours per night, or 27 amp-hours total.

The charge controllers in the systems using the Deka DF30H and GNB 12-5000X batteries were set with a regulation voltage of 14.1 volts at 25 ^{o}C. The five systems using the Concorde PVC 1295H battery have a charge regulation voltage of 14.4 volts per recommendations by the manufacturer.

With the nominal 200 amp-hour battery capacity for each system, the system autonomy to 90% depth of discharge was estimated to be seven (7) days, and the average daily depth of discharge was estimated to be approximately 12 percent state of charge. Further details on the design and sizing for each system are given on the spreadsheet included in the Appendix.

3 System Evaluation

The performance of the VRLA batteries operating with the PWM controllers in these systems is the central focus of this evaluation. To establish and document performance trends, extensive baseline measurements were made before installation on each component, including the lamps, controllers, batteries and arrays. This information, along with similar data measured after the initial period of operation, is the basis for this evaluation.

Throughout the seven-month initial operation period, data was collected and observations were made on at least a monthly basis. Also recorded were load elapsed time readings, illuminance measurements and other observations. For documentation purposes, a record of all systems activity and measurements were noted in a logbook.

3.1 Data Acquisition

Three (3) systems, consisting of ones using each of the three battery types, were outfitted with Campbell CR10 data acquisition units to measure the solar irradiance, battery voltage, battery currents and temperatures over the first seven-months of operation. The data measurement interval was 5 seconds, and averages, minimums and maximums were recorded on an hourly basis for battery voltage and current, solar insolation and temperatures. The data availability factor was 100 percent for the first seven-months of operation for the monitored systems.

Data was downloaded on at least a monthly basis and processed in a series of hourly and daily data files for each of the three DAS systems (Systems 5, 10 and 15). For each of these systems, monthly charts of hourly data and year-to-date charts of daily data were created, and are included in the Appendix. A summary of this data, in tabular and bar chart form, is presented on the next pages for the period February 13 through September 15, 1997.

Table 2. Performance Summary for Systems 5, 10 and 15

	System Number		
	B05	**B10**	**B15**
Analysis Period: February 13 - September 15, 1997 **Start Date: 97044** **End Date: 97258** **Total Days: 215**			
SYSTEM SPECIFICATIONS	**B05**	**B10**	**B15**
PV Array	**Solarex**	**Solarex**	**Solarex**
Maximum Power Current at STC (A)	8.3	8.3	8.3
Maximum Power at STC (W)	125	125	125
Charge Controller	**Morningstar**	**Morningstar**	**Morningstar**
Model	SunSaver 10	SunSaver 10	SunSaver 10
Regulation Set Point (V)	14.1	14.1	14.4
Battery	**Deka**	**GNB**	**Concorde**
Model	DF30H	12/5000X	PVC1295H
Configuration	2 in parallel	2 in parallel	2 in parallel
Nominal Battery Voltage (dc)	12	12	12
Nominal Capacity @ 3 amp rate	200	200	200
Light Fixture	**C-Ran**	**C-Ran**	**C-Ran**
Model	LPS-35	LPS-35	LPS-35
Nominal Current @ 12 vdc (A)	3	3	3
Measured Current @ System Voltage (A)	3.1	3.4	3.6
Nightly Operation Period (hr)	9	9	9
SYSTEM PERFORMANCE DATA	**B05**	**B10**	**B15**
Average Daily Solar Insolation (kWh/m^2-day, 45^o tilt)	4.86	4.86	4.86
Battery Temperatures	**B05**	**B10**	**B15**
Average Daily Maximum Battery Temperature (^{o}C)	32.46	34.03	32.63
Maximum Battery Temperature (^{o}C)	39.03	41.22	38.84
Average Daily Minimum Battery Temperature (oC)	23.71	23.73	23.47
Minimum Battery Temperature (^{o}C)	13.07	12.43	13.24
Battery Voltages	**B05**	**B10**	**B15**
Average Daily Maximum Battery Voltage (V)	13.83	13.80	14.12
Maximum Battery Voltage (V)	14.21	14.21	14.51
Average Daily Minimum Battery Voltage (V)	12.57	12.11	12.48
Minimum Battery Voltage (V)	12.14	11.38	12.03
Battery Ampere-Hours	**B05**	**B10**	**B15**
Average Daily Positive Battery Ampere-Hours (Ah)	30.47	32.26	33.03
Average Daily Negative Battery Ampere-Hours (Ah)	27.89	30.13	31.89
Average Daily Net Battery Ampere-Hours (Ah)	2.59	2.13	1.14
Average Daily Overcharge (%)	109	107	104
OTHER DATA			
Avg. Daily PV Array Utilization Efficiency (%)	75	80	82
Avg. Daily PV to Load Energy Ratio	1.45	1.34	1.27
Elapsed Timer Readings (hrs/night)	9	9	9

Figure 7 shows the average daily minimum and maximum battery voltages, as well as the absolute minimum and maximum battery voltages for each of the three monitored systems. The average daily and absolute maximum voltages for Systems 5 and 10 are very consistent, as the charge controllers for both of these systems (Deka and GNB batteries) are set for a regulation voltage of 14.1 volts. The maximum of 14.21 volts for these systems occurred during cooler weather, showing a small degree of temperature compensation. The maximum voltages for System 15 (Concorde battery) were generally 0.3 volt higher then the other two systems, due to the higher 14.4 volt regulation setting.

There were considerable differences between the average daily and absolute minimum battery voltages for the three systems, with System 5 (Deka battery) holding the highest of the minimum voltages. In general, the average daily minimum voltages for all systems were above 12 volts, however System 10 (GNB battery) was the only one with an absolute minimum below 12 volts, reaching the low voltage disconnect point of 11.3 volts a few times during the seventh month of operation. Subsequent investigations revealed that this was due to a failure of one of the two parallel GNB batteries in this system. More details on this issue are provided later in this report.

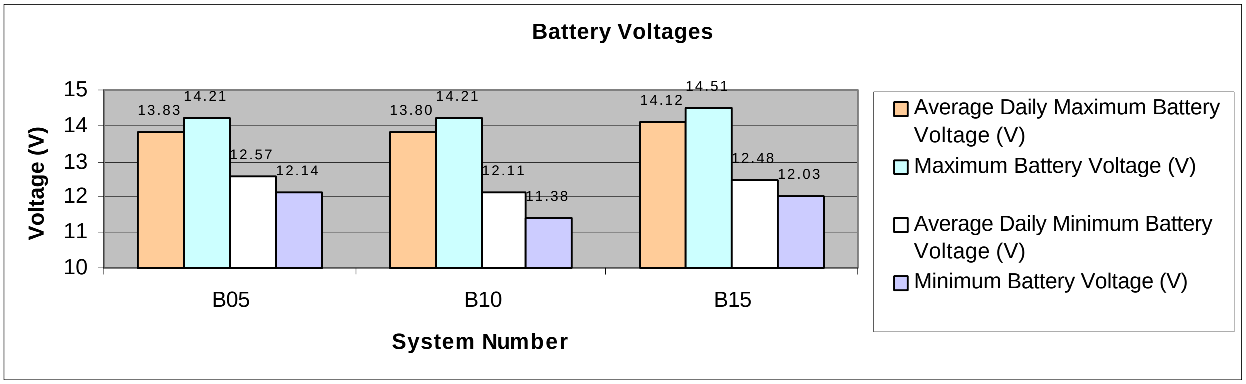

Figure 7. Battery voltages for Systems 5, 10 and 15.

Figure 8 shows the average daily and absolute minimum and maximum battery temperatures for Systems 5, 10 and 15. The average daily maximum battery temperatures were on the order of 32 ^{o}C, although the maximums approached 40 ^{o}C. In general, the batteries followed closely with ambient temperature. While this data was collected predominately during the warmer summer months, this is considered to be the highest temperature environment that one would want to operate VRLA batteries.

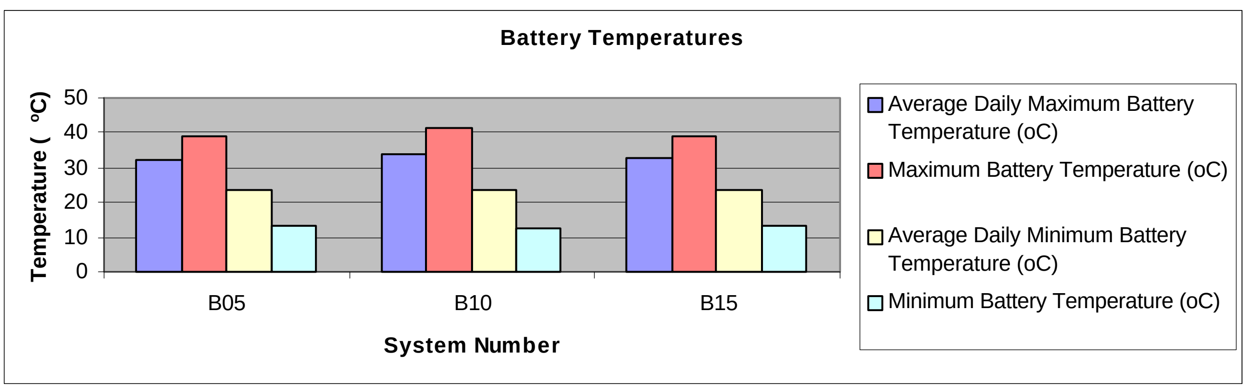

Figure 8. Battery temperatures for Systems 5, 10 and 15.

Figures 9 and 10 show the battery ampere-hours and overcharge for Systems 5, 10 and 15 for the period February 13 through September 15, 1997. Although the battery negative (load) amp-hours varied by 14 percent or 4 ampere-hours, this was not thought to have affected the amount of overcharge received by the batteries due to the proportional increase in battery positive (charging) ampere-hours.

Systems 5 and 10 (Deka and GNB batteries) received about the same amount of overcharge, 109 and 107 percent, respectively. The amount is typically recommended for these batteries, indicating that the regulation voltage of 14.1 volts is appropriate for the PWM charge controller used with these batteries. Even with the higher regulation voltage of 14.4 volts used for the Concorde AGM batteries in System 15, the overcharge was only 104 percent, and is thought to be too low. The estimated PV to load ratio for this system is lower than Systems 5 and 10 due to the higher load current, however this does not appear to be the problem. This point will be discussed further in following sections on battery measurements.

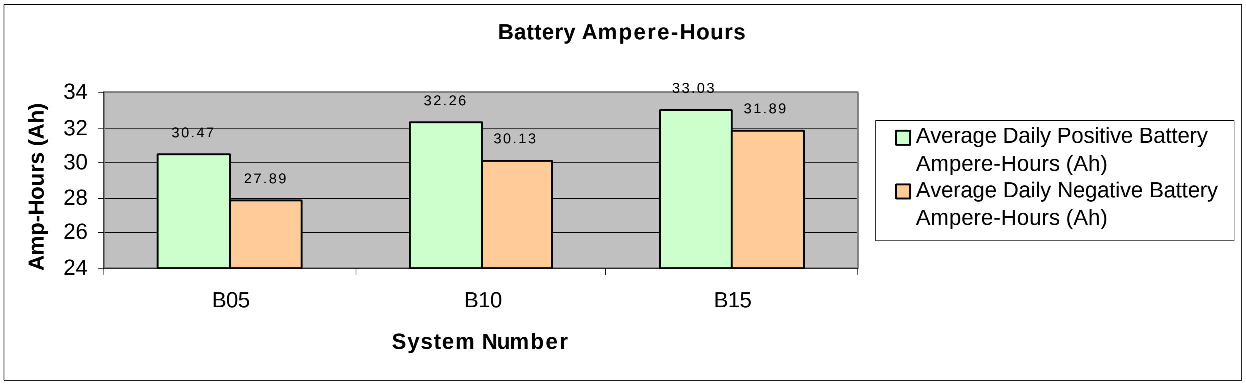

Figure 9. Battery ampere-hours for Systems 5, 10 and 15.

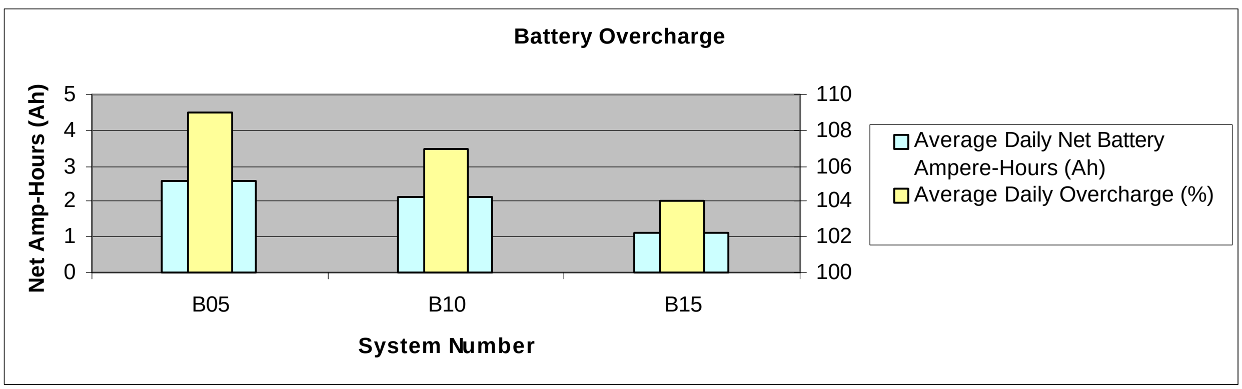

Figure 10. Battery net ampere-hours and overcharge.

3.2 Battery Measurements

Prior to installation, all batteries were weighed and grouped in pairs, then discharged 100% and charged using the rates experienced in the systems. In addition to the capacity tests, high rate load tests were conducted on each battery at 100 amps for 5 minutes prior to installation. This relatively simple test was performed to validate the in-field accuracy of this measurement in predicting loss of battery health and capacity over time. High rate load tests were conducted after seven months of operation on all batteries and capacity tests were conducted on the three batteries removed from System 5, 10 and 15 with data acquisition units.

3.2.1 Battery Capacity Tests

While the primary purpose of the initial battery tests was to establish baseline capacities for later comparison, we were also interested in the approximate battery state-of-charge at which specific control actions would occur. These levels included the depth-of-discharge at 11.3 volts (the controller LVD), the state-of-charge at 12.3 volts (the controller LRV), and the state-of-charge at 14.1 or 14.4 volts (the controller regulation voltages).

3.2.1.1 Initial Battery Tests

All batteries were initially boost charged, the Deka and GNB batteries to 14.1 volts at 7 amps, and the Concorde batteries 14.4 volts also at 7 amps, all using a 12 hour float period. After the boost charge, the battery pairs were discharged at 3 amps to 10.5 volts, then recharged using the same profile as the boost charge (Figure 11).

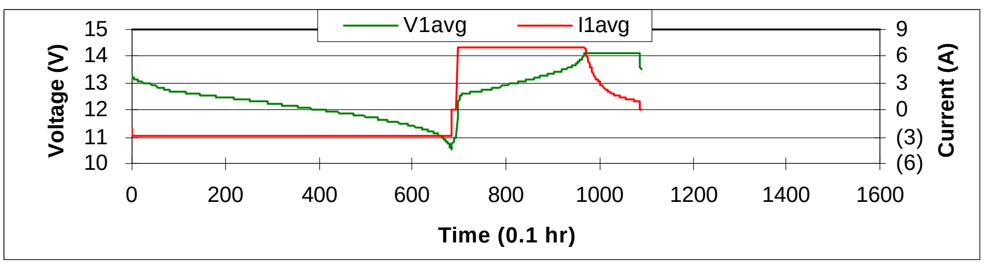

Figure 11. Typical battery initial cycle test.

Table 3 shows the tabular data for the initial cycle tests conducted on each battery pair (plus one spare set for each battery type). The same data is presented in bar chart format on the following page in Figures 11-13.

At the low 3-amp discharge rate used in this application, all battery pairs delivered between 193 and 206 amp-hours capacity to 10.5 volts, and between 179 and 190 amp-hours to 11.3 volts. This data compares favorably with manufacturer's ratings, and is relatively consistent between the three battery types. The resulting depth-of-discharge at 11.3 volts (controller LVD) ranged from 89 to 94% of the total battery capacity, a low level for systems with marginal PV to load ratio. While the Deka and Concorde batteries received an acceptable amount of overcharge on the recharge cycle (107 to111 percent), the six pair of GNB batteries received only 103 to 104 percent on this initial recharge. As shown in the performance data for System 10 presented in the previous section, the overcharge in systems operation for these batteries was 107 percent.

Table 3. Initial Battery Capacity Test Data

Boost Charge (CV)	GNB1	GNB2	GNB3	GNB4	GNB5	GNB6	CBC1	CBC2	CBC3	CBC4	CBC5	CBC6	DEK1	DEK2	DEK3	DEK4	DEK5	DEK6
Regulation Voltage (V)	14.15	14.15	14.15	14.15	14.15	14.15	14.43	14.42	14.42	14.42	14.42	14.42	14.14	14.14	14.13	14.13	14.13	14.13
Charge Rate (A)	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Float Time (hr)	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Discharge																		
Cut-Off (V)	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
Discharge Rate (A)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Capacity (Ah)	196	193	202	198	199	206	193	197	196	197	198	197	201	202	201	204	192	199
Capacity to 11.3 V (Ah)	178	176	180	177	178	185	179	185	184	185	184	185	183	184	183	187	177	183
DOD to 11.3 V (%)	91	91	89	89	89	90	93	94	94	94	93	94	91	91	91	92	92	92
Recharge (CV)																		
Regulation Voltage (V)	14.16	14.16	14.16	14.16	14.16	14.16	14.43	14.42	14.42	14.42	14.42	14.42	14.14	14.14	14.13	14.13	14.13	14.13
Charge Rate (A)	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Float Time (hr)	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Charge (Ah)	204	201	209	204	205	212	214	215	214	215	214	214	218	218	218	218	209	213
Charge to Reg (Ah)	182	180	186	180	179	186	185	183	182	181	183	183	190	190	188	190	182	186
SOC at Reg (%)	89	90	89	88	87	88	86	85	85	84	86	86	87	87	86	87	87	87
Charge to 12.3 V (Ah)	60	59	56	57	59	58	54	51	50	50	53	51	2	2	2	2	2	2
SOC at 12.3 V (%)	29	29	27	28	29	27	25	24	23	23	25	24	1	1	1	1	1	1
Overcharge (%)	104	104	103	103	103	103	111	109	109	109	108	109	108	108	108	107	109	107

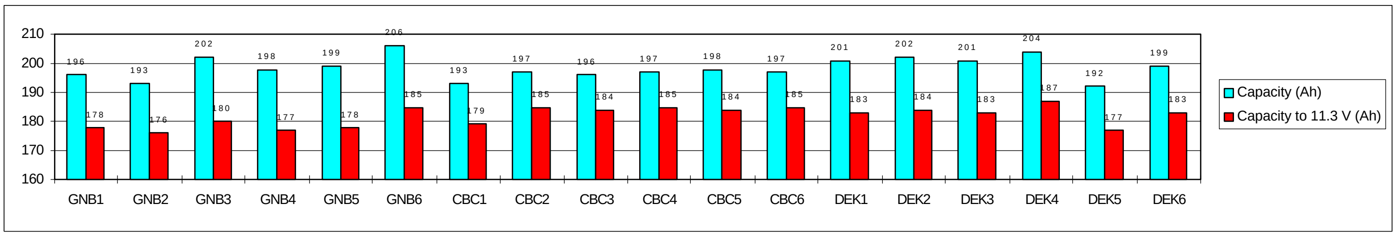

Figure 12. Initial battery capacities.

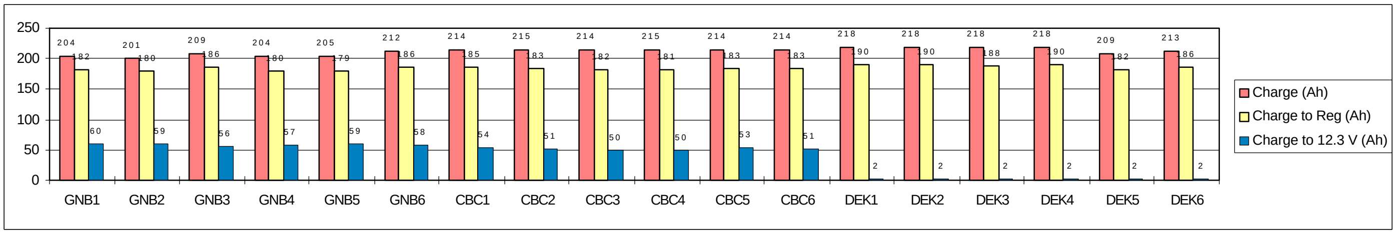

Figure 13. Initial battery recharge.

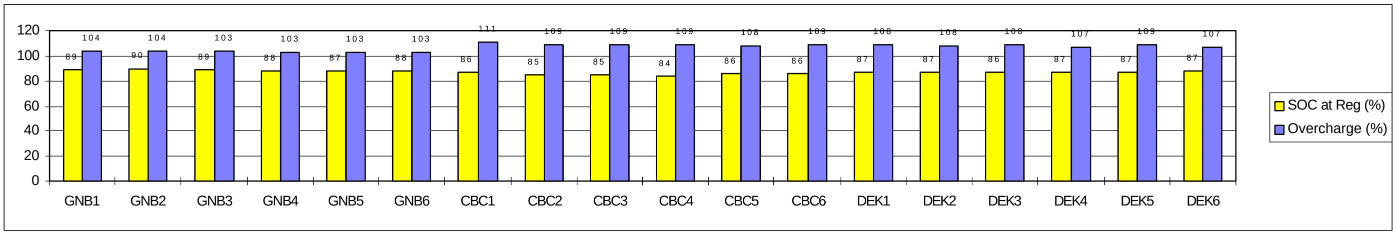

Figure 14. Initial battery overcharge and regulation.

3.2.1.2 Seven-Month Capacity Tests

On September 15, 1997 after seven months of operation, the batteries from the three systems with DAS units (Systems 5-Deka, 10-GNB and 15-Concorde) were removed for another capacity test. The batteries were removed for testing after one-week with the insolation at or above 5 kWh/m^2/day and at the end of a complete day of charging to reflect as much as possible the maximum state of charge for the batteries in the systems. The lighting load was operational through the previous night. Note that the design insolation for 1.25 PV to load ratio is 4 kWh/m^2/day. Under the conditions preceding the battery capacity tests, the average daily insolation was 5.89 kWh/m^2/day, resulting in a design-based PV to load ratio (based on nominal rated load current and time of operation) was approximately 1.81. For each of the three sets of batteries tested the actual PV to load ratios for the preceding week were 1.78, 1.67 and 1.54 for the Deka, GNB and Concorde batteries, respectively. The amount of overcharge accepted by the batteries was 112, 116 and 106 percent for the Deka, GNB and Concorde batteries, respectively.

These seven-month tests were conducted at the same conditions as the initial cycle tests, although two or three complete discharge/charge cycles were performed this time to determine any recoverable capacity (if the batteries were not somehow fully charged when removed from the systems). The battery pairs were discharged at 3 amps to 10.5 volts, then recharged at constant current of 7 amps up to the respective regulation voltages, followed by a 12-hour float period at constant-voltage and current-limiting. The regulation voltage for the Deka and GNB batteries was 14.1 volts, while the Concorde battery used 14.4 volts.

Table 4 lists tabular data for the initial battery cycle tests prior to installation, and similar tests conducted after seven-months of operation. Figures 15-17 on the following page show the same information in bar chart format.

Table 4. Comparison of Initial and Seven-Month Battery Capacity

Date >> / Battery >>	12/96 GNB5 Initial	9/97 GNB5 1st	9/97 GNB5 2nd	9/97 GNB5 3rd	12/96 CBC5 Initial	9/97 CBC5 Ist	9/97 CBC5 2nd	12/96 DEK5 Initial	9/97 DEK5 1st	9/97 DEK5 2nd
Boost Charge (CV)										
Regulation Voltage (V)	14.15				14.42			14.13		
Charge Rate (A)	7				7			7		
Float Time (hr)	12				12			12		
Discharge										
Cut-Off (V)	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
Discharge Rate (A)	3	3	3	3	3	3	3	3	3	3
Capacity (Ah)	199	26	35	32	198	178	170	192	181	191
Capacity to 11.3 V (Ah)	178	25	35	32	184	168	160	177	168	177
DOD to 11.3 V (%)	89	96	100	100	93	94	94	92	93	93
Capacity (Ah to 9.5 V)		74								
Recharge (CV)										
Regulation Voltage (V)	14.16	14.13	14.13	14.13	14.42	14.42	14.42	14.13	14.12	14.12
Charge Rate (A)	7	7	7	7	7	7	7	7	7	7
Float Time (hr)	12	12	12	12	12	12	12	12	12	12
Charge (Ah)	205	85	44	42	214	177	174	209	198	208
Charge to Reg (Ah)	179	64	28	26	183	153	141	182	170	181
SOC at Reg (%)	87	75	64	62	86	86	81	87	86	87
Charge to 12.3 V (Ah)	59	4	0	0	53	50	48	2	1	1
SOC at 12.3 V (%)	29	5	0	0	25	28	28	1	1	0
Overcharge (%)	103	115	126	131	108	99	102	109	109	109

As suspected by the minimum battery voltages for System 10 (11.3 volts, LVD) during the prior week, the GNB 12-5000X batteries had suffered severe loss of capacity.   This pair of batteries delivered only 26, 35 and 32 amp-hours on three successive discharge tests. During the first discharge, the batteries were inadvertently discharged below 10.5 volts, and held 9.5-9.7 volts delivering the 3-amp load for over 12 hours before the test was aborted. This explains the amount of overcharge received after the first discharge.

This data, although a mistake, clearly showed the battery had lost the voltage of about one cell (2 volts) under the 3-amp discharge at approximately 11.8 to 12 volts. Data presented later in this report on high rate load tests isolated the problem to one of the batteries in the pair. This battery was also disassembled in attempt to identify the cause of the cell failure. More on this issue later. For now, this pair of batteries has been condemned and replaced with the spare set of GNB 12-5000X batteries (#6) from the initial cycle tests.

The pair of Deka DF30H batteries (System 5) delivered 181 amp-hours compared with the initial 192 amp-hours, or about 94 percent SOC. On the second cycle, all of the initial measured capacity was recovered for this pair of batteries.

The pair of Concorde PVC 1295H batteries from System 15 delivered 168 and 160 amp-hours on the two successive cycles. This decrease in capacity was unexpected and attributed to the low amount of overcharge received (99-102 percent). These batteries had been regulating in system operation and seem to have been performing well, although the overcharge in systems operation was lower than expected at 104 percent. The apparent temporary?? cause for the loss of battery capacity may be due to the lower PV to load ratio resulting in less finish charging, leaving it in a state of partial charge. All lead acid batteries left in a partial state of charge over an extended period of time will sulfate to some degree: this will result in premature loss of capacity. If premature loss of capacity occurs, this condition may be corrected by equalization charging the batteries according to the manufacturers recommendations

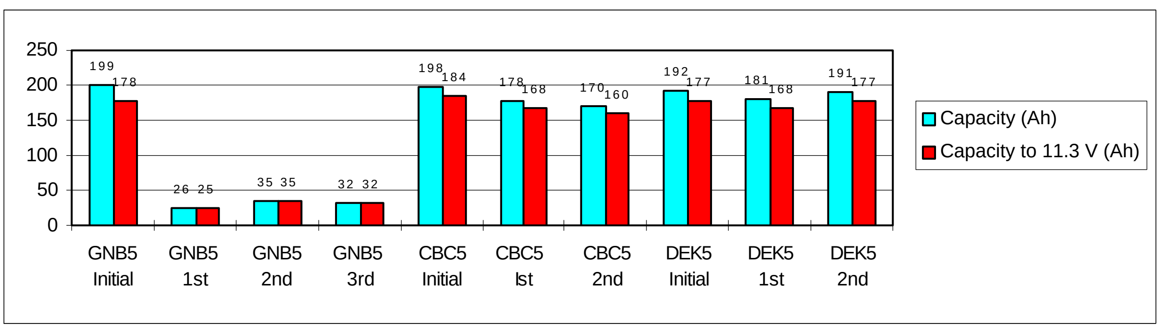

Figure 15. Initial and seven-month battery capacities.

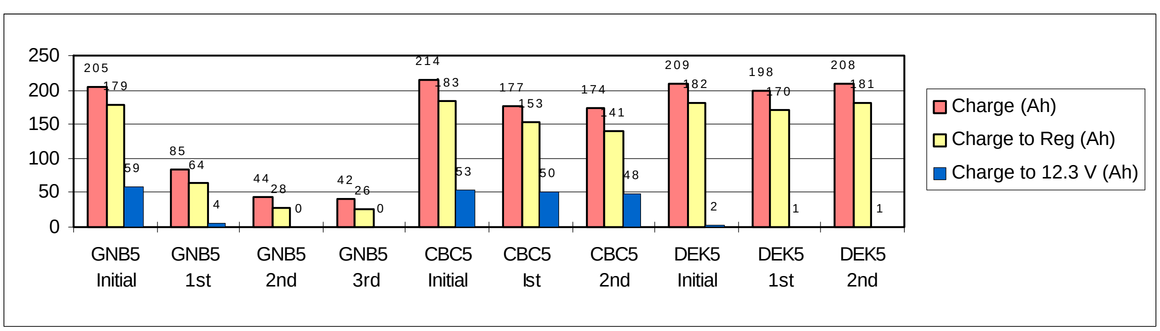

Figure 16. Initial and seven-month charge acceptance.

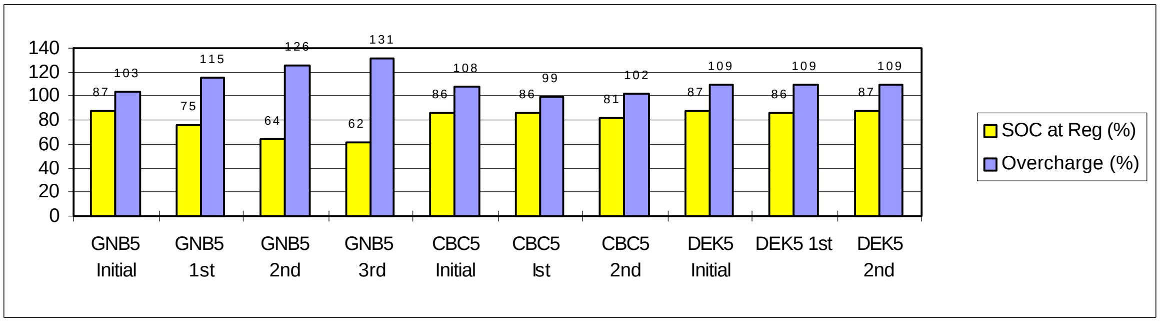

Figure 17. Initial and seven-month overcharge.

3.2.2 Battery High Rate Load Tests

Prior to installation and after seven months of operation, all batteries (15 systems, 2 batteries per system) were subjected to high rate load tests. Initially the tests were conducted on each battery at 100 amps for 5 minutes. After seven months, the tests were conducted at the same 100-amp rate but for only 15 seconds. The seven-month tests were conducted just prior to the capacity tests on the batteries from Systems 5, 10 and 15, after a week of good sunlight and a complete day of charging.

Figures 18-23 show the load test data for each battery type for the initial and seven-month tests. The “A” and “B” designations refer to the pair of batteries in each system.

Figures 18 and 19 show the load test data for the Deka DF30H batteries in Systems 1-5. This data from the seven-month test clearly shows the lower voltage (and state-of-charge) for the batteries in System 1. As will be discussed later, there is a problem with the array causing a reduction in the peak charging current, possibly a shorted bypass diode internal to the laminate. This issue will is discussed and investigated later in this report.

Of particular note is how the voltage under load for the DekaDF30H battery was much higher than the GNB 12-5000X and Concorde PVC 1295H battery voltages during both the initial and seven-month tests.

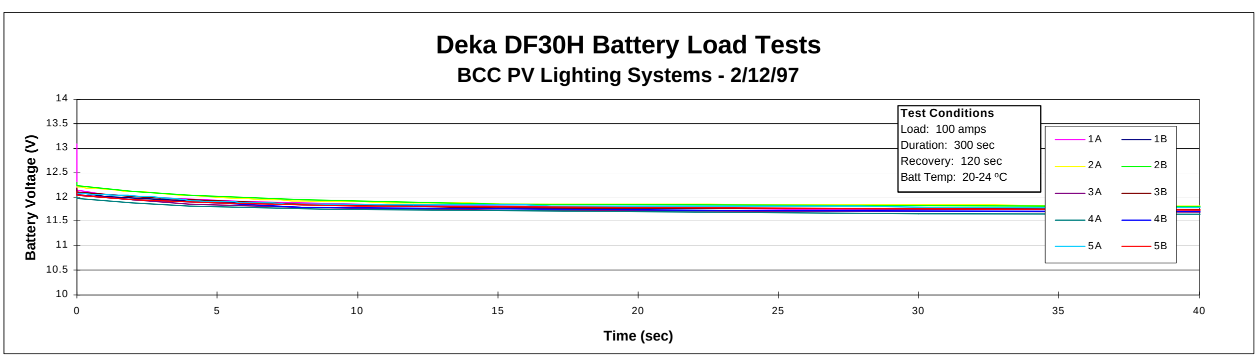

Figure 18. Deka DF30H initial load tests.

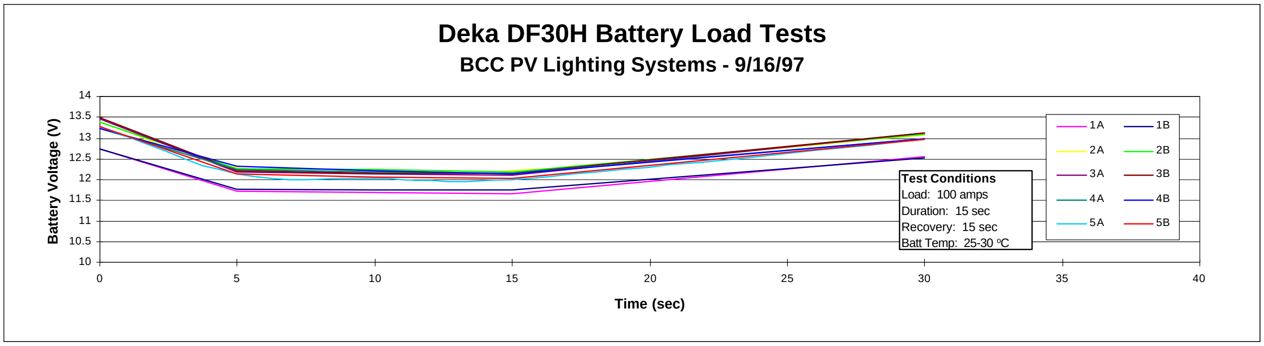

Figure 19. Deka DF30H seven-month load tests.

Figure 20 and 21 show the load test data for the GNB 12-5000X batteries in Systems 6-10. With the exception of the batteries 8A and 9A, the rest of the batteries maintained approximately 11.5 volts during the test. In the seven-month test, these two batteries appeared consistent with the majority of other GNB batteries, however batteries 10A and 8B clearly showed a problem. Battery 10A showed the possibility of a shorted cell, with the voltage dropping to 10.25 volts. This battery was found to have suffered severe capacity loss as discussed previously in this report.

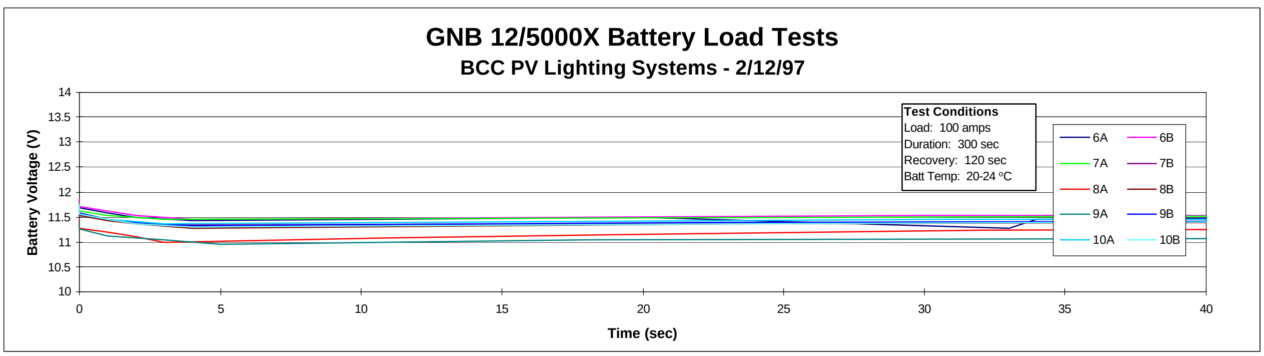

Figure 20. GNB 12-5000X initial load tests.

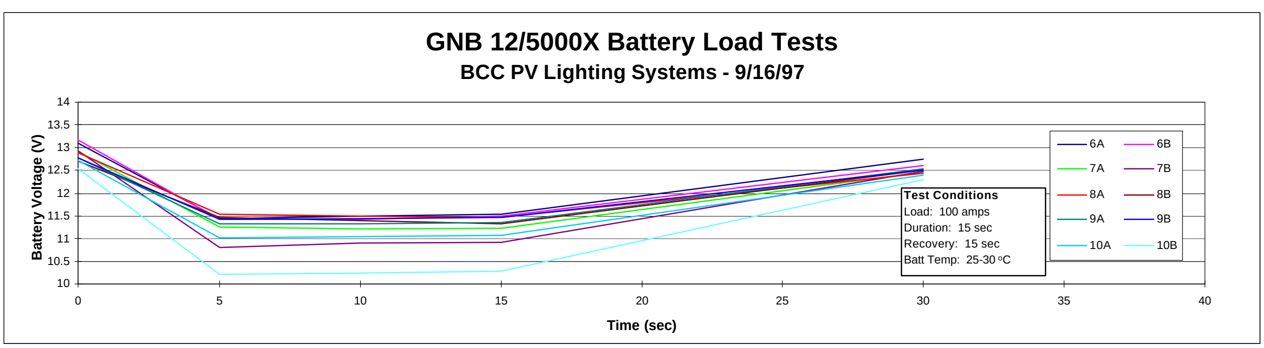

Figure 21. GNB 12-5000X seven-month load tests.

Figures 22 and 23 show the load test data for the Concorde PVC 1295H batteries in Systems 11-15. No significant observations were made from this data, with the initial and seven-month data being consistent with the initial data, varying between 11.5 and 12 volts under load.

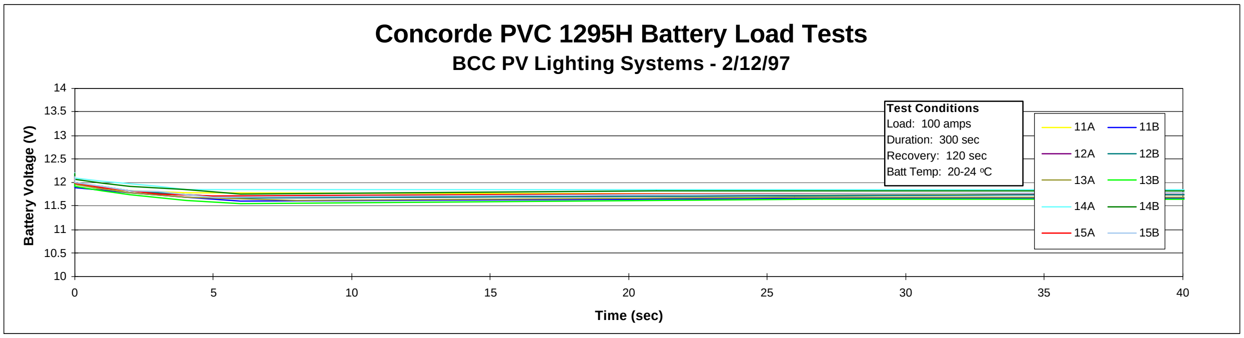

Figure 22. Concorde PVC 1295H initial load tests.

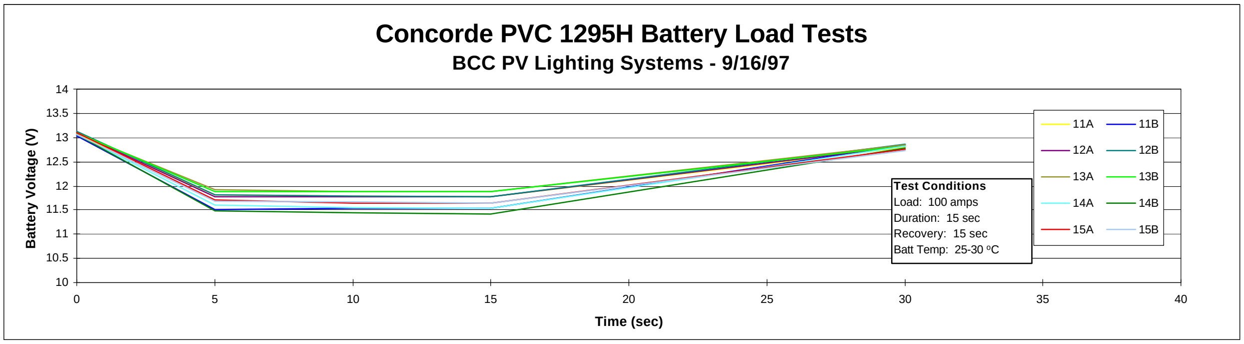

Figure 23. Concorde PVC 1295H seven-month load tests.

3.2.3 Battery Weights

To quantify electrolyte loss, all batteries were weighed prior to installation, and the batteries from Systems 5, 10 and 15 were weighed prior to the seven-month capacity test. The weight loss for the GNB 12-5000X and Concorde PVC 1295H batteries was negligible, less than 0.1 pound per 12-volt unit. The weight loss for the Deka DF30H batteries was somewhat more, 0.36 and 0.51 pounds for the two batteries, respectively.

3.3 *Battery Autopsy from System 10*

After the failure of one of the GNB 12-5000X AGM batteries from System 10 was discovered, a limited post-mortem autopsy was performed on this battery after the seven-month capacity and load tests. Results from the capacity and high rate load tests indicated a possible failed or shorted cell in battery 10A, causing the recent LVD condition in system operation.

The first step was to isolate the bad cell in the battery by means of a high rate load test (Figures 24-25). The top of the battery was cut open so that individual cell voltages could be measured. During this 200-amp load test for 15 seconds, the cell voltages (from positive to negative) were 1.7, 1.95, 1.95, 1.95, 1.95 and 0.87 volts, respectively. This test identified the bad cell as the negative-most cell in the 12-volt unit.

Figure 24. Battery load test.

Observation of each cell indicated some cells were dryer than others, although this was difficult to determine with the AGM batteries. Note that no significant weight loss was recorded for this battery after seven months of operation. When the battery was tipped on it's side (Figure 26), cells 2-5 had excess liquid electrolyte that collected in the cavity in the top of the battery case. Specific gravity readings for these cells were 1.295, 1.295, and 1.290, respectively for cells 2-4. No excess electrolyte was available in cells 1, 5 or 6.

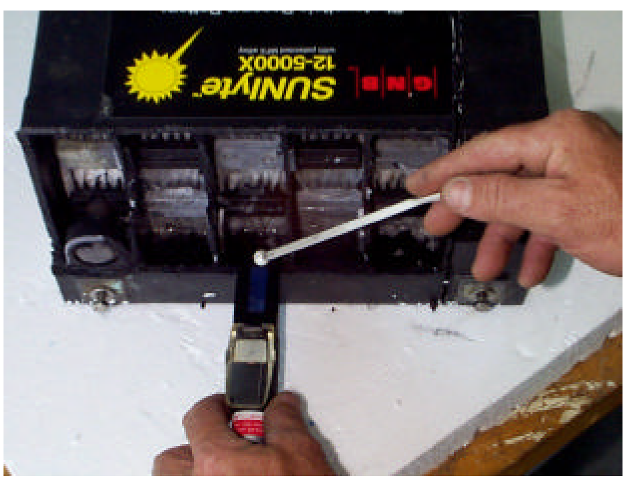

Figure 25. Electrolyte measurement.

Figure 26. Exposed top of GNB 12-5000X battery.

After the load test identified the failed cell as the one at the negative terminal of the battery, this cell stack was extracted from the rest of the battery for a detailed inspection of the plates and separators for signs of short-circuiting.

The bottom part of positive plates are wrapped with glass mats, and no signs of short-circuiting were observed there. Similarly, no unusual problems were observed at the sides of the plate stack. A problem could have been overlooked at the inter-cell connections at the top of the cell, but nothing unusual was observed.

Upon disassembly of the plates, two noteworthy observations were made. The first was a lump of brownish material (probably lead-dioxide) removed from the positive plate (Figure 28). This material had indented the glass mat and separator, possibly coming into contact with the adjacent negative plate. However, no apparent signs of short-circuiting were observed.

The second observation from the disassembly of the plate stack was a dark "stain" on a couple of plate groups near the middle of the cell, and appeared to continue from the positive to negative plates (Figure 29). Again, it was not certain if this was related to the cell problem, but appeared possible.

Figure 27. Negative cell extracted from GNB battery 10A.

Figure 28. Indentation caused by excess material on positive plate.

Figure 29. Stain on glass mat between positive and negative cell.

3.4 Charge Controller and Systems Operation Measurements

Each charge controller was bench tested prior to installation to verify proper operation and set point values. The specified controller set points are 14.1 or 14.4 volts regulation voltage (jumper selectable), 11.3 volt load disconnect and 12.3 volt load reconnect. Figure 30 shows the initial controller set points measured in the lab at 25 +/- 2 ^{o}C.

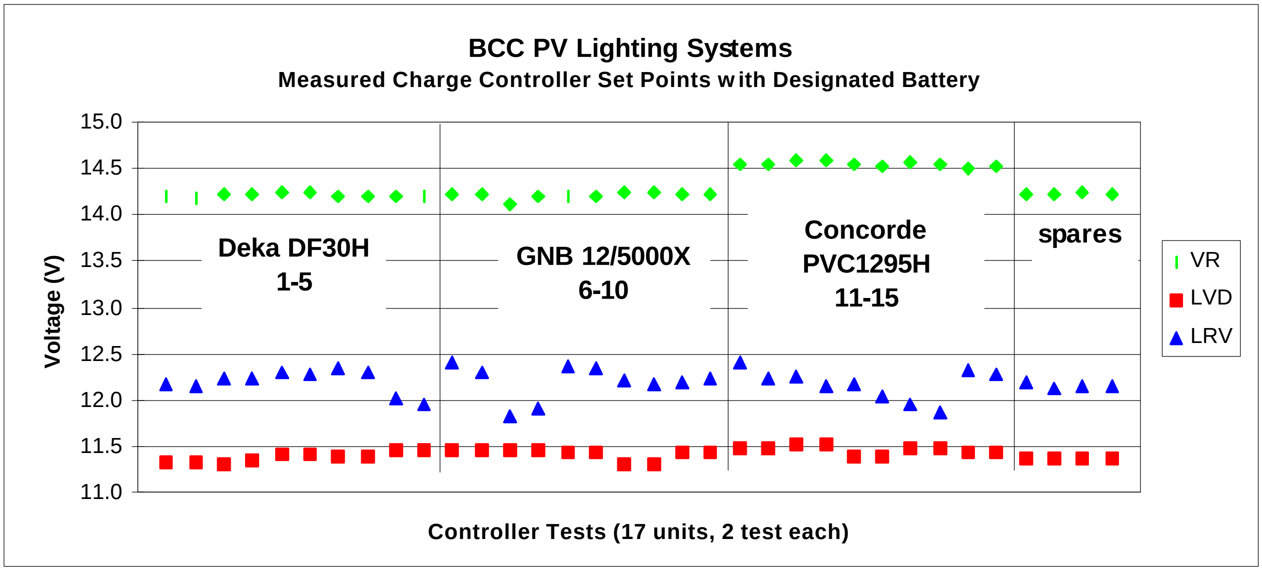

Figure 30. Measured charge controller set points.

Based on these charge controller measurements and the battery state-of-charge levels at which the specified control voltages occur, some concern is raised about the appropriateness of the load control set point values. While the low battery state-of-charge at load disconnect is a concern, another issue is the low 12.3 volt load reconnect set point.

During the battery recharge test from 100% DOD, we integrated the amp-hours received by each battery pair to 12.3 volts. For the GNB and Concorde batteries, the batteries had received approximately 25% of their full charge at 12.3 volts, while the Deka batteries had received essentially no charge at this voltage. While a load reconnect at only 25% state-of-charge for the GNB and Concorde batteries concerns us, the problem with the Deka battery is more serious. Due to the high voltage rise in this battery after the load is disconnected, it's probable that the load reconnect voltage of 12.3 volts could be reached even with no charge applied to the battery. This could result in a load cycling problem and delay the battery state-of-charge recovery from LVD. This data was provided to the charge controller manufacturer for consideration in set point specifications for future designs.

3.4.1 Voltage Measurements in Systems Operation

At the end of seven months, battery voltages were measured in systems operation at selected times to estimate the battery condition and to obtain data from the systems which ongoing data collection was not conducted. Figure 31 charts the results of these voltage measurements.

The first measurement was made within one-hour of load activation, after dusk on September 15, 1997. The voltages for the GNB and Concorde batteries were consistent among the same battery types, approximately 12.5 volts for the GNB and 12.8 volts for the Concorde. The voltage for the Deka batteries in System 1 was abnormally low (12.5 volts) compared with the other four pair of batteries in Systems 2-5. This was later found to be a problem with the PV array.

The second measurement was conducted the following morning, September 16 before sunrise, near the end of the load operation period. These voltages generally followed the trend for the voltages the preceding evening, with the exception of System 10 using the GNB batteries. This pair of batteries was later found to have significant capacity loss. With the exception of System 1, the other four systems using Deka batteries had approximately 0.5 volt drop overnight. The five systems using the Concorde battery showed approximately a 0.3 volt drop, and the voltages were very consistent among the five systems. Systems using the GNB 12-5000X batteries had the most variation in overnight voltages, ranging from 0.3 to nearly 1 volt drop.

The other voltages shown in Figure 31 were measured during sun hours with the system charging and at a battery/controller temperature of approximately 30 ^{o}C. For reference, the measured voltage regulation set point (at 25 ^{o}C) for the charge controllers installed in each system are plotted. Note that data for Systems 5, 10 and 15 was unavailable due to the batteries being removed for capacity testing. At this time, the load was disconnected in all other systems.

For the Deka batteries in System 1, the voltage was lower than others due to the problem noted in this report concerning the PV array. After a week with the load disconnected the battery voltage was approaching the regulation voltage, however the battery still seems to be suffering the effects from the deficit created by the array problem. The voltage for all other systems using the Deka batteries approached 14 volts during measurements made over the following week with the load disconnected.

The GNB batteries in Systems 6-9 and the Concorde batteries in Systems 11-14 had reasonably consistent voltages between the systems using the same battery type, approaching the regulation voltages the day after the load was disconnected.

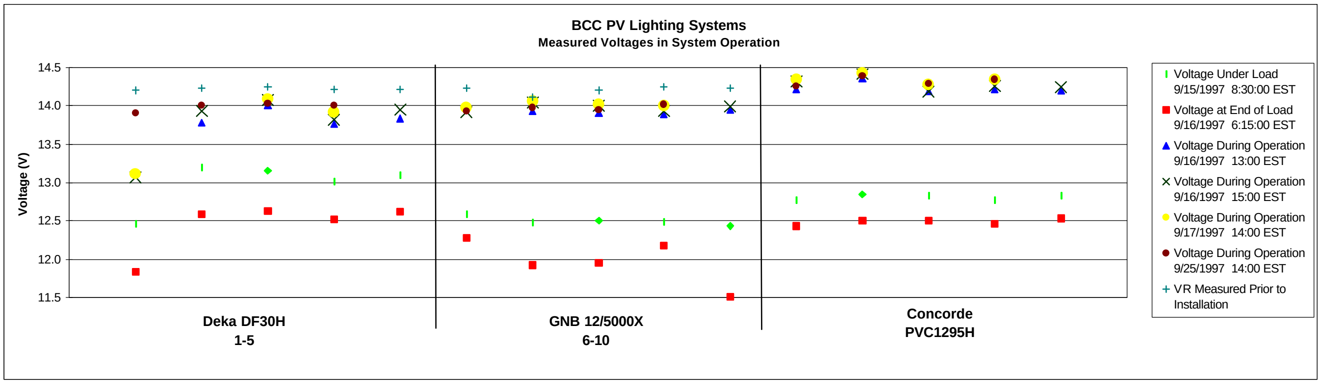

Figure 31. Voltage measurements in systems operation.

3.5 PV Array Measurements

Array I-V curve measurements were made prior to installation and after seven-months of operation to verify consistency among the arrays. During the initial tests, the arrays were performing consistently, with the average array maximum power current determined to be 8.3 amps at STC. This measurement was used as the basis for determining the desired PV to load energy ratio of 1.25 to 1 under the wintertime design insolation of 4 kWh/m^2/day.

Figure 32 shows the maximum power currents and maximum power voltages measured for each system prior to installation and after seven months of operation. The designations "A" and "B" refer to the first and second curves taken on each array for both dates. Although most of the arrays were performing consistently, the arrays from Systems 1 and 4 showed obvious problems. These problems are clearly shown in the IV curves contained in the Appendix.

The problem with the array in System 1 is much more severe, resulting in approximately a one-third reduction in the maximum power current (at nominal battery voltages). Although the arrays were carefully checked and tested prior to installation, this problem was not entirely unexpected, as similar problems have occurred with this batch of modules before (c. 1983 Solarex product). At this time, the load has been correspondingly reduced on these systems to account for the lack of array output and to maintain the 1.25 to 1 PV to load energy ratio. Plans are being made to replace all arrays in the near future with newer modules to achieve better consistency among the arrays.

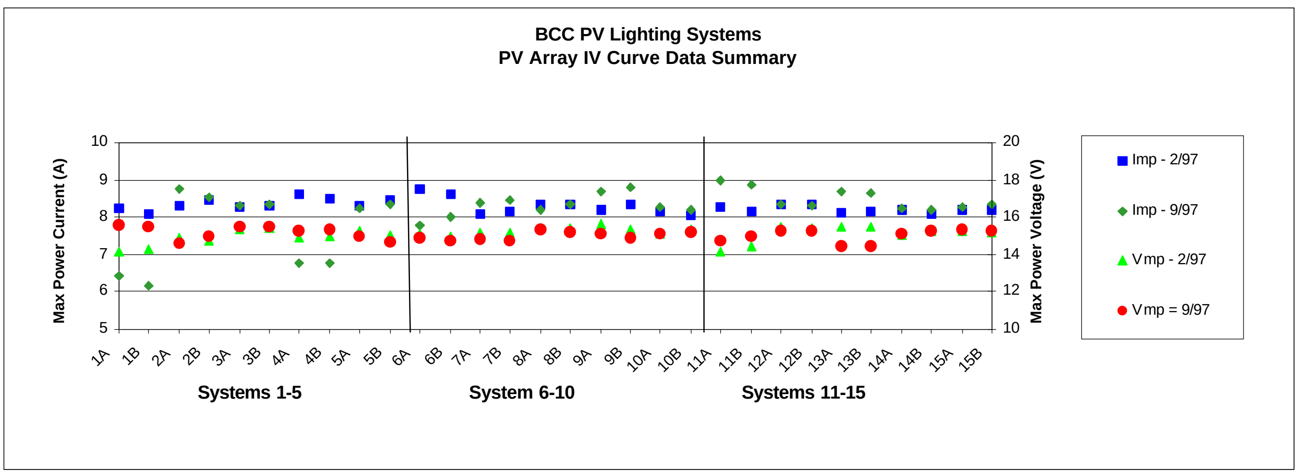

Figure 32. PV array IV curve data summary.

3.6 Lighting Load Performance

Measurements of the lighting load were taken before installation and after seven months of operation. These measurements included load current readings and illumination levels. In addition, elapsed time recordings for the load operation were taken periodically over the first seven months of operation.

3.6.1 Elapsed Time Recordings

Elapsed time meters were installed on all systems to record the load operation time. Over the first seven months of operation, these readings were typically recorded every two weeks.

Figure 33 shows the load operation times, determined by elapsed time meter readings and taking the differences to determine the average daily load operation hours over each period. With the exception of Systems 1, 3, 7 and 10, all other systems operated the lighting load the prescribed 9 hours per night during the first seven months of operation.

The problem with System 1 was attributed to the problem with the PV array discussed elsewhere this report. During the last two months of operation, LVD's occurred several times due to the reduced array output. The load operation time has been reduced until the array problem is corrected.

During observations in July, the 5-amp load fuse in System 3 was found blown, and was replaced. The cause of this fuse failure was not determined, and the system has worked fine ever since. The problem with the load in System 7 was traced to a faulty time clock that had a loose connection. The clock was replaced and the system resumed normal operation. The problem with System 10 during the last week of operation was caused by a loss of capacity loss as discussed previously in this report.

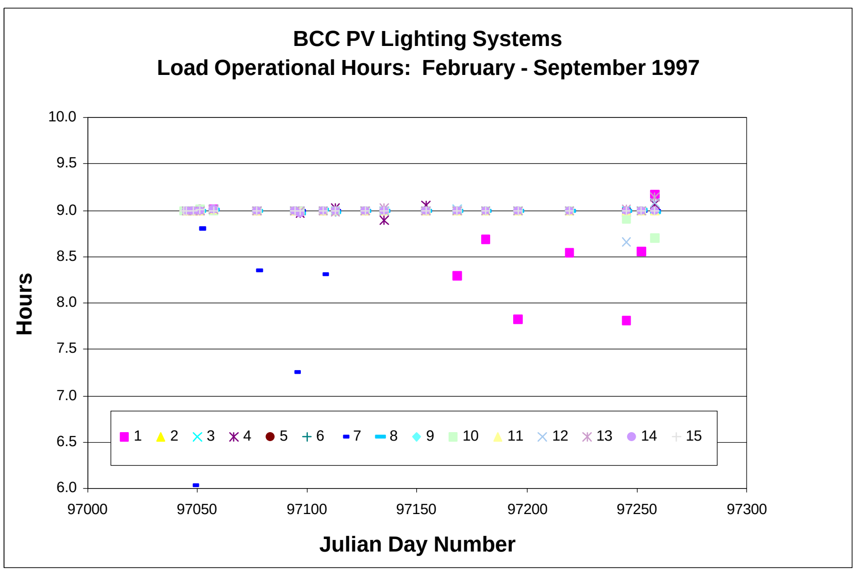

Figure 33. Elapsed time meter recordings.

3.6.2 Load Current Measurements

To establish the consistency between the lighting subsystems, load currents were measured for all fixtures during a 36-hour burn-in period prior to installation. Results of these measurements indicated the load currents varied between 2.9 and 3.2 amps at 12 volts.

Figure 34 shows the load currents measured after seven months of operation, with surprising results. In all cases the load currents were higher, some more than 40% higher consuming over 4 amps. Although the system voltages were generally higher during this second measurement, this is not considered to be the cause of the higher load currents. Observing the data for Systems 5, 10 and 15 (with DAS units), the load currents (and nightly amp-hours) were proportionally higher for Systems 5, 10 and 15, respectively.

Based on this data, the load currents appear to be significantly affecting the PV to load energy ratios, and may require adjustment of the load time clocks to achieve a higher consistency in the daily load amp-hours. Additional load current measurements will be performed and contact will be made with the fixture manufacturer regarding this issue.

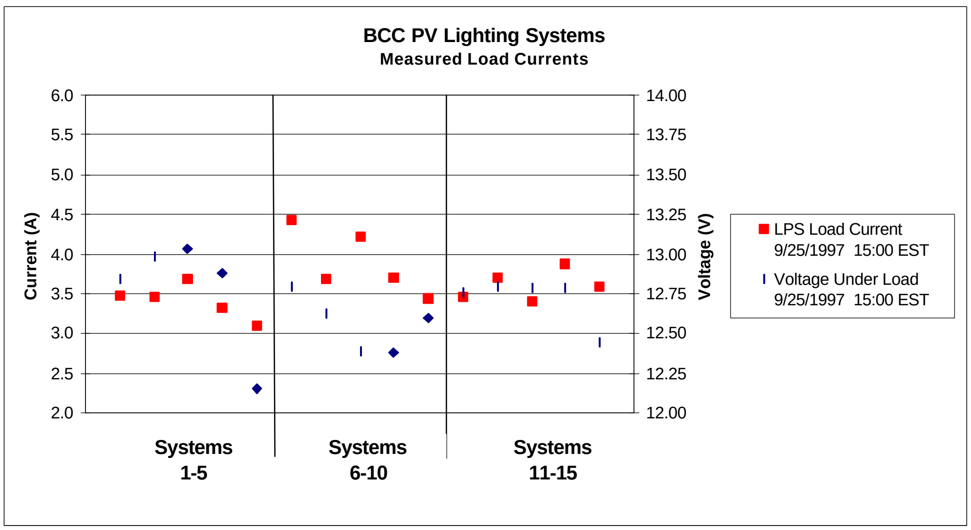

Figure 34. Seven-month load current measurements.

3.6.3 Illuminance Measurements

Initial illuminance measurements were made on each system after approximately 100 hours of operation. The measurements were made at ground level directly beneath the fixture, and at 20 and 40 feet horizontally along the path. The ambient temperature was approximately 23 °C during these tests.

Figures 35 shows the results of illuminance measurements for the 15 BCC PV lighting systems on February 23, 1997. At this time the illuminance directly below the fixture averaged about 2.2 foot-candles (fc), ranging from 2 to 2.5 fc.

Figure 35. PV lighting system at night.

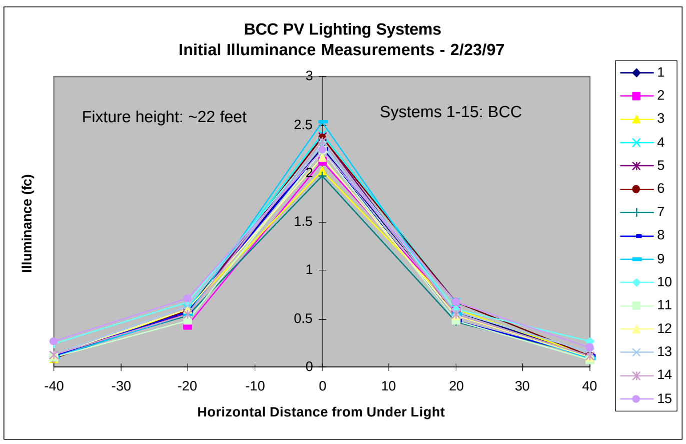

Figure 36. Initial illuminance measurements.

On September 15, 1997, another set of illuminance measurements were recorded as shown in Figure 37. These data were measured at slightly warmer ambient temperature (approximately 28 °C), and were generally lower than the initial measurements. System #8 provided the highest illuminance level at nearly 2.3 fc underneath the fixture, and also had a high load current (greater than 4 amps). However, no other correlation between load current and illumination levels were found. Further tests will be conducted on the lighting loads to investigate these issues.

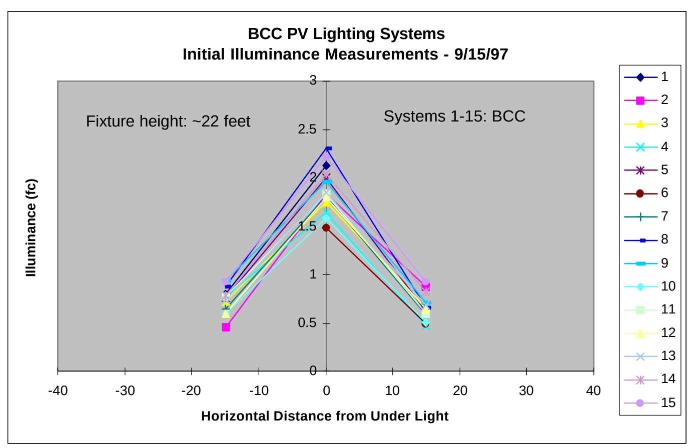

Figure 37. Seven-month illuminance measurements.

4 Summary and Conclusions

This report summarizes the seven-month performance of fifteen PV lighting systems operating with VRLA batteries and PWM charge control. The testing and monitoring performed for this report were quite extensive. Every effort was made to have each of the systems components operate identically, excepting the batteries that were from three different battery manufacturers, Concorde, Deka, and GNB. It is unfortunate that the lighting systems current consumption and light output varied during the testing. This caused the load on the battery systems to vary and made and ABC comparison of the three batteries questionable. Three types of VRLA batteries are used, including the Concorde PVC 1295H (absorbed-glass-mat), GNB 12/5000X (absorbed-glass-mat) and Deka DF30H (gelled) batteries. Extensive initial baseline data is compared to similar data collected after seven months of operation, and analyzed with respect to the continuous data collected on three of the systems with data acquisition units.

Following are noteworthy events from the first seven-months of operation:

1. One of the two GNB 12-5000X AGM batteries in System 10 failed during the last month of operation, possibly from a shorted cell. The pair of batteries from this system delivered only a fraction of their initial measured capacity on tests conducted after seven months of operation, and no capacity increase was achieved after two additional charge/discharge cycles. This set of batteries was condemned and replaced with a spare set of GNB 12-5000X batteries. A postmortem inspection of this battery identified the specific cell failure and potential causes for the failure.

2. As can be seen in the report the systems were sized for a load of 27 A.H./day with a December PV to load ratio of 1.25 to 1.0. The Concorde PVC-1295H AGM batteries in system B15 were subjected to a load of almost 32 A.H./day. That represents a minimum December PV to load ratio of about 1.06 to 1.0. Because of the increased load, new PV to load ratios for the February through September test period were calculated using the PVCAD system design program. This program uses published TMY solar resource data from Orlando, PV module data with an Imp of 8.3-amps, and Concorde battery data for a 200 Ah battery. The PVCAD results indicate that although the new December and January PV to load ratio was 0.99 to 1.10, the new February through September PV to load ratio was 1.21 to 1.54 with September being the lowest month. This is down from the original system design of about 1.43 to 1.82 PV to load ratio for the same time interval. The significance of this PVCAD calculation is that the batteries had available to them less excess PV charge from the original design of 11.6 to 22.1 Ah per day down to the new lower values of 6.7 to 17.2 Ah per day. Even with less finish charge available We should note that the B15 system with the Concorde batteries did not fail or cause the system to have the LVD disconnect from the load. The Concorde batteries performed well under these adverse conditions.

3. The Deka DF30H gelled batteries in System 15 had a battery size consistent with design and, consequently, performed well. The batteries from System 5 delivered 94 percent of their initial measured capacity, and recovered 1 00 percent their initial capacity after a complete recharge during the seven month cycle tests.

4. With the exception of Systems 1, 3, 7 and 1 0, all other systems operated the lighting load for the intended 9 hours per night.

- The problem with System 1 was attributed to an array problem discovered by IV measurements. This array will need to be replaced or repaired.
- The problem with System 3 was found to be a blown load fuse. The fuse was replaced and the system has operated fine over the last two months.
- The loss of load System 7 was due to a failure of the load time clock resulting from a loose internal connection. The time clock was replaced and the system has operated fine ever since.
- The problem with System 10 was found to be a failure of one of the GNB 12-5000X AGM batteries. These batteries were replaced with a spare set.

5. No problems or other operational concerns were experienced with the PWM battery charge controllers.

6. The load currents for the low-pressure sodium light fixtures have increased by as much as 40 percent over the first seven months of operation. In addition, there has been up to a 20 percent decrease in illumination output.

7. Problems were found with two of the arrays, one having a one-third reduction in the maximum power current output. These arrays will be repaired or replaced.

PVCAD System Designs

Sandia National Labs. PVCAD Version 2.1
Photovoltaic Design Assistance Center Dept. 6218

Load	Description	Load Profile	Amperes	Average Hours/day	Weekly Profile Days of Week On
1	Light	Night only	3.540	9.00	1 2 3 4 5 6 7

Nominal PV System Voltage: 12 Array mounting = Fixed tilt Array
Power system type: DC System with battery , NO maximum power tracker

Solar data and temperature location: ORLANDO, FLORIDA U.S.A.
Latitude= N 28:32 Longitude= W 81:18 Elevation= 36 (M)
Azimuth = 0 Albedo = 20%

- - - - - - - - PV ARRAY DESCRIPTION (ratings at 25½C)- - - - - - - - - - -

Modules: SIEMENS, M45 Total Modules = 3
Series = 1 Parallel = 3 Power = 144 Peak Watts
Max. power voltage= 17.3 Max. power current = 8.3
Open circuit voltage= 21.6 Short circuit current = 9.6
Mismatch loss(%)= 3 Dirt loss(%)= 5 Wiring loss(%)= 2

- - - - - - - - - - - BATTERY SUBSYSTEM (ratings at 25½C) - - - - - - - - -

Battery: CONCORDE, R-12100 Amp-hr/ea = 110 Volts/ea = 12
Series = 1 Parallel = 2 Total= 2 Max. month daily DOD = 15.90%
Total Amp-hrs.= 220 Battery Charge Efficiency = 95% Weight= 68 Kg
Equivalent to 5.32 days at highest monthly load to 80% DOD

- - - - - - - - - - - - - - ESTIMATED PERFORMANCE - - - - - - - - - - - - - -

Month	Global kWh/M»	Tilt	@Tilt kWh/M»	Mean ½C	Gross A-hr/d	Array Net A-hr/day	Load A-hr/day	Deficit A-hr/d	SOC	Array/Load Ratio
Jan	3.18	35	4.34	14.7	36.21	35.15	31.86		85-100	1.10
Feb	3.97	35	4.96	17.4	41.39	40.19	31.86		85-100	1.26
Mar	4.97	35	5.64	19.5	47.00	45.64	31.86		84-100	1.43
Apr	6.03	35	6.07	21.6	50.65	49.22	31.86		85-100	1.54
May	6.35	35	5.78	24.5	48.21	46.16	31.86		84-100	1.45
Jun	5.72	35	5.02	26.4	41.84	39.34	31.86		84-100	1.23
Jul	5.65	35	5.03	27.1	41.99	39.43	31.86		84-100	1.24
Aug	5.27	35	5.02	27.1	41.85	39.62	31.86		85-100	1.24
Sep	4.66	35	4.89	26.1	40.80	38.65	31.86		86-100	1.21
Oct	4.14	35	4.93	23.5	41.08	39.31	31.86		84-100	1.23
Nov	3.55	35	4.79	20.2	39.99	38.76	31.86		85-100	1.22
Dec	2.87	35	3.92	15.1	32.67	31.51	31.86		84- 98	0.99

Test Period

Lowest array to load Amp-hr/day ratio is 0.99

(Array Gross: 25½C, no losses. Array Net: All losses and temperature effects.)
Saved as: BCC1.SSS Calculated by PVCAD

Sandia National Labs. PVCAD Version 2.1
Photovoltaic Design Assistance Center Dept. 6218

Load	Description	Load Profile	Amperes	Average Hours/day	Weekly Profile Days of Week On
1	Light	Night only	3.000	9.00	1 2 3 4 5 6 7

Nominal PV System Voltage: 12 Array mounting = Fixed tilt Array
Power system type: DC System with battery , NO maximum power tracker

Solar data and temperature location: ORLANDO, FLORIDA, U.S.A.
Latitude= N 28:32 Longitude= W 81:18 Elevation= 36 (M)
Azimuth = 0 Albedo = 20%

- - - - - - - - - PV ARRAY DESCRIPTION (ratings at 25½C)- - - - - - - - - - -

Modules: SIEMENS, M45 Total Modules = 3
Series = 1 Parallel = 3 Power = 144 Peak Watts
Max. power voltage= 17.3 Max. power current = 8.3
Open circuit voltage= 21.6 Short circuit current = 9.6
Mismatch loss(%)= 3 Dirt loss(%)= 5 Wiring loss(%)= 2

- - - - - - - - - - - BATTERY SUBSYSTEM (ratings at 25½C) - - - - - - - - - -

Battery: CONCORDE, R-12100 Amp-hr/ea = 110 Volts/ea = 12
Series = 1 Parallel = 2 Total= 2 Max. month daily DOD = 13.47%
Total Amp-hrs.= 220 Battery Charge Efficiency = 95% Weight= 68 Kg
Equivalent to 6.28 days at highest monthly load to 80% DOD

- - - - - - - - - - - - - - - ESTIMATED PERFORMANCE - - - - - - - - - - - - -

Month	Global kWh/M»	Tilt	@Tilt kWh/M»	Mean ½C	Gross A-hr/d	Array Net A-hr/day	Load A-hr/day	Deficit A-hr/d	SOC	Array/Load Ratio
Jan	3.18	35	4.34	14.7	36.21	35.15	27.00		87-100	1.30
Feb	3.97	35	4.96	17.4	41.39	40.19	27.00		87-100	1.49
Mar	4.97	35	5.64	19.5	47.00	45.64	27.00		86-100	1.69
Apr	6.03	35	6.07	21.6	50.65	49.22	27.00		87-100	1.82
May	6.35	35	5.78	24.5	48.21	46.16	27.00		86-100	1.71
Jun	5.72	35	5.02	26.4	41.84	39.34	27.00		86-100	1.46
Jul	5.65	35	5.03	27.1	41.99	39.43	27.00		86-100	1.46
Aug	5.27	35	5.02	27.1	41.85	39.62	27.00		87-100	1.47
Sep	4.66	35	4.89	26.1	40.80	38.65	27.00		88-100	1.43
Oct	4.14	35	4.93	23.5	41.08	39.31	27.00		87-100	1.46
Nov	3.55	35	4.79	20.2	39.99	38.76	27.00		87-100	1.44
Dec	2.87	35	3.92	15.1	32.67	31.51	27.00		87-100	1.17

Lowest array to load Amp-hr/day ratio is 1.17

(Array Gross: 25½C, no losses. Array Net: All losses and temperature effects.)
Saved as: BCC1.SSS Calculated by PVCAD