PROGRAM AND PROCEEDINGS

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Procedures for Determining the Performance of Stand-Alone Photovoltaic Systems

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Introduction

Standard test procedures are being developed to assess the performance of stand-alone photovoltaic (PV) systems. This paper will present an overview of the latest procedures.

The procedures being developed fill the need for a short-term (approximately one month) test that can assess the performance of a stand-alone PV system. The majority of PV systems being installed around the world are small lighting systems that consist of an array, a lighting load, a controller, and a battery. These systems are essentially PV-powered battery chargers with a small load. With this in mind, we wanted procedures to indicate how well the PV system can charge the battery.

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

Background

The procedures outlined in this paper fill a void and establish the technical foundation needed to reduce uncertainty that a system's performance will be what its designers and builders claim. The need for this document was recently made more apparent with the initiation of a PV Global Approval Program at the international level. These tests will serve as the basis for national and international stand-alone PV system test standards.

In July 1998, the National Renewable Energy Laboratory (NREL) published "Interim Test Methods and Procedures for Determining the Performance of Small PV Systems" [1]. This document provided an initial performance test for stand-alone PV systems. Validation testing was conducted at four U.S. laboratories: NREL, Florida Solar Energy Center (FSEC), Southwest Technology Development Institute (SWTDI), and Photovoltaics for Utility-Scale Applications (PVUSA). Based on this testing, NREL updated the test procedures and published "Procedures for Determining the Performance of Stand-Alone PV Systems" [2] in September 1999. This test document was used as the basis for IEEE P1526/D1 "Recommended Practice for Testing the Performance of Stand-Alone PV Systems." The procedures presented in this paper describe the latest version of the IEEE P1526 document.

The Procedures

Figure 1 is a graphical representation of the testing in terms of battery voltage and time. The time periods shown are approximate. During the test, the battery temperature is kept at an average 30±5°C. This is meant to simulate a tropical climate where many stand-alone PV systems are being installed.

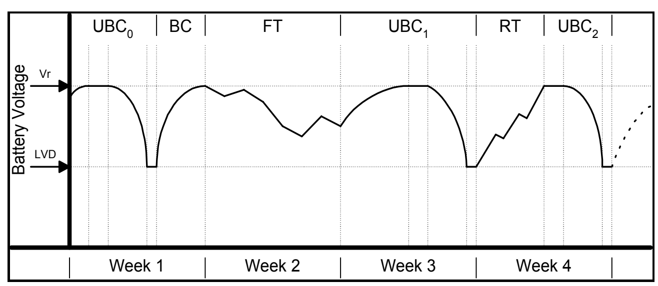

Figure 1 – Sample test profile for the stand-alone PV system performance test

UBC_0 - Initial Capacity Test

This test establishes a baseline capacity measurement for the battery. First, the battery is charged by the PV array with the load disconnected. Next, with the array disconnected, the battery is discharged by operating the load continuously until the system reaches its low-voltage disconnect (LVD). The initial usable battery capacity (UBC_0) is measured during the discharge.

The three battery capacity tests, UBC_0, UBC_1, and UBC_2, are conducted the same way. The change in UBC is determined by comparing UBC_0 to UBC_2.

BC – Battery Charge

The battery is recharged using the array before starting the functional test.

FT – Functional Test

The functional test is run at least 7 days to determine if the system and load can operate as designed. The load is set to operate 4 hours per night. For at least 2 consecutive days, the array should receive "low" solar insolation (≤ 2 kWh/m^2 per day). For at least 2 days, not necessarily consecutive days, the array should receive "high" solar insolation (≥ 5 kWh/m^2 per day).

RT – Recovery Test

The recovery test determines the ability of the array to charge the battery from its LVD state to voltage regulation (Vr) while the load is 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 is operated until the battery reaches Vr and then for at least another 3 days. The battery Ah and sun hours to regulation are measured.

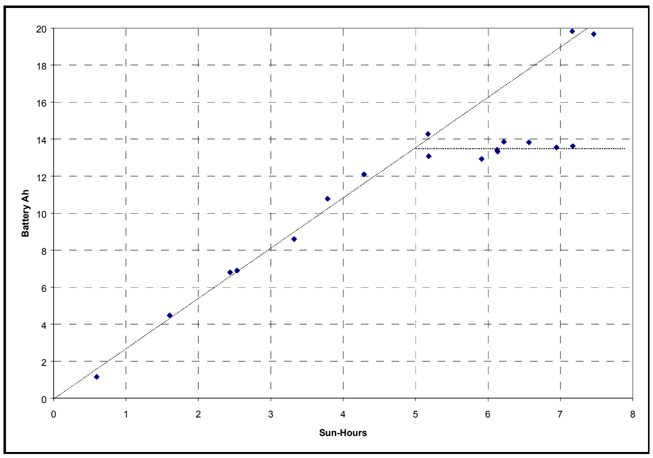

Figure 2 – Sample P-Chart displays daily battery Ah vs. sun hours

The Performance- or P-Chart in Figure 2 is generated using the daily battery-Ah and the sun-hour data from both the functional and recovery tests [3,4,5]. The P-Chart 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. The data should tend to fall along two lines similar to those shown in Figure 2. In this example, it takes about 5 sun hours for the battery to reach regulation voltage after the load has operated for 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. The level of this line depends on the array size and load run time.

Validation of the Procedures

The latest procedures are being validated at four U.S. labs (NREL, FSEC, PVUSA, and SWTDI) on two PV-lighting systems manufactured in the United States. A lighting system manufactured overseas will also be validated at NREL and at GENEC in France. All three lighting systems consist of a silicon module, a fluorescent lighting load, a lead-acid battery, and a charge controller. The validation is being conducted primarily to determine if the procedures can be followed and, secondarily, to compare the system test results run at different labs in different climates. Results of the testing will be presented at the 28th IEEE Photovoltaic Specialists Conference in September 2000.

Conclusion

These procedures have been submitted to IEEE for use in the IEEE document, P1526 "Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems." A standardized stand-alone PV-system performance test will help in the verification of systems design. Future work will include developing qualification tests to evaluate the design of stand-alone PV systems.

References

[1] "Interim Test Methods and Procedures for Determining the Performance of Small Photovoltaic Systems." NREL/TP-520-25077, July 1998. Golden, Colorado.

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[5] J.M. Servant, J.C. Aigullon, "Test of PV Lighting Kits." 11th EC Photovoltaic Solar Energy Conference, 1992, Montreux, Switzerland.