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PV Hybrid Battery Testing

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ABSTRACT

A laboratory PV hybrid battery test procedure has been defined and tested at Sandia to evaluate and improve battery performance. Test results have identified several battery designs with improved performance. In addition, common battery management strategies have been shown to result in significant premature capacity loss in many cases. The test data has also been very useful in identifying hybrid battery management strategies that are more effective in maintaining battery capacity. The objective is to improve battery cycle-life and thus lower system life-cycle costs.

1. Introduction

PV hybrids represent a relatively large group of renewable energy power systems with multiple power sources that vary considerably with respect to system design, size, load characteristics, and possible battery management strategies. Previous laboratory and field test results at Sandia for stand-alone PV systems, using vented (flooded) and valve regulated lead-acid (VRLA) batteries, indicated that battery capacity can fade prematurely in PV systems [1,2]. This premature capacity loss stems primarily from an operational mode known as deficit-charge cycling. Deficit-charge cycling occurs when a discharged battery is not fully recharged after each discharge. This is a common occurrence that results from cost-reduction practices, themselves a result of the high cost of sizing the photovoltaic array to fully recharge the battery or the added engine generator runtime required to finish-charge the battery. The work presented here will attempt to identify the maximum deficit-charge interval time and charging requirements for specific lead-acid battery technologies used in PV hybrids.

2. Laboratory Test Procedure

The essential premise of the PV hybrid test procedure is that the battery cannot be fully charged every cycle. The questions that this test procedure attempts to answer are: 1) How often does the battery need a finish-charge to maintain capacity? 2) What charge parameters are needed to maintain capacity? 3) What PV hybrid controls are needed to maintain battery capacity? and 4) What battery is most appropriate for a given system design? The test parameters include; 1) charge and discharge rate, 2) bulk-charge termination voltage, 3) discharge termination voltage, 4) finish-charge regulation voltage, 5) finish-charge interval, 6) finish-charge time, and 7) number of deficit and finish-charge intervals required to obtain battery capacity trends.

The PV hybrid test procedure in this case makes an assumption about "typical" charge and discharge rates. It is important to understand that if system rates deviate significantly from the chosen rates, then the results may change. These rates are specified in hours required to charge or discharge the rated battery capacity. The charge and discharge currents are specified by the capacity (C) in amp-hours (Ah) divided by the required charge or discharge hours. In this case, a charge rate of C/24 and a discharge rate of C/35 were chosen to simulate a "typical" PV hybrid. If 60% of the battery capacity is discharged, then in theory, the battery would require 14.4-hr to charge and 21-hr to discharge every cycle. The resulting total cycle time would be about 1.5 days. The actual cycle time did vary due to changes in actual capacity and finish-charge time.

The other test parameters, such as voltage, were chosen based on the battery manufacturer's recommendations, previous battery test experience, and PV hybrid system design requirements. Below in Figure 1 is a typical PV hybrid cycle test profile with a 30-day deficit-charge interval showing battery voltage and cycle Ah. The test sequence includes 20-deficit-charge cycles discharging to 1.98 vpc and charging to 2.35 vpc with a 12-hr finish-charge at the end of 20-cycles. This sequence is repeated three times.
In this case the results clearly show that the available battery

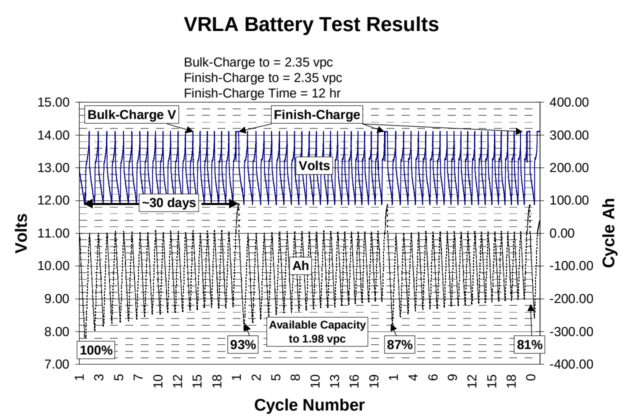

Fig. 1. PV Hybrid Battery Test Procedure

discharge capacity to 1.98 vpc after the finish-charge is dropping at a consistent rate of about 6 to 7% per deficit-charge interval (30-days). If the battery maintains this capacity loss rate, a 50% capacity loss would occur in 7 to 8 months. Modification of the test parameters would be indicated for this VRLA battery. Such modifications could include reducing the deficit-charge interval to 7-days and/or increasing the bulk termination voltage and finish-charge regulation voltage to 2.40 vpc. In either case the objective is to maintain a stable battery capacity which implies a longer cycle-life.

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3. Test Results

In Figure 2, the percent of initial capacity for the above VRLA battery is plotted as a function of the number of finish-charges. In the last three cases, a 12-, 6-, and 3-hr finish-charge was provided every cycle instead of every 5-, 10-,or 20-cycles. The battery capacity measured as percent of initial capacity for the last three cases is recorded at every 5th cycle as would be the case for the ~7-day deficit-charge interval test. The ~15-day deficit-charge interval measurement was made every 10th cycle after the finish-charge and discharge to 1.98 vpc.

The results demonstrate that deficit-charge intervals of ~7-days or less are required to maintain the capacity of this VRLA battery. If finish-charges are conducted every cycle, then a 3- to 6-hr finish-charge is required for the given test conditions vs the 12-hr finish-charge used in the deficit-charge cycle tests. This clearly indicates that longer deficit-charge intervals require a longer finish-charge time.

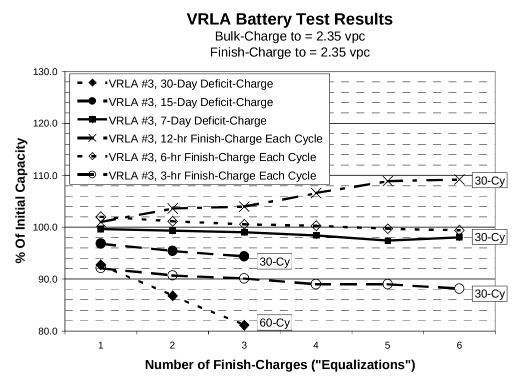

Fig. 2. PV Hybrid VRLA Battery Test Results

Test results from a vented industrial motive power deep-cycle battery, are in Figure 3, and show a much greater tolerance to deficit-charge cycling. A key factor in this battery's performance is the grid alloy content, positive plate active mass, bulk-charge termination voltage (2.55 vpc) and the finish-charge voltage and time (2.55 vpc, 6-hr). The bulk-charge termination voltage recovers the electrolyte from excessive stratification and the finish-charge voltage and time recovers the battery from sulfation and other degradation mechanisms in the grid and positive active mass [1].

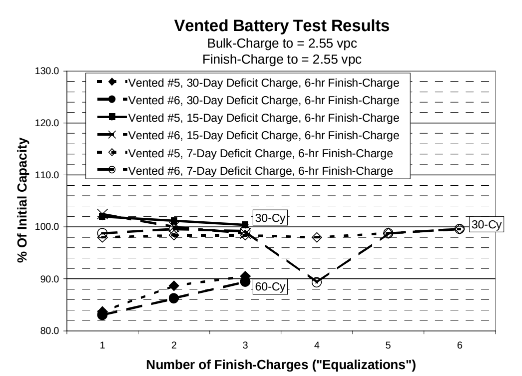

Fig. 3. PV Hybrid Vented Battery Test Results #1

In Figure 4 are other test results from a popular PV hybrid vented deep-cycle battery. The results show that deficit-charge intervals of ~7-days will result in a continued loss of battery capacity. If capacity loss continues, this vented deep-cycle battery would be at 50% of its initial capacity in about 4.5 to 5.0-months. This battery would probably not be the best choice for a PV hybrid system.

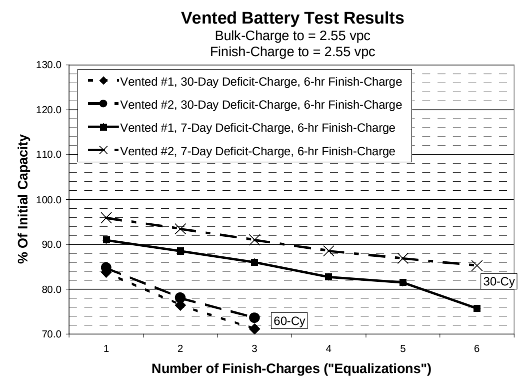

Fig. 4. PV Hybrid Vented Battery Test Results #2

4. Summary

The questions of how often does a PV hybrid battery need to be finish-charged or "equalized", and what regulation voltages should be used and/or which battery is most appropriate for PV hybrids can be answered by this test. The answer to the above questions based on the test results is dependent on the battery and how that battery is used. Since different lead-acid batteries and different system designs may require different voltages for charging, the system should have adjustable voltages and time setpoints. In addition, the system must provide a means to finish-charge or "equalize" the battery at regular intervals based on battery and system design requirements.

In some cases the net affect of using appropriate battery technology and the necessary battery controls may increase system capital costs. This possible increase in capital costs should be offset by lower life-cycle costs resulting from a significant increase in battery cycle-life and the resulting lower system repair costs.

REFERENCES

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