TWO TYPICAL HYBRID CYCLING TESTS: RESULTS FROM THE HYBRID TEST BENCH

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SUMMARY

This document reports on two test sequences executed on the hybrid system test bench of the Photovoltaic and Hybrid Systems Group at the CANMET Energy Technology Centre—Varennes. These tests involved cycling the battery under genset power; in future tests, a photovoltaic array will be included. The first test discussed here repeatedly executed a cycle of partial discharge followed by bulk and absorb charging; the second test was different only in that absorb charging was eliminated from the cycle.

During the first four cycles of the second test, only 81% to 95% of the charge withdrawn from the battery is returned on recharge. As a consequence, the charge that can be withdrawn prior to the battery reaching the end-of-discharge threshold decreases by 50% over five cycles. While temperature appears to influence the battery behaviour, there is clearly some other mechanism at play here, perhaps stratification of the electrolyte or the accumulation of lead sulfate on the surface of the negative plates. This is a significant observation because it lends credibility to the contention that absorbed glass mat batteries—like flooded batteries but unlike gelled electrolyte batteries—can not be cycled between partial states-of-charge, may indicate significant stratification in these absorbed glass mat batteries, implies that regular absorb charging may be required in hybrid PV systems, and may go some way toward explaining the abbreviated charge-discharge cycles occurring in some hybrid systems.

The results of the second test were inconclusive, however, and this test should be rerun. In addition, if further tests are to be conducted next summer, some changes to the hybrid test bench should be made. These changes would help control the battery temperature more accurately and thus reduce the confounding influence this variable.

CONTENTS

1 INTRODUCTION

Within the context of photovoltaic technology, the term “hybrid systems” refers to power sources combining a photovoltaic generator with one or more generators drawing on non-solar energy resources. Often these systems are used off-grid, that is, to supply electricity to sites not serviced by an electrical network, such as remote homes, monitoring equipment, and telecommunication repeater stations. In Canada, hybrid systems typically combine a photovoltaic array with a fossil-fuel driven generator (a “genset”); systems also include lead-acid batteries for energy storage over the period of a day to several days, controllers to manage charging of the battery, controllers to effect genset dispatch (starting and stopping), and circuitry to convert between AC and DC, as required.

Since 1998, the Photovoltaics and Hybrid Systems group of the CANMET Energy Technology Centre—Varennes (CETC-V), with the assistance of the NRCan Program on Energy Research and Development (PERD), has researched the optimal utilisation of hybrid systems in Canada. The overall goal of this effort has been to enlarge the market for photovoltaic technology by assisting the Canadian PV industry build better hybrid systems and by disseminating information about the capabilities and operation of hybrid systems to consumers and potential consumers. A number of activities aimed at this goal are presently underway: a half-dozen hybrid systems in various parts of Canada are monitored to determine the operational behaviour of existing systems; a regular newsletter is published and widely distributed (e.g., [Roussin and Turcotte, 2004]); and a flexible PV simulation package (“PV Toolbox”, developed by CETC-V [Sheriff et al., 2003]) and a configurable physical hybrid system test bench (also built under the auspices of the hybrid system program) are being used in a cycle of simulation and verification to improve understanding of how hybrid systems function—and how they may be improved.

The hybrid test bench consists of a 7.5 kVA diesel genset, a 24 V bank of Absolyte IIP batteries with a 20 hour discharge capacity of 600 Ah, a configurable photovoltaic array (up to 1.5 kW), a 48 Amp PWM charge controller, a Xantrex Prosine 3 kW inverter/charger, a variable DC and AC resistive load, and a monitoring and control system. It is located in a separate building on the CETC-V premises. The interior temperature of the building can be controlled through an electric heater and a fresh air damper.

The hybrid test bench has been operating since 2002, but it is only in the last 8 months that all of the minor problems associated with the operation of a brand-new test bench have been resolved. To this point in time, most of the tests that have been run on the hybrid test bench have cycled the battery under genset power, permitting characterization of the behaviour of the battery as well as validation of PV Toolbox [Ross, 2003].

The tests described in this document involve cycling the battery under genset power; they facilitate understanding the operation of the battery under controlled conditions typical of hybrid power systems. In future tests, the photovoltaic array will be included in the test. The first test discussed here repeatedly executes a cycle of partial discharge followed by bulk and absorb charging; the second test is different only in that absorb charging is eliminated from the cycle.

2 TYPICAL HYBRID CYCLING WITH BATTERY FULLY CHARGING

2.1 Test Description

The test begins with the battery fully charged; this is achieved through a bulk and absorb charge followed by a 16.5 hour float charge. Then the following sequence is executed four times:

1) Battery is open circuited for one hour.
2) DC load of approximately 12.2 Amps is connected and battery discharges to a voltage of 24.36 V (i.e., 2.03 Vpc).
3) Battery is open circuited for one hour.
4) Genset is started and charger supplies approximately 48.5 Amps to the battery until the battery voltage rises to approximately 28.05 V, or 2.34 Vpc (bulk charging).
5) The charger reduces its current output in order to maintain approximately 28.4 V at its terminals (absorb charging). The current supplied to the battery falls from about 48.5 Amps to approximately 10.5 Amps and, due to the voltage drop in the cables between battery and charger, the battery voltage rises from about 28.05 V to approximately 28.3 V (2.36 Vpc).
6) The genset is stopped.

Following the execution of this six step sequence a total of four times, a final discharge, followed by a complete recharge, is executed:

1) Battery is open circuited one hour.
2) DC load of approximately 48.1 Amps is connected and battery discharges to a voltage of 23.4 V (i.e., 1.95 Vpc).
3) Battery is open circuited for one hour.
4) Genset is started and charger supplies approximately 48.5 Amps to the battery until the battery voltage rises to approximately 28.05 V, or 2.34 Vpc (bulk charging).
5) The charger reduces its current output in order to maintain approximately 28.4 V at its terminals (absorb charging). The current supplied to the battery falls from about 48.5 Amps to approximately 10.5 Amps and, due to the voltage drop in the cables between battery and charger, the battery voltage rises from about 28.05 V to approximately 28.3 V (2.36 Vpc).
6) The genset is stopped.
7) The battery is held on float charge for 24 hours: the low current necessary to maintain the battery voltage at approximately 27.1 V is provided by a power supply.

The 48.1 Amp discharge current and the 23.4 V end-of-discharge threshold are the same as were previously used in battery characterization (see [Ross, 2003]). This facilitates a determination of the state of the batteries after the five cycles of the test.

During this test, the indoor air temperature was maintained at 25ºC or as close thereto as possible.

2.2 Results

A number of pertinent quantities were measured throughout the test, and two-minute averages were saved to a file. These data are found in the file 040818a.xls. The quantities that were examined included battery voltage, discharge current, charge current from the inverter/charger, charge current from the power supply during float charging, and the temperature of the outside air, the inside air, and the battery (as measured by a thermocouple placed between two cells).

These data are displayed graphically in Figures 1 and 2. Both figures span the entire test: initial charge of the battery to 100% SOC, four cycles of discharge and charge (without float), final discharge at the elevated current, and final charge of the battery to 100% SOC. Figure 1 shows the current into the battery, and Figure 2 shows the measured temperatures. Both figures show the battery voltage, which helps associate the evolution of temperature with the operation of the genset and the charging of the battery.

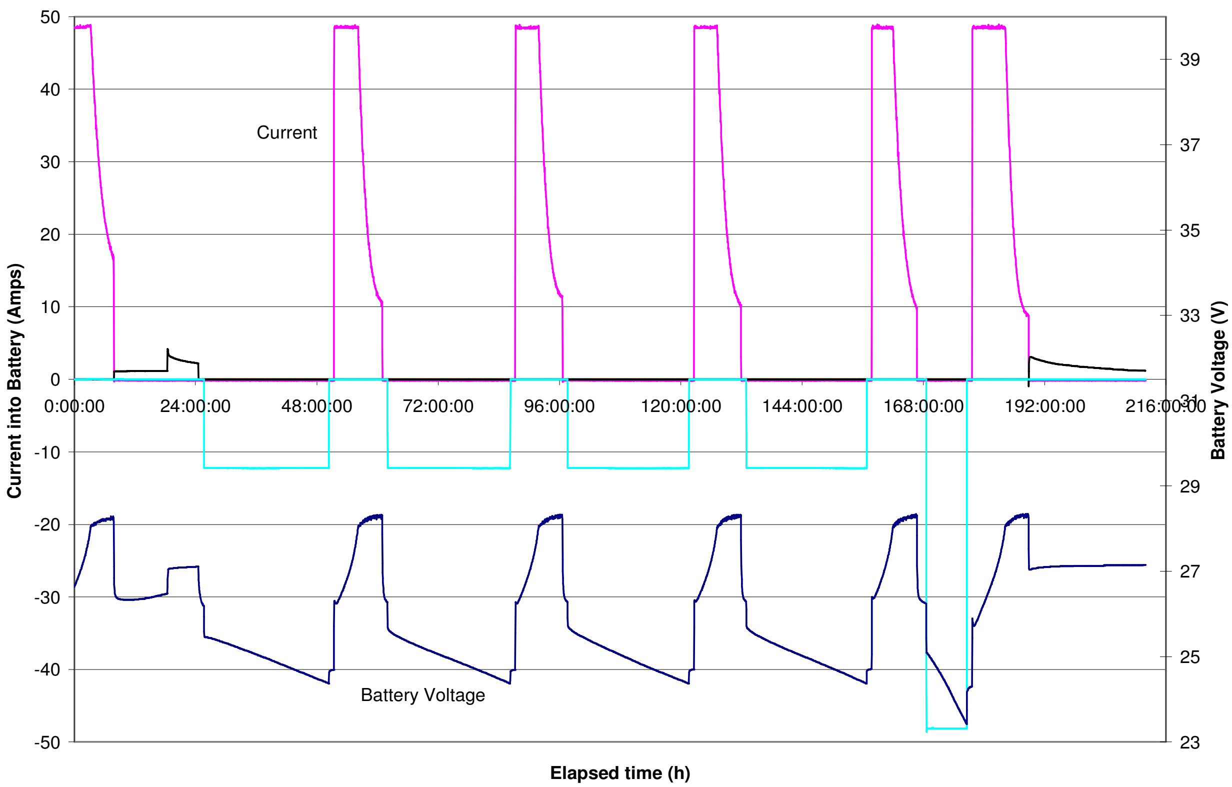

Figure 1. Current and Voltage during the Test

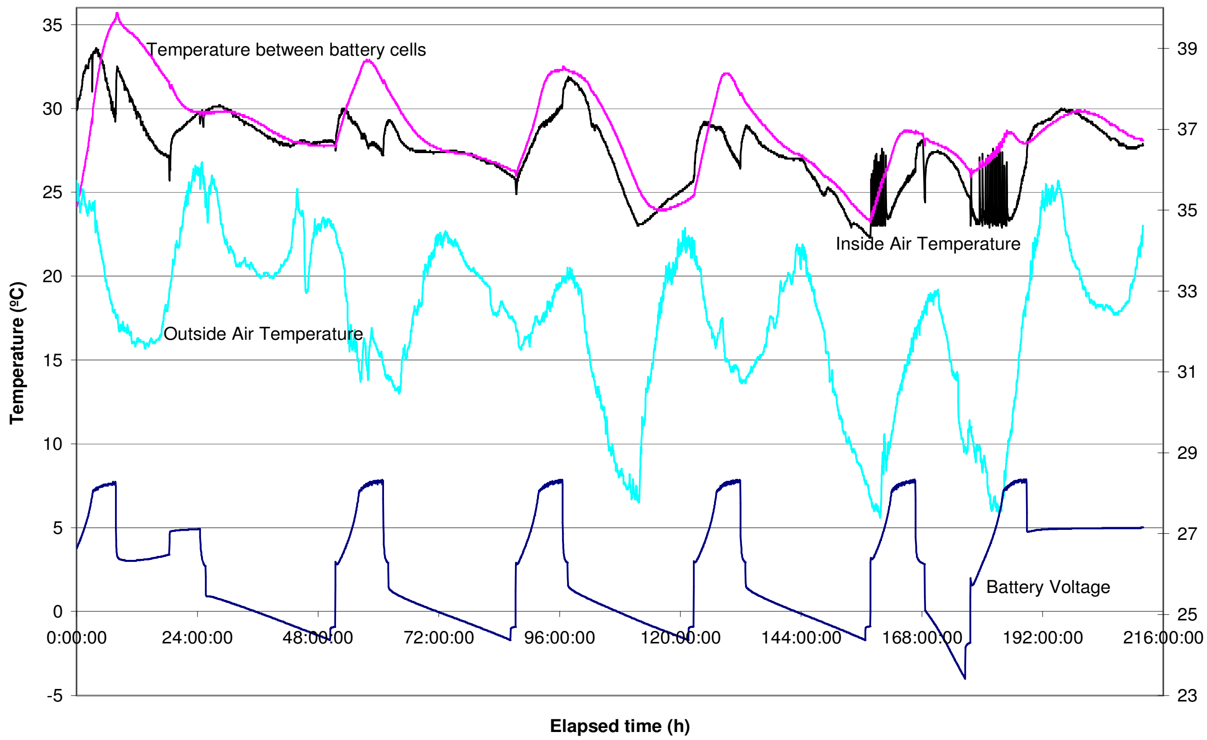

Figure 2 Temperature during the Test

In Figure 2, there is rapid oscillation in the interior air temperature during charging in cycle 4 and the final recharge. This is due to rapid oscillation in the position of the warm air damper while the genset is in operation. When the inside air temperature drops below 23ºC, the hot air from the genset radiator is vented into the test bench. The inside air temperature rises rapidly until it reaches 26ºC. Then the damper that permits this hot air to vent to the outside begins to open. It takes tens of seconds for this damper to open, so the temperature overshoots the 26ºC setpoint.

To convey more precisely the behaviour of the battery during a single cycle, the current and voltage of the battery during the first discharge and subsequent recharge are shown in Figure 3.

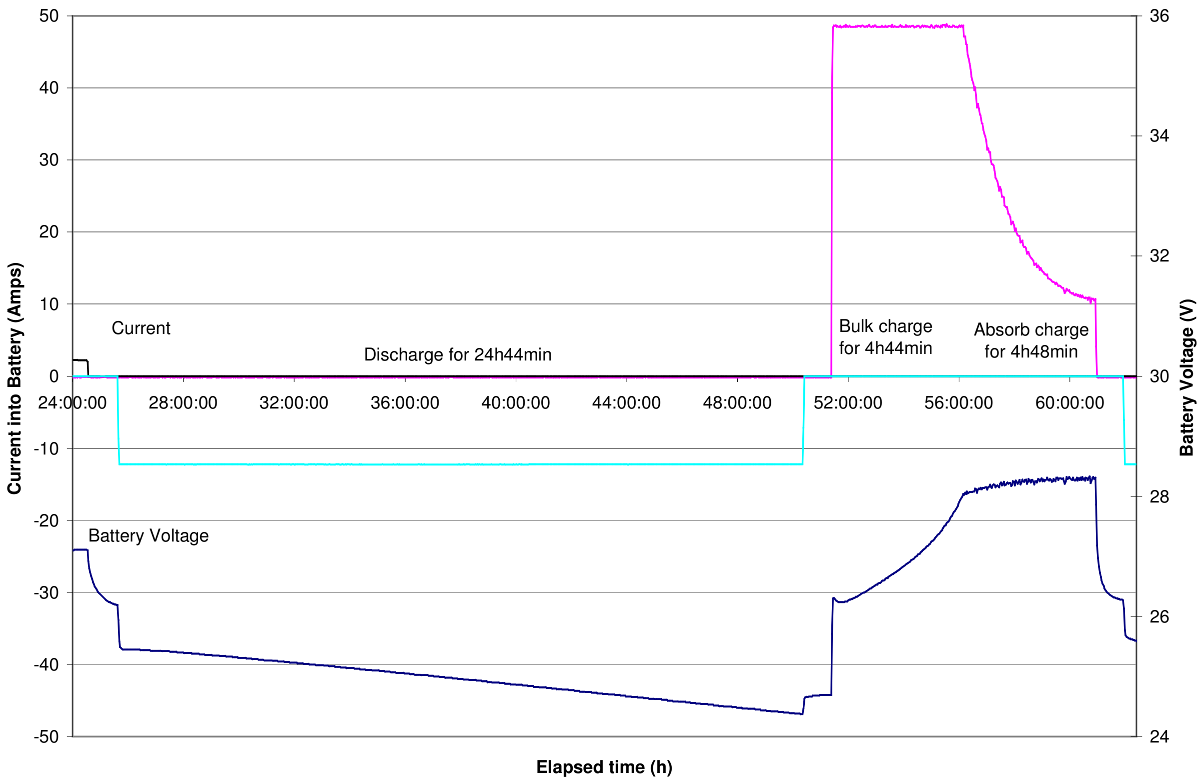

Figure 3 Current and Voltage during the First Cycle

The charge removed from and returned to the battery on each cycle is indicated in Table 1. In addition, the table shows the temperature at the end of discharge and charge measured by a thermocouple placed between two cells in the battery; these data may be useful in the interpretation of the Amp-Hour results since the battery voltage at a given discharge current and the battery charge current at a given absorb voltage will be affected by temperature. On discharge, higher temperatures raise the voltage of the battery, and, on absorb charge, raising the temperature will increase the current required to maintain a given voltage: in short, an increase in temperature decreases the battery resistance.

Table 1 Summary of Test

	Ahr Discharged	Cell temperature at end (ºC)	Ahr Returned	Cell temperature at end (ºC)
Cycle 1	302	27.8	331	31.5
Cycle 2	297	26.3	325	32.3
Cycle 3	294	24.6	322	30.8
Cycle 4	291	23.5	307	28.5
Final Discharge & Bulk+Absorb	387	26.6	408	28.0
Float			41	

2.3 Discussion

The most interesting observation that can be made from this test is that from cycle to cycle there is an apparent decline in the capacity of the battery. A reasonable hypothesis for this decline is the monotonic decline in the battery temperature recorded at the end of discharge over the four cycles (see Table 1).

This hypothesis is more probable than the alternative: that the battery is not being fully charged in the bulk and absorb charging. Nine-and-a-half hours of charging with the genset, including an absorb charge of nearly 5 hours, should be sufficient to fully charge the battery. The voltage threshold for absorb charging is roughly 28.3 V, or nearly 2.36 Vpc; the battery manufacturer recommends that for constant voltage charging the threshold should be 2.35 Vpc at 25ºC, with this setpoint being reduced at higher temperatures (for this test, temperatures were well in excess of 25ºC, and generally above 30ºC during absorb). On the other hand, their setpoint recommendation is based on the battery being on absorb for 12 hours, not 5 hours. Furthermore, the ratio of charge returned to charge withdrawn is over 109% for the first three cycles. The battery manufacturer states that normally 105 to 110% of the withdrawn charge must be returned for the battery to reach full charge.

A second interesting aspect of this test is the dissimilarity between the recharge portion of cycle 4 and the preceding three cycles: on cycle 4, only 105% of the withdrawn charge is returned to the battery, while in cycles 1 through 3, 109% is returned to the battery. This, too, is probably an effect of temperature. While the end of recharge battery temperature is not much lower in cycle 4 than cycle 3, the average temperature during recharge is significantly lower for cycle 4 than for the others, as seen in Figure 2. In fact, the battery temperature during recharge is 29.8 to 31.2ºC for cycles 1 through 3, but 26.9ºC for cycle 4.

The average battery temperature, and not just the final battery temperature, is important during recharge because it influences the amount of charge that will be diverted to gassing. At higher temperatures, the gassing current is higher at a given voltage. Thus, the battery recharges less efficiently at higher temperatures.

The above two observations underline the critical role of temperature in the operation of the battery. Unfortunately, this test also demonstrates the difficulty of maintaining the interior air temperature and the battery temperature at 25ºC when the outside air temperature is above roughly 15ºC. This is especially true when the genset is operating. With high outdoor air temperatures, the heat lost by the test bench when at 25ºC is less than that transferred to the test bench by the genset. This is especially true just after the test bench has been turned off: the exhaust fan shuts down, and the unforced current of air through the test bench does not exhaust much heat.

This situation could be addressed in several steps:

1) A supplemental exhaust fan, driven by an electric motor turned on and off by the test bench control system, could be added to the test bench. One option would be to add it to the exterior of the building, in series with the current exhaust port. It would be operated when the genset was off, drawing air into the building through the fresh air port. This would permit more controlled operation with outdoor air temperatures approaching 25ºC.

2) Temperature control could be based on the battery temperature rather than the inside air temperature. The inside air temperature must be below the battery temperature for the latter to lose heat; therefore, if a battery temperature of 25ºC is desired, and the battery temperature is actually 30ºC, it would be good to lower the indoor air temperature to 20ºC to enhance heat losses. Note that the battery is the only component whose operation is strongly affected by temperature; the other components would function largely unaffected by temperature over the range 10ºC to 30ºC. For the most part, basing temperature control on the battery temperature would be a matter of changing the software. The main exception to this would be the thermostat for the space heater; this could be replaced by a relay.

3) If operation with stable battery temperature under all outside air conditions is desired, then the addition of an air conditioner may be necessary. Under the current arrangement, there will be a roughly two-month period during summer when the battery temperature will be nearly impossible to limit to 25ºC.

Fortunately, this is a consideration only during the warm summer months, and therefore will not be a concern for the next 8 months.

It should also be noted that, while not apparent from the results apparent here, there appears to be a roughly 2ºC offset between the temperature measured at the exterior of the battery casing by an RTD sensor and the temperature measured between the battery cells by a thermocouple. The exterior casing measurement is always higher, so this appears to be a case of calibration rather than temperature gradient. It would be good to resolve this discrepancy and verify the correct calibration of the thermocouple.

3 TYPICAL HYBRID CYCLING WITH BATTERY NOT FULLY CHARGED

3.1 Test Description

This test resembles the one reported on in Section 2, except that the absorb portion of the recharge has been eliminated.

The test starts with the battery fully charged; in fact, the test begins with the completion of the float charge occurring at the end of the sequence described in Section 2.1. The following sequence of 5 steps is then repeated 5 times:

1) DC load of approximately 12.3 Amps is connected and battery discharges to a voltage of 24.36 V (i.e., 2.03 Vpc).
2) Battery is open circuited for one hour.
3) Genset is started and charger supplies approximately 48.5 Amps to the battery until the battery voltage rises to approximately 28.05 V, or 2.34 Vpc (bulk charging).
4) The genset is stopped and the battery is open-circuited for one hour (cycles 1, 2, and 4), 7h48mins (cycle 3) or 15h48mins (cycle 5).

Following the execution of this sequence a total of five times, a final discharge, followed by a complete recharge, is executed:

1) DC load of approximately 48.5 Amps is connected and battery discharges to a voltage of 23.4 V (i.e., 1.95 Vpc).
2) Battery is open circuited for one hour.
3) Genset is started and charger supplies approximately 48.5 Amps to the battery until the battery voltage rises to approximately 28.05 V, or 2.34 Vpc (bulk charging).
4) The charger reduces its current output in order to maintain approximately 28.4 V at its terminals (absorb charging). The current supplied to the battery falls from about 48.5 Amps to approximately 14.1 Amps and, due to the voltage drop in the cables between battery and charger, the battery voltage rises from about 28.05 V to approximately 28.3 V (2.36 Vpc).
5) The genset is stopped.
6) The battery is held on float charge for 24 hours: the low current necessary to maintain the battery voltage at approximately 27.1 V is provided by a power supply.

During this test, the indoor air temperature was maintained at 25ºC or as close thereto as possible.

3.2 Results

As in the test of Section 2, a number of pertinent quantities were measured throughout the test, and 2 minute averages were saved to a file. These data are found in the file 040830slow.xls.

These data are displayed graphically in Figures 4 and 5, which span the entire test. Figure 4 shows the current into the battery, and Figure 5 shows the measured temperatures. Both figures show the battery voltage, which helps associate the evolution of temperature with the operation of the genset and the charging of the battery.

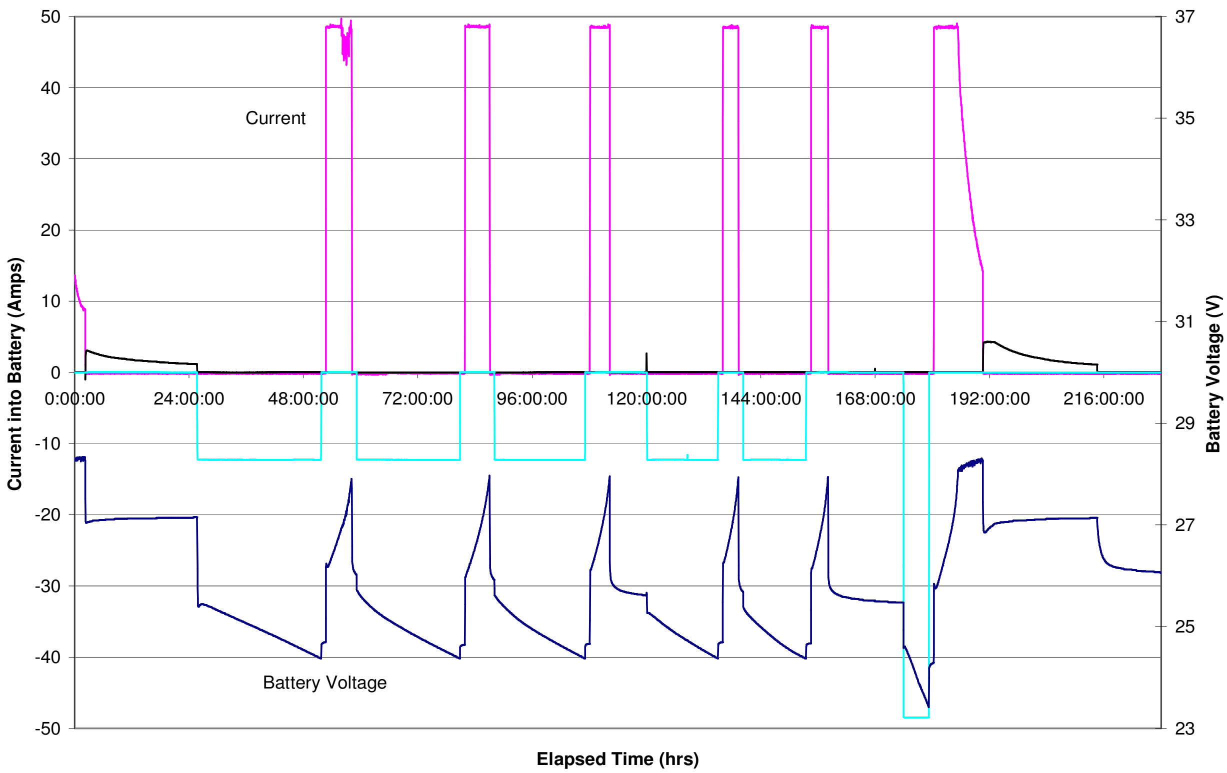

Figure 4 Current and Voltage during the Test

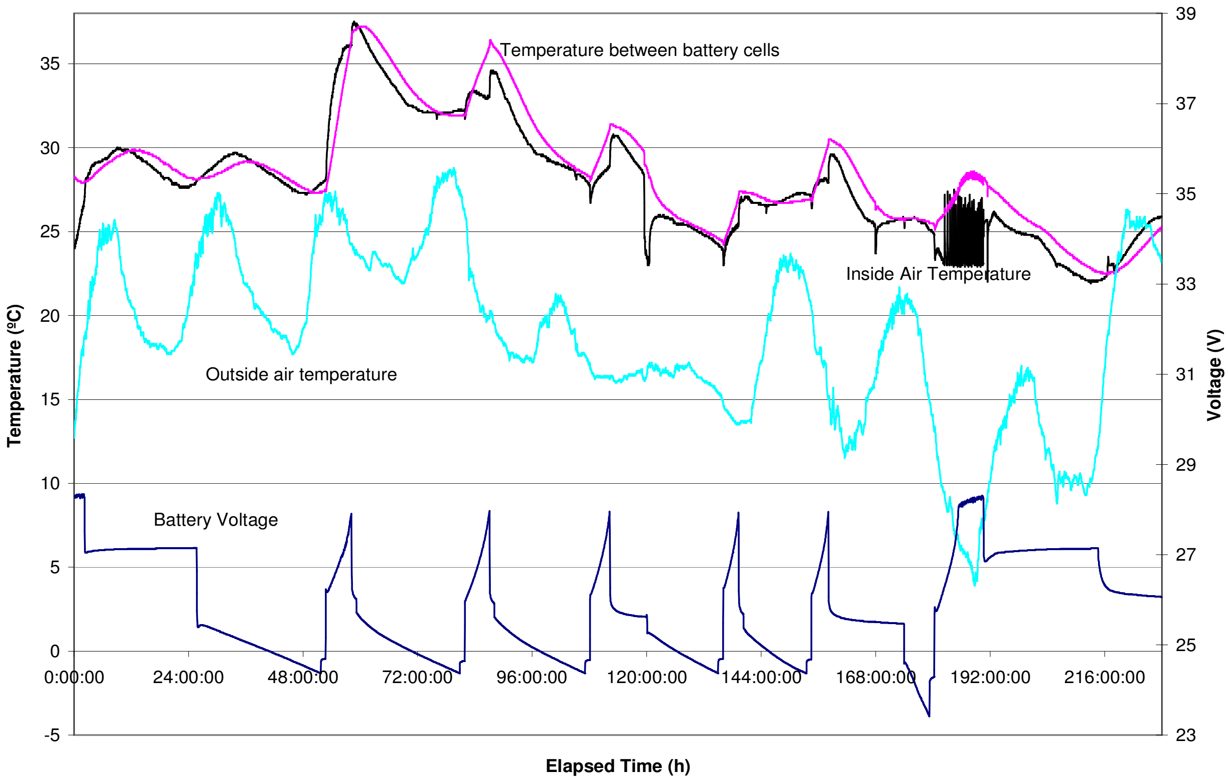

Figure 5 Temperature during the Test

The charge removed from and returned to the battery on each cycle is indicated in Table 2. In addition, the table shows the temperature at the end of discharge and charge measured by a thermocouple placed between two cells in the battery as well as the average temperature over the cycle.

Table 2 Summary of Test

	Ahr Discharged	Cell temp. at end (ºC)	Ave. cell temp. (ºC)	Ahr Returned	Cell temp. at end (ºC)	Ave. cell temp. (ºC)
Cycle 1	319	27.3	28.4	260	36.6	32.0
Cycle 2	266	31.9	34.1	253	36.1	34.1
Cycle 3	234	28.4	31.5	202	31.2	29.5
Cycle 4	183	24.6	25.9	159	27.2	25.6
Cycle 5	162	26.9	26.9	174	30.3	28.5
Final Discharge & Bulk+Absorb	258	25.5	25.7	382	28.1	27.2
Float				55	22.6	25.1

3.3 Discussion

As in the test described in Section 2, the charge that can be withdrawn from the battery before the end-of-discharge threshold voltage is reached declines from cycle to cycle. In fact, the charge liberated in cycle 5 is only one-half that liberated on cycle 1. In contrast, I expected that the charge withdrawn from the battery would fall from the cycle 1 to cycle 2, then stabilize: since the charge current and the end-of-charge voltage limit are the same from cycle to cycle, the battery should be raised to the same state-of-charge at the end of each charge. In addition, assuming that the absorbed glass mat battery used in the test bench is immune to effects such as stratification, the use of the same current and end-of-discharge voltage limit for all cycles should guarantee that state-of-charge at the end of discharge is identical from cycle to cycle. This type of behaviour is evidenced in PV Toolbox simulations of this test, as seen in Table 3. However, this is not observed in the real test.

Table 3 Simulated versus Actual Results

	Ah Discharged		Ah Returned	
	Simulated	Actual	Simulated	Actual
Cycle 1	322	319	204	260
Cycle 2	199	266	204	253
Cycle 3	199	233	204	202
Cycle 4	199	183	204	159
Cycle 5	199	162	204	174

This is a troubling observation. At first glance, it may suggest that absorbed glass mat batteries are not necessarily immune to effects, such as stratification, normally associated with cycle-to-cycle decline in useable capacity seen when flooded batteries are cycled between partial states-of-charge. This would make cycling between partial states-of-charge a less attractive scheme with absorbed glass mat batteries. It would require batteries to be regularly taken into constant voltage charging at an elevated setpoint, resulting battery inefficiencies and in partial load operation of the genset, at least during winter. Thus the matter merits some delving into.

On the face of it, the reason for the decline in useable capacity from one cycle to the next is quite simple: insufficient charge is being returned to the battery during each recharge cycle. Table 4 shows that on cycles 1 through 4, only 80 to 95% of the withdrawn charge was returned to the battery. Whenever this ratio is less than 100%, it is clear that the useable capacity will decline on the subsequent cycle, all other factors being constant.

But why does the battery take five cycles to stabilize? One could posit a role for battery temperature on charge. Looking at all the cycles as a group, however, the ratio of charge returned to discharged does not seem to be closely correlated, as seen in Table 4.

Table 4 Ratio of Charge Returned to Charge Withdrawn

	Ah Recharged/ Ah Discharged	End of charge cell temperature (ºC)	Average cell temp. during charge (ºC)
Cycle 1	81%	36.6	32.0
Cycle 2	95%	36.1	34.1
Cycle 3	87%	31.2	29.5
Cycle 4	87%	27.2	25.6
Cycle 5	108%	30.3	28.5

Another way of examining the results is to calculate the cumulative charge withdrawn from and returned to the battery over the whole test. This is done in Table 5. These data are plotted in Figure 6, which also shows the end-of-discharge battery temperature and the average battery temperature during recharge.

Table 5 Net Cumulative Charge Withdrawn from and Returned to Battery

	Net cumulative charge (Ah)	
	At end of discharge	At end of recharge
Cycle 1	-319	-59
Cycle 2	-325	-72
Cycle 3	-306	-103
Cycle 4	-286	-127
Cycle 5	-289	-115

Figure 6 is quite revealing. The difference between the end of recharge point and the end of discharge point provides an estimate of the capacity that will be available on the subsequent cycle. Two trends are evident. First, there is a general decline in the capacity available. Second, the temperature of the battery modulates this: higher battery temperatures tend to increase the difference between the two lines, and vice-versa. That this tendency was not observed in the data as whole, but rather only when the cycle-to-cycle trend has been separated out, suggests that there is something at work here beyond merely the influence of battery temperature. Unfortunately, the variability in temperature during this test makes it difficult to determine the extent to which it influences the results.

There are at least two mechanisms that could be underlying the observed decline in useable capacity. One paper, citing Japanese work, asserts that absorbed glass mat batteries "can suffer from acid stratification" [Newnham and Baldsing, 1995]. These same authors propose a second mechanism in a more recent paper [Newnham and Baldsing, 2004]. They indicate that in cycling between partial states-of-charge, the "ToCV", or voltage at the end of a recharge returning a fixed amount of charge to the battery, rises significantly from cycle to cycle in absorbed glass mat batteries used for hybrid electric vehicle operation. This is attributed to the accumulation of lead sulfate on the surfaces of the negative plates. This lowers the negative plate electrode potential significantly, "reduces the rechargeability of the battery and, if allowed to reach a critical level, curtails battery life". While the hybrid electric vehicle cycling involves much higher currents than used here, Newnham and Baldsing believe that this mechanism is at play in PV hybrid systems. In addition, they find that the "window" of state-of-charge over which the battery is cycled is critical.

If the apparent capacity decline is due to accumulation of lead sulfate on the surfaces of the negative plates, the selection of a different state-of-charge window might reduce the problem. If, on the other hand, stratification is the culprit, then this would partially confirm Newnham and Baldsing's choice of gelled valve-regulated batteries. In their development of a regime for cycling batteries between two partial states-of-charge, they avoided absorbed glass mat because of the possibility of stratification [Newnham and Baldsing, 1995].

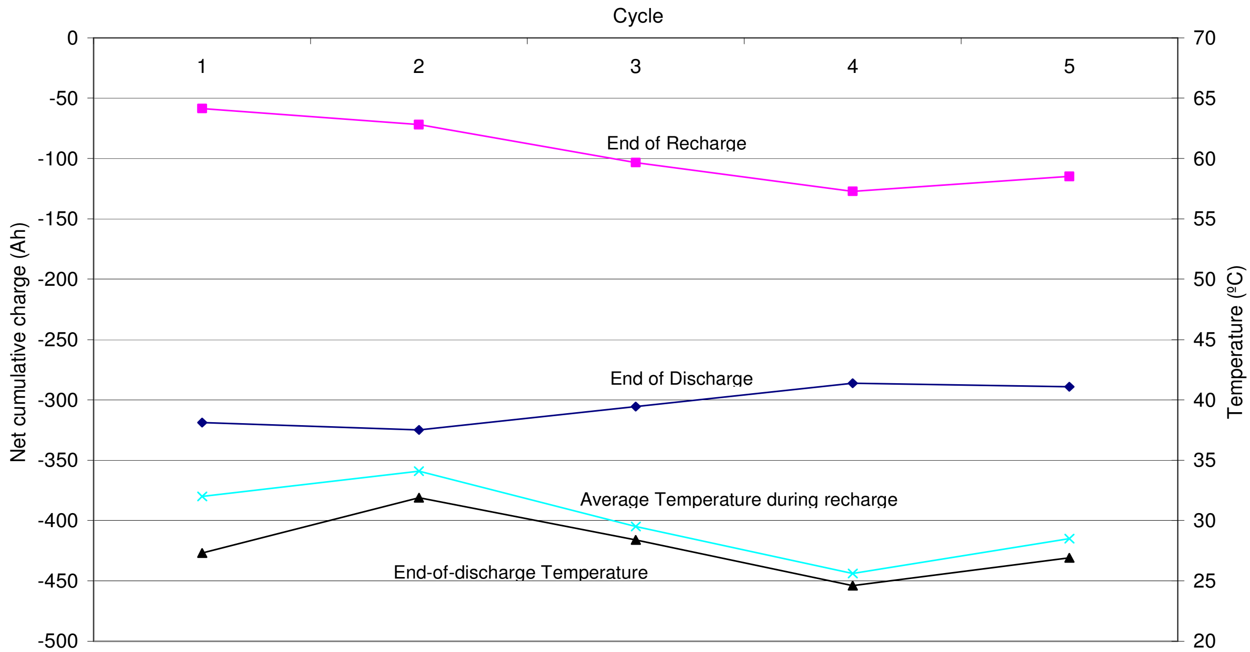

Figure 6 Net Cumulative Charge Withdrawn from and Returned to the Battery

The ratio of charge returned to charge withdrawn jumps from much less than 100% to 108% on Cycle 5. Unfortunately, cycling stopped at this point. As the operator of the test, I should have noticed this anomalous behaviour prior to continuing to the final discharge (at elevated current) and recharge. At present it is impossible to know whether the sudden jump is due to changes in temperature, a stabilization of the decline in useable capacity, or some other factor.

In order to further investigate the role of temperature and to determine whether the useable capacity truly stabilizes after five cycles, this test should be rerun. The outside air temperature for this test should be in a range where maintaining the battery at a temperature close to 25ºC is not so problematic.

Returning to Table 3, where simulation results are compared with measured data, it is observed that the PV Toolbox appears to be quite accurate in predicting the charge withdrawn on the first discharge, but significantly low in its estimate of the charge returned on recharge. If the simulation is rerun with each recharge returning the battery to the state-of-charge implied by the cumulative net charge withdrawn (i.e., from Table 5), the battery model performs reasonably well on discharge for the first two cycles, as seen in Table 6. On subsequent cycles, the PV Toolbox diverges from the measured data. This divergence may be attributed to transport effects in the battery, such as stratification, or to a significant portion of the recharge current being lost in gassing.

Table 6 Simulated versus Actual Discharge

	Actual Ah discharged	Simulated Ah discharge	Simulated end of recharge condition
Cycle 1	319	322	SOC=0.90
Cycle 2	266	270	SOC=0.88
Cycle 3	234	261	SOC=0.83
Cycle 4	183	224	

In short, while the discharge behaviour of the model appears to be reasonable, the recharge behaviour is not terribly precise. Some of this may be attributed to the high battery temperatures on charge: there was no calibration data available for fitting the model to these types of conditions.

CONCLUSIONS

In two test sequences run on the PV and Hybrid System Group's hybrid test bench, useable battery capacity appears to decline from one cycle to the next. In the first test the genset recharges the battery with a bulk and absorb charge following a moderately deep discharge. In this test, the apparent decline can be attributed to a decrease in temperature over the period of the test. In the second test, however, temperature's role is insufficient to explain the decline. In this second test, discharge is followed by recharge at a constant current to a voltage threshold of around 2.34 Vpc. During the first four cycles, only 81% to 95% of the charge withdrawn from the battery is returned on recharge. As a consequence, the charge that can be withdrawn prior to the battery reaching the end-of-discharge threshold decreases by 50% over five cycles. While temperature appears to influence the battery behaviour, there is clearly some other mechanism at play here, perhaps stratification of the electrolyte of the accumulation of lead sulfate on the negative electrode. This is a significant observation because it lends credibility to the contention that absorbed glass mat batteries—like flooded batteries but unlike gelled electrolyte batteries—can not be cycled between partial states-of-charge, may indicate significant stratification in these absorbed glass mat batteries, implies that regular absorb charging may be required in hybrid PV systems, and may go some way toward explaining the abbreviated charge-discharge cycles occurring in some hybrid systems.

The results of the second test are inconclusive, however, because of uncontrolled variation in the battery temperature and because the operator (i.e., the author of this report) ended the test just when the decline in the useable capacity may have been stabilizing. This test should be rerun, therefore, with more attention paid to battery temperature.

When daytime outside air temperatures exceed approximately 15ºC, maintaining the battery temperature at 25ºC is difficult, especially when the genset is operating. As a consequence, there was considerable variation in the battery temperature during these tests; with the battery temperature being so critical to the operation of the system, this creates difficulties in the interpretation of the results. There are a number of minor changes that could be made to the hybrid test bench that would help control the battery temperature.

REFERENCES

Newnham, R. H. and W. G. A. Baldsing. "New Operational Strategies for gelled-electrolyte lead/acid batteries". *Journal of Power Sources* 59 (1996), pp. 137-141.

Newnham, R. H. and W. G. A. Baldsing. "Advanced management strategies for remote-area power-supply systems". *Journal of Power Sources* 133 (2004), pp. 141-146.

Ross, Michael. *Validation of the PVToolbox Against The First Run of the Battery Capacity Cycling Test.* Varennes, Québec: CANMET Energy Technology Centre—Varennes. November, 2003.

Roussin, Sophie and Dave Turcotte. *Hybridinfo—The Semi-annual newsletter on photovoltaic hybrid systems in Canada.* CANMET Energy Technology Centre—Varennes. Summer 2004, Issue #7.

Sheriff, F., D. *Turcotte*, and M. Ross. "PV Toolbox: A Comprehensive Set of PV System Components for the Matlab®/Simulink® Environment". *Proceedings of the 2003 Conference of the Solar Energy Society of Canada Inc., Kingston, Ontario, Canada, August 18 to 20, 2003.*