Civil Engineering Studies
Transportation Engineering Series No. 140
Traffic Operations Lab Series No. 17

UILU-ENG-2005-2009

ISSN-0917-9191

Effect of High and Low Temperatures on UPS systems for Intersection Traffic Signals

By
Madhav V. Chitturi
Rahim F. Benekohal

A study conducted by
Traffic Operations Laboratory
Department of Civil and Environmental Engineering
University of Illinois at Urbana-Champaign

Prepared for
Illinois Department of Transportation

September 2005

Technical Report Documentation Page

1. Report No, FHWA-IL/UI-TOL-17	2. Government Accession No.	3. Recipient's Catalog No
4. Title and Subtitle Effect of High and Low Temperatures on UPS systems for Intersection Traffic Signals		5. Report Date September 20, 2005
		6. Performing Organization Code
7. Author(s) Madhav V. Chitturi and Rahim F. Benekohal		8. Performing Organization Report No. UILU-ENG-2005-2009
9. Performing Organization Name and Address Department of Civil and Environmental Engineering University of Illinois at Urbana-Champaign 205 N. Mathews Ave. Urbana, Illinois 61801		10. Work Unit (TRAIS)
		11. Contract or Grant No.
		13. Type of Report and Period Covered Project Report 2004-2005
12. Sponsoring Agency Name and Address The Illinois Department of Transportation		14. Sponsoring Agency Code
15. Supplementary		

16. Abstract

Temperature significantly affects the performance of UPS systems. Four different UPS systems were evaluated at sub-zero temperatures and hot temperatures from -25 °C to +72 °C (-13 °F to +162 °F). At high temperatures, tests were performed to ascertain the run times under normal signal operation, whether the UPS shutsdown the charging and that there is no gassing of the batteries. At sub-zero temperatures tests were performed to find the run times under normal, flashing and a combination of normal and flashing modes of operation. All the UPS systems showed longer run times as the temperature increased and drastically shorter run times as the temperature decreased. For normal operation at +72 °C condition, the percentage change in run time relative to room temperature ranged from +6% to +26%. Relative to room temperature the percentage change in run time at -25 °C condition ranged from -32% to -80% for normal operation. At the coldest temperature, the increase in duration of flashing compared to duration of normal operation ranged from 89% to 158% and the increase in combination of normal and flashing duration compared to normal operation duration ranged from 35% to 81%. It is recommended to switch to flashing or a combination of normal and flashing mode of operation in cold temperatures to increase the run time. It was also found that a UPS with a greater battery capacity may not yield greater run times under all temperature conditions.

17. Key Words Uninterruptible Power Supply for Intersections, UPS, Intersection Traffic Signals, LED Signal Modules, Battery Back up System for Traffic Lights, BBS.	18. Distribution Statement		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 60	22. Price

`Form DOT F 1700.7 (8-72)

Acknowledgment and Disclaimer

This study was conducted by the Traffic Operations Laboratory (TOL) at the University of Illinois at Urbana-Champaign. The Illinois Department of Transportation sponsored the study. The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not reflect the official views or policies of the Illinois Department of Transportation. This report does not constitute a standard, specification, or regulation.

TABLE OF CONTENTS

INTRODUCTION

In normal conditions, signalized intersections are controlled by traffic signals that are powered by AC power. An AC power failure could cause a “black-out” situation which can pose serious safety concerns and operational inefficiencies. If the power outage occurs after dark, the presence of a blacked-out signal may not be readily apparent to a driver. With an Uninterruptible Power Supply (UPS) system installed at an intersection, the traffic signals can continue to operate for some time even when there is a power failure. UPS systems can provide crucial time for the maintenance personnel to either restore power or provide alternative sources of power before the batteries are completely discharged. Newly installed traffic signals utilize energy saving LED lights that use up to 85 percent less energy than that needed by incandescent lamps. This tremendous decrease in power consumption has made the use of UPS systems for traffic signals economically viable. The Illinois Department of Transportation (IDOT) has been installing UPS systems at intersections throughout the state and has developed a specification for UPS systems for signalized intersections [1]. The specification deals with several aspects of a UPS system such as: operation, maintenance, displays, controls and diagnostics of the UPS system, batteries used, battery cabinet for holding the batteries, quality assurance program of the manufacturer, battery charge and discharge times, etc.

Temperature affects the battery run time and therefore is an important factor that affects the performance of the UPS. Illinois experiences a wide range of temperatures during any year. Consider Rockford, Urbana and Carbondale which are situated in Northern, Central and Southern Illinois, respectively, to be representative of Illinois. The meteorological data from the last ten years indicate that for Rockford the daily temperature ranged from -31°C to +37°C. For Urbana it ranged from -32°C to +38°C and for Carbondale it ranged from -28°C to +38°C. Consequently, it is necessary to evaluate the run time provided by these units under the high and low temperatures experienced in Illinois. In addition, the use of UPS systems in an outdoor location, such as a traffic controller cabinet, necessitates that the systems have certain special features such as temperature compensation for charging, charging shutdown at high temperatures, etc. Therefore, before installing the systems in the field it is imperative that they be evaluated.

Four manufacturers furnished their UPS systems for evaluation at the high and low temperatures. The UPS systems furnished were:

1. Myers PB2000ITS UPS with 4 Chairman AGM-12100T batteries from US Traffic Corporation (Santa Fe Springs, CA).
2. Alpha Novus 1000TP UPS with 4 Alpha 180GXL-5 batteries from Alpha Technologies (Bellingham, WA).
3. TechPower ME1000 UPS with 4 Optima D34M batteries from TechPower Developments Inc. (Oakville, Ontario, Canada).
4. Dimensions 24M11 UPS with 4 Deka Unigy 24HR3000 batteries from Dimensions Unlimited Inc. (Minneapolis, MN).

Henceforth the four systems will be referred to as PB2000ITS, Novus 1000TP, ME1000 and 24M11 systems. The batteries used by all four systems are Valve Regulated Lead Acid (VRLA) batteries that are non-spillable and maintenance free. The nominal voltage of the batteries used in all four systems is 12 V. Chairman AGM-121000T batteries have Absorbed Glass Mat (AGM) microporous glass separators. They are designed for general purpose applications and their capacity is 100 AH. Alpha 180GXL-5 batteries are gel cell batteries with a capacity of 94 AH. Optima D34M batteries use the wound cell configuration utilizing the proprietary SPIRALCELL technology. They are designed for starting and deep cycle applications and for use in boats with large accessory loads. Their capacity is 55 AH. Deka Unigy 24HR3000 batteries are designed specifically for high-rate UPS systems. Their capacity is 79AH. All the capacities are at the 20 hr discharge rate at 77° F (25°C).

In this report, the results of the testing of the UPS systems at high (up to +72 °C) and low temperatures (down to -25 °C) are presented. The results and discussions in this report are for the UPS systems when used in conjunction with the above mentioned batteries. Before performing the testing at high and low temperatures a questionnaire was sent to the vendors/manufacturers about the UPS charger characteristics, performance of the systems at high and low temperatures, recommended practices in those conditions, etc. These issues are briefly discussed in the next section. The questionnaire also asks whether the UPS systems have any advanced features, like varying the cutoff voltage with the load or with the battery temperature, which might improve their performance. The questionnaire and the details of the responses are discussed in Appendix A of the report.

ISSUES AT HIGH AND LOW TEMPERATURES

The major issues regarding the performance of the UPS systems at high and low temperatures are discussed in this section. The issues discussed include Run Time Performance, Effect of Battery Capacity and Cutoff voltage, Temperature Compensation, and Gassing and Thermal Runaway.

Run Time Performance

The amount of time the UPS system can power the traffic signals in the event of a power failure is called run time and it is an important performance characteristic. An estimate of run time and how it varies with temperature will provide the maintenance personnel an idea about the time available before the intersection goes dark in the event of a power failure. This information can also be used to decide in which mode the traffic signals should operate in the event of power failure. For example, if an intersection is far from a service location, the UPS can be set up such that the signals go to flash instead of solid operation. This would give a longer run time because the power consumed during flashing is less than the power consumed during solid operation.

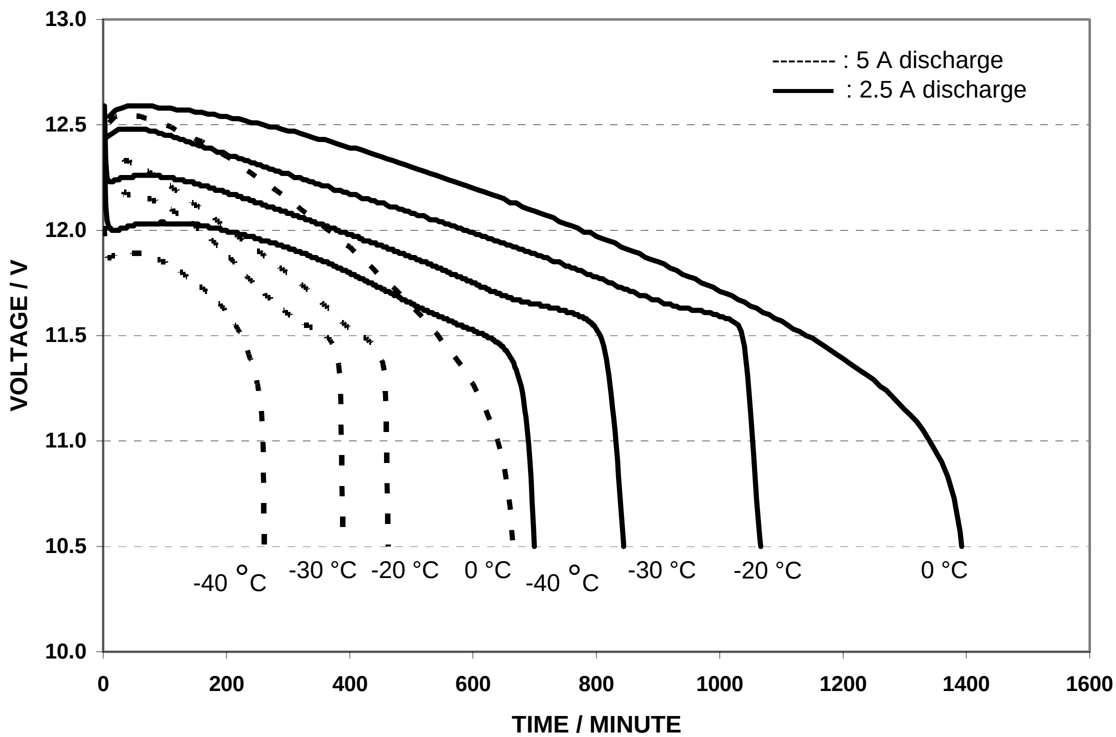


Figure 1. Discharge of Optima D34M batteries at various temperatures.

The temperature at which the battery is discharged has a pronounced effect on its service life (capacity) and voltage characteristics [2]. This effect is more significant under lower temperatures. As the temperature decreases, the chemical activity decreases and the internal resistance of the battery increases. Figure 1 provided by TechPower Developments
Inc.,

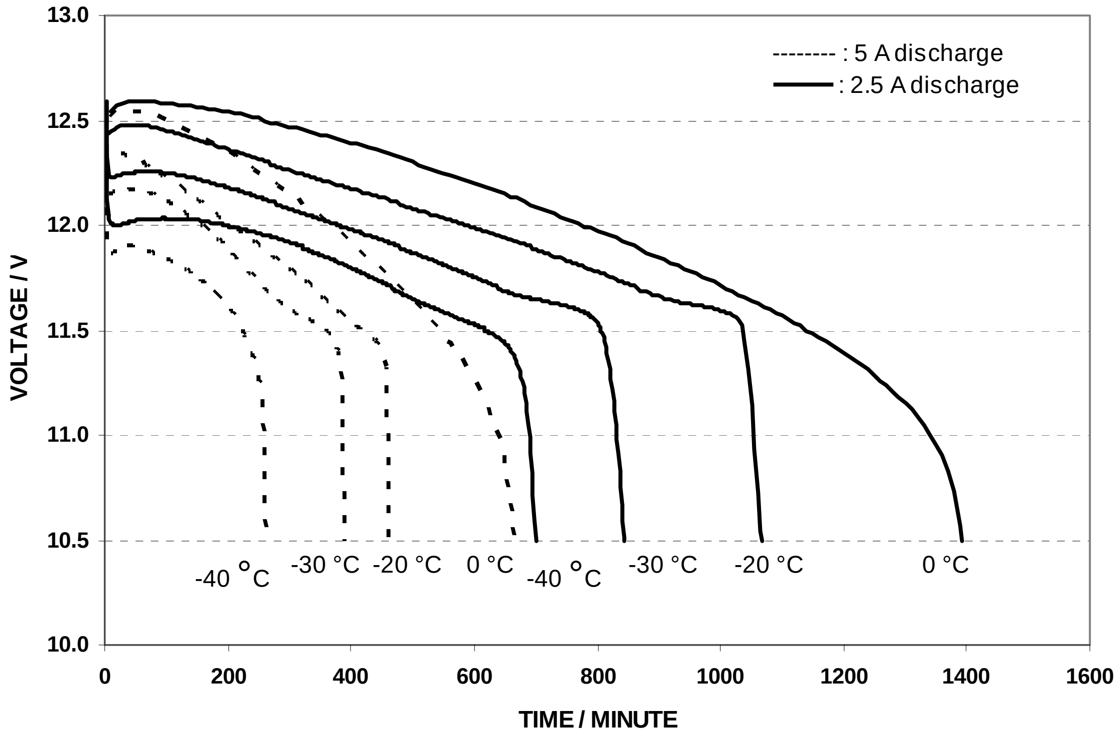


Figure shows battery voltage versus time at various temperatures for the current drains of 2.5 A and 5 A. From Figure 1 it can be noted that as the temperature decreases the run time decreases. Also, the rate of drop in voltage increases as the temperature decreases. From Figure 1, it can also be seen that when the current drain is halved from 5 A to 2.5 A, the run time is more than doubled.

Temperature varies widely in Illinois over a year. The meteorological data from the last ten years indicate that the daily temperature ranged from -32°C to +38°C in Illinois. Consequently it is necessary to evaluate the performance of these units under the extreme temperatures experienced in Illinois. Battery capacity and the voltage at which the UPS system disconnects the load from the batteries are two other factors that affect the run time.

Effect of Battery Capacity and Cutoff Voltage

Battery capacity is usually expressed in Amp-hrs and is a direct indicator of the amount of energy in the battery. The greater the capacity of the batteries, the more energy there is available for the UPS to power the traffic signals. All other factors remaining the same, a UPS with a greater battery capacity will give greater run time.

When a battery is deeply discharged, the reaction in the battery occurs close to the grids, and weakens the bond between the active materials and the grids. When a battery is excessively discharged repeatedly, loss of capacity and life will eventually occur [3]. Therefore to avoid deep discharge, the UPS manufacturers program the UPS systems to disconnect the batteries from supplying power to the load once the batteries reach a cutoff voltage. Therefore run time of the batteries is directly related to the specified cutoff voltage. All other factors remaining the same, the lower the cutoff voltage, the greater the run time provided by the UPS.

Temperature Compensation

Varying the float voltage with the temperature is referred to as temperature compensation. When temperature extremes are expected in the environment, temperature compensation is a required feature. The recommended float charging voltage should vary with the temperature because:

a) At low temperatures, the internal resistance of the battery to current flow is higher. Therefore, a higher charging voltage should be used. Similarly at warmer temperatures, a lower charging voltage should be used to prevent the battery from accepting higher currents.
b) Also, the voltage at which gassing begins decreases as the temperature increases. Therefore, as the temperature increases, the charging voltage should be reduced.

Gassing and Thermal Runaway

Under high temperatures, gassing and thermal runaway are two issues of concern. When the batteries are almost fully charged the excess current supplied for charging electrolyzes water to produce hydrogen and oxygen. In the case of a flooded lead acid battery these gases are vented out, thus necessitating the replenishment of water to those batteries. In the case of valve regulated lead acid (VRLA) batteries, the oxygen gas produced at the positive plate percolates through the immobilized electrolyte and recombines with the hydrogen gas at the negative plate to form water. This is referred to as the oxygen recombination cycle. This is an exothermic reaction i.e., this generates heat. VRLA batteries typically have a recombination rate of 95 to 99% and will emit only a fraction of the hydrogen as would be emitted by a wet lead acid battery [4]. However, at higher temperatures the rate at which oxygen and hydrogen are produced is greater than the rate of recombination. So at high temperatures there could be significant amount of emission of hydrogen. If hydrogen is allowed to accumulate and mix with the atmosphere at a concentration of between 4% and 79%, an explosive mixture would be present which would be ignited in the presence of a spark or a flame [2]. Therefore, it is required to verify that the UPS systems would not create such potentially hazardous situations under high temperatures.

During charging of the batteries heat is generated in the batteries. This can be attributed to two sources: 1) driving of the current through the internal resistance of the batteries and 2) Exothermic oxygen recombination cycle (discussed above). A major portion of the heat is due to the oxygen recombination cycle. Thermal runaway occurs in a battery when the rate of internal heat generation exceeds the rate at which heat can be dissipated into the environment [4]. A prolonged occurrence of thermal runaway could increase the battery temperature until the cells dry out.

Battery float charging in a hot environment is the most common cause of thermal runaway [4]. During float charging conditions, as the temperature of the battery increases, the rate of the oxygen recombination cycle increases. Figure 1 (from Alpha Technologies response to our questionnaire) shows float current vs. the battery temperature at a constant float voltage of 2.30 VDC/cell. As depicted in Figure 1, this leads to an increase in the float current and thereby further increases the amount of heat generated, forming a vicious cycle. Therefore several manufacturers recommend that under high temperature conditions the float charging of the batteries stop completely. Specifically IDOT requires that the battery charging be completely stopped when the battery temperature exceeds 50±2 °C.

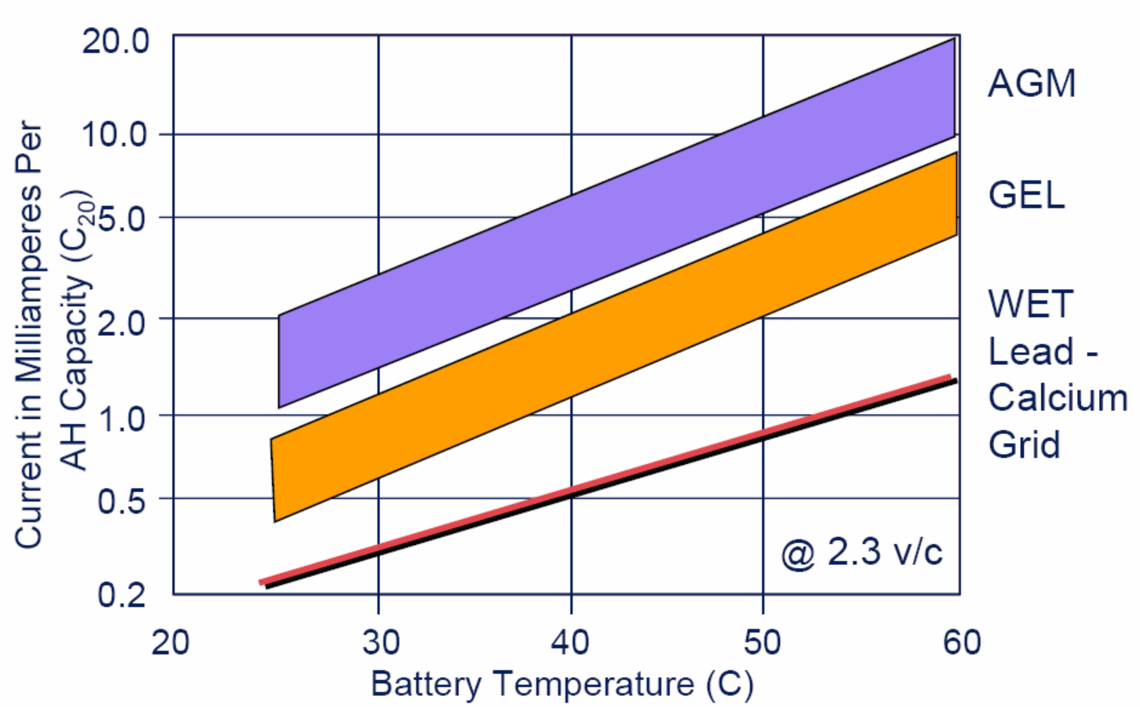


Figure 1. Float Current Vs Temperature at constant float charging voltage of 2.3 VDC/cell

TEST SETUP & METHODOLOGY

UPS systems from four manufacturers were evaluated. The testing was done at sub-zero temperatures and high temperatures. It is expected that there would be some variability in the run times. Therefore multiple tests were performed on each unit to build confidence in the results obtained from the testing. The UPS system being evaluated was connected to a controller cabinet in the lab and the signal load was provided by the traffic signal heads. A schematic diagram of the test-setup is shown in Figure 3. The power consumed by the traffic signals during solid operation was approximately 700 W and during flashing operation was about 350 W. A digital voltmeter was used to monitor the voltage of the batteries and this data was logged into a computer. Figure 2 also shows a hydrogen sensor which was used to detect any hydrogen emissions from the batteries. Having established that the performance of the UPS systems is consistent under room temperature [5],[6],[7] &[8] a few repetitions under extreme temperatures were sufficient to give confidence in the test results. The limited repetitions also ensured that the extreme temperature conditions did not damage the batteries or the UPS unit.

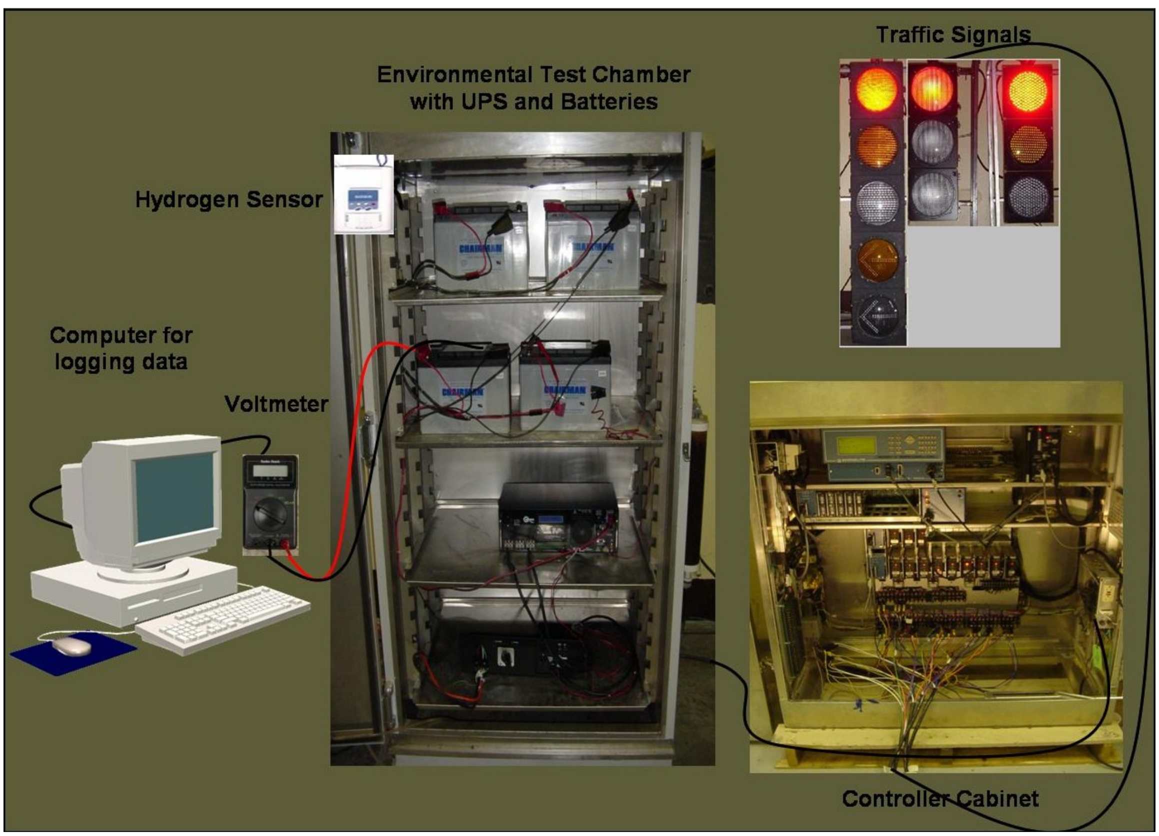


Figure 2. The experimental setup.

High Temperature Testing

The air temperature within a traffic controller cabinet without the ventilation fan was recorded using a digital thermometer during the summer. The controller cabinet was in direct sunlight. The data indicated that the temperature within a traffic controller cabinet, without a fan could reach +50°C and higher when the outside temperature was around 32.2°C (90 °F) on a sunny day. The specification requires that the UPS function in the temperature range -25°C to +74°C. The research team did not want the testing temperature to exceed +74 °C, but get as close to it as possible. Also, the oven in the laboratory could reach only a temperature of +72°C. Therefore, hot temperature testing was performed at two temperatures:

1. 50 °C referred to as high temperature test and
2. 72 °C referred to as very high temperature test.

The primary performance measure that is of concern is the run time provided under these extreme conditions. It is expected that for the same load the batteries would yield a longer run time at a higher temperature. The UPS along with the fully charged batteries was placed in a +50°C (or a +72°C) oven for 1.5 hrs (or 2.5 hrs) for the batteries to warm up. At the end of that duration the discharge test was begun by applying a load of approximately 700W (for normal signal operation) and the run time was measured. It should be noted that the batteries were fully charged at room temperature because charging at high temperatures could potentially damage the batteries. All other factors remaining constant, as the temperature of the operating environment increases, the run time provided by the UPS is expected to increase.

The IDOT specification requires that the batteries not be charged when their temperature exceeds 50±2°C. At the end of the very high temperature tests (+72°C), the battery temperature was around +65°C. At this time the AC power was restored to the UPS to check if the UPS shuts down charging at high temperatures. In order to verify that none of the units emit any hydrogen under high temperature conditions, a hydrogen sensor which is sensitive to 10 ppm of hydrogen was placed in the oven. When the hydrogen concentration exceeds the threshold of 10 ppm, the sensor would activate an audible alarm.

Sub-Zero Temperature Testing

Since these UPS systems would be installed at different locations in Illinois, it is imperative that they are tested at sub-zero temperatures that are typical during the winter in Illinois. To account for the climatic differences due to geographical location, temperature data at three locations, one each in northern, central and southern Illinois were examined. The three locations are:

1. Carbondale in southern Illinois
2. Urbana in central Illinois

3. Rockford in northern Illinois

The daily minimum temperatures at these three locations over a period of ten years were obtained from the National Climatic Data Center (NCDC). The ten-year period for the three different locations is shown in Table 1. The lowest temperature in this ten-year period is also shown in Table 1.

Location	Time period	Lowest Temperature in the 11-year period (°F)
Carbondale	11/1993 – 11/2003	- 19
Urbana	11/1993 – 11/2003	- 25
Rockford	09/1993 – 09/2003	- 24

Table 1. Time Period of data for the three locations.

Figure 3 shows the frequency distribution of the daily minimum temperatures during the ten-year period for the three locations. Because Rockford is in northern Illinois, Urbana in central and Carbondale in southern Illinois, it would be reasonable to expect that we would find higher frequencies of low temperatures in Rockford followed by Urbana and Carbondale. For the same reason, it would be reasonable to expect that we would find higher frequencies of high temperatures in Carbondale followed by Urbana and Rockford. From Figure 3 it can be seen that Rockford has the highest frequencies, and is followed by Urbana and Carbondale in the lowest temperatures. Exactly the opposite trend is present in the high temperatures.

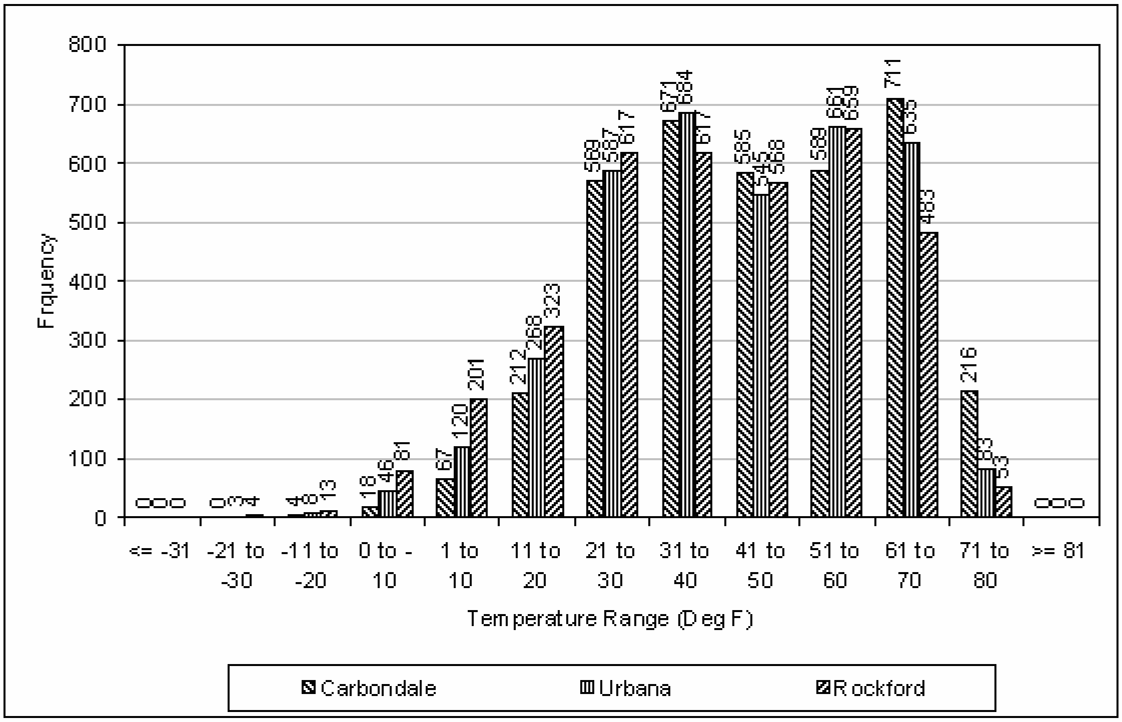


Figure 3. Frequency Distribution of Daily Minimum Temperature in the 10-year period

From Figure 3, it can be seen that sub-zero temperatures are typical even in Carbondale, which is in southern Illinois. Over the ten-year period, the frequency of sub-zero temperatures is 22, 57 and 98 for Carbondale, Urbana and Rockford, respectively. On the average sub-zero temperatures occurred on 2.2 days, 5.7 days and 9.8 days in each year over the ten year period. However, it could be possible that all these temperatures occurred only in a few unusually cold years. To verify this, year-wise frequencies of sub-zero temperatures were plotted for the three locations and are shown in Figures 5 - 7. Table 2 summarizes the data presented in Figures 5 - 7. Table 2 shows the number of days that had sub-zero temperatures and also the number of calendar years in which these days occurred, for each of the three locations.

Location →	Carbondale		Urbana		Rockford	
↓ Interval	# of days	# of years	# of days	# of years	# of days	# of years
0 to –10 °F	18	7	49	10	81	11
-11 to –20 °F	4	2	8	4	13	5
-21 to –30 °F	0	0	3	2	4	3

Table 2. Number of days and number of calendar years with sub-zero temperatures during the 10-year period

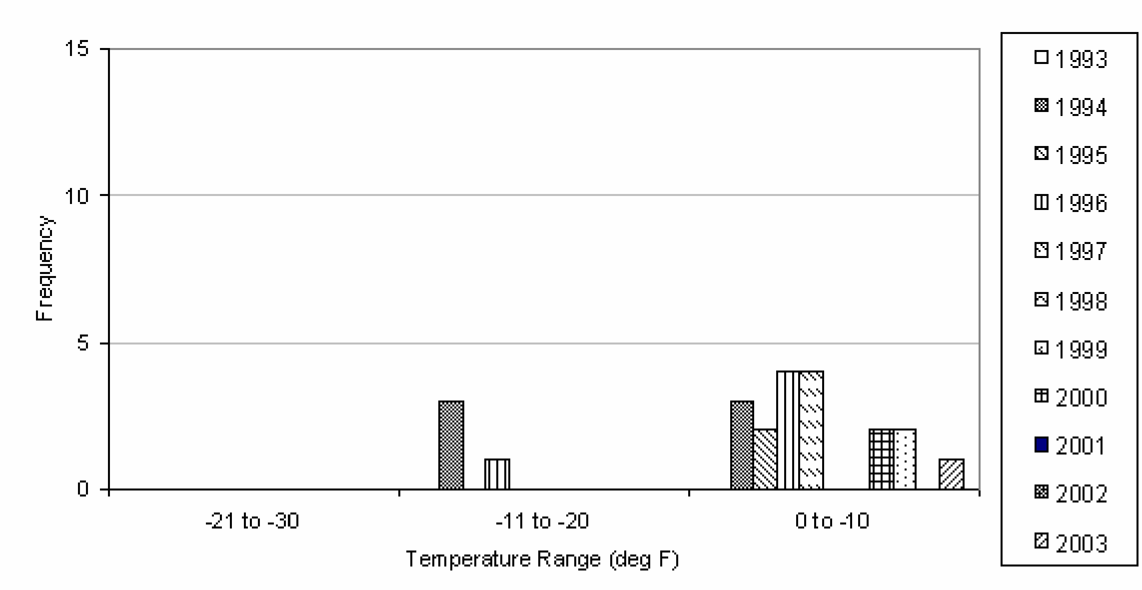


Figure 4. Year-wise frequencies of sub-zero temperatures in Carbondale

From Table 2, it can be seen that during the 10-year period, temperatures in the range of 0 to –10 °F occurred in 7, 10 and 11 calendar years in Carbondale, Urbana and Rockford, respectively. Carbondale had temperatures in this range on 18 days in 7 calendar years. Urbana experienced temperatures in this range on 49 days in 11 years and Rockford on 81 days in 11 years. Temperatures in the range of -11 to –20 °F occurred in 2, 4 and 5 calendar years in Carbondale, Urbana and Rockford, respectively. Carbondale had temperatures in this range on 4 days in 2 years. Urbana experienced temperature in this range on 8 days in 4 years and Rockford on 13 days in 5 years. Carbondale did not have temperatures in the range of –21 to –30 °F. But Urbana and Rockford experienced these temperatures on 3 days in 2 years and 4 days in 3 years, respectively.

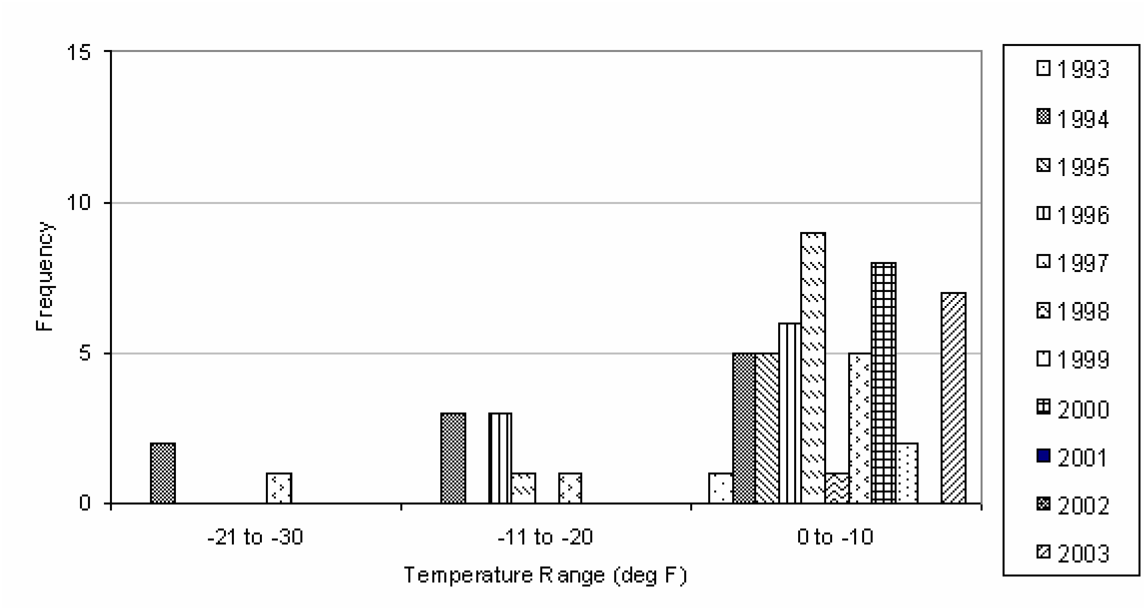


Figure 5. Year-wise frequencies of sub-zero temperatures in Urbana

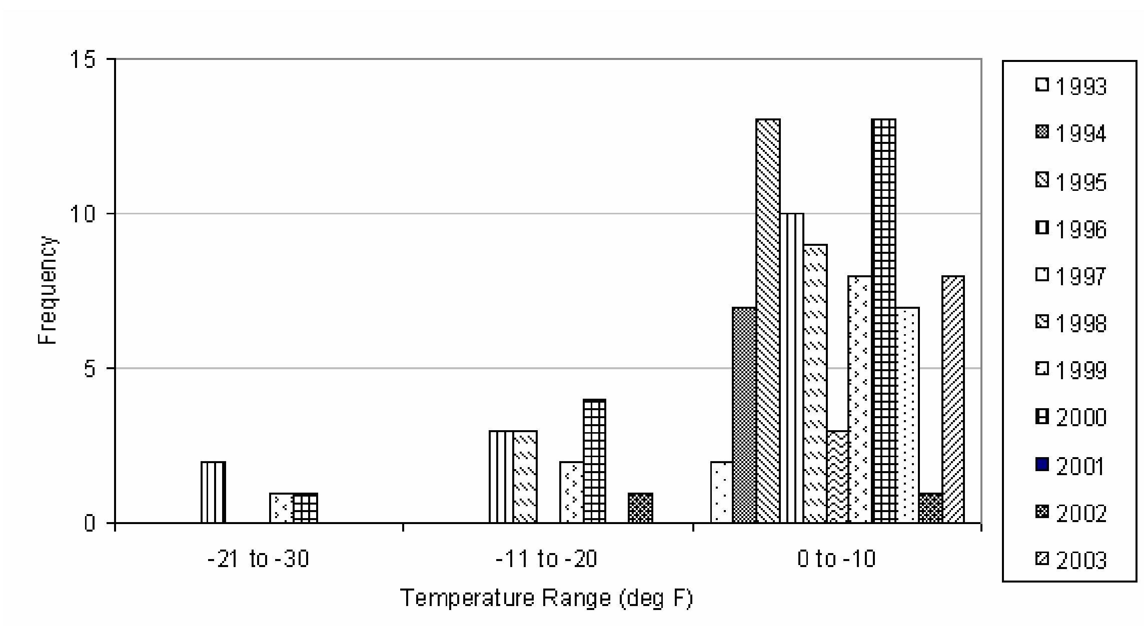


Figure 6. Year-wise frequencies of sub-zero temperatures in Rockford

From this data it can be concluded that temperatures in the range of –21 to –30 °F occur very infrequently in Illinois and testing the UPS systems at this temperature is unnecessary at this point. Temperatures in the range 0 to –10 °F are common and occur almost every year in all the three locations. Temperatures in the range of –11 to –20 °F occurred in all the three locations and are less frequent but are not rare. Therefore, testing the UPS systems in this range of temperatures (–11 to –20 °F) would ensure that the systems are tested at low temperatures that are not uncommon and also at the same time not the absolute coldest temperatures that are very rare. The specification requires that the UPS function in the temperature range -25 °C to +74 °C (-13 °F to +165 °F). Therefore the coldest testing environment was set at -25 °C (-13 °F). Also, tests were conducted at intermediate freezing temperatures between -25 °C and zero.

The primary performance measure that is of concern is the run time provided under these extreme conditions. It is expected that for the same load the batteries would yield a shorter run time at a lower temperature. The UPS and the batteries were placed in the freezer. All the batteries and the UPS were covered with plastic sheets to ensure that no water seeps into the unit if the freezer were to thaw out for some reason. The system was placed in the freezer for sufficient time to cool it down to the desired temperature. The discharge test was performed using a load of approximately 700W and the run time was measured. All other factors remaining constant, as the temperature of the operating environment decreases, the run time provided by the UPS is expected to decrease.

When there is a power failure the UPS supplies the power from the batteries to the traffic signals to continue normal signal operation. It is known that the run times would decrease significantly when the temperature drops to sub-zero conditions. Therefore, a traffic engineer may want to consider the option of going to flashing operation as soon as there is a power failure in the winter. Also, some districts are considering the option of running the intersection in normal signal operation until the batteries reach a 40% level of charge and then switch to flashing operation. Therefore, under sub-zero temperature conditions, the following tests were performed on the UPS systems at the coldest temperatures:

1. Normal signal operation
2. Flashing red operation
3. Normal signal operation until the batteries reached 40% level and flashing red from then on.

The rationale for performing these tests at the coldest temperature is that these tests would yield the lowest run times one might experience. Multiple tests were performed at the lowest temperature to establish the consistency in performance. In addition, run times for solid operation were obtained at some intermediate temperatures. Having established that the systems are consistent at room temperature [5],[6],[7] &[8] and at the coldest temperature, only one test was performed at each of the intermediate temperatures.

RESULTS OF HIGH TEMPERATURE TESTING OF UPS SYSTEMS

The results for the four manufacturers' units are presented in the four sections to follow. In each section the results of the run time for the high temperature tests (+50°C tests) are presented followed by the results for the very high temperature tests (+72°C tests). Following these results, observations of charging under high temperature conditions and gassing are stated.

PB2000ITS UPS

The results of the discharge test performed in a +50°C oven for PB2000ITS system are shown in Table 3. The load used for the discharge test was approximately 700 W. Five tests were performed to ensure that there is consistency in the results of the tests. Table 3 also shows the voltage at which the UPS shutdown the load to avoid the deep discharge of batteries. It should be noted that the voltage shown here is the voltage of one of the four batteries used in the UPS. Based on these results the minimum and maximum run times for a 700 W load in a +50°C oven are 3hr 45min and 4hr 11min, respectively. The average run time is 3hr 53min. The earlier tests [8] have indicated the average run time for a 700 W load under room temperature to be 3 hr 31 min. As expected the run time increased with the increase in the temperature of the operating environment.

Test #	Date	Run time (h:mm)	Cutoff Voltage (VDC)*
1	2/12/2004	4:11	39.08
2	2/15/2004	3:52	43.64
3	2/19/2004	3:45	44.9
4	2/21/2004	3:49	44.96
5	2/24/2004	3:48	42.92

Table 3. Results of the discharge tests performed in +50°C oven for PB2000ITS.

** : This voltage is four times the voltage of a single 12VDC battery.*

The results of the discharge test performed in a +72°C oven are shown in Table 4. The load used for the discharge test was approximately 700 W. Two tests were performed to ensure the consistency of the results. Because +72°C is very close to the extreme operating temperature of the unit, more tests were not repeated. The average run time is 4hr 25min. This is an increase in run time over the average run times obtained under room temperature (increase of 43 min) and +50° C temperatures (increase of 32 min).

Test #	Date	Run time (h:mm)	Cutoff Voltage (VDC)
1	4/26/2004	4:26	42.98
2	4/30/2004	4:24	43.01

Table 4. Results of the discharge tests performed in +72°C oven for PB2000ITS.

At the end of the +72°C discharge tests, the battery temperature was around +65°C. At this time the AC power was restored to the UPS and it was observed that the UPS failed to charge the batteries. It was also observed that the UPS started charging the batteries only when their temperature dropped below +50°C. Therefore the PB2000ITS system meets the specification requirement of not charging the batteries when their temperature exceeds 50±2°C.

In order to verify that there is no emission of hydrogen gas by the batteries, a hydrogen sensor was installed in the oven. The hydrogen sensor triggers an audible alarm once the hydrogen concentration reaches the 10 ppm level. The hydrogen sensor did not trigger the alarm during any high temperature tests. This indicates that there was no emission of hydrogen greater than 10 ppm.

Novus 1000TP UPS

The results of the five discharge tests performed in a +50°C oven for Novus 1000TP are shown in Table 5. Also, the cutoff voltages (of the four battery string) used by the UPS are presented. The minimum and maximum run times for a 700 W load in a +50°C oven are 3hr 32min and 3hr 47min respectively. The average run time is 3hr 38min. This is an increase of 11 min over the average run time for a 700 W load under room temperature (which was 3hr 27min for Novus 1000TP [6]). The increase in run time is in accordance with the expected trend.

Test #	Date	Run time	Cutoff Voltage (VDC)
1	5/11/2004	3:47	42.54
2	5/12/2004	3:42	42.47
3	5/13/2004	3:34	42.54
4	5/18/2004	3:37	42.35
5	5/20/2004	3:32	42.61

Table 5. Results of the discharge tests performed in +50°C oven for Novus 1000TP.

The results of the two discharge tests performed in a +72°C oven are shown in Table 6. The average run time is 3hr 43min. This is an increase of 5 min over the average run time observed at +50°C and an increase of 16 min over the average run time observed at room temperature.

Test #	Date	Run time (h:mm)	Cutoff Voltage (VDC)
1	5/21/2004	3:49	42.51
2	5/23/2004	3:37	42.59

Table 6. Results of the discharge tests performed in +72°C oven for Novus 1000TP.

At the end of the +72°C discharge tests, the battery temperature was around +65°C. When the AC power was restored to the UPS, the UPS failed to charge the batteries. The UPS started charging the batteries only when their temperature dropped to +50°C. Therefore the Novus 1000TP system meets the specification requirement of not charging the batteries when their temperature exceeds 50±2°C.

After each discharge test in the oven, the oven was shutdown and the batteries were charged at room temperature. Out of seven tests that were performed at high temperature, Novus 1000TP system activated the hydrogen sensor three times. The hydrogen alarm was activated twice when the Alpha batteries were being charged in the closed oven (but at room temperature) for around 5 days. During one of the discharge tests in the oven the hydrogen alarm was activated. The alarm ceased as soon as the oven door was opened. This indicates that in some cases the Alpha batteries emit a very small amount of hydrogen to activate a 10 ppm sensor. This should not be a major concern because 10 ppm corresponds to traces of hydrogen gas. It should be noted that hydrogen poses a safety hazard only when the concentration is 4% or more. In addition this problem will most likely not occur in the field because all the cabinets are ventilated.

ME1000 UPS

Five discharge tests were performed to measure the run time of the ME1000 UPS in a +50°C oven. The results of these tests are shown in Table 7. The cutoff voltages used by the TechPower UPS are also shown. It should be noted that the TechPower UPS runs on a 24VDC battery string as opposed to the other two UPS systems which run on 48VDC battery strings. The minimum and maximum run times are 2hr 35min and 2hr 47min, respectively. The average run time is 2hr 43min. Under room temperature the average run time was found to be 2hr 32min [8]. This corresponds to an increase of 11 min in the average run time.

Test #	Date	Run time	Cutoff Voltage (VDC)
1	3/2/2004	2:43	19.08
2	3/4/2004	2:45	19.10
3	3/9/2004	2:47	19.08
4	3/11/2004	2:35	19.07
5	3/18/2004	2:46	19.11

Table 7. Results of the discharge tests performed in +50°C oven for ME1000.

Two discharge tests were performed in +72°C environment. The results of these two tests are shown in Table 8. The average run time is 2hr 46min. This corresponds to an increase of 2 min over the average run time observed in +50°C environment and an increase of 13 min when compared with the room temperature tests.

Test #	Date	Run time (h:mm)	Cutoff Voltage (VDC)
1	4/13/2004	2:50	18.99
2	4/15/2004	2:42	18.96

Table 8. Results of the discharge tests performed in +72°C oven for ME1000

AC power was restored to the UPS when the battery temperature was around +60°C. It was observed that the UPS started charging the batteries immediately. Therefore ME1000 does not meet the IDOT specification requirement of not charging the batteries when their temperature exceeds 50±2°C. The hydrogen sensor alarm was not triggered during any of the tests of the ME1000 system. This indicates that there was no hydrogen emission that exceeded the 10ppm threshold.

24M11 UPS

Five discharge tests were performed to measure the run time of the 24M11 UPS in a +50°C oven. The results of these tests are shown in Table 9. The cutoff voltages used by the Dimensions 24M11 UPS are also shown. It should be noted that 24M11 UPS runs on a 24VDC battery string. The minimum and maximum run times are 2hr 58min and 3hr 29min, respectively. The average run time is 3hr 9min. Under room temperature the average run time was found to be 2hr 57min [8]. This corresponds to an increase of 12 min in the average run time.

Test #	Date	Run time	Cutoff Voltage (VDC)
1	3/23/2005	3:29	22.43
2	3/30/2005	3:18	22.40
3	4/8/2005	2:58	22.47
4	4/11/2005	3:00	22.39
5	4/13/2005	3:00	22.40

Table 9. Results of the discharge tests performed in +50°C oven for 24M11 UPS.

Three discharge tests were performed in +72°C environment. The results of these tests are shown in Table 10. The average run time is 3 hr 28 min and the minimum and maximum values are 3 hr 18 min and 3 hr 38 min respectively. This corresponds to an increase of 19 min over the average run time observed in +50°C environment and an increase of 30 min when compared with the room temperature tests.

Test #	Date	Run time (h:mm)	Cutoff Voltage (VDC)
1	4/6/2005	3:38	22.49
2	4/15/2005	3:18	22.37
3	4/19/2005	3:27	22.43

Table 10. Results of the discharge tests performed in +72°C oven for 24M11 UPS.

At the end of the +72 °C test, the battery temperature was around +65 °C. When AC power was restored after the +72 °C test, the UPS did not start charging the batteries. The charging of batteries began after the battery temperature dropped to +50°C. Therefore 24M11 satisfies the IDOT specification requirement of not charging the batteries when their temperature exceeds 50±2°C.

The hydrogen sensor alarm was triggered during two of the tests of the 24M11 UPS system. In both those cases, the batteries were in the closed oven at room temperature for 2 days when the hydrogen alarm was set off. Within a minute after the oven door was opened, the alarm turned off. This indicates that there was some hydrogen emission that exceeded the 10 ppm threshold. As explained before, this should not be a major concern because 10 ppm corresponds to traces of hydrogen gas. It should be noted that hydrogen poses a safety hazard only when the concentration is 4% or more. In addition this problem will most likely not occur in the field because all the cabinets are ventilated and have a fan.

RESULTS OF SUB-ZERO TEMPERATURE TESTING OF UPS SYSTEMS

The sub-zero testing procedure was discussed in the Test Setup and Methodology chapter of the report. In this chapter, the results for the four systems are presented in the four sections to follow.

PB2000ITS UPS

Normal Signal Operation

The results of the discharge tests, with normal signal operation, performed in the freezer for PB2000ITS are shown in Table 11. Table 11 shows the date of the test, the freezer condition, the battery temperature at the beginning of the discharge test and the run time observed. It also shows the voltage at which the UPS shutdown the load to avoid the deep discharge of batteries. It should be noted that the voltage shown here is the voltage of the string of four 12V batteries (in series) used by the UPS.

It can be observed in Table 11that the battery temperature is higher than the ambient temperature in the freezer though the batteries were inside the freezer for more than 20 hours. Once the batteries are fully charged, they are continuously float charged. This is an exothermic reaction and therefore warms up the batteries. So the batteries do not reach the ambient temperature.

It can be seen from Table 11 that as the battery temperature decreases from -10°C to -19 °C, the run time decreases. This is the expected trend. Three tests were performed when the battery temperature was -19 °C and the run time varied between 42 and 43 min. At -15° C two tests were performed and the run time in both the cases was 44 min. These tests establish that the PB2000ITS system performed consistently at the sub-zero temperatures. The earlier tests [8] have indicated the average run time for a 700 W load under room temperature to be 3 hr 31 min. The 42 min run time at lowest temperature corresponds to a 73% decrease in run time when compared to the room temperature conditions.

Test Number	Date	Freezer condition	Battery Temp (°C)	Run time (h:mm)	Cutoff Voltage (V)
1	8/20/04	-12 °C for 44 hrs	-10	1:03	42.92
2	7/9/04	-18 °C for 28 hrs	-12	0:50	42.59
3	7/7/04	-25 °C for 20 hrs	-15	0:44	42.74
4	7/8/04	-25 °C for 22 hrs	-15	0:44	43.04
5	8/24/04	-25 °C for 4 days	-19	0:43	42.79
6	8/27/04	-25 °C for 3 days	-19	0:42	42.65
7	8/29/04	-25 °C for 2 days	-19	0:43	42.71

Table 11. Run Times under solid operation for PB2000ITS UPS in sub-zero temperatures.

Effect of Heater Mats

In response to the questionnaire (discussed in Appendix A) sent to the manufacturers, the manufacturer of PB2000ITS system recommended the use of battery heater mats while testing the UPS system in the sub-zero temperature conditions. The manufacturer furnished 4 heater mats upon our request. Each heater mat consumes 85 W of power. A thermostat in each of the heater mat starts the heating when the ambient temperature drops below 0 °C and stops the heating when the ambient temperature reaches +10 °C. The heater mats are not powered when the UPS is drawing power from the batteries.

Three tests were performed to ascertain the effect of heater mats on the run time. The UPS along with the batteries and heater mats were placed in the freezer and the freezer was turned on. At the end of 24 hours the discharge test was performed. This would ensure that the heater mats experience the transition in the temperature from room temperature to sub-zero temperatures. The results are presented in Table 12. When the UPS system was in the freezer at -12 °C (Test 1 of Table 11), the battery temperature was -10 °C. However with the heater mat the temperature of the batteries was +7.5°C and the run time increased from 1:03 to 2:10, which is an increase of 106%. Tests 2 and 3 yielded similar results. These results indicate that the run time of the PB2000ITS system increases significantly with the use of heater mats.

Test Number	Date	Freezer condition	Battery Temp (°C)	Run time (h:mm)	Cutoff Voltage (V)
1	12/04/04	-12°C for 24 hrs	+7.5 °C	2:10	42.80
2	12/06/04	-10 °C for 24 hrs	+10.5 °C	2:33	42.82
3	12/09/04	-10°C for 24 hrs	+10.5 °C	2:34	42.77

Table 12. Run Times under solid operation for PB2000ITS UPS in sub-zero temperatures with heater mats.

Flashing Operation

The results of the discharge tests under flashing operation at the sub-zero temperatures for PB2000ITS system are reported in Table 13. Three tests were performed when the UPS and the batteries had been in the freezer at a temperature of -25 °C for a few days. The run time varied from 1:48 to 1:55 with an average run time of 1:51. This corresponds to 164% increase in run time when compared with the run time for solid operation (0:43 is the average run time at -19 °C for solid operation) under similar freezer conditions (-25 °C for a few days).

Test Number	Date	Freezer condition	Battery Temp (°C)	Run time (h:mm)	Cutoff Voltage (V)
1	9/1/04	-25 °C for 3 days	-18.4 °C	1:48	43.43
2	9/3/04	-25 °C for 2 days	-18.1 °C	1:51	43.19
3	9/9/04	-25 °C for 6 days	-17.9 °C	1:55	43.27

Table 13. Run Times under flashing operation at sub-zero temperatures for PB2000ITS UPS.

Normal+Flashing Operation

Two tests were performed to obtain the run times of normal+flashing operation. PB2000ITS system has a relay contact closure that indicates when the batteries reach 40% battery level. This relay was monitored and the load was manually changed to flashing when the relay was activated. The results of these tests are presented in Table 14. In both the tests, the batteries reached 40% level of charge in 32 min and then powered the flashing load for an additional 46 min (on the average) before the UPS disconnected the batteries. These results are discussed in the Findings chapter.

Test #	Date	Freezer condition	Battery Temp (°C)	Normal time (h:mm)	Flashing time (h:mm)	Cutoff Voltage (VDC)
1	9/16/04	-25 °C for 3 days	-17.7	0:32	0:45	43.53
2	9/23/04	-25 °C for 2 days	-17.1	0:32	0:46	43.04

Table 14. Run Times under Normal+Flashing operation at sub-zero temperatures for PB2000ITS UPS.

Thaw Test

There was a long power failure due to a thunderstorm while the batteries were being charged in the freezer. This caused the freezer to defrost. Although the batteries and the UPS were covered with plastic sheeting to avoid seepage of water, it was found that a fault had occurred in the UPS. According to the diagnostics in the UPS, the fault was due to a short circuit. As recommended by the manual, when the UPS was restarted, the fault disappeared and the unit recovered. However, the unit did not supply power to the load when the AC power was cut. After a few days it was found that the unit was functioning properly. The temporary failure of the UPS may be due to condensation.

Novus 1000TP UPS

Normal Signal Operation

The results of the discharge tests performed in the freezer for the Novus 1000TP system are shown in Table 15. Table 15 shows the date of the test, the freezer temperature condition before the test, the battery temperature at the beginning of the discharge test and the run time observed. It also shows the voltage (of the battery string) at which the UPS shutdown the power to the load to avoid the deep discharge of batteries.

Two tests were performed at -10°C and the run time was 1 hr 56 min and 1 hr 58 min. However it should be noted that the run times at the coldest temperatures were not consistent. Consider tests 3 through 6. The system was in the freezer for 2 days in all these tests and the battery temperature was around -19 °C. But the run time dropped steadily from 1:18 to 0:42. It was hypothesized that probably 2 days was not sufficient to charge the batteries. Therefore, following test 6 a long gap of 9 days was given for the batteries to charge. The run time for test 7 was 1:23. However, the run time for test 8 again decreased to 1:11. Considering all the tests performed at the coldest temperature setting, it can be seen that the variability in run time for Novus 1000TP at the sub-zero temperatures is large. Therefore further testing was not performed on the Novus 1000TP system.

Test Number	Date	Freezer condition	Battery Temp (°C)	Run time (h:mm)	Cutoff Voltage (V)
1	6/25/04	-10 C for 43 hrs & -25 C for 2 hrs	-10	1:56	42.14
2	6/28/04	-10 C for 71 hrs & -25 C for 2 hrs	-10	1:58	42.27
3	12/30/2004	-25 °C for 2 days	-19.7	1:18	42.97
4	1/1/2005	-25 °C for 2 days	-18.7	1:01	42.86
5	1/3/2005	-25 °C for 2 days	-18.8	0:51	42.90
6	1/5/2005	-25 °C for 2 days	-19.5	0:42	43.67
7	1/14/2005	-25 °C for 4 days	-18.1	1:23	43.51
8	1/17/2005	-25 °C for 3 days	-17.7	1:11	43.47
9	2/7/2005	-25 °C for 5 days	-20.3	1:26	42.79
10	2/10/2005	-25 °C for 2 days	-20.1	1:24	43.05

Table 15. Run Times under normal operation for Novus 1000TP UPS in sub-zero temperatures.

Thaw Test

While the batteries were being charged in the freezer, there was a long power failure. This caused the freezer to defrost. The Novus 1000TP system failed. We suspected that water may seeped through possible holes on plastic that covered the unit while it was thawing out in turned-off freezer. The unit was returned to Alpha Technologies for determining the cause of failure and for fixing the unit. Alpha Technologies indicated that the failure was a MOSFET (Metal Oxide Semiconductor Field Effect Transistor) failure in the inverter circuitry and they believe that the failure was caused by excessive amount of water causing a small short in the MOSFET digital control circuitry. Alpha fixed the unit and returned it to the Lab. Further testing of the unit did not cause any failure.

ME1000 UPS

Normal Signal Operation

The results of the discharge tests performed in the freezer for ME1000 are shown in Table 16. Table 16 shows the date of the test, the freezer temperature condition before the test, the battery temperature at the beginning of the discharge test and the run time observed. It also shows the voltage (of the battery string) at which the UPS shutdown the power to the load to avoid the deep discharge of batteries. It should be noted that ME1000 is a 24VDC system as opposed to Novus 1000TP and PB2000ITS, which are 48 VDC systems.

It can be observed from Table 16 that as the battery temperature decreases from -10 °C to -20 °C, the run time also decreases. Three tests at -19 °C resulted in an average run time of 1:24 at the coldest temperature. There is some variability in the run times of the two tests that were performed at -20 °C and the average run time is 1:20. Nevertheless the trend of decreasing run time with decreasing temperature holds true.

The earlier tests [8] have indicated the average run time for a 700 W load under room temperature to be 2 hr 36 min. Therefore the 1:24 run time at -19 °C corresponds to a 40.9% decrease when compared with the room temperature run time.

Test Number	Date	Freezer condition	Battery Temp (°C)	Run time (h:mm)	Cutoff Voltage (V)
1	8/3/2004	-10 °C for 5 days & -25 °C for 2 hrs	-10	1:42	19.61
2	7/8/2004	-10 °C for 2 days & -25 °C for 2 hrs	-12	1:35	20.58
3	8/12/2004	-25 °C for 2 days	-18	1:26	19.41
4	10/9/2004	-25 °C for 2 days	-19	1:26	20.13
5	10/13/2004	-25 °C for 2 days	-19	1:25	20.12
6	10/11/2004	-25 °C for 2 days	-19	1:22	19.94
7	10/15/2004	-25 °C for 2 days	-20	1:24	20.14
8	7/27/2004	-25 °C for 1 day	-20	1:16	19.67

Table 16. Results of the discharge tests performed in the freezer for ME1000 system.

Flashing Operation

The results of the flashing tests at sub-zero temperatures are reported in Table 17. Two tests were performed with the system in the freezer at -25 °C for two days. The average run time was 2:39. Under similar freezer conditions, the average run time with solid operation was 1:24. Therefore with flashing operation the run time increased by 89.3% when compared with the run time at solid operation.

Test Number	Date	Freezer condition	Battery Temp (°C)	Run time (h:mm)	Cutoff Voltage (V)
1	11/06/2004	-25 °C for 2 days	-18.8 °C	2:40	20.14
2	11/08/2004	-25 °C for 2 days	-18.4 °C	2:37	20.15

Table 17. Run Times under flashing operation at sub-zero temperatures for ME1000 UPS.

Normal+Flashing Operation

The results of Normal+Flashing tests are presented in Table 18. It should be noted that the ME1000 system does not have a relay contact closure to indicate when the batteries reach the 40% battery level. Therefore, it was determined that the batteries would reach 40% level after 50 min of normal operation (based on the run time of 1:24 for full solid operation). After this duration the load was switched to flashing manually. The average flashing duration was 1:03.

Test #	Date	Freezer condition	Battery Temp (°C)	Normal time (h:mm)	Flashing time (h:mm)	Cutoff Voltage (VDC)
1	10/26/2004	-25 °C for 4 days	-19.4	0:50	1:05	20.16
2	11/04/2004	-25 °C for 2 days	-18.7	0:50	1:01	20.10

Table 18. Run times under Solid+Flashing operation of ME1000 UPS at sub-zero temperatures.

Thaw Test

The freezer was made to thaw (by simulating a power failure) while the batteries were getting charged. The ME1000 unit was not disrupted by the sudden increase in temperature. The batteries were charged by the UPS and the UPS functioned normally following the thaw.

24M11 UPS

Normal Signal Operation

The results of the discharge tests, with normal signal operation, performed in the freezer for 24M11 UPS are shown in Table 19. Table 19 shows the date of the test, the freezer condition, the battery temperature at the beginning of the discharge test and the run time observed. It also shows the voltage at which the UPS shutdown the load to avoid the deep discharge of batteries. It should be noted that 24M11 UPS is a 24VDC system.

Three tests were performed when the battery temperature was around -17 °C and the run time varied between 1 hr 57 min and 2 hr 4 min. The room temperature tests [8] had indicated the average run time for a 700 W load was 2 hr 57 min. The 2 hr 1 min average run time at lowest temperature corresponds to a 32% decrease in run time when compared to the room temperature conditions. It can be seen from Table 11 that as the battery temperature decreases from -6.3°C to around -17 °C, the run time also decreases. This is the expected trend.

Test Number	Date	Freezer condition	Battery Temp (°C)	Run time (h:mm)	Cutoff Voltage (V)
1	2/16/2005	-25 °C for 2 days	-17.5	2:04	22.19
2	2/18/2005	-25 °C for 2 days	-16.7	2:03	22.26
3	2/21/2005	-25 °C for 2 days	-16.4	1:57	22.13
4	3/3/2005	-10 C for 2 days	-6.3	2:25	22.35
5	3/7/2005	-15 C for 4 days	-8.6	2:22	22.27
6	3/10/2005	-20 C for 3 days	-15.4	2:10	22.28

Table 19. Run Times under solid operation for 24M11 UPS in sub-zero temperatures.

Flashing Operation

The results of the discharge tests under flashing operation at the sub-zero temperatures for 24M11 system are reported in Table 20. Two tests were performed when the UPS and the batteries had been in the freezer at a temperature of -25 °C for a few days. The run times were 4 hr 31 min and 4 hr 32 min. This corresponds to 124% increase in run time when compared with the run time for solid operation (2:01 is the average run time at -17 °C for solid operation) under similar freezer conditions (-25 °C for a few days).

Test Number	Date	Freezer condition	Battery Temp (°C)	Run time (h:mm)	Cutoff Voltage (V)
1	2/23/2005	-25 °C for 2 days	-15.7 °C	4:31	21.53
2	3/1/2005	-25 °C for 6 days	-16 °C	4:32	21.56

Table 20. Run Times under flashing operation at sub-zero temperatures for 24M11 UPS.

Normal+Flashing Operation

Two tests were performed to obtain the run times of normal+flashing operation. 24M11 system has a NO/NC relay contact closure that indicates when the batteries reach 40% battery level. This relay was monitored and the load was manually changed to flashing when the relay was activated. The results of these tests are presented in Table 21. The batteries reached 40% level of charge in 1 hr 25 min and 1 hr 22 min and then powered the flashing load for an additional 2 hr 7 min and 2 hr 5 min before the UPS disconnected the batteries. These results are discussed in the Findings chapter of this report.

Test #	Date	Freezer condition	Battery Temp (°C)	Normal time (h:mm)	Flashing time (h:mm)	Cutoff Voltage (VDC)
1	3/15/2005	-25 °C for 2 days	-15 C	1:25	2:07	21.56
2	3/18/2005	-25 °C for 3 days	-16 C	1:22	2:05	21.64

Table 21. Run Times under Normal+Flashing operation at sub-zero temperatures for 24M11 UPS.

Thaw Test

The freezer was let to thaw (by simulating a power failure) while the batteries were getting charged. The 24M11 unit was not disrupted by the sudden increase in temperature. The batteries were charged by the UPS and the UPS functioned normally following the thaw.

FINDINGS

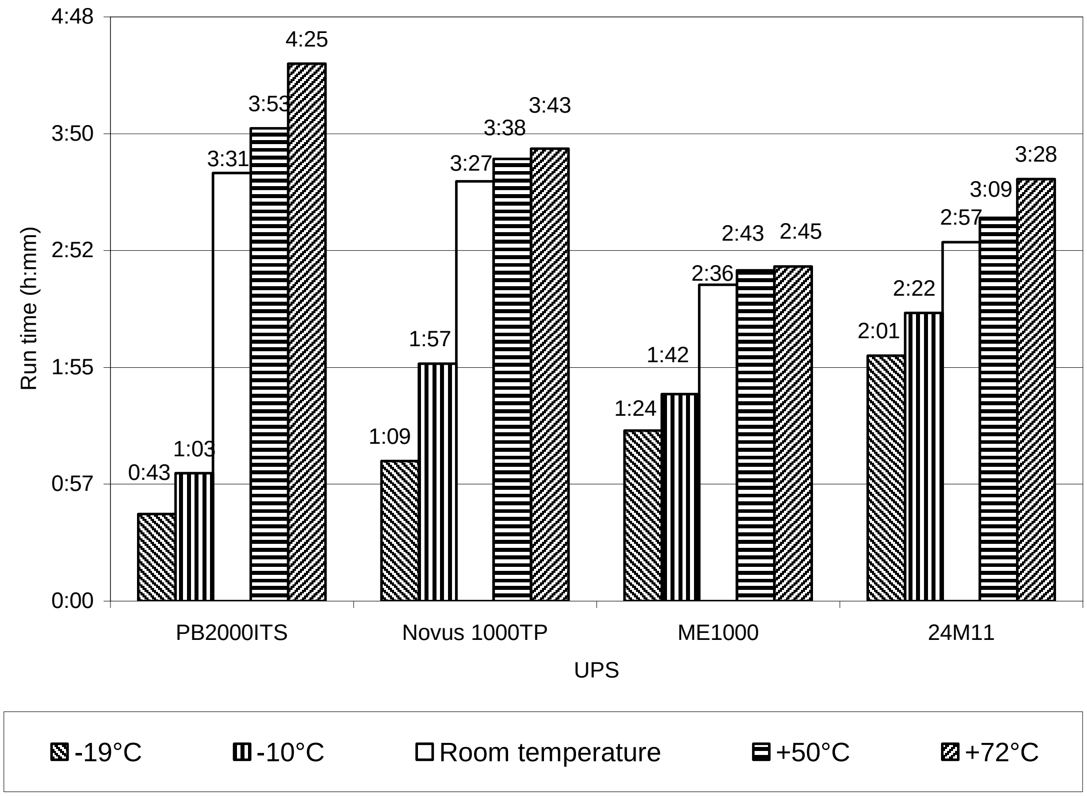
In this report, the run times provided by four UPS systems at high temperature and sub-zero temperature conditions for operation of the traffic signals have been reported. Chitturi and Benekohal [5],[6],[7] & [8] reported the performance of these units under room temperature conditions. Table 22 summarizes the run times provided by the four UPS systems under room temperature, high temperature and sub-zero temperature conditions for normal signal operation (700 W) of the traffic signals.

UPS → / Environment ↓	Myers PB2000ITS	Alpha Novus 1000TP	TechPower ME1000	Dimensions 24M11
	Avg. Run Time (h:mm)	Avg. Run Time (h:mm)	Avg. Run Time (h:mm)	Avg. Run Time (h:mm)
+72°C	4:25	3:43	2:45	3:28
+50°C	3:53	3:38	2:43	3:09
Room temperature	3:31	3:27	2:36	2:57
-10°C	1:03	1:57	1:42	2:22*
-19°C	0:43	1:09	1:24	2:01#

* : 2:22 run time is at -8.6 °C
# : 2:01 run time is at ~ -17 °C (the coldest temperature reached by 24M11 UPS)

Table 22. Run times of the four UPS systems at various operating temperatures for normal signal operation.

PB2000ITS system uses four batteries each with a capacity of 100 Amp-hr, while Novus 1000TP system uses four batteries of 94 Amp-hr capacity, ME1000 system uses four batteries of 55 Amp-hr capacity and 24M11 system uses four batteries of 79 Amp-hr capacity. All the factors remaining same, the UPS system with highest battery capacity is expected to give the highest run times. Under room temperature and high temperature conditions PB2000ITS system provided the longest run time followed by Novus 1000TP, 24M11 and ME1000 systems. However under sub-zero temperature conditions this does not hold true.



[*] : 2:22 run time for 24M11 UPS is at -8.6 °C
[#] : 2:01 run time for 24M11 UPS is at ~ -17 °C (the coldest temperature reached by 24M11 UPS)

Figure 7. Run times of the four UPS systems under the five operating environments.

Figure 8 shows the run times of the UPS systems under the five operating environments. As the operating temperature increases the run time of the UPS systems increases. All the systems that were evaluated showed an increase in run time as the temperature was increased. However it should be noted that for the same change in the temperature, the amount of change in run time is different for different systems.

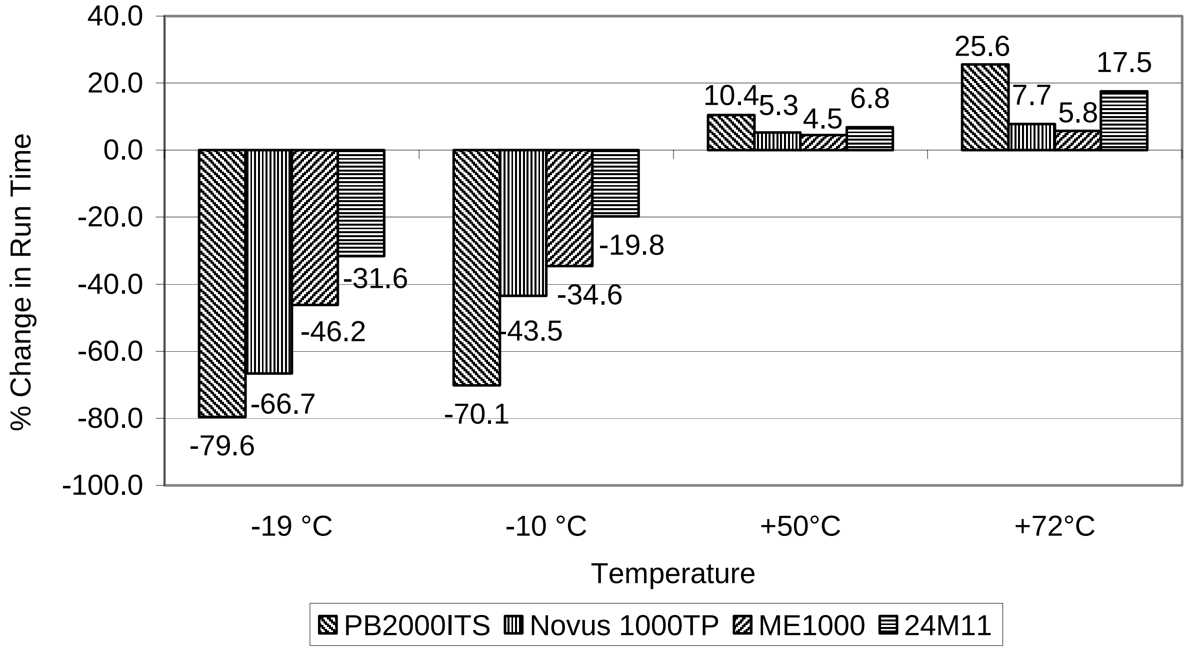


Figure 8. Percentage change in Run Time at various temperatures for the four UPS systems.

The percentage increase in run time compared to the room temperature conditions of the four systems are shown in Figure 8. From Figure 8 it can be seen that the PB2000ITS system has the maximum percentage change in all the conditions. Under sub-zero conditions, PB2000ITS was followed by Novus 1000TP, ME1000 and 24M11. However, under +50 °C and +72 °C, PB2000ITS was followed by 24M11, Novus 1000TP and ME1000. In other words, of the four units evaluated, the run time of Myers PB2000ITS is most sensitive to temperature changes. Also, 24M11 UPS has the lowest sensitivity to temperature changes when the temperatures drop to sub-zero conditions and is second most sensitive to temperature changes in hotter conditions.

Figure 8 also shows that the percentage decrease in run time (compared to room temperature) for solid operation when the battery temperature is -19°C ranges from -31.6% to -79.6% for the four UPS systems. The actual run times varied from 43 min to 2hr 1 min. Considering that the run times for solid operation are significantly lower in the freezing conditions than in the room temperature conditions, it is advisable to go to flashing operation or normal+flashing operation during freezing conditions. Therefore, tests for determining the run times during flashing operation and normal+flashing operation of the traffic signals were performed for sub-zero temperature conditions. These tests were performed when the UPS systems were in the freezer at -25 °C for a few days.

Table 23 compares the run times of PB2000ITS, ME1000 and 24M11 systems for these different modes of operation. These tests were not performed on Novus 1000TP system because of the high variability in the run times during normal signal operation under sub-zero temperature conditions.

<table>
<tr><th colspan="2">UPS → / Mode of Operation ↓</th><th>PB2000ITS Avg. Run Time (h:mm)</th><th>ME1000 Avg. Avg. Run Time (h:mm)</th><th>24M11 Avg. Avg. Run Time (h:mm)</th></tr>
<tr><td colspan="2">Normal</td><td>0:43</td><td>1:24</td><td>2:01</td></tr>
<tr><td colspan="2">Flashing</td><td>1:51</td><td>2:39</td><td>4:31</td></tr>
<tr><td rowspan="2">Normal+Flashing</td><td>Normal</td><td>0:32</td><td>0:50</td><td>1:23</td></tr>
<tr><td>Flashing</td><td>0:46</td><td>1:03</td><td>2:06</td></tr>
</table>

Table 23. Average run times for different modes of operation at the coldest temperatures.

All three systems showed a significant increase in run time when operating in flashing mode instead of the normal signal operation. Flashing duration was 158% greater than the normal signal duration for PB2000ITS, 89% greater for ME1000, and 124% greater for 24M11. The normal+flashing duration was greater than normal signal operation by 81% for PB2000ITS, 35% for ME1000 and 73% for 24M11 systems.

In their response to the questionnaire, the manufacturer of PB2000ITS system recommended the use of heater mats while testing their unit under sub-zero temperature conditions. Tests were performed with the use of heater mats in the freezer. The system was in the freezer at -12°C. Without the heater mats, the battery temperature reached -10°C, while it reached +7.5 °C with the heater mats. The run times without and with heater mats are 1:03 and 2:10 respectively. This corresponds to 106% increase in run time due to the heater mats.

PB2000ITS, Novus 1000TP, and 24M11 systems shutdown the charging of the batteries when their temperature exceeded +50° C. ME1000 system however failed to shutdown the charging. The vendor claimed in his response to the questionnaire (Discussed in Appendix A) that the batteries used in ME1000 system (Optima D34M) can be charged at high temperature without causing any damage.

PB2000ITS and ME1000 systems did not activate the hydrogen sensor during the high temperature testing. This indicates that the hydrogen emission, if any, was less than 10 ppm. Novus 1000TP and 24M11 systems activated the alarm in some cases. It should be noted that this happened when the UPS and batteries were in a closed environment without any ventilation for an extended duration. In a traffic signal controller cabinet this may not be an issue because the cabinet is well ventilated and has a fan also.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Four UPS systems were tested under high and sub-zero temperature conditions. The four systems are PB2000ITS from U.S. Traffic Corp, Novus 1000TP from Alpha Technologies, ME1000 from TechPower Developments Inc., and 24M11 from Dimensions Unlimited, Inc. For high temperature conditions, tests were performed by placing the systems in +50°C and +72 °C oven. At high temperatures, tests were performed to ascertain the run times under normal signal operation, to check whether the UPS shutsdown the charging and to verify that there is no gassing of the batteries. For sub-zero temperature tests, the units were placed in a freezer. Under sub-zero temperature conditions, the units were tested to determine their run times under normal signal operation, flashing operation and normal+flashing operation. It should be noted that for all the run time tests the load was 700W during normal signal operation and 350 W during flashing.

It was found that the temperature has a significant effect on the run times provided by the UPS systems. All the systems showed an increase in run time at higher temperatures and decrease in run time when they were in the sub-zero temperatures. PB2000ITS showed the maximum percentage change in run time (26% for +72°C and -80% for -19°C) when the temperature conditions were varied. The percentage changes for Novus 1000TP were 8% for +72°C and -67% for -19°C, for ME1000 were 6% for +72°C and -35% for -19°C and for 24M11 the percentage changes were 18% for +72°C and -32% for -19°C. These results indicate that the run time of PB2000ITS is the most sensitive to temperature changes. 24M11 system is least sensitive to temperature changes under sub-zero conditions. However, it is the second most sensitive to temperature changes under hotter conditions.

The run times for normal signal operation, when the units had been in the freezer at -25°C for a few days were 0:43, 1:09, 1:24, and 2:11 for PB2000ITS, Novus 1000TP, ME1000, and 24M11 systems respectively. PB2000ITS, ME1000 and 24M11 were tested for run times under flashing and normal+flashing modes of operation in the freezer. Novus 1000TP system was not tested because of the high variability in the run times of normal signal operation under sub-zero conditions. The average flashing durations for PB2000ITS, ME1000, and 24M11 were 1:51, 2:39, and 4:31 respectively. PB2000ITS provided 32 min of normal signal operation before the batteries reached 40% level and provided a further 46 min of flashing operation. ME1000 provided 50 min of normal signal operation and 1hr 3 min of flashing operation. 24M11 provided 1hr 23 min of normal operation followed by 2hr 6min of flashing operation. At the coldest temperature, the increase in duration of flashing compared to duration of normal operation ranged from 89% to 158% and the increase in combination of normal and flashing duration compared to normal operation duration ranged from 35% to 81%.

The manufacturer of PB2000ITS recommended the use of heater mats and therefore their unit was tested with heater mats in the freezer. Heater mats were found to increase the run time of PB2000ITS system dramatically. For a similar freezer condition (-12 °C) the run time with heater mats was 106% greater than the run time without heater mats.

The UPS Systems were tested to check that the charging of the batteries is shutdown when the battery temperature exceeds 50 °C. PB2000ITS, Novus 1000TP, and 24M11 systems shutdown the charging of the batteries, while ME1000 did not. At high temperatures, ME1000 and PB2000ITS did not activate the hydrogen sensor, which is sensitive to 10 ppm of hydrogen. Novus 1000TP and 24M11 systems activated the sensor when it was in the oven (closed, but at room temperature) for an extended duration. However this should not be a major issue as the traffic controller cabinets are well ventilated and have fans also.

RECOMMENDATIONS

- Consider operating the signals on flashing or normal+flashing during cold weather conditions to increase the run time.
- Consider using heater mats especially for PB2000ITS system from U.S. Traffic Corp to increase the run time during the winter.
- Ensure that the fan in the cabinet is working properly to keep the cabinet temperature at a predetermined level.
- Consider keeping the battery temperature high at sub-zero weather conditions or use more batteries to have longer run time.

REFERENCES

[1] Illinois Department of Transportation, Bureau of Operations. Specification for Uninterruptible Power Supply For Traffic Signals utilizing Light Emitting Diodes (LED) Traffic Signal Modules, Springfield, 2003.

[2] Linden D. & T.B. Reddy. Handbook of Batteries. McGraw-Hill Handbooks, New York, 2001.

[3] Dunlop J.P. Batteries and Charge Control in Stand-Alone Photovoltaic Systems: Fundamentals and Application. Florida Solar Energy Center, FL, 1997.

[4] C& D Technologies Inc. Thermal Runaway in VRLA Batteries – Its Cause and Prevention. Milwaukee, 1999.

[5] Chitturi M.V. & R.F. Benekohal. Evaluation of UPS for Intersection Traffic Signals with LEDs: Findings for Myers PB1250PC UPS. University of Illinois Urbana-Champaign, TOL Series 7, Dec 2003.

[6] Chitturi M.V. & R.F. Benekohal. Evaluation of UPS for Intersection Traffic Signals with LEDs: Findings for Alpha Novus 1000 UPS. University of Illinois Urbana-Champaign, TOL Series 8, Dec 2003.

[7] Chitturi M.V. & R.F. Benekohal. Evaluation of UPS for Intersection Traffic Signals with LEDs: Findings for TechPower M1000 UPS. University of Illinois Urbana-Champaign, TOL Series 9, Dec 2003.

[8] Chitturi M.V. & R.F. Benekohal. Evaluation of Three Recent Models of UPS for Intersection Traffic Signals with LEDs. University of Illinois Urbana-Champaign, TOL Series 16, July 2005.

APPENDIX A: RESPONSES TO THE QUESTIONNAIRE SENT TO THE MANUFACTURERS

Prior to performing the high and sub-zero temperature tests on the UPS systems, a questionnaire was developed and sent to the manufacturers. A copy of the questionnaire is given at the end of this section. In this chapter each question is presented followed by the responses of the three manufacturers which are followed by a brief explanation of the question and comment on the responses. In the following text, the explanations/comments are in *italics*, while the questions are in bold text format.

QUESTIONS ABOUT UPS UNIT

The questions in this section are regarding the performance of the UPS system.

1. **What type of charging does the battery charger use? Please give the values of all the relevant parameters of the charging method. (For example, if float charging is used, what is the voltage and what is the temperature compensation factor, if trickle charging is used what is the rate?)**

Myers Response: The Battery charger uses the temperature compensated constant current – constant voltage linear charging scheme. It has 3 optional charging rates. The charger charges at constant current of 10 Amps (that can be adjusted if so desired via potentiometer) till the batteries are 80% charged. It is followed by tapering of charging current, and finally a constant voltage charging till batteries are fully charged. The float voltage at 25 degrees C is 55.2 VDC.

Alpha Response: The battery charger uses a temperature compensated switch mode charger at constant current with a temperature compensation factor of -4mV/°C/cell. As a result, the battery charging voltage is reduced by 4mV/per cell for every degree above 25°C and increased by 4mV/per cell for every degree below 25°C. The compensation factor is easily adjustable to meet –5mV/°C/cell when temperature extremes are anticipated. The AlphaCell battery float voltage is limited to the range of 2.25 to 2.30 volts per cell or 13.5 – 13.8V per battery. The charger is disabled when the battery temperature sensor exceeds 50°C ± 3°.
(Please see attached charger compensation chart)

TechPower Response: No Response

Dimensions Response: We use the float charge method. The range is 2.5-4.0 mV/°C/Cell.

COMMENTS
This question dealt with the charger characteristics of the UPS system. Under high temperature conditions, continuously charging a battery could cause thermal

runaway and damage the batteries. Therefore knowledge of the charger characteristics was essential before performing the high temperature tests.

2. **What is the voltage at which the UPS disconnects the load from the batteries to prevent deep discharge?**

Myers Response: 42.5 VDC

Alpha Response: The low battery shutdown voltage (inverter off) is at: 42 ± 1

TechPower Response: No Response

Dimensions Response: The inverter shuts down when the voltage of the batteries is less than or equal to 21VDC. The unit will also go into sleep mode once the voltage drops to 18 VDC. Sleep mode draws only 30 mA.

COMMENTS

Batteries that are discharged too deeply tend to provide fewer cycles of charge and discharge before failing. So, the UPS should stop providing backup power to the load once the batteries reach a minimum state of charge. As a battery discharges, i.e., the state of charge drops, the voltage of the battery drops. Therefore, battery voltage can be used as a measure of the state of charge. The minimum state of charge is translated into a voltage called the cutoff voltage, at which the UPS disconnects the load. Therefore, the run time directly depends on the cutoff voltage. This information is useful in comparing the performance of the different UPS systems. Myers and Alpha use very similar cutoff voltages and batteries with similar capacities. It should be noted that TechPower and Dimensions UPS systems that were evaluated were 24VDC systems whereas the UPS systems from Myers and Alpha were 48 VDC systems. Consequently under room temperature conditions the run times provided by both the systems were similar.

3. **Does the voltage in Question 2 vary with the rate of discharge?**

Myers Response: No

Alpha Response: No. The low battery shutdown voltage is fixed at the above value regardless of the rate of discharge.

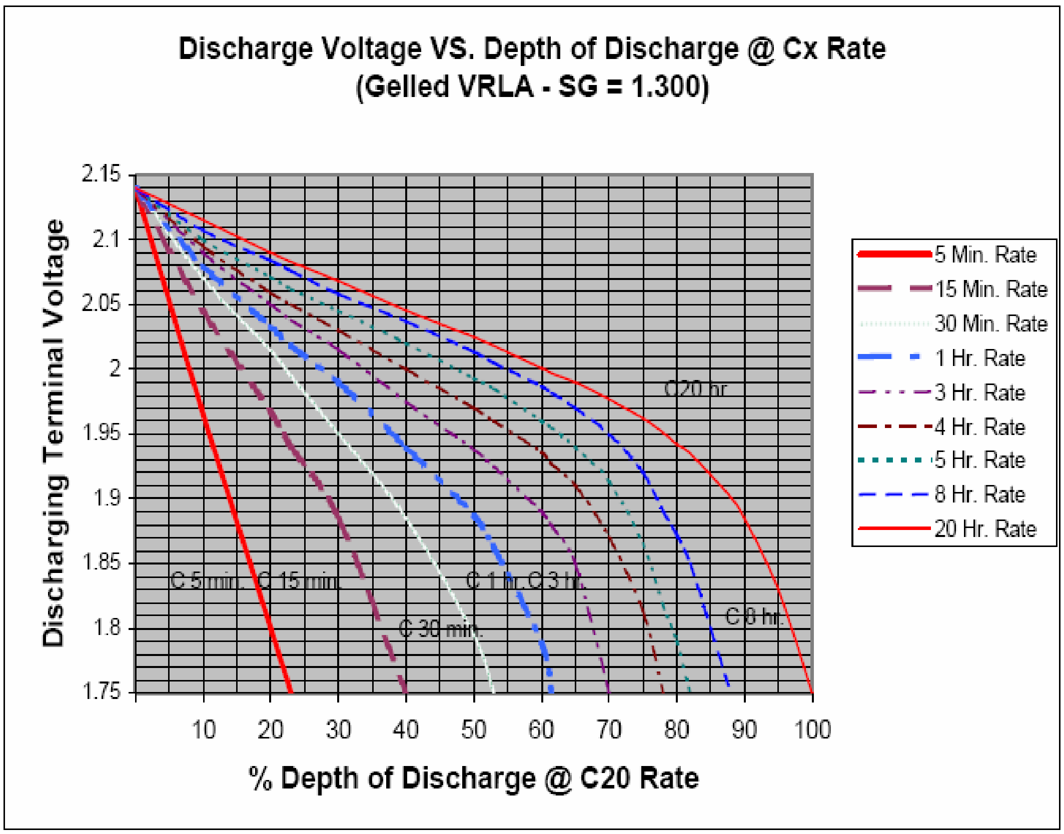
TechPower Response: No Response

Dimensions Response: No

COMMENTS

As stated before, battery voltage is used as a measure for the state of charge of the batteries. However, it should be noted that the battery voltage is affected by not only the state of charge but also by the rate of discharge and temperature of the battery. This is illustrated in the below figure (provided by Alpha Technologies in their responses to our questionnaire)

The figure shows the battery voltage vs depth of discharge of the batteries for various rates of discharge. Consider the two extreme curves corresponding to the 5 min rate (highest discharge rate) and 20 hr rate (lowest discharge rate). In the case of 20 hr rate, the battery reached a voltage of 2.09V when it was 20% discharged, while in the case of 5 min rate the battery reached 1.8V when it was 20% discharged. This illustrates that for the same level of discharge the battery voltage would be different for different discharge rates. For getting the most out of the batteries, the level of discharge at which the batteries are shutdown should be a constant. Therefore, the cutoff voltage should vary with the discharge rate. If this were to be implemented in a UPS system, it would make the UPS more efficient. The Alpha, Dimensions and Myers UPS systems did not have this advanced feature, and we don't know if the TechPower unit has it because they didn't respond.



4. Is the voltage in Question 2 temperature compensated?

<u>Myers Response</u>: NO

<u>Alpha Response</u>: No. The low battery shutdown voltage is not temperature-compensated.

<u>TechPower Response</u>: No Response

<u>Dimensions Response</u>: No

COMMENTS

Temperature also affects the voltage. As the temperatures drop, the chemical reactions within the battery are hampered, thereby increasing the internal resistance to current flow in the battery. Consequently, for the same amount of discharge, the lower the temperature, the higher the voltage drop. Therefore to disconnect the load at a fixed state of charge, the cutoff voltage should be a function of the temperature. However, neither Alpha nor Myers nor Dimensions has this feature which would ensure that the UPS is operating at its optimum capacity even when the temperature is different from room temperature. We do not know if TechPower has this feature as they didn't respond.

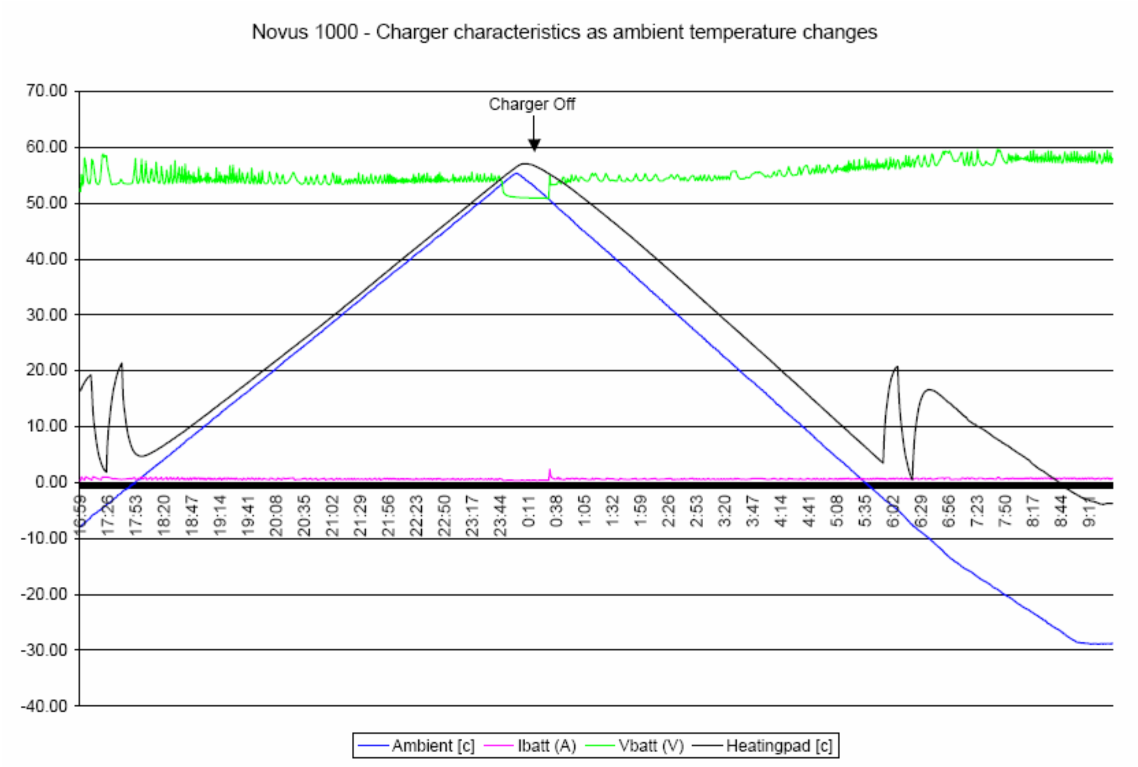
QUESTIONS ABOUT BATTERIES

This section dealt with the performance of the batteries under extreme temperatures. Before performing the extreme temperature testing we wanted to know the manufacturers' experience and get any feedback (including precautions to be taken) from them regarding the proposed experiments. Among our concerns were the possibility of gassing of batteries under high temperatures and freezing of batteries under sub-zero temperatures.

5. **Have you tested the batteries under high or low temperatures? If yes, how did the temperature affect the charge and discharge times of the batteries?**

<u>Myers Response</u>: YES. More back-up time at high temperature while less time at low temperature was observed.

<u>Alpha Response</u>: Yes. The unit was placed inside an environmental chamber with fully charged batteries connected as a backup source. A data logger was connected to monitor the battery voltage and ambient temperature inside the chamber as temperature was varied. (Please see attached charger characteristics chart)



TechPower Response: No Response

Dimensions Response: Yes. Only a Pass/Fail test was performed to make sure that the UPS achieved the Caltrans specification for run time.

6. **Have you observed any gassing while charging the batteries at high temperatures?**

Myers Response: NO

Alpha Response: No. Batteries start to gas when we attempt to charge them faster than they can absorb the energy. The excess energy is turned into heat, which then causes the electrolyte to boil and evaporate. Critical to minimizing the gas emitted is the use of proper float charging voltage between 2.25 to 2.30 volts per cell. The use of temperature compensation for battery charging is vital to minimizing the effect of gassing at high temperature. As a result, our charger is disabled when the battery temperature sensor exceeds 50°C ± 3°.

TechPower Response: No Response

Dimensions Response: No. The charger stops charging at 50 °C.

COMMENTS

When the batteries are almost fully charged, the excess current supplied for charging electrolyzes water to produce hydrogen and oxygen. In the case of flooded lead acid batteries these gases are vented out, thus necessitating the replenishment of water to those batteries. In the case of Valve Regulated Lead Acid (VRLA) batteries, the oxygen gas recombines with the hydrogen gas at the negative plate to form water. This is referred to as the oxygen recombination cycle. Generally this process has an efficiency of 95 – 99% resulting in negligible or no emission of gases. However, at higher temperatures the rate at which oxygen and hydrogen are produced is greater than the rate of recombination. So at high temperatures there could be a significant amount of emission of hydrogen. Venting of hydrogen is of concern because a 4% mixture of hydrogen in air is an explosive mixture when ignited. Alpha, Dimensions and Myers did not observe gassing in their testing (TechPower did not respond). Out of 7 tests, twice we observed that the Alpha unit activated the hydrogen sensor alarm. Both the times, the Alpha unit has been in the oven at room temperature for 5 days. Similarly for the Dimensions UPS, the hydrogen sensor was activated when it was in the oven at room temperature for 2 days. The hydrogen sensor is very sensitive and is activated at 10 PPM concentration of hydrogen. The oven did not have any air circulation. The alarm stopped immediately after the oven door was opened. In an actual signal cabinet the hydrogen sensor would not have been activated due to air circulation.

7. Did the electrolyte freeze under freezing conditions?

Myers Response: NO. The heating mats were used to keep the battery case warm.

Alpha Response: No. To understand this concept, we need to define specific gravity. Specific Gravity (SG), or gravity, is a measure of the density of a liquid as compared to that of water, which has a SG of 1.000. For example, pure sulfuric acid has a specific gravity of 1.835. Lead acid battery electrolyte is a mixture of water and sulfuric acid, which typically has a specific gravity of between 1.200 and 1.300. The electrolyte in a fully charged AlphaCell battery, with a specific gravity of 1.280 to 1.300, will not freeze until a temperature of -71°C is reached. The AlphaCell batteries can be exposed to freezing temperatures without catastrophic damage.

TechPower Response: No Response

Dimensions Response: No

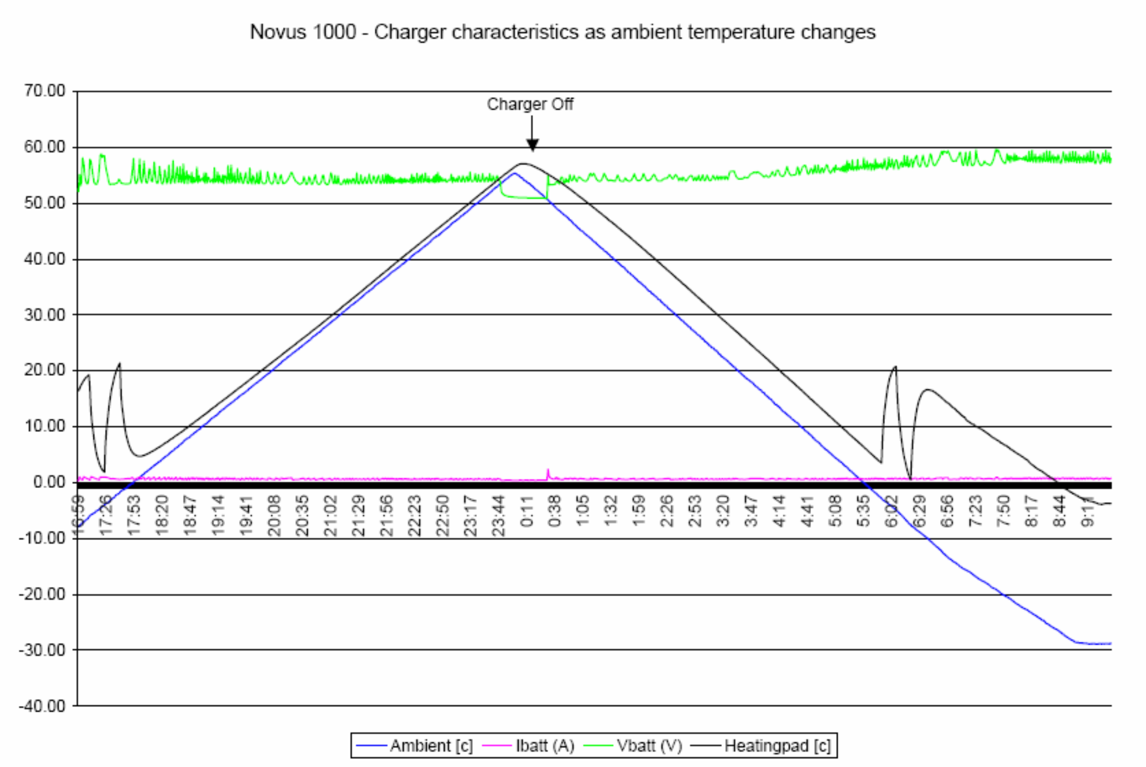
COMMENTS

If the battery is frozen, there might be damage to the active material in the battery and could reduce the capacity of the battery. It is improbable that a fully charged battery would get frozen in any inhabitable location. As explained in the *comments to question 4, the internal resistance is higher at cold temperatures leading to a higher voltage drop. Therefore the battery performs inefficiently at the cold temperatures. When the discharging is performed at the room temperature the sulfuric acid in the electrolyte is consumed and resultant electrolyte's specific gravity decreases. This would cause the electrolyte to freeze at a higher temperature. For example sulfuric acid with a specific gravity of 1.1 would freeze at approximately +20 °F. When a battery with such electrolyte experiences freezing temperatures, the electrolyte would freeze and charging a frozen battery may cause damage. Therefore, the critical condition that needs to be avoided is discharging the battery at room temperature and letting the discharged battery experience freezing temperatures.*

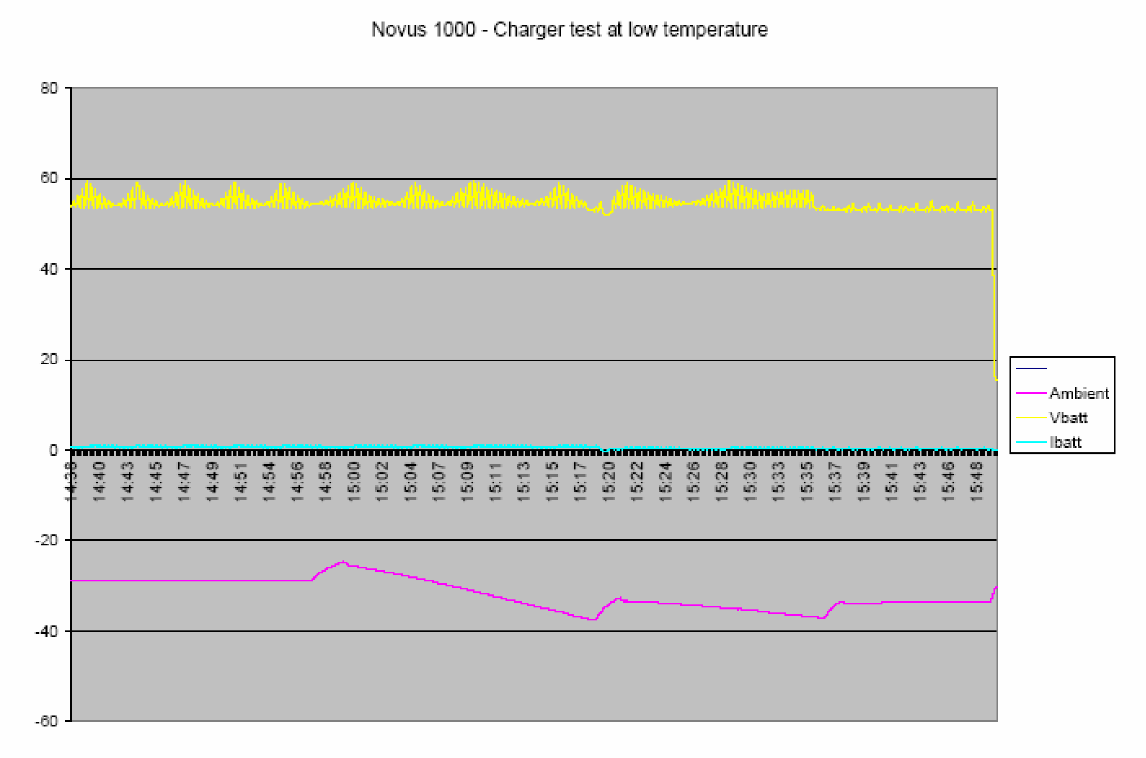
8. Do you have any other observations or results from your testing that would be helpful for us in testing your unit?

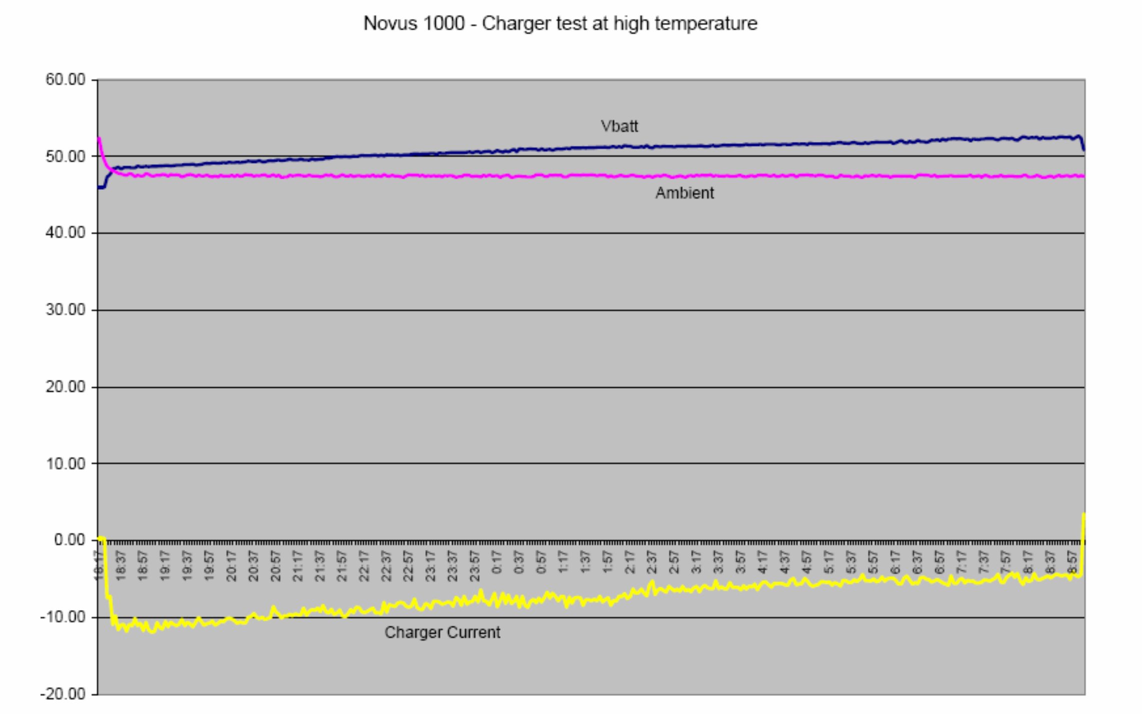
Myers Response: The proper test would be when using a field installed cabinet with proper fan cooling for high temperature & thermostatically controlled heat pads for cold temperatures.

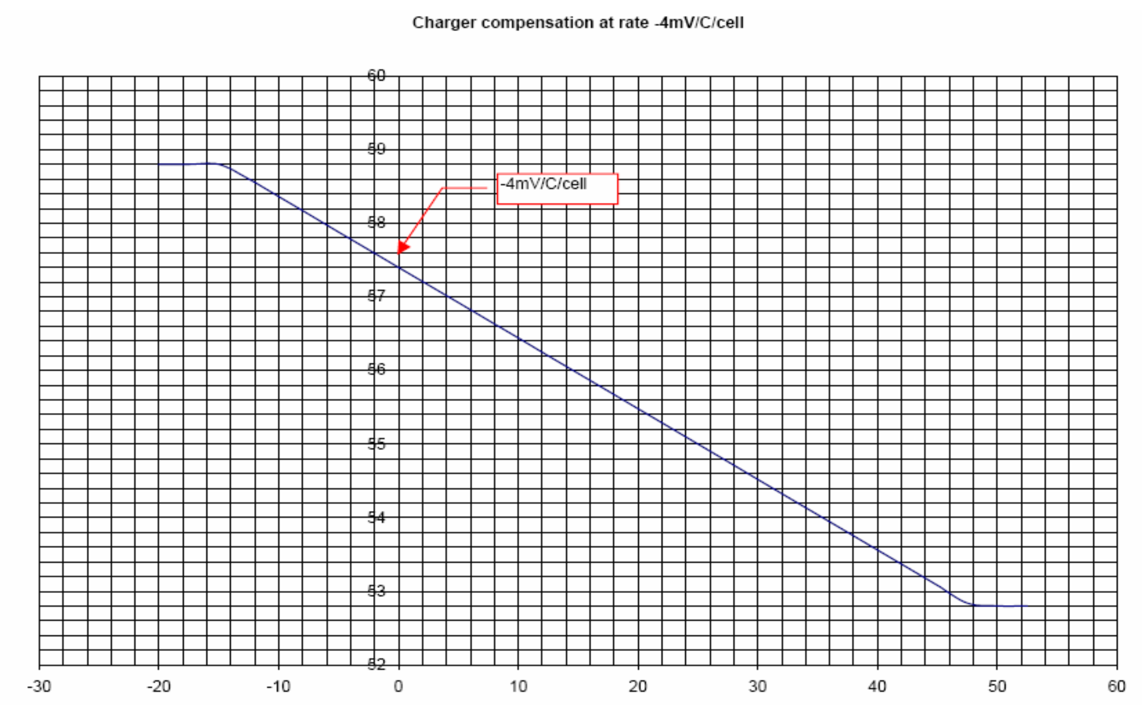
Alpha Response: Please see attached: Charger compensation chart, Charger test at high temperature, Charger test at low temperature, Efficiency chart and Charger characteristic chart). Other test results are available upon request.



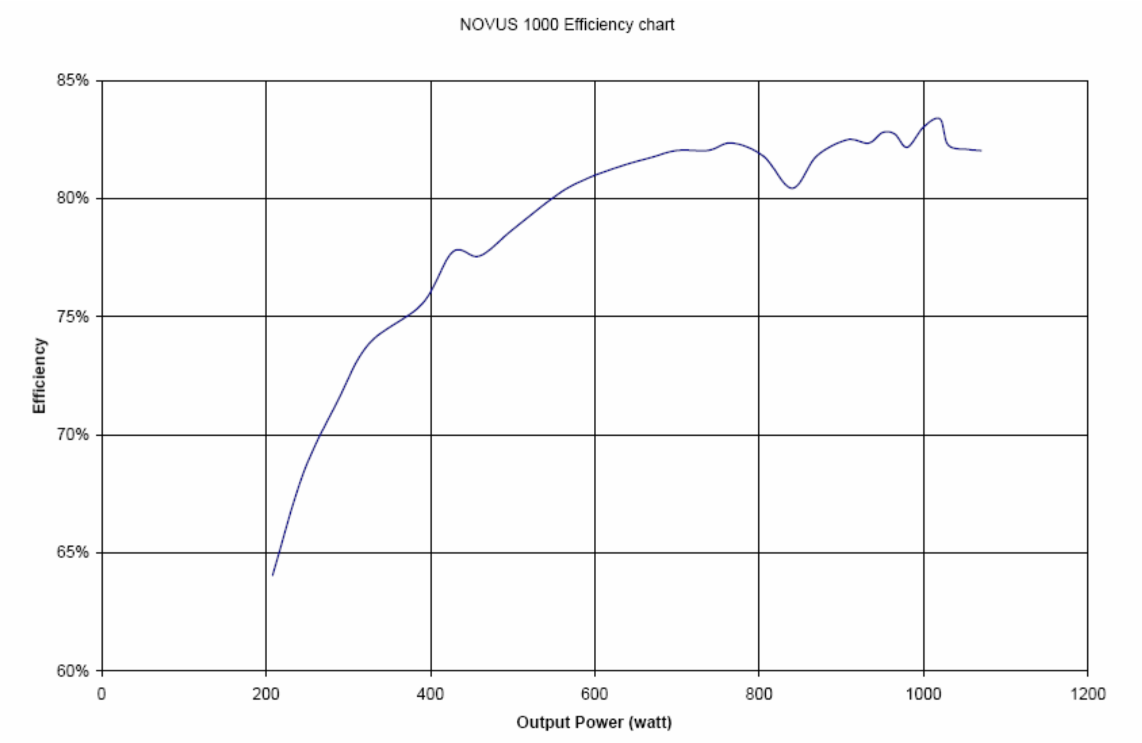
The graph above shows that the charger shutdown the charging when the ambient temperature exceeded 50°C and it resumed the charging after the temperature dropped below 50 °C.







Alpha UPS uses temperature compensation factor of -4 mV/°C/Cell as shown in the graph above. As the temperature increases the charging voltage decreases and vice versa.



The efficiency of the UPS also depends on the amount of power being drawn. The maximum efficiency as shown in the above graph is reached when the UPS is supplying 1000W, its rated output.

TechPower Response: No Response

Dimensions Response: No

9. **Would you suggest any specific precautions to be taken while performing the tests described above?**

Myers Response: Proper cooling in the cabinet from high temperature as well as thermostatically controlled heating pads for the BATTERIES as utilized in our cabinets is recommended.

Alpha Response: None

TechPower Response: No Response

Dimensions Response: Yes, Make sure that the batteries are at full charge prior to the test.

DETAILED INFORMATION ABOUT BATTERIES

10. What is the maximum temperature at which the batteries can be charged?

Myers Response: 50 degrees C, above which the charger will stop charging to prevent an explosion.

Alpha Response: The charger is disabled when battery temperature sensor exceeds 50°C ± 3°.

TechPower Response: No Response

Dimensions Response: The charger stops charging at 50 °C due to many specifications requiring this. The battery could be charged at a higher temperature if temperature compensated properly.

COMMENTS

Thermal runaway occurs in a battery when the rate of internal heat generation exceeds the rate of heat dissipation into the environment. A prolonged occurrence of thermal runaway could increase the battery temperature until the cells dry out. Battery float charging in a hot environment is the most common cause of thermal runaway of batteries. Therefore several manufacturers recommend that under high temperature conditions the float charging of the batteries stop completely. Myers, Dimensions and Alpha recommend shutting down the charging at around 50 °C. In the testing it was verified that these UPS systems actually shut down the charging. TechPower did not shutdown the charging and the distributor claimed that the Optima batteries can be charged at high temperatures without any damage to the batteries.

11. What is the charging voltage at which gassing of the battery begins at various temperatures?

Myers Response: 65 VDC

Alpha Response: As charging voltage per cell is increased above 2.3 volts per cell the gassing rate increases dramatically. The effect of the temperature compensated charger circuit will control the rate of the charge and shutdown the charger circuit when the battery temperature exceeds 50°C ± 3° (please see charger compensation chart).

TechPower Response: No Response

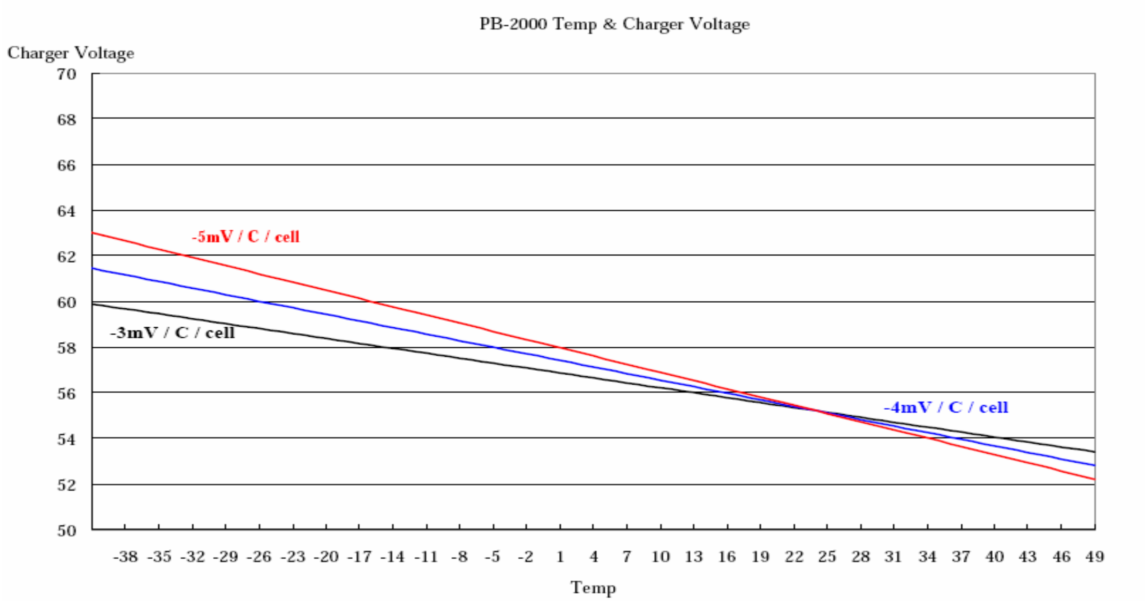
Dimensions Response: Varies per battery type.

COMMENTS

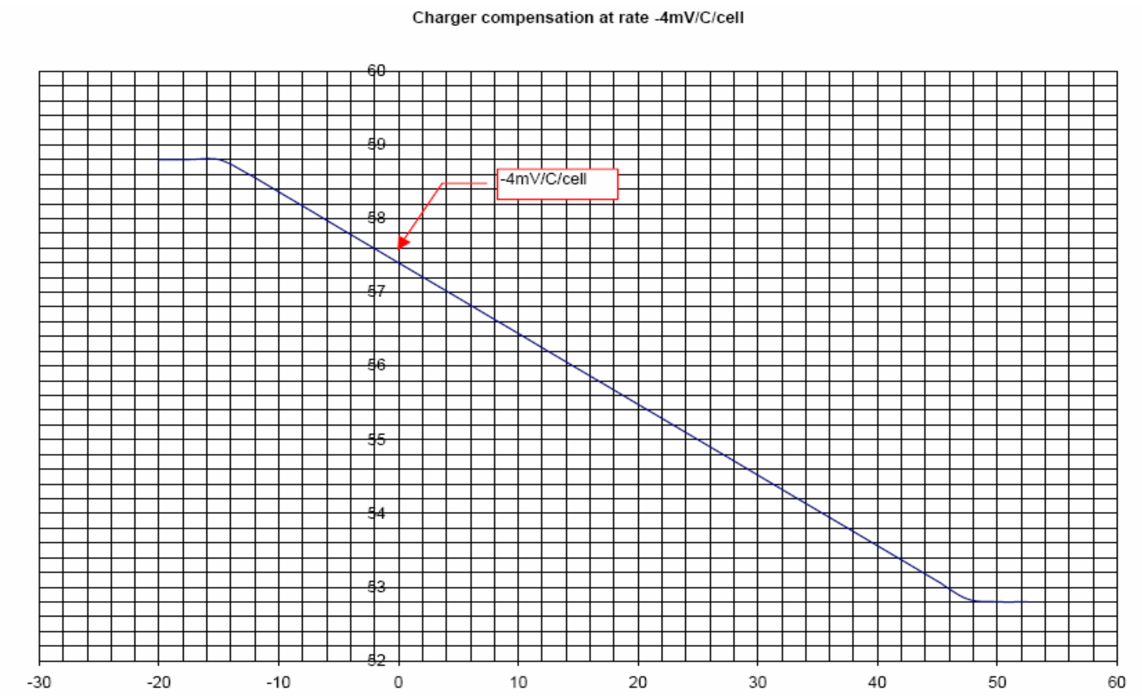
As the float voltage used is increased, the oxygen generation rate increases. After a certain voltage, the oxygen generation rate will be greater than the rate at which it can recombine with hydrogen at the negative plate. At this point, the battery would begin venting gases. This voltage at which gassing begins depends on the temperature of the battery. As the temperature increases, gassing begins at a lower voltage.

12. What is the recommended float charging voltage at various temperatures?

Myers Response: Please see attached temperature compensation chart.



Alpha Response: The charging voltage is temperature compensated at -4mV/°C/cell when temperature extremes are anticipated. The maximum voltage to be allowed at cold temperature is 2.5 volts per cell while the minimum voltage allowed at hot temperatures is 2.17 volts per cell. (Please see charger compensation chart)



TechPower Response: No Response

Dimensions Response: Varies per battery type.

COMMENTS

The recommended float charging voltage should vary with the temperature because:

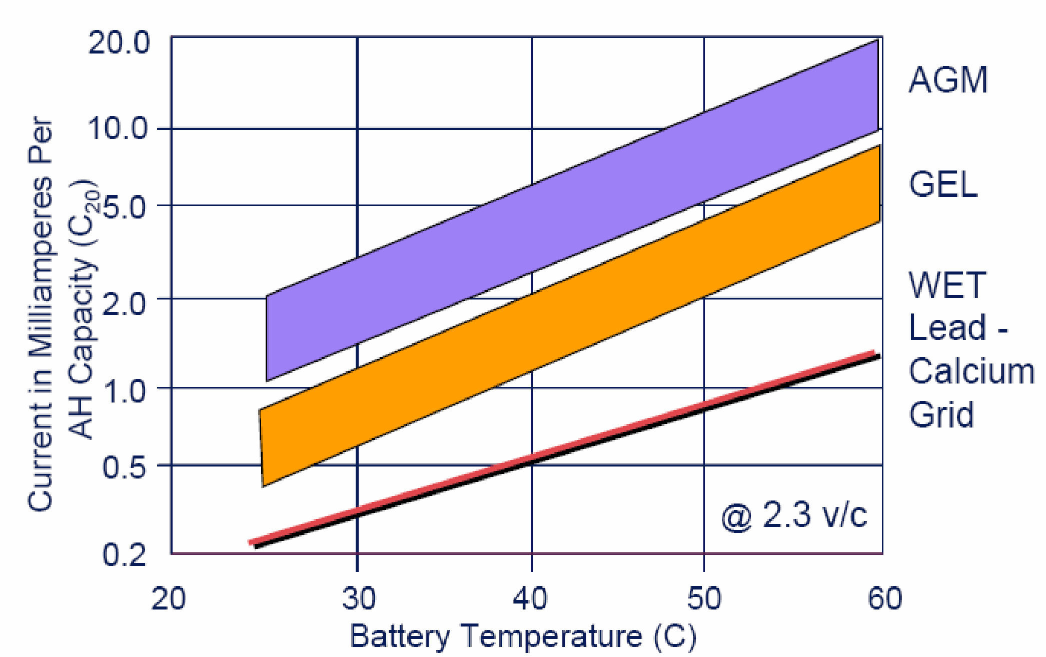
a) *At low temperatures, the battery's internal resistance to current flow is higher. Therefore, a higher charging voltage should be used. Similarly at warmer temperatures, a lower charging voltage should be used to prevent the battery from accepting higher currents.*
b) *Also, the voltage at which gassing begins decreases as the temperature increases. Therefore, as the temperature increases, the charging voltage should be reduced.*

In Myers PB2000ITS, the user can choose one of the three temperature compensation factors: -3 or -4 or -5 mV/°C/Cell. When extreme temperatures are expected, a higher temperature compensation factor is recommended. In the case of Alpha, -4mV/°C/Cell is used.

13. Do you have charts showing float current Vs temperature for the recommended float charging voltage in Question 13? If yes, please attach the chart.

Myers Response: NO. The charger will be a constant current charger till the batteries come up to 90% of their capacity at the rate and a shown voltage at that specific temperature.

Alpha Response:



Float Current VS. Temperature at 2.3 V/C Charging Voltage

TechPower Response: No Response

Dimensions Response: No

COMMENTS

As stated before, as the temperature of the battery decreases, the internal resistance to current increases. Therefore for a given float charging voltage, as the temperature drops, the charging current decreases and vice versa. As shown in the graph provided by Alpha, Absorbed Glass Mat (AGM) batteries have high float current and as a result are more susceptible to thermal runaway than gelled batteries or flooded lead acid batteries.

14. What is the recommended temperature compensation factor to be used in float charging the batteries?

Myers Response: 3 mV / °C / Cell of a battery.

Alpha Response: The charging voltage should be temperature compensated at -0.0028 volts per cell per °F (-0.005 volts per cell per °C) when temperature extremes are anticipated.

TechPower Response: No Response

Dimensions Response: The range is 2.5 – 4.0 mV/°C/Cell.

COMMENTS
As explained for question 13, the charging voltage should be a function of the battery temperature. This variable charging voltage is accomplished by the use of a temperature compensated charger, which automatically increases or decreases the charging voltage depending on whether the batteries are colder or warmer. The rate at which the voltage is decreased or increased is referred to as the temperature compensation factor. The default value for temperature compensation in Myers PB2000ITS is -3 mV/°C/cell. The user can change it to -4 or -5 mV/°C/cell. In Alpha the default values is -4 mV/°C/cell. Alpha recommends -5 mV/°C/cell when temperature extremes are anticipated. The range of values is 2.5 – 4.0 mV/°C/Cell. This change cannot be done by the user.

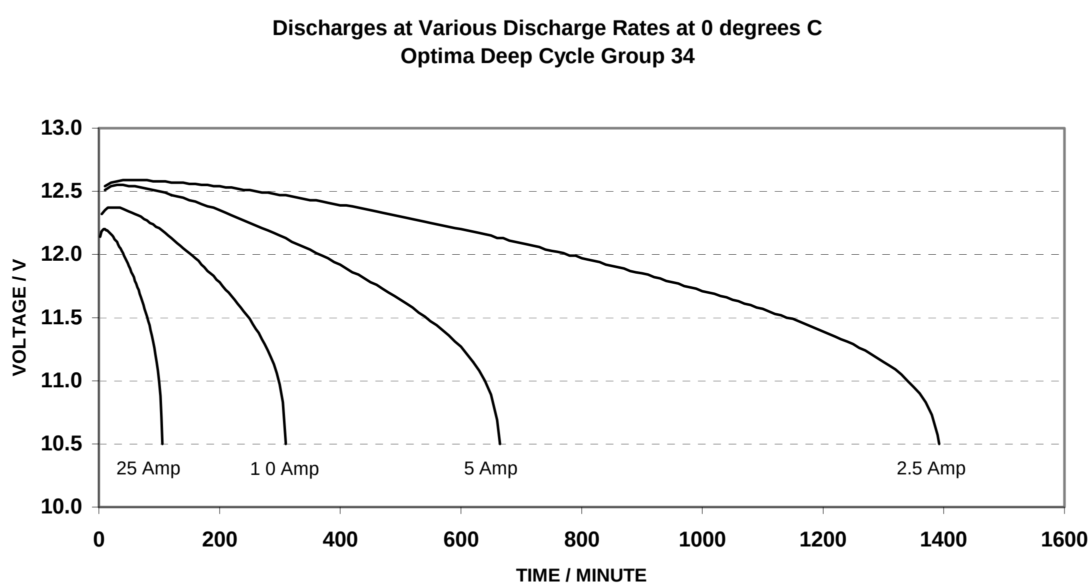
15. Do you have graphs showing:

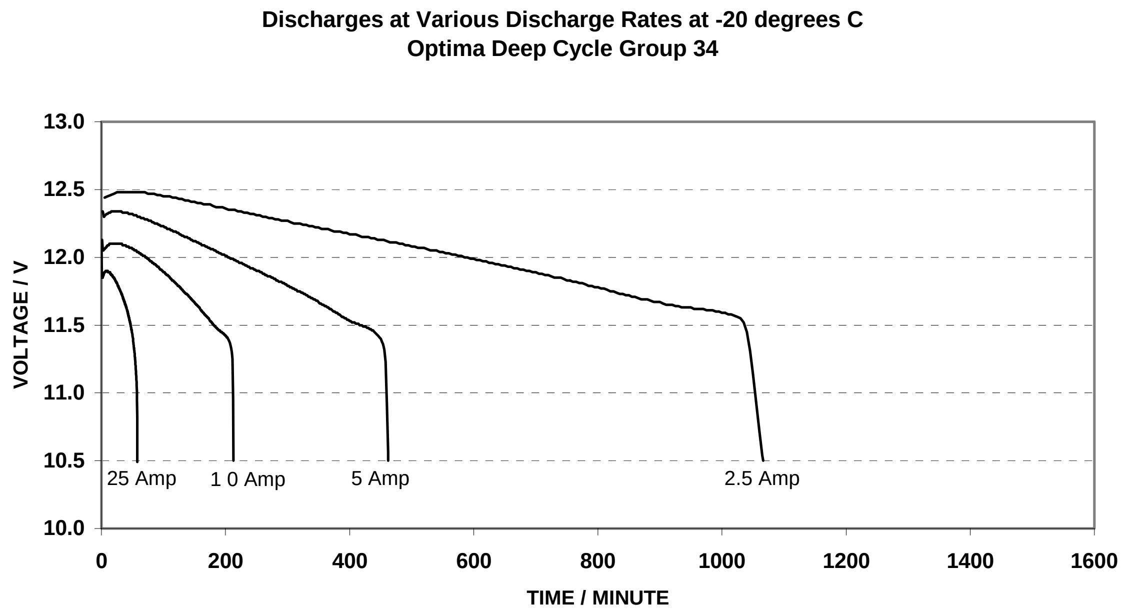
a) Discharge voltage Vs time at various discharge rates

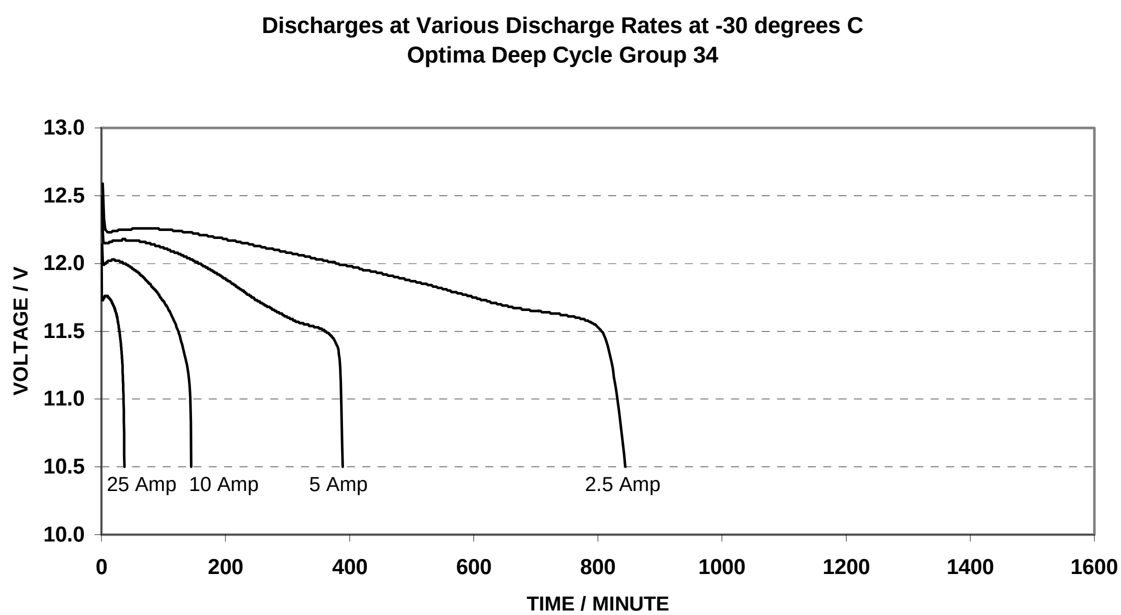
Myers Response: NO

Alpha Response: Graph is unavailable at this time.

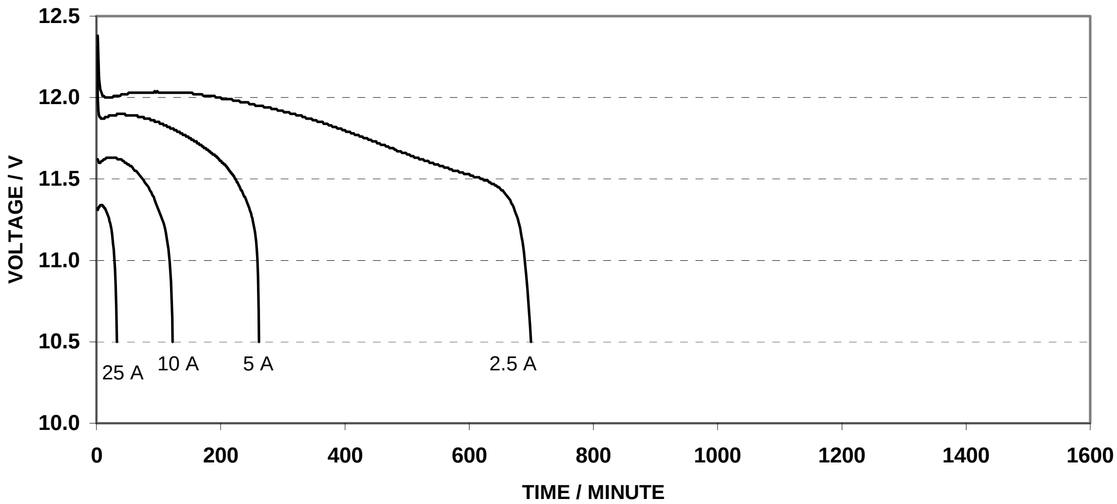
TechPower Response:




Discharges at Various Discharge Rates at -20 degrees C
Optima Deep Cycle Group 34
13.0
12.5
12.0
11.5
11.0
10.5
10.0
VOLTAGE / V
25 Amp
1 0 Amp
5 Amp
2.5 Amp
0
200
400
600
800
1000
1200
1400
1600
TIME / MINUTE


Discharges at Various Discharge Rates at -30 degrees C
Optima Deep Cycle Group 34
13.0
12.5
12.0
11.5
11.0
10.5
10.0
VOLTAGE / V
25 Amp
10 Amp
5 Amp
2.5 Amp
0
200
400
600
800
1000
1200
1400
1600
TIME / MINUTE

Discharges at Various Discharge Rates at -40 degrees C
Optima Deep Cycle Group 34



<u>Dimensions Response</u>: No. We can test for this if required.

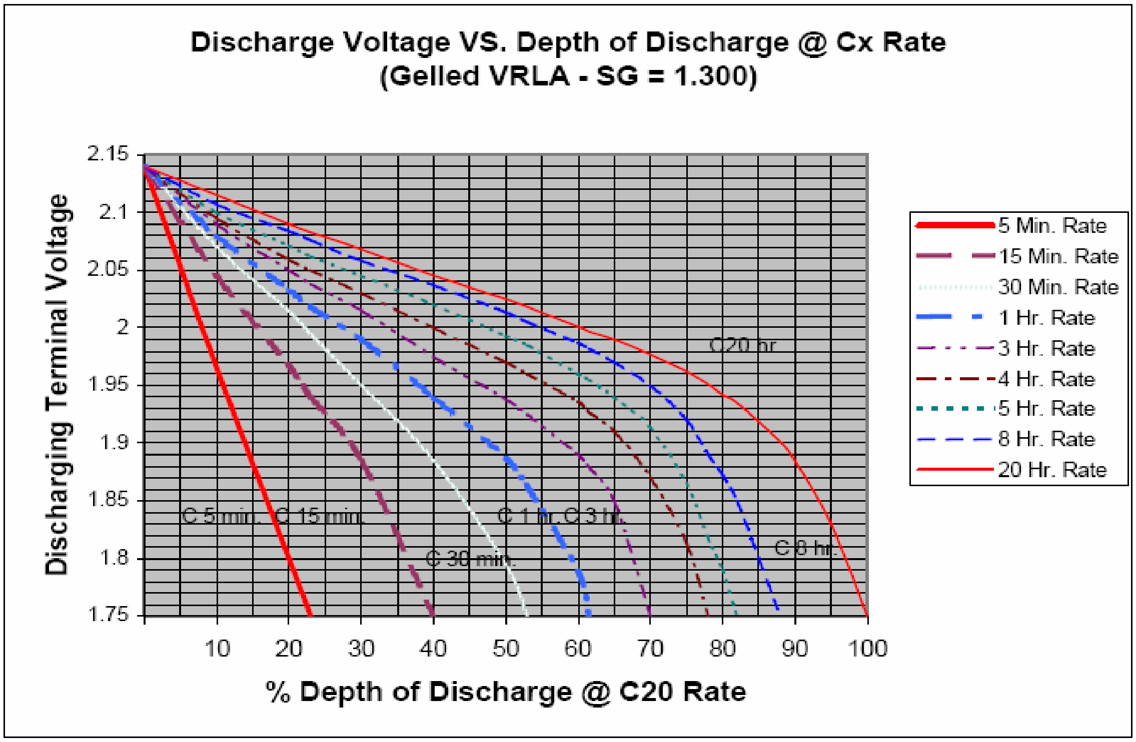
COMMENTS

The battery voltage drops with time as they are being drained. The rate of drop in the voltage depends on the discharge rate. The greater the discharge rate, the quicker the drop in the voltage. The graphs provided by TechPower clearly depict that as the discharge rate increases the rate at which the voltage drops also increases. It can also be seen that for a given discharge rate as the temperature decreases the run time decreases.

b) Discharge voltage Vs depth of discharge at various discharge rates and temperatures.

<u>Myers Response</u>: NO

<u>Alpha Response</u>: See the following figure



TechPower Response: No Response

Dimensions Response: No. We can test for this if required.

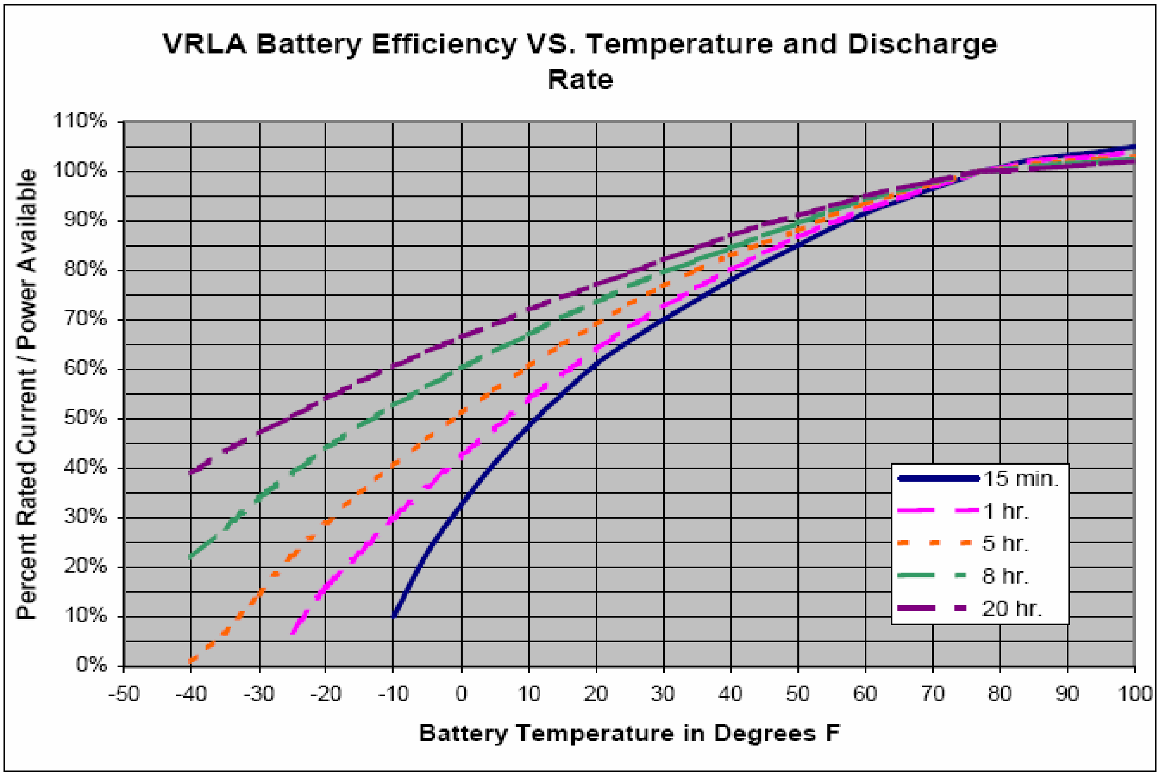
COMMENTS

The graph provided by Alpha shows that the voltage depends on the depth of discharge and the rate of discharge. It also depends on the temperature, but is not depicted in this graph.

c) Battery efficiency Vs temperature at various discharge rates.

Myers Response: NO

Alpha Response: See the following figure



<u>TechPower Response</u>: No Response

<u>Dimensions Response</u>: No. We can test for this if required.

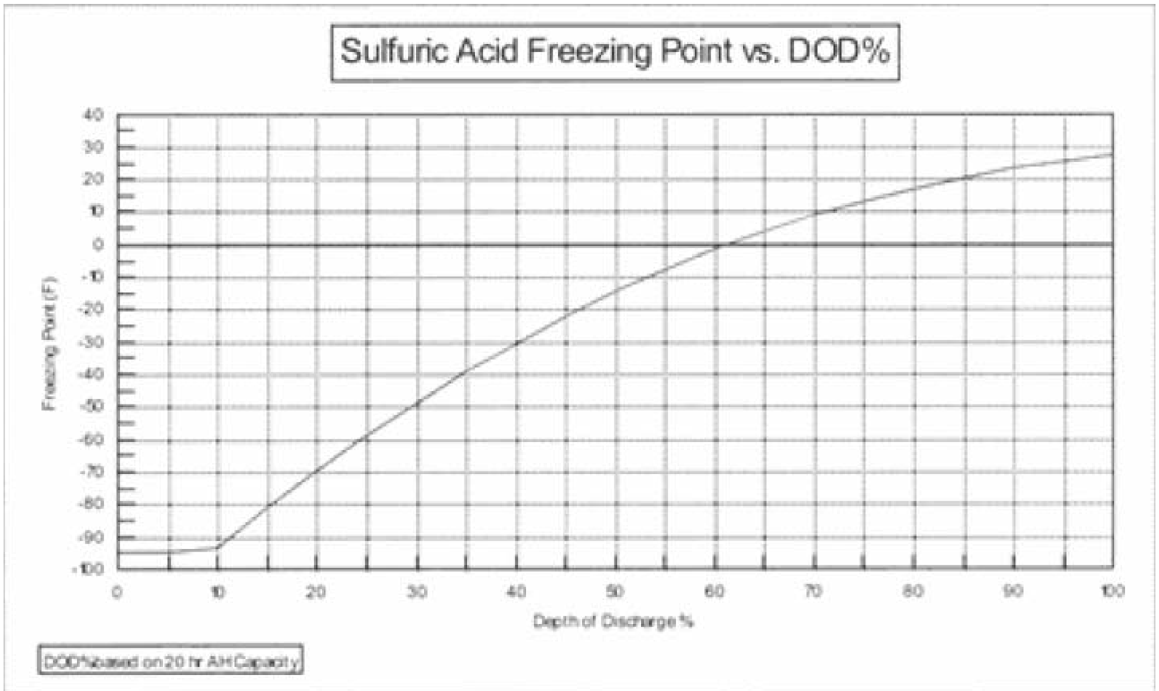
COMMENTS

As shown by the above graph, at colder temperatures, battery efficiency drops. In other words, everything remaining the same, the batteries provide a lower amount of energy at colder temperatures compared to room temperature. The efficiency also depends on the rate of discharge. Therefore to provide the same amount of energy in the winter as in summer a larger number of batteries would be required. At around -20 °C battery temperature, Myers and TechPower units were tested for run time under normal and flashing operation. The load during flashing operation is roughly half the load during normal operation. In the case of Myers the run times during normal and flashing operations were 0:45 and 1:51 respectively. This illustrates that the efficiency is a function of rate of discharge also.

d) Depth of discharge Vs electrolyte Freezing point

<u>Myers Response</u>: NO

<u>Alpha Response</u>: See the following figure



<u>TechPower Response</u>: No Response

<u>Dimensions Response</u>: No. We can test for this if required.

COMMENTS

The specific gravity of the electrolyte in a fully charged battery is of the order of 1.30. With such a specific gravity, the electrolyte will not freeze until the temperature drops to -95 °F as shown in the above graph. However as the depth of discharge increases, the specific gravity of the electrolyte drops, thereby increasing the freezing point. When it is completely discharged, the specific gravity is around 1.10, which would result in freezing at a temperature of +28 °F. Therefore it is essential to avoid the scenario in which a completely discharged battery is exposed to a freezing temperature.

Questions for Manufacturers about High and Low Temperatures

We have completed testing your UPS unit at room temperature. In the next phase, your UPS and batteries will be tested under high (50 °C and 74 °C) and low (-25 °C) temperatures. The following tests are planned:

1. Charge the batteries at room temperature, put UPS and batteries in a 50 °C oven and run the discharge test.
2. Charge the batteries at room temperature, put UPS and batteries in a oven and run the discharge test.
3. Charge the batteries in an oven at a temperature of around 48 °C. Once they are charged, run the discharge test.
4. Charge the batteries at room temperature, put UPS and batteries in a -25 °C freezer and run the discharge test.

QUESTIONS ABOUT UPS UNIT

1. What type of charging does the battery charger use? Please give the values of all the relevant parameters of the charging method. (For example, if float charging is used, what is the voltage and what is the temperature compensation factor, if trickle charging is used what is the rate?)

2. What is the voltage at which the UPS disconnects the load from the batteries to prevent deep discharge?

3. Does the voltage in Question 2 vary with the rate of discharge?
   No, Yes, if "YES" what are the values for different discharge rates?

4. Is the voltage in Question 2 temperature compensated?

   No Yes, If "YES" what is the compensation factor?

QUESTIONS ABOUT BATTERIES

5. Have you tested the batteries under high or low temperatures?
   No Yes, If yes, how did the temperature affect the charge and discharge times of the batteries?

6. Have you observed any gassing while charging the batteries at high temperatures?
   No Yes

7. Did the electrolyte freeze under freezing conditions?
   No Yes

8. Do you have any other observations or results from your testing that would be helpful for us in testing your unit?

   No Yes, (Please attach the observations/results)

9. Would you suggest any specific precautions to be taken while performing the tests described above?

   No   Yes, Please describe

DETAILED INFORMATION ABOUT BATTERIES

10. What is the maximum temperature at which the batteries can be charged?

11. What is the charging voltage at which gassing of the battery begins at various temperatures?

12. What is the recommended float charging voltage at various temperatures?

13. Do you have charts showing float current Vs temperature for the recommended float charging voltage in Question 13.
    No   Yes, please attach the chart

14. What is the recommended temperature compensation factor to be used in float charging the batteries?

15. Do you have graphs showing:
    a) Discharge voltage Vs time at various discharge rates

    b) Discharge voltage Vs depth of discharge at various discharge rates and temperatures.

    c) Battery efficiency Vs temperature at various discharge rates.

    d) Depth of discharge Vs electrolyte Freezing point