EnerSys® DataSafe® XE Battery Series: Purpose Built For Modern Critical UPS Applications

March 21, 2016

Introduction

Recent years have seen significant changes in the nature of the Uninterruptible Power Supply (UPS) market, and on the requirements of batteries in those markets. Until now, battery manufacturers have been slow to respond to those shifts. In response to this need for a purpose built battery, EnerSys® has introduced the DataSafe® XE battery series. The DataSafe® XE battery series has been developed on the foundation of EnerSys® Thin Plate Pure Lead (TPPL) technology, but further optimized to meet the unique demands of the modern critical UPS market.

Background

Historically, batteries sold into the UPS market have focused on 15 minute rate discharges, and have required tightly temperature controlled environments. Taking a look back, there were a couple of key driving factors for the 15 minute runtime specification. First, in the era when standards were being established, well before modern computing, blade servers, interconnected functions, etc., organizations relied on isolated main-frame computers, going as far back as the use of punch cards for programming instructions. These units were extremely sensitive to changes in power quality or loss of power. In fact, if power was lost during operation, the result was not only a loss of the functions being performed during the outage; moreover, the entire data set may have been irrevocably corrupted. Thus, the loss of power was deemed catastrophic. This sensitivity to loss of power required engineers to determine how long the main-frame operators would require to reliably: 1) realize the outage was occurring, and then 2) perform an orderly shutdown to prevent the loss and, worse, corruption of data. Algorithms were designed and tested and a certain value was assigned to the support time, with appropriate safety margins.

A second factor in the determination of battery autonomy requirements was generator start time. Historically, stand-by generators (gensets) had a drastically limited capability set compared with their modern descendants. There were two issues: 1) power transfer, and 2) phase-sync. Genset models in those days required a manual transfer, plus several minutes to achieve full phase-synch to be able to match the output sine wave requirements of the system. Later, automatic transfer switches were implemented that nonetheless required additional time to become fully synchronous with the input power requirements of the system. On average, this process could require six to nine minutes or more.

Thus, 15 minutes was the merging of these requirements to allow either an orderly shutdown or for the standby generator to become fully operational and capable of assuming the supported load. This criterion has remained the standard for battery autonomy requirements, and battery manufacturers have tended to optimize around this requirement.

Today, the UPS world is a different place. Now we have automatic transfer of gensets and phase sync in seconds or even fractions of a second. We have interconnected servers, flash memory (RAID) and the ability to mirror data and transfer it instantaneously all over the world. Where historically users thought about reliability in terms of keeping a system alive until power was restored or a genset started, today, reliability is often more about holding a system up for the seconds or minutes required to switch operations to a redundant operation, perhaps on a different continent. Thus, for a large and growing portion of the UPS market, the 15 minute standard has become irrelevant and is being replaced by autonomy times of five minutes or less. A typical autonomy requirement in today’s UPS environment may be that the battery must support two back to back discharge events, or “hits,” of less than two minutes. As the autonomy time goes down, there is a desire to minimize battery size and weight and to reduce capital costs associated with the mechanical and electrical infrastructure.

At the same time, there is a trend toward reduced temperature management in battery rooms. This is driven by reduced temperature control requirements on the electronics, and/or is simply driven by a desire to reduce energy costs by reducing air conditioning. Of course, the battery user has no desire to accept a reduced battery life in exchange for reduced temperature control.

Below is a listing of requirements and desirable features for batteries serving the modern critical UPS market:

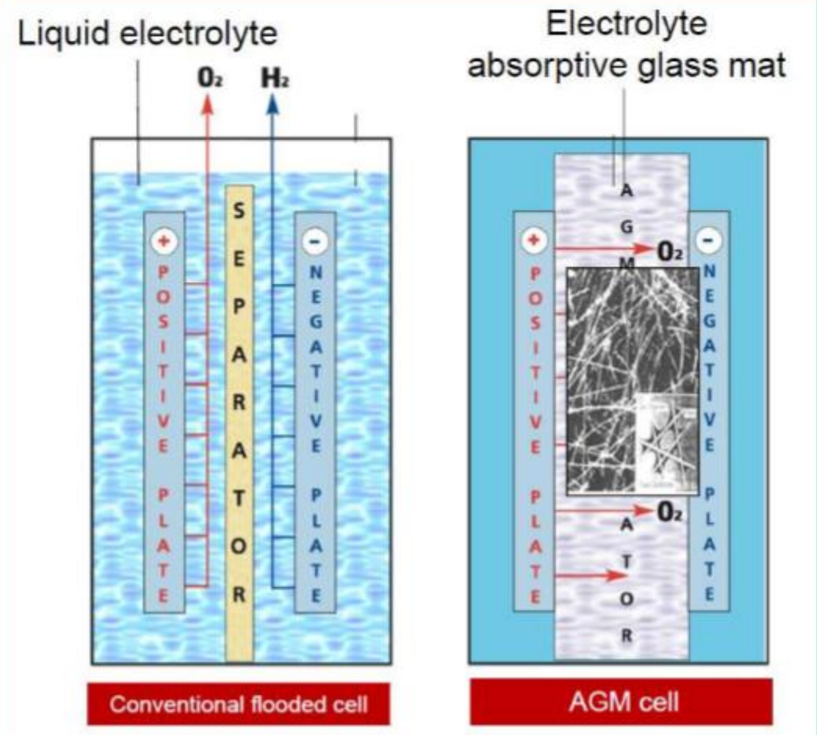
- Optimization around discharges shorter than five minutes so that battery size and weight can be reduced
- Reduced requirements for temperature control in the battery room
- Long life, even at increased operating temperatures
- Ability to recharge quickly
- Minimal gas generation and emission
- Low self-discharge rates
- Low long term cost of ownership

Faced with these battery requirements, EnerSys®, who has a long and successful history with a wide range of battery technologies as well as the traditional UPS market, looked to its extensive technology portfolio for the ideal foundation for focused optimization to meet the demands of this application. The EnerSys® TPPL product family was identified as having features that are uniquely suited to meet the needs of the modern critical UPS market. With some optimization of design to meet the specific needs of the application, EnerSys® is able to introduce the DataSafe® XE battery series. DataSafe® XE is the first battery specifically designed to address the evolving data center space.

What is Thin Plate Pure Lead Technology?

Nearly 50 years ago, Gates Energy, which later became part of EnerSys®, invented and patented the Absorbed Glass Mat (AGM) lead acid battery technology, often referred to as Valve Regulated Lead Acid (VRLA) technology. This technology allowed the manufacture of products that were not flooded with electrolyte and that did not require replacement of water. The effective utilization of the Oxygen Recombination Process, which is the key to AGM technology, revolutionized the lead acid battery industry. Figure 1 gives an explanation of AGM operation.

Over the decades, this AGM technology has been adopted by most lead acid battery manufacturers and has become the standard offering for many UPS applications. EnerSys® has taken this, now a largely mature technology, and dramatically enhanced it to create its TPPL technology. As the name implies, TPPL technology involves the use of electrodes that are of high purity and thin compared to more conventional technologies. In order to understand the critical nature of lead purity in TPPL products, it is important to understand some key failure modes and performance characteristics associated with lead acid batteries, and subsequently how lead purity and plate thickness affect them. Following is a discussion of some of the features of TPPL technology that make it uniquely suited to the modern critical UPS market.



AGM Operation Explained *- In conventional flooded batteries, illustrated on the left, oxygen gas is generated on the positive electrode and hydrogen gas is generated on the negative electrode. The bubbles float to the top and are released to the atmosphere. Periodically, the battery must be topped off with replacement water.*

By contrast, the AGM system is illustrated on the right. In AGM product, often referred to as VRLA, oxygen is generated at the positive electrode like in flooded batteries. Unlike flooded batteries, the AGM is not flooded. The AGM separator, which is a highly absorbent glass mat, is slightly under-saturated so that there are voids allowing the oxygen to travel to the negative electrode. At the negative electrode, the oxygen goes through a series of reactions which in turn include discharging Negative Active Material (NAM) and ultimately results in returning to water. Along the way, heat is generated proportional to the rate of recombination.

During this process, as long as the recombination process remains efficient, the hydrogen released from the water in the first step goes to the ionic state, but is recombined with oxygen before becoming hydrogen gas.

Note that during the recombination reaction, a necessary step is the discharge of NAM, so energy is used recharging the NAM. Minimizing the oxygen generation rate reduces the rate of recombination and energy consumption.

Figure 1: AGM Operation

Extended High Rate Run Times and Long Life

The positive grid of a lead acid battery is the lead framework, which supports the Positive Active Material (PAM) of the battery. Together, the grid and PAM form an electrode, which is often referred to as a plate. The grid provides a physical structure for the PAM to cling against so that the PAM is held together. Additionally, the grid is an electrical conductor which allows current flow, which originates from reactions in the active material, through the plates and out of the plates.

However, over the life of the battery, the lead in the grid tends to corrode. This corrosion is the process of metallic lead converting to lead oxide. Positive grid corrosion is always present in a lead acid battery because the positive grid is operating in a sulfuric acid environment at a voltage where it is thermodynamically favored to oxidize. As this corrosion occurs, it is ultimately destructive to the battery in two ways. First, as the grid corrodes, it loses conductivity so that it is less effective at allowing the current to flow. Second, since the corrosion product, an oxide of lead, is less dense than the original metallic lead, the grid volume will increase and the grid will begin to grow. As lead along the surface of the grid, and in the grain boundaries of the lead, are converted to lead oxides, stress is created on the remaining metallic lead, stretching it and making it even more subject to corrosion. This growth can cause the PAM to lose electrical contact with the grid. Both grid corrosion and grid growth reduce the conductivity and performance of the battery, and eventually the battery will fail.

This grid corrosion occurs in all lead acid batteries, but the rate at which it occurs is controlled by a number of factors, some of which relate to the application, such as float voltage and temperature. However, an extremely important factor controlling the rate of grid corrosion is the purity of the lead. High purity lead has a lower corrosion rate than lead with alloys, especially alloys such as calcium or antimony which are often used in battery grids. Not only is the corrosion rate higher for lead calcium alloys, but the corrosion tends to follow the calcium rich grain boundaries which means that corrosion can relatively quickly extend through the thickness of the grid resulting in loss of grid integrity. TPPL technology, with high purity lead, greatly delays these issues. Figure 2 shows a comparison of pure lead and lead calcium positive grids after life testing. Note that there is some loss of metallic lead from the TPPL grid, but it is homogenous along the surface and minimal in depth. The calcium grid shows a complete loss of integrity, reflecting both the increased rate of corrosion and the fact that the corrosion has effectively cut the grid into small pieces via the corrosion along grain boundaries. Figure 3 shows life projections, based on elevated temperature testing, for DataSafe® XE batteries at 25°C and at 30°C.

Comparison of TPPL grid and lead calcium alloy grid after elevated temperature float life testing – Batteries were torn down after elevated temperature float life testing and positive electrodes were removed. Positive Active Material (PAM) was carefully removed and the remaining grid was photographed. The TPPL positive grid on the left, is fully intact with minimal loss of grid mass. The conventional lead calcium grid (shown on the right) is no longer intact, having lost a large portion of its material through grid corrosion.

Figure 2: Positive Grid Corrosion

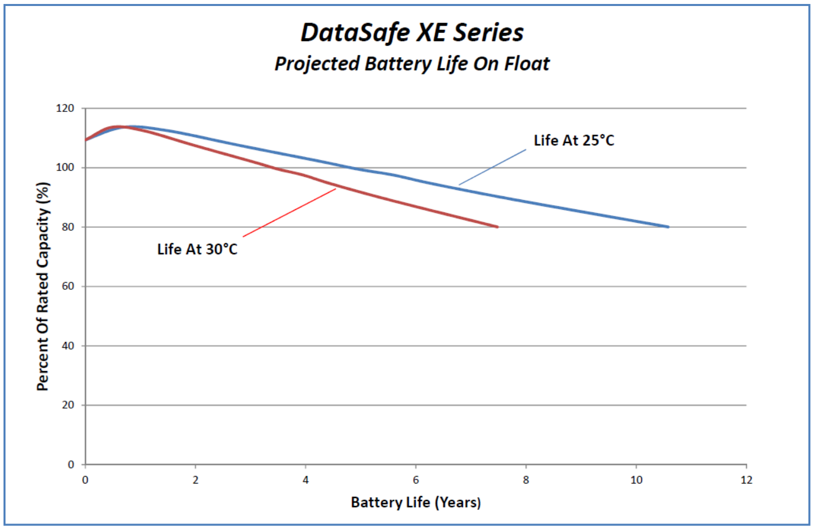
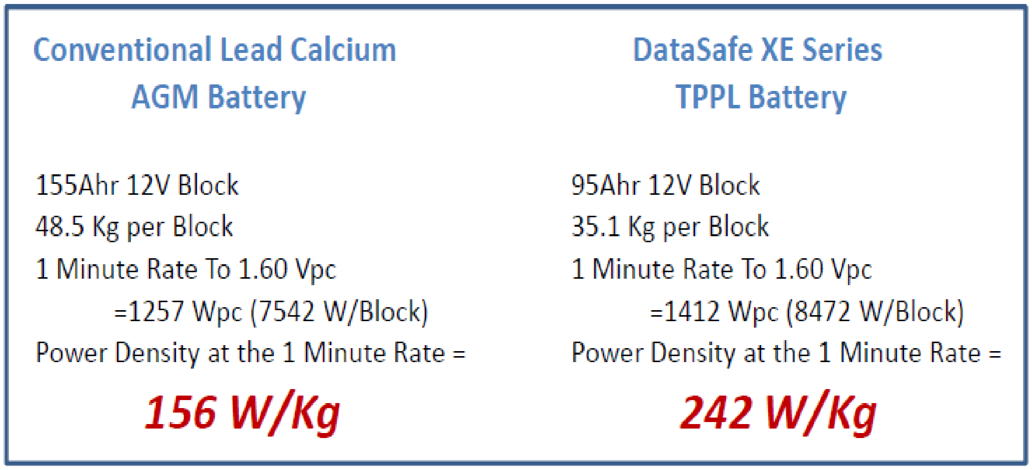


Figure 3: DataSafe® XE Battery Life Projections at 25°C and 30°C

Other lead acid battery designs utilizing alloys such as calcium tend to use thicker grids, effectively carrying extra lead thickness as sacrificial material to extend the battery life as the corrosion eats the grid away. Alternatively, they may use thin grids and accept the reduction in battery life that is inherent to the alloyed grid. The practice of using thicker grids to extend the life of alloyed grids can be effective when proper care is taken to manage grain boundaries, but results in a thicker plate. The downside is that thicker plates do not discharge as efficiently as thinner ones because the active material at the center of the plates has limited access to electrolyte. With the non-alloyed TPPL design, the use of thinner electrodes means that more electrodes can be used within the cell. More electrodes equal more electrode surface area, or specifically, more REACTIVE electrode surface area. Higher reactive surface area, like thinner active material, results in better active material utilization. As the discharge rate increases, the effectiveness of a thick electrode at utilizing the active material at the center of the plate drops to lower and lower levels. To the UPS engineer, this means that with thin plate batteries, smaller batteries can be used to achieve the same run times, and as discharge rates increase the TPPL advantage grows. Figure 4 shows a comparison of the

DataSafe® XE battery series to conventional lead calcium AGM batteries. This example shows a 50% increase in power density, which could allow for a 30% plus reduction in battery weight, a similar reduction in volume.



Conventional Lead Calcium AGM Battery	DataSafe XE Series TPPL Battery
155Ahr 12V Block	95Ahr 12V Block
48.5 Kg per Block	35.1 Kg per Block
1 Minute Rate To 1.60 Vpc	1 Minute Rate To 1.60 Vpc
=1257 Wpc (7542 W/Block)	=1412 Wpc (8472 W/Block)
Power Density at the 1 Minute Rate =	Power Density at the 1 Minute Rate =
156 W/Kg	**242 W/Kg**

Figure 4: Comparison of Power Density during Short Discharges

The bottom line is that TPPL products are able to use thinner grids without sacrificing battery life due to the fact that corrosion rates are reduced. This results in thinner electrodes and thus higher capacity, especially during high rate discharges. Put more simply, the use of thinner plates means more plates can be used so that there is greater reactive plate surface area. This gives the user increased power and energy from the battery without giving up battery life.

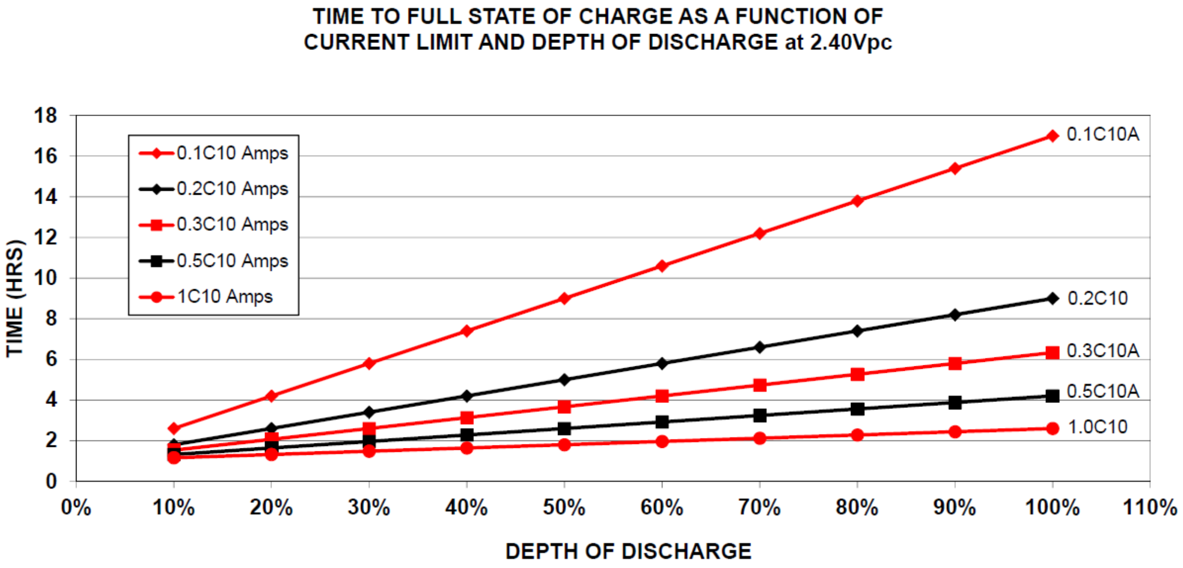
Rapid Recharge Capability

The same factors that control active material utilization efficiency during discharge come into play during recharge. Recharge rates are limited by the reactive surface area and rate at which acid can diffuse to and from the most difficult to reach active material at the center of the plate. As electrodes become thinner, the distance that electrolyte has to diffuse becomes shorter. If adequate recharge current is available, TPPL offers the opportunity to reduce the recharge time of the UPS battery after a discharge event.

Lead calcium grid batteries generally require that the recharge current be limited to 0.4C (40 amps for a 100 Ahr battery) or less. Thus, from a full discharge after a 1 hour charge, the battery will have achieved at most a 40% State of Charge (SOC). Beyond that point, the amount of current the battery will accept will diminish so that the rate of recharge drops even further. A lead calcium grid battery would require 5 to 10 hours, or longer, before reaching a full SOC after a full discharge.

With TPPL, the situation is significantly different. The DataSafe® XE battery series do not require a limit to the current, which can be made available to the battery as long as the charge voltage is properly regulated. As an example, the TPPL battery will readily accept 1C (100A for a 100Ahr battery) until it approaches 85% SOC while maintaining a very high level of energy efficiency. That means that the battery can achieve 85% SOC in around 51 minutes following a full depth of discharge. Beyond that point, the current will diminish, but 100% SOC can still be achieved in less than 2.5 hours. Under the more typical condition of less than full discharges, recharge times will be shorter. Figure 5 shows the relationship between available current to charge the DataSafe® XE battery series products and the time to recharge to 100% SOC, as a function of depth of discharge.

Figure 5: Charging Time for DataSafe® XE Battery Series Based on Depth of Discharge and Available



Charge Current

Low Gas Generation and Emission

Lead acid batteries use an electrolyte, which is a mixture of water and sulfuric acid. In the battery's internal environment, the water is thermodynamically favored to decompose to oxygen and hydrogen. This oxygen and hydrogen from decomposition will either exit the battery causing dry out (a failure mode) or react with other materials in the cell. If the reaction is with the grid, the result is grid corrosion and shortened life. If the reaction is with the active material, the result is self-discharge of the battery. However, even though decomposition of water is thermodynamically favored inside a lead acid battery, the rate (kinetics) is heavily influenced by other factors. Electrolysis tends to require a metallic surface which serves as a catalyst. On a pure lead surface, electrolysis tends to occur very slowly. Metallic impurities, however, tend to provide a surface which promotes electrolysis. The suppression of electrolysis on the high purity lead surface of TPPL greatly reduces the rate of gas generation. This reduces the rate of battery dry out, and it also reduces the amount of potentially explosive gas which can exit the battery.

There are two additional key points associated with this topic which may not be obvious, but are critical to TPPL technology. The first relates to the purity of ALL of the materials used in cell manufacturing. Unlike grid corrosion, which is most directly impacted by alloys only in the grid metal, gas generation is dependent on the purity of all of the materials inside the cell, including the electrolyte and anything which comes in contact with the electrolyte. In addition to the grid, potential sources of impurities in the cell are: the lead oxides used to manufacture the active materials; the acid and water used to produce the electrolyte; and the glass mat that absorbs the electrolyte. In the manufacture of TPPL products, EnerSys® has established the highest levels of purity for all of these materials, and vigorously tests those materials to assure that gassing rates are at industry leading low levels.

The second point is that a key difference between TPPL and other AGM designs is the level of gas *GENERATION*, not to be confused with gas emission. Many AGM designs have advanced to the point where oxygen recombination efficiency is high. This means that gas emission, or the amount of gas which exits the cell, is relatively small. However, that does not necessarily infer that the amount of gas being generated within the cell is low. It only means that the cell is very good at preventing the gas from leaving the cell.

Why does this matter? To find the answer, we need to look at what happens to the gas in the cell. As previously noted, if it stays in the cell it will basically be consumed in one of two reactions. One is to react with the lead on the positive grid to form lead oxide, which shows up as positive grid corrosion, an unrecoverable condition. The other option is to react with the active material (typically on the negative). This is known as the recombination reaction. While this reaction is not necessarily permanently destructive, like grid corrosion, it does have the effect of discharging the negative electrode. If the battery is on float, this shows up as increased float current. In addition, the recombination reaction is exothermic, so it adds to the heat load on the air conditioners.

The oxygen recombination efficiency of TPPL technology is high, like many other AGM batteries, but, unlike other AGM batteries, with TPPL technology, the rate of gas generation is reduced. This reduction in gas generation has the benefit of providing reduced operating temperatures, reduced float currents, and reduced positive grid corrosion. So, recombination efficiency is not necessarily the most critical measure of gassing behavior.

Low Self-discharge Rates

As describe previously, self-discharge is a secondary result of hydrogen gas generation in lead acid batteries. A reduction in gas generation rate, as TPPL provides, will directly reduce the rate of self-discharge. TPPL products show a reduced self-discharge rate compared to more conventional batteries. This means reduced issues associated with long supply lines to remote installations and reduced inventory management issues. Figure 6 illustrates the self-discharge rate of TPPL products, including the DataSafe® XE battery series, and compares

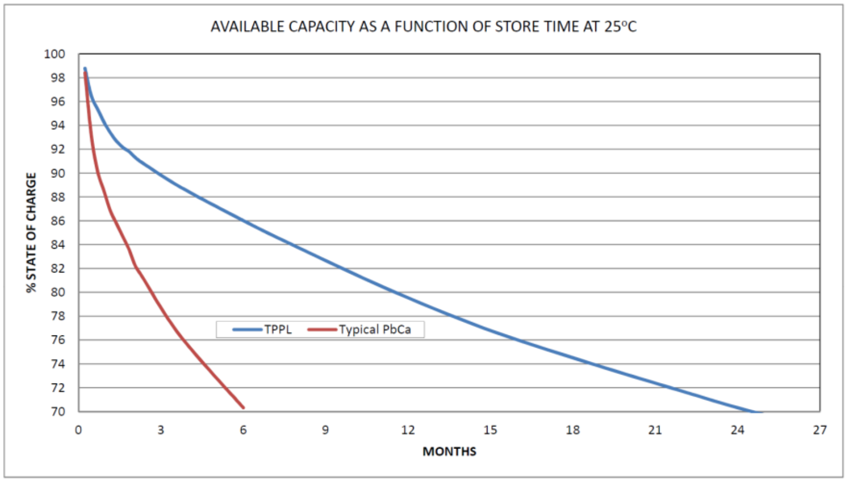


Figure 6: Comparison of Self-discharge Rates

that rate to typical lead calcium batteries.

Lowest Cost of Ownership

The features and benefits of the DataSafe® XE series of TPPL technology batteries give the UPS operator a battery that is smaller, lighter, more able to handle multiple hits and consumes less energy, and all while providing longer life and higher reliability. All of these characteristics help manage the long term cost via lower purchase cost, less frequent replacement, reduced energy cost, and reduced care and maintenance of the battery string. Along with the opportunity to reduce the cost of temperature control in battery rooms come new options for where batteries can be located. As the first truly purpose built battery for the modern critical UPS industry, the DataSafe® XE battery series offers the best opportunity to minimize the lifetime cost of the battery.