HELIX™ TECHOLOGY INCREASES FLOODED SLI BATTERY LIFE AND CUTS RISK OF CATASTROPHIC BATTERY FAILURE IN EMERGENCY GENERATOR APPLICATIONS

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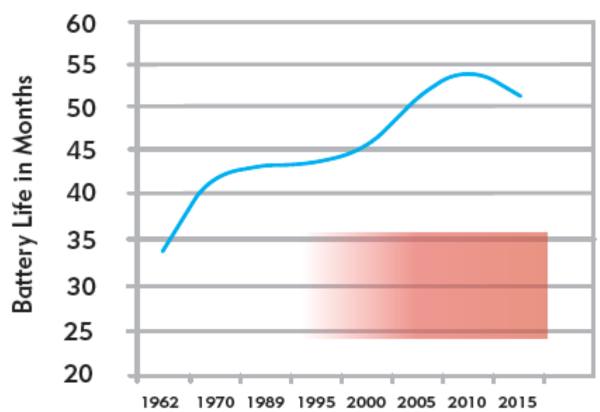
INTRODUCTION

Despite significant investments made by end users in preventive maintenance, starting batteries remain the number one cause of emergency generator (genset) failure. “Weak or undercharged starting batteries are the most common cause of standby generator system failures.”[1] “Over 80% of all starting failures… are due to dead starting batteries.”[2] When they do fail, generator batteries frequently fail suddenly, seemingly without warning.

In contrast, most of our experience with starting batteries in personal and work vehicles is generally very positive. The rate of failure-to-crank in modern vehicles is extremely low. And, prior to vehicle batteries failing, advance warning is frequently available in the form of observable deterioration in engine crank performance, typically caused by the weakening battery.

Customers aware of the reliability shortcomings of genset batteries typically replace them under preventive maintenance (PM) contract every two to three years. The very same SLI batteries used in vehicles typically last nearly twice this long:

Comparison of Average Vehicle and Genset Starting Battery Life, Months



Average **vehicle** starting battery life[3]
Average **genset** starting battery life[4]

Although the exact same type of flooded starting, lighting and ignition (SLI) battery is used in both gensets and vehicles, there are legitimate technical reasons why reliability, longevity, and suddenness of failure of the exact same battery differ between genset and vehicle applications. This paper summarizes the apparent root cause for these differences, and presents SENS’ solution, called HELIX (High Efficiency LIfe eXtending), that is expected to bestow upon starting batteries in gensets similar levels of reliability, life and gradual nature of failure as exist in vehicle applications.

[1] Iverson, James R., Digital Control Technology Enhances Power System Reliability and Performance, Cummins Power Generation publication PT-7002, Minneapolis MN: Cummins Power Generation
[2] Ibid.
[3] BCI Technical Subcommittee Report on Battery Failure Modes, May 2015
[4] Life range from 24 to 36 months, based on typical PM service replacement

Although brief mention is made of AGM (non-flooded) batteries later in the paper, the mechanisms discussed apply exclusively to *flooded* (employing free liquid electrolyte) types of lead-acid SLI batteries that are typically employed to start engines.

WHY FLOODED SLI BATTERIES IN GENSET APPLICATIONS FAIL SOONER AND MORE SUDDENLY THAN IN VEHICLE APPLICATIONS

Even though the batteries perform the identical job of delivering high-rates of current to crank internal combustion engines, the "use model" of batteries employed in gensets is different in one key respect from those employed in vehicles. Batteries used on gensets are charged around the clock, whereas vehicle batteries are charged only intermittently.

Flooded SLI batteries used in genset applications fail sooner and more suddenly than vehicle applications because of a series of very logical assumptions, one of which is incorrect.

In vehicle applications the different materials composing batteries tend to fail in a gradual manner at about the same time.[5] This graceful failure mode is not an accident. Battery manufacturers have had decades to optimize SLI battery designs such that batteries *used in vehicles* enjoy a reasonable battery lifespan. All non-value adding cost is eliminated from the battery such that all components of the battery have approximately the same longevity under normal use conditions. The battery works very well *in the application for which it was designed*. The fact that the same batteries don't last as long in genset applications suggests that the difference in <u>use models</u> between gensets and vehicles likely accounts for the difference in battery longevity and suddenness of failure.

One of the basic assumptions made by SLI battery designers is that batteries are charged intermittently. The assumption is logical and reasonable because the majority of vehicles are shut down a large part of each day -- no charging is taking place. Batteries in gensets, however, are on charge around the clock. As we will see, the number of hours a battery is on charge is very relevant to both SLI battery life and the actual failure mechanism.

Gensets employ a battery charging strategy that is very different from vehicle charging. Mandated by the National Electric Code, the National Fire Protection Association and Underwriter's Laboratories, emergency and standby gensets employ static battery chargers that continuously "float" charge the battery. The purpose of this is twofold: to insure that that battery is fully charged at all times, and to power accessory equipment connected to the DC bus such as electrical switchgear and supervisory systems necessary for the generator system to function.

> *The flaw is that telecom and switchgear batteries are purpose-built to be continuously float charged.... SLI batteries, however, are not designed to be float charged, and suffer premature failure when they are.*

The tacit assumptions behind mandating continuous float charging for gensets are as follows.

- Emergency generators are a critical application.
- Float charging is successfully employed in other critical applications such as telecommunications and electrical switchgear.
- Therefore continuous float charging should be employed with genset starting batteries.

Although in hindsight these assumptions seem logical, there is a flaw. The flaw is that telecom and switchgear batteries are purpose-built to be continuously float charged. In contrast, starting batteries are purpose-built only to be *intermittently* charged. Here is why continuous float charging of flooded SLI batteries is a problem.

THE PROBLEM WITH CONTINUOUS FLOAT CHARGING FLOODED SLI BATTERIES

Continuous float charging flooded SLI batteries accelerates the deterioration of polyethylene plate separators to a life shorter than that which battery designers intended. When subjected to continuous float charging, the dominant and earliest failure mode tends to be premature failure of the polyethylene separator. Separator failure typically results in short circuits that prevent the battery from functioning normally. And, because of the large amount of current available in a battery, short circuits are more likely to cause catastrophic (i.e. sudden release of large amounts of energy) battery failure than other types

[5] *BCI Technical Subcommittee Report on Battery Failure Modes,* Davis Knauer, East Penn Manufacturing Company, Presentation at BCI 127th PowerMart & Expo, May 2015

of failures.[6] In contrast, in vehicle applications with intermittent charging, nearly all components in the battery tend to fail around the same time.[7]

Battery separators keep apart the positive and negative electrodes of a galvanic cell to prevent short circuit. A separator has to serve over a long period of time to physically separate the electrodes without excessive hindrance to ionic current flows. In the hostile environment of a lead-acid battery, i.e. sulfuric acid and very strong oxidizers such as lead dioxide or nascent oxygen, only a few substances are stable over a long time. These substances include primarily silica, glass fibers, a few salts and a few synthetics. In contrast, all organic separator materials including polyethylene decompose and, via several intermediate steps, oxidize to carbon dioxide and water. In addition to sensitivity to oxidation, solubility and temperature, *the amount of electric charge (in particular overcharge) accelerates oxidation*.[8] [9]

Emergency generator and diesel fire pump regulations specify continuous float charging of lead-acid batteries. Around-the-clock charging greatly exceeds the limited daily charging time anticipated by the batteries' designers. The mandated continuous charging accelerates oxidation of polyethylene separators such that the separator fails before other battery components. SLI batteries used in these applications thus fail sooner, and more catastrophically, than batteries used in the vehicle applications for which they were designed.

It is this mechanism of separator oxidation that appears to account for the relatively shorter life and more sudden failure of genset batteries than the same batteries employed in vehicles.

It must be noted that this polyethylene separator failure mode has yet to be validated by statistically significant laboratory analysis of failed genset batteries. There is no known "junk bin" study differentiating the failure mechanisms of batteries used in gensets from those used in vehicles.

There is another important fact to note. Genset starting batteries account for less than 5% of the total market for SLI batteries used for engine starting. This small market[10] means that there is little incentive for suppliers of SLI batteries to manufacture special genset starting batteries designed to survive continuous float charging. The solution to this problem therefore lies elsewhere.

A NEW INTERMITTENT CHARGING ALGORITHM ADDRESSES PREMATURE SLI BATTERY FAILURE

A new charging algorithm addresses the problems of short genset battery life and sudden battery failure discussed above, while meeting the regulatory needs to deliver non-stop DC power to critical applications.

The principle is simple and straightforward. Emulate the beneficial intermittent vehicle charging regime for which SLI batteries were originally designed, but continue charger operation to support continuous DC loads. This "have your cake and eat it" approach reduces battery charging voltage to just above battery open-circuit voltage for most of the time that the battery would have been on continuous float charge. In this manner the charger remains available to power DC loads, preventing them from discharging the battery. To insure that the battery remains fully charged the charger periodically increases its voltage to insure that the battery remains at full capacity and capability to perform its duties. This arrangement thus emulates the intermittent type of charging that an SLI battery installed in a vehicle would see.

By significantly reducing the duration of separator-damaging float charging voltage, this charge regime reduces the rate at which polyethylene separators suffer oxidation degradation. This improvement in turn reduces the frequency of premature and catastrophic battery failures when SLI batteries are used in genset or firepump applications. Reducing the time that the battery is actively charged also significantly cuts the amount of electrolyte lost due to electrolysis.

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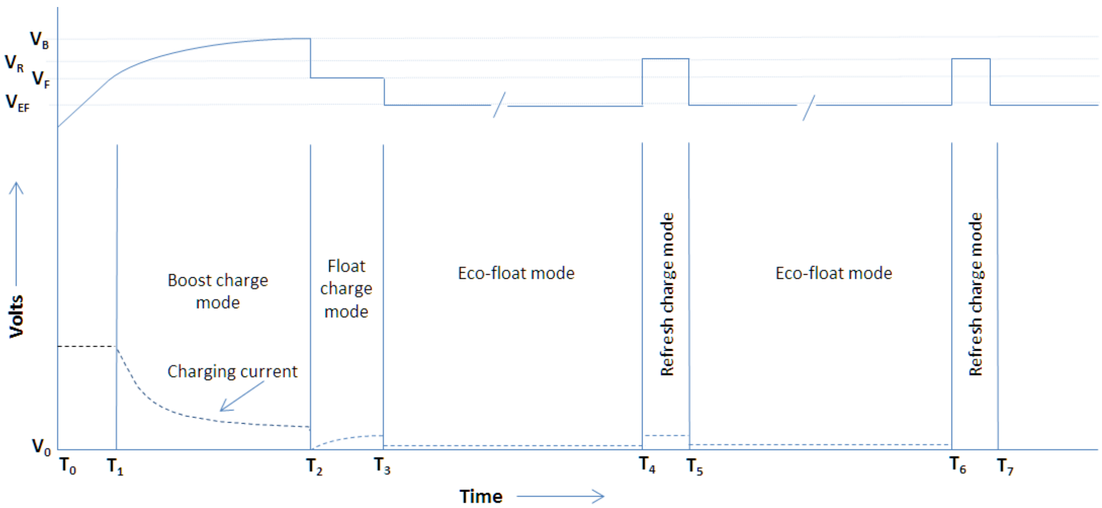
[6] *Technical Bulletin: Oxidation Stability*, Daramic Corporation, Undated
[7] *BCI Technical Subcommittee Report on Battery Failure Modes*, Davis Knauer, East Penn Manufacturing Company, Presentation at BCI 127th PowerMart & Expo, May 2015
[8] *Separators and organics for lead-acid batteries*, Werner Bohnstedt, Daramic Corporation, Journal of Power Sources, 29 March 2006
[9] *BCI Separator Oxidation Testing*, James W. Klang, GNB Technologies, Institute of Electrical and Electronic Engineers Journal 0-7803-4098-1/98/, 1998
[10] The United States enjoys a new vehicle market of greater than 15 million new cars and trucks annually, and a replacement market of greater than 260 million vehicles. In contrast, there are only a few tens of thousands of new gensets sold each year in the US, and the total US installed base of gensets is around 10 million.

Four different charging voltages are employed in the intermittent charging system that is controlled by a microprocessor. Figure 1 and the descriptions below it describe operation.

FIGURE 1 – INTERMITTENT CHARGING ALGORITHM OPERATION



At the start time of zero T_0, we assume a discharged battery. The charger starts operation in the Boost[11] mode V_B. The charger maintains V_B until T_2, when the charger's controller causes it to shift to the Float[12] mode. Note that the correct duration of the Boost mode is variable, and depends on many factors.[13]

Duration of Float mode at V_F could be either fixed or variable. The only purpose of Float mode is to fully complete battery recharge. If the battery becomes fully charged during the boost charge there is no need to float charge the battery. Because the battery will spend very little time in Float mode the exact value of the float voltage, which in the case of stationary (not starting) batteries is all-important to battery life, is now of little importance.

When the Float mode ends at T_3 the charger switches to a new mode, referred to here as Eco-float[14] mode, V_{EF}. The charger remains in Eco-float mode the time T_3 to T_4, which is measured and governed by the charger's microprocessor.

When the Eco-float timer expires at T_4 the charger switches to another new charging mode called Refresh charge[15], at voltage V_R. The charger remains in Refresh mode for a predefined period T_4 to T_5. At the end of the Refresh time T_5 the charger returns to Eco-float mode.

The alternating cycle of Eco-float to Refresh mode repeats until an AC failure or battery discharge occurs, in which case the charger reverts to T_0.

The ideal ratio of time the charger operates at the Eco-float voltage versus Refresh voltage varies depending on what the charger designer is attempting to optimize. Closely mimicking vehicle charging, for example, might result in a ratio of Eco-

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[11] **Boost voltage**, or $\mathbf{V_B}$ is a relatively high charging voltage that is employed for short durations to recharge a partially or fully depleted battery more quickly than would be possible at lower voltages.
[12] **Float voltage**, or $\mathbf{V_F}$ is a voltage value recommended by battery makers for long-term maintenance of a battery at full charge. Commonly recommended for charging of stationary batteries, continuous float charging causes premature damage to the polyethylene separators employed in most flooded SLI batteries.
[13] *Achieving Both Fast Recharge and Low Risk of Overcharge in Charger-controlled Systems*, William Kaewert, Stored Energy Systems LLC, presentation at Battcon 2016
[14] **Eco-float voltage**, or $\mathbf{V_{EF}}$ is a new charging voltage slightly higher than battery open circuit voltage. This voltage prolongs the life of polyethylene separators in flooded SLI batteries.
[15] **Refresh voltage**, or $\mathbf{V_R}$ is a charging voltage higher than float. This voltage periodically tops up the battery's capacity such that the battery remains fully charged.

float to Refresh hours of somewhere around 18:1, depending on the user's assumptions.[16] Some SLI battery designers indicate that maximum flooded SLI battery life would be achieved using ratios much greater than 18:1. Regardless, both design goals agree that flooded SLI batteries should spend the majority of time at Eco-float voltage versus any other charging voltage, provided that there is regular refreshing charge.

WHAT ABOUT AGM TYPE SLI BATTERIES?

Instead of polyethylene, AGM type SLI batteries typically employ separators made of fiberglass. Because fiberglass does not oxidize like organic polyethylene, float charging at the battery manufacturer's recommended float voltage is not inherently harmful to AGM type SLI batteries. Therefore, the intermittent charging method discussed is unlikely to increase the life of AGM type batteries.

The differing tolerance for float charging between flooded and AGM types of SLI batteries raises a question whether AGM batteries would be *harmed* by the intermittent charging plan presented. The manual for a recently purchased AGM starting battery recommended a relatively low voltage for float applications, and a higher charging voltage when employed for engine starting. Both charging schemes appear to be viable.

Because intermittent charging system presented in this paper substantially emulates vehicle battery charging, and because AGM starting batteries are sold for vehicle starting, it is reasonable to conclude that the method discussed in this paper is acceptable for use with AGM type SLI batteries. Put another way, arguing that this intermittent charge regime harms AGM batteries would be tantamount to declaring that AGM SLI batteries are inherently unsuited for engine starting duty either in gensets or vehicles.

From this we reach the conclusion that this intermittent charging system clearly benefits flooded types of SLI batteries, but will not harm AGM type starting batteries any more than installing them in a vehicle would.

IF INTERMITTENT CHARGING IS GOOD,
WHY IS FLOAT CHARGING SPECIFIED BY THE BATTERY MANUFACTURER?

Some makers of SLI batteries provide recommendations on how to float charge their products. Such recommendations conflict with the intermittent charging regime discussed here. The likely explanations for this conflict are as follows:

- Although SLI batteries were never designed for float charging, battery manufacturers needed to provide *some* sort of guidance to the group of customers including genset suppliers that are required by regulatory authorities to float charge the battery;
- That in the cases where battery makers recommend float charging flooded SLI batteries that this is done solely to satisfy customer demands for float charging guidance;
- That the apparent lack of teardown analysis differentiating genset batteries from vehicle batteries has kept battery manufacturers from thoroughly understanding why the same batteries live shorter useful lives in gensets than in vehicles;
- The lack of understanding of these mechanisms has until now inhibited the development of battery charger technology that could meet the various competing requirements of battery performance, longevity and regulatory compliance.

SUITABILITY OF COMPETING CHARGING SOLUTIONS IN GENSET APPLICATIONS

<u>Float-type battery chargers</u>: Float-type battery chargers, including those with "multi-rate" float and boost charging modes - even when the chargers are adjusted to the battery manufacturer's specified charging voltage value - cannot solve the separator oxidation problem. This is because the requirement to operate continuously in the float mode is the root cause of polyethylene separator failure. Float-type battery chargers therefore contribute to, rather than solve the problem of premature separator failure.

<u>On/off type battery chargers</u>: One potential solution for emulating automotive duty would be to apply the crude battery charger regulation technique of on/off charging. This technique regulates the charger's output by turning the charger full on

[16] 18:1 is arbitrary number that assumes a starting battery is employed in a car that is driven 15,000 miles/year at an average speed of 30 mph. This is 500 hours of charging time per year. The ratio of 8760 total hours in a year to 500 charging hours is just under 18:1.

when voltage drops below a preset value indicating partial discharge, and then turning it off when battery voltage rises above another present value that represents the battery achieving full charge[17]. One potential benefit of this scheme is that charging is shut down periodically, as it would be in the vehicle application for which SLI batteries are designed. There are, however, two significant problems with on/off regulation schemes. The first problem is that such schemes cannot be classified by regulatory authorities as "float" chargers, since they turn off some of the time. A second, more significant, problem is that such chargers perform poorly when tasked to support periodic or constant DC loads that are typically connected in parallel with the battery and charger in emergency generators. When faced with continuous DC loads on/off type chargers would cause the battery's active materials to wear prematurely because of repeated charge and discharge cycles.

In contrast, the intermittent charging mechanism discussed in this paper enables useful reduction in the rate of separator oxidation by emulating the charging duty cycle of the average vehicle, while allowing the charger to deliver continuous DC to power connected loads, and also to be classified for regulatory purposes as a float charger.

<u>Highly configurable battery chargers</u>: Some chargers offer sufficient programmability as to enable battery charging at voltages near battery open-circuit, similar to the Eco-float mode discussed above. This apparent similarity, however, to the intermittent charging system presented herein is only superficial. Without clear guidance about how to program highly configurable chargers, non-expert users are unable to exploit such chargers' adjustable function to achieve useful benefit. In contrast, a commercially available charger employing the intermittent charging discussed contains all necessary operating rules necessary to enjoy the benefits of intermittent charging. Operation is fully automatic, and no user programming is necessary.

SUMMARY OF EXPECTED BENEFITS OF INTERMITTENT CHARGING IN GENSETS EMPLOYING FLOODED SLI STARTING BATTERIES

Because the Eco-float voltage is lower than traditional float charging voltage (just above battery open-circuit voltage), a material reduction in the rate of separator oxidation is expected. Because charger operation is continuous, connected DC loads smaller than the charger's ampere output do not discharge the system battery as they would with a charger that shuts down periodically.

This implementation of intermittent charging thus enables the same longevity and gradual failure mechanism in gensets as SLI batteries in vehicle applications, while allowing the charger to provide 24/7 support of critical applications.

Because this intermittent charging system reduces oxidation damage inside the battery it reduces the risk of premature battery failure. Benefits accrue even if PM requirements demand that the battery still be changed out every two years. This is because reducing the rate of separator oxidation promises to further reduce the risk of failures that occur *prior* to the normal PM interval.

By reducing the risk of catastrophic battery failure, this intermittent charging system reduces the chances that hazardous battery materials, including sulfuric acid, lead metal and lead-bearing compounds could be released into the end user's facility should a battery fail catastrophically.

By slashing the float current consumed by the battery this intermittent charging method significantly reduces the battery's water usage, allowing the watering maintenance interval to be extended as long as watering intervals enjoyed in vehicle applications. In some cases these watering intervals are measured in years, rather than in months that is typical of today's float chargers employed on gensets.

One byproduct of cutting battery float current, is that the charger will consume less AC power from the grid. In a properly engineered high efficiency charger this reduction of energy usage can equal or exceed the charger's original purchase price.

> *If properly implemented, intermittent charging will enable SLI batteries employed in gensets to enjoy similar longevity and gradual wear out, versus potentially catastrophic failure, as in vehicle applications – while allowing the charger to provide 24/7 support of critical applications.*

[17] Walsh, US patent 3,305,755; Spiteri, US patent 3,991,356