# Whitepaper

## Improve Genset Availability By Detecting Bad Batteries Early

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# INTRODUCTION

Failure to start is the most significant avoidable cause of diesel generator malfunction. Over 80% of failures to start are caused by battery problems.

Genset customers invest significant amounts of money purchasing and maintaining generators. Yet the Achilles heel of these large, costly machines is a commodity product little changed since its invention in the late 1800s. Today most gensets do not include any means to detect that the starting battery has deteriorated, and may not be fit to start the engine. Genset failure can cause large economic losses and, in some cases, loss of life.

End-users have tolerated this situation because there has been no practical, cost-effective battery failure detection system. The low-cost, practical battery failure detection proposal made in this paper would, if deployed, significantly reduce the number of genset start failures and associated business risk. Eliminating the leading cause of genset failure would likely improve customer satisfaction with gensets overall, and with the companies that supply them.

## ■ "Average downtime costs Source:

*Powering E-Business: Strategies & Planning; November 2000, Nashville, TN*

| | |
|---|---|
| – Cellular communications | $ 41,000 per hour |
| – Telephone ticket sales | $ 72,000 /hour |
| – Airline reservations | $ 90,000 /hour |
| – Credit card operation | $2,580,000 /hour |
| – Brokerage operation | $6,480,000 /hour" |

## ■ 15-minute outage at semiconductor manufacturing facility:

*$30 million Source: EPRI/Hewlett Packard*

# GENSET FAILURE TO START: THE BIG PROBLEM NO ONE TALKS ABOUT

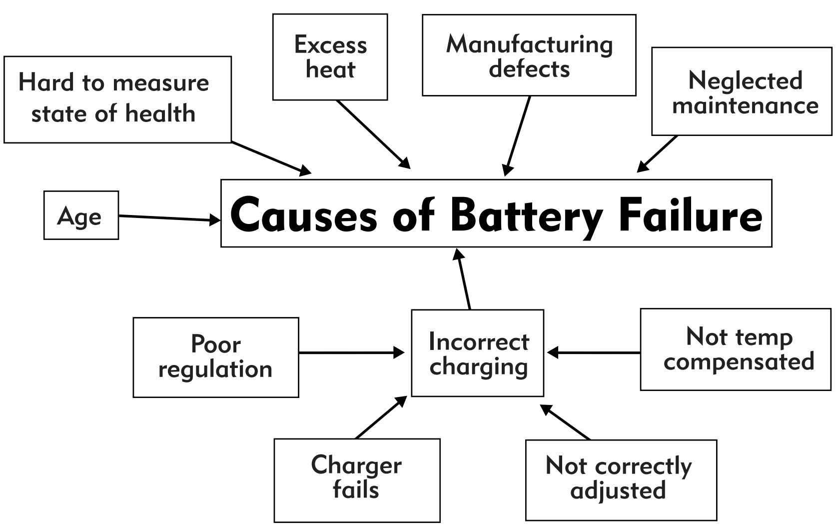
Despite advances in nearly every aspect of standby and emergency diesel generator performance, failure to start continues to be the biggest avoidable cause of diesel generator failures: "Weak or undercharged starting batteries are the most common cause of standby power system failures." [1] "Negligent battery maintenance is the most common reason for failure of critical power systems." [2]

This is a problem because the diesel generator set (genset) is an *insurance policy* protecting against electric power outages or electricity priced at peak rates. Like most insurance, users expect it to deliver, without excuses, as promised, when needed. An organization's investment in a genset defines the application as "very important" or "critical", even though some jaded end-users purchase grudgingly "just to satisfy Code". Codes and standards exist because people died and property was lost in avoidable accidents.

Hard data on the total genset start failure rate is not easy to find: "About 1% of all nuclear power plant diesels will fail to start when required." [3] (Nuclear plant diesels typically use compressed air starting systems, generally considered more reliable than electric starting.) "Standby diesels in medical facilities do not perform nearly so well" (i.e. worse than 1% start failure rate).[4] Given that the *best* maintained gensets fail to start 1% of the time, a reasonable assumption for the overall failure rate of electric start sets might be three to four times worse than gensets used at nuclear plants. A 3% to 4% failure rate means that more than ten thousand gensets in the US – insurance that customers paid good money for – are *not* available for use on any given day. This is an enormous amount of dead iron representing potentially large economic losses and a customer satisfaction problem for genset makers and service organizations.

The root cause of most starting problems is the battery. "The number one reason standby generators fail to start is due to dead starting batteries. Over 80% of all starting failures are from this cause."[5] "Even when kept fully charged and maintained, lead-acid starting batteries are subject to deterioration over time and must be periodically replaced when they no longer hold a proper charge."[6] In contrast to modern self-diagnosing digital electronic technology, the lead-acid battery is an anachronism. First invented in the late 1800s, it has, maintenance-wise, evolved little since then. It is perishable when off charge, has a shorter lifetime than electronic equipment, needs regular water replenishment, can be overcharged or undercharged easily and has no built-in warning mechanism prior to failure. We continue to use the lead-acid battery only because its purchase price is low compared to the alternatives. What's needed is a way to detect the need for battery replacement *before* engine start failure.

# Causes of Battery Failure




**Assuming zero manufacturing defects, there are three chief causes of battery failure:**

1. *Failure to replenish water on time:* Since recharge is not 100% efficient, some recharge energy electrolyzes water molecules of the electrolyte into hydrogen and oxygen gas that exit the battery through vent caps. If neglected long enough, failure to replenish lost water causes the battery's plates to go dry, causing permanent loss of capacity.

2. *Incorrect charging* multiplies the water replenishment problem. Some chargers run open-loop, alternately under-and overcharging the battery. Chargers with closed loop regulation systems, but without lack battery temperature compensation, also undercharge or overcharge the battery as seasons change. Overcharging accelerates water loss. Undercharging causes sulfation with consequent permanent capacity loss.

3. *Difficulty in assessing the battery's state of health:* The most difficult aspect of battery maintenance is that there is no simple way to measure the battery's ability to start an engine. There is no automatic "self diagnostic" within the battery to detect plate deterioration or partial short or open circuits. Leonidas states, "it is not sufficient to simply test the charging current to the group of batteries. The situation requires more reliable testing to evaluate each cell and replace those showing signs of degradation…"[7] According to Cummins, "only a regular schedule of inspection and testing under load can prevent generator starting problems. Merely checking the output voltage of the batteries is not indicative of their ability to deliver adequate starting power. As batteries age, their internal resistance to current flow goes up, and the only accurate measure of terminal voltage must be done under load."[8]

Regardless of what causes battery failure, it is not reasonable to expect much change in field maintenance practices or battery technology anytime soon. Given these limitations, end-users and the genset industry would benefit from an automated method to assess the health of starting batteries that alerts users and/or service personnel that batteries have weakened and should be replaced well before they fail to start the genset.

| Proactive cost of quality is low | | | |
|---|---|---|---|
| |  |  |  |
| **ITEM** | Battery Monitor | Customer genset failure | Genset failure at end user site |
| **COST** | $300? | Field service call | $20K to $MM<br>Life safety? |
| **IMPACT** | Averts end user crisis. Improves customer relations | Angry customer, potential lawsuit | Wasted investment, lost opportunity |

## TESTING AND MONITORING TO REDUCE BATTERY FAILURES

Lead-acid battery monitoring technology has matured to the point where the IEEE issued a standard (IEEE 1491) in 2005 to describe the various battery health assessment methods. Most large data centers, for example, spend tens of thousands of dollars for battery monitoring equipment designed to predict whether their UPS batteries will work. Data centers with downtime costs of six figures per minute often make large investments in battery monitors that can provide early warning of weak battery cells. Battery monitor capital costs frequently reach $40,000. Additional monies are spent installing the battery monitor systems and interpreting their data. Sometimes, interpretation of abundant battery monitor data is outsourced to a battery service company or the monitor's manufacturer.

Stand-alone ohmic battery monitoring systems designed for data center application are not suited for a genset environment. Although ohmic monitors work, they are expensive (estimated at $2,000 for a 24-volt system), time-consuming to install, and require trained personnel to interpret their data output. To achieve widespread adoption in the genset market any battery monitoring technology will need to be low in cost, simple, functional and easy for existing service personnel to employ. The following chart summarizes general requirements for battery monitoring in a genset environment:

**Summary of Battery Assessment Needs at Genset Sites**

| Parameter | Requirement | Likely general characteristics of the successful solution |
|---|---|---|
| Low capital cost | Minimal ($0 to $250) | Cost target likely dictates integrating battery assessment function with other familiar hardware. |
| Simplicity and convenience | Simple to install. Gives easy to read, unambiguous results | Can be installed and activated by an electrician. Needs no software to load or setup. Short installation time. No need for special parts, tools, instruments or training. Information output is easily understood GO/ NO GO indicator. System provides remote indication using already established means for other equipment. |
| Adapts to user's environment | Demands no new budget or procedure to buy or use | Make it easy to specify and buy. The solution should be integrated into hardware with which the user is already familiar (e.g. battery charger). The user decides whether, and how, to employ the new function. |
| Delivers useful predictive function | Reduce probability of simultaneous AC outage and battery failure | Use a credible battery assessment technique requiring least reasonable marginal cost. Comply with guidance in IEEE Standard 1491 and employ proven, documented techniques. |

# BATTERY ASSESSMENT SUITED FOR GENSET APPLICATION

Delivering useful predictive function means choosing the best compromise between performance, cost and simplicity from the menu of techniques described in IEEE 1491.

### Choice of Battery Assessment Method

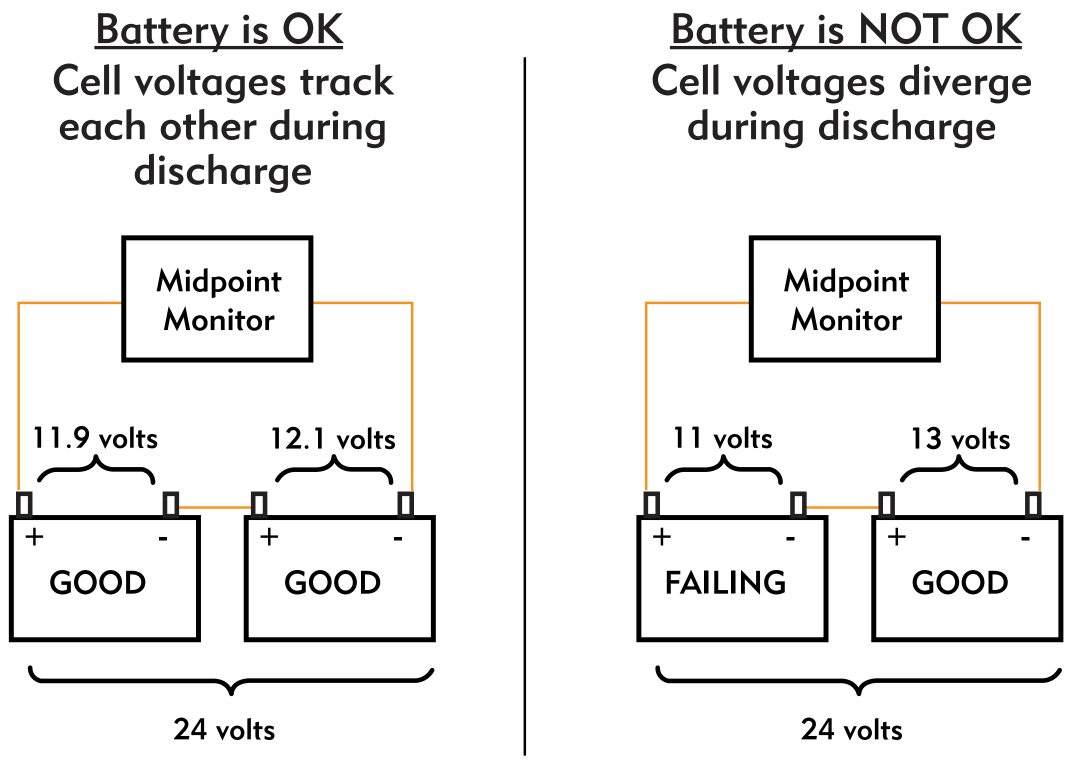
The original, and still most accurate, way to evaluate whether a battery can perform is to actually load test it. We can exploit this fact by taking advantage of the fact that the starting battery gets "tested" under heavy load each time it cranks the engine. Measurement of **battery discharge voltage** under load is a simple technique, and can indicate whether there are battery problems. At least one manufacturer of genset transfer switches has adopted this technique.

The general theory of operation is straightforward: Assume that a 24-volt starting battery normally falls to, say, 19 volts during engine crank. During the most recent engine start, it dropped under 19 volts. This is an important change that could indicate that the battery is weakening. Unfortunately, the information is not complete. Another equally viable explanation for the lower voltage reading during engine crank could be a heavier load on the battery – as is likely to occur during winter or if engine oil was changed to a heavier viscosity.

Two INTELEC papers from the 1990s presented a straightforward battery failure prediction technique, called "**battery middle point voltage comparison**" [10] [11] (midpoint monitor) that can reduce the ambiguity associated with simple voltage readings. This midpoint monitoring technique divides the battery in half for measurement purposes and continuously compares the voltage of each half of the battery to the other. An alarm is activated if voltage deviation exceeds a predetermined range. There are three principles of operation: The first is that one weak cell makes the whole battery bad. The second principle is that voltage drop in healthy cells tracks the others during discharge. In contrast, weak cells show early, and faster voltage decay. A weak cell creates an imbalance between the two battery halves, activating the failure alarm. The third principle is that one battery cell almost always weakens before any of the others.

The practical difference between the two techniques is amount of advance warning of battery failure. Assume a 24-volt battery with 12 cells, one of which has weakened but not failed completely: when simply detecting total battery string voltage, the weaker cell can be disguised by the performance of the other 11 cells in series. If the starting current demand is light – say a warm engine on a warm day – total battery voltage would remain above alarm limits during engine cranking. In contrast, midpoint monitoring would measure a voltage imbalance between the two 12-volt series batteries and issue an alarm regardless of total battery voltage. This means that the midpoint monitor gives earlier warning of battery problems with associated lower risk of start failure.

### 24V Midpoint Monitor System Compares 12V Batteries To Eachother



# IMPLEMENTING BATTERY MONITORING IN A DEPLOYABLE PRODUCT

## Limitations and Refinements to Midpoint Monitoring

Since the midpoint monitor requires even numbers of battery blocks, it cannot be applied to 12-volt monoblock batteries. So, in 12-volt starting systems the total battery discharge voltage may be the most practical balance between performance and low cost.

If the customer does not exercise his genset very often, the battery discharge voltage technique is of no value. The midpoint monitor is also of little value when the battery is on float charge because discharge stress is needed to emphasize cell-to-cell imbalance. Periodic reduction of the charger's float voltage, however, can reveal whether the battery is able to support any connected loads and whether its halves remain in balance. This is a significant fact that influences how and where a low cost midpoint monitor should be realized.

## Keeping the Solution Low in Cost and Simple

The remaining three goals – low cost, simplicity and adaptability to the user's environment – can be achieved only if the monitoring function is bundled into some other type of product normally supplied with the genset that contains appropriate computing and measurement resources.

The product into which the battery monitoring system is integrated will need to be microprocessor controlled, contain accurate voltage measurement capability, an alarm system, a means to record data and some sort of communications capability. Battery chargers are supplied with most gensets, and have a significant advantage over the alternatives (control panel or switchgear): The battery charger controls DC voltage when the genset is not running. If the genset is not exercised regularly, the charger's output can be changed as needed to force battery discharges for testing purposes. The charger is the only device in the genset with this capability.

## Required Capabilities of Integrated Battery Charger and Monitor

- *High accuracy charging:* The "Causes of Battery Failure" illustration shows a variety of battery problems associated with incorrect charging. The charger must deliver precise voltage regulation, be easy to set up, temperature compensated and highly reliable.

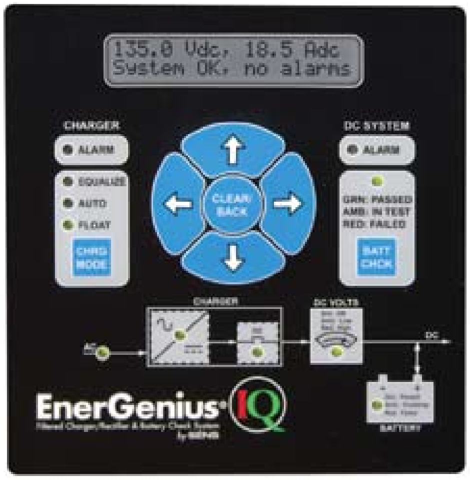

- *Clear communication:* Failure of the battery to pass its midpoint voltage test should result in clear indication of problem that is communicated visually and via an appropriate supervisory or network-based communication system.

- *History log:* Technical products, including batteries, sometimes fail without clear cause. A log of all relevant site events can speed troubleshooting. For example, a record of battery temperature over time since installation will help determine if excessive temperature over time has affected the battery's life. A log of all user adjustments can help isolate human factor problems, such as need for training. [12] [13]

- *Integrated design:* The battery monitor function should be built into the charger to minimize installation labor, to keep the user interface simple and provide a single point of customer contact for information and troubleshooting.

## SUMMARY

**Integrated Charger/Monitor Display & Control Panel**




1. Failure to start continues to be the biggest avoidable cause of diesel generator failures. Over 80% of failures to start are caused by battery problems. Battery failure is thus the leading cause of diesel generator failure.
2. Automated battery monitoring can detect battery failures before actual failure to start. End-users and service organizations can use this warning time to pro-actively replace batteries based on real data, rather than rule of thumb.
3. A simple battery monitoring technique called "battery middle point voltage comparison", or midpoint monitoring, can deliver earlier warning of battery problems than simple battery discharge voltage measurement.
4. Battery monitoring technology can make a significant reduction in biggest cause of failures in generator sets. Commercializing it and deploying it will reduce business risk to end-users, reduce the number of emergency repair calls and improve customer satisfaction with genset products.

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