

InfraStruXure Battery Safety in the IT Environment: What happens When Ventilation Fails?

Abstract

This paper examines the cause of some past battery incidents and demonstrates why many layers of safeguards built into the InfraStruXure design are intended to prevent the build-up of hydrogen gas to a dangerous level.

Introduction

Historically, data centers and computer rooms – now better known as “information technology (IT) centers” – were *perceived* to rely for emergency power on uninterruptible power systems (UPS) and generator systems that were located in another part of the facility. Battery systems consisted of long racks of battery “jars” filled with electrolyte. They were located in “battery rooms” that had special ventilation and firewalls to isolate them from the rest of the building.

We use the word “perceived” advisedly. The truth is that batteries have shared spaces with electronic equipment for the better part of twenty years, and are permitted to do so by most codes. That was about the time when valve regulated lead-acid (VRLA) batteries were widely embraced by integrators and users alike.

Initially the use of VRLA batteries was restricted to small UPS systems. That was partly because the early batteries were only available in small power ratings. That changed as battery manufacturers continually improved their products and expanded the power envelope, so that today one can buy VRLA battery cells rated up to 3,000 Ampere-hours. It was also due partly to misgivings by some users about the reliability and/or safety of VRLA batteries.

Their concerns were not entirely unfounded. Early VRLA battery designs went through many growing pains... both figuratively and literally! VRLA capabilities were overstated and batteries were misapplied. Cells expanded; seals cracked; electrolyte leaked; and some overheated and were implicated in fires. Today, however, the state of the art is so much improved that properly applied VRLA batteries can be easily and safely used in IT centers of all sizes.

The VRLA difference

Until recently, fire and electrical codes treated all lead-acid batteries the same. Today the codes are being rewritten to acknowledge the difference between VRLA and “vented” (also called “flooded”) batteries. Whereas “vented” batteries have open valves to allow the gasses produced by a chemical reaction (mostly hydrogen) to continuously escape into the air around

the battery, VRLA batteries are sealed. The hydrogen is recombined with oxygen inside the battery to form water so that no gas escapes. In fact, the VRLA design depends on the fact that no air can get in or out of the battery.

In normal circumstances a flooded battery vents approximately sixty times more hydrogen than a VRLA battery. However, all batteries must have safety features to prevent a battery from building too much internal pressure. Vented batteries have flame arrestors. VRLA batteries have a one-way valve/flame arrestor that will release hydrogen when internal pressure gets too high - hence the "V" in "VRLA." Circumstances that can cause this to happen include over-charging the battery (at too high of a voltage), excess charging current (possibly due to build-up of internal resistance), and/or excessively high ambient temperature around the battery. A combination of the above conditions can lead to an event called "thermal runaway" that could heat up the battery and open its vents until it runs out of gas or it melts. The way to prevent it or to stop it is to remove one or more of the elements: voltage, current, and/or heat.

The Question - Are VRLA batteries safe to use in an IT environment?

VRLA batteries are no longer relegated to small systems such as the personal UPS connected to a desk-top computer. Significant numbers of VRLA batteries are present in IT centers. What happens if the ventilation system fails and the room heats up? An IT center full of electronic equipment could heat up quickly if the ventilation failed and the equipment kept running. Could the batteries overheat and vent enough hydrogen to reach an explosive level?

This is a fair question. There have been reports of poorly ventilated battery cabinets actually blowing up, mostly in outdoor telecommunication applications. The question was asked more than once after a spectacular event in California. The circumstances there were extraordinary and have almost no relevance to InfraStruXure applications, but it is reasonable to ask the question if one does not know the details.

Case Study

Details of that specific event will probably be argued in litigation for the next ten years, but this is what is believed to have happened. The data center was closed down but the UPS was left on to keep the batteries float charged. The building remained vacant for over a month with the air conditioning system shut down – including the ventilation system for the battery room. The latter was full of flooded batteries. Temperatures were believed to have gotten quite high, thereby speeding the evolution of hydrogen by the vented batteries, until after 3-4 weeks the concentration of hydrogen in the room built to dangerous levels. (The lower hazard level for hydrogen is at 4% concentration; hydrogen becomes explosive at levels around 15-16%). Had anyone opened a door or a window a catastrophe might have been avoided, but nobody came. Gas detectors

set off alarms, but when nobody had responded after three days of constant alarms, something ignited the hydrogen and it blew a hole in the roof.

A number of people speculated about what caused the event and how it could be prevented from happening again. Internet chat rooms filled with conjecture, including suggestions that UPS systems should include circuits to shut down the charger when the ventilation system fails. This seed has taken root in some minds. An underlying assumption seems to be that if it happened once it could happen again, even though it was an extremely unusual set of circumstances. Another assumption seems to be that one could apply identical rules to VRLA as to vented batteries. Caution is advised when basing a broad set of rules on a single data point.

The Answer – How InfraStruXure batteries avoid dangerous build-up of flammable gas

The InfraStruXure (ISX) architecture includes solutions for power, racks and air. Small and medium IT centers (up to about 100 racks) typically use a rack-integrated power system. The key to ISX reliability and safety is its modular, redundant design, including modular battery cartridges (MBC). The latter are modules that allow “hot swap” replacement of batteries. Several cartridges make up a “string.” Several strings can be paralleled to make up a battery system. Multiple battery systems could be present in a data center. Each cartridge contains several VRLA batteries, fuse protection, temperature sensing, and voltage sensing.

The following features build in safety:

- **N+1 redundant chargers** - Unlike some UPS systems, the InfraStruXure architecture includes the Symmetra design with multiple chargers. Failure of a single charger causes it to be removed from the system without affecting availability or performance of the remaining chargers or batteries. The chargers will not turn off in case of a temperature fault because the system is designed to prevent a single point of failure. (See below)
- **N+1 battery modules** - A battery string contains multiple modules. A problem in one module can be identified and isolated from the remaining modules. Because they are redundant, one or more strings could be removed if necessary while still ensuring some level of battery back-up protection.
- **Smaller battery units** - One school of thought says to use the largest battery possible, with the fewest number of strings possible, in order to conserve size and cost. InfraStruXure architecture, by contrast, is based upon the concept of reliability and ease of use. The base building block is a small battery (e.g., 7.2 Ampere-hour). Besides being light-weight, this small format keeps to a minimum the amount of gas that could be created in a single failed battery. One would have to see massive and simultaneous thermal failure of all batteries to create a significant hydrogen ventilation event. Such a situation is precluded by the other safety features described herein. Small VRLA batteries in a thermal condition will dry out in a comparatively shorter time than would larger batteries.
- **Temperature compensated charging** – Every battery cartridge contains a thermal sensor. When the temperature is maintained within the normal operating range (around 25C / 75F or less), the battery is kept on float charge in accordance with the battery manufacturer's recommendation. When sensors detect that temperature is rising, the charger will reduce voltage in proportion to the increase in temperature. All chargers are under the control of an Intelligence Module (also N+1 redundant). The IM sets the temperature compensated float voltage, but it can also command the chargers to OFF – which essentially disconnects batteries from the chargers, but not from the load.
- **Over-current protection** - Each power module incorporates two independent sets of over-current protection – one for the ac load and one for the batteries. The battery over-current can be overridden by the Intelligence Module if it senses that too many power modules are on line compared to the load. When the number of power modules exceeds the number of batteries, the current limit is proportionally reduced. This feature prevents too much power being available to the battery. (By comparison, some UPS systems without this feature provide power to the load plus additional power to charging batteries [typically 20 to 25% additional current]. If the UPS

is not operated at full load, the surplus capacity is available to the batteries, so a huge amount of current could be fed to the battery without exceeding the upper current limit threshold.)

- **Fail Safe** - Chargers are heavily monitored. If a charger fails, or if the communication link between the charger and the intelligence module is disrupted, the affected power module (including the power source of the faulty charger) will be disabled.
- **Emergency power off** - As required by code, ISX includes an EPO circuit that will disconnect power to the input of the UPS and will open the battery disconnects. This circuit could, in theory, be also activated by a contact closure caused automatically by an external device (such as an environmental alarm or a gas detector). However, use of such a circuit is discouraged because of its potential for single-point failure.
- **Environmental Monitoring Unit** - APC offers an option for environmental monitoring that can be installed in cabinets, racks, or elsewhere. The EMU can detect an abnormal increase in temperature at a localized level (e.g., in a single rack), and initiate an alarm or programmed response.
- **Computer-integrated power** - Most large UPS systems are classified as power systems. However, the InfraStruXure UPS types A and B are UL listed as IT equipment. If the IT equipment is ever removed from a data center, the corresponding ISX system will probably go with it, thereby eliminating the possibility of human error such as was described earlier.
- **Natural thermal mass** - Batteries naturally tend to maintain a constant temperature. They are largely immune to short-term changes in ambient temperature. Ambient temperatures must remain high for several hours or days in order to get VRLA batteries to a high-enough level to cause their vents to open.
- **Battery monitoring** - Each modular battery cartridge is individually monitored. A history log is kept on each module, allowing the system to "learn" in order to accurately predict runtimes and life expectancies. All data is reported back to NMS/BMS systems. Performance outside of the expected range can create an alarm to warn of a failing battery so that it can be replaced before it reaches runaway potential.
- **Battery testing** - The most accurate measure of a battery's performance is through an actual load test. InfraStruXure can be programmed to perform tests on the batteries. The Power Distribution Unit (PDU) section of the system has an optional load test port feature to allow this test.

Conclusion

InfraStruXure architecture meets the intent of a circuit to prevent thermal runaway and/or excess gassing from the batteries. If the ventilation system in a room were to fail, several features of ISX would detect the condition and prevent the build-up of gas.

Extreme caution should be used when trying to assume that the type of failure described earlier in this paper could apply to a InfraStruXure installation because so many of the conditions would be different. First, the incident involved vented batteries. Unless ambient temperatures reach very high temperatures, the VRLA batteries would vent little or no gas, whereas vented batteries out-gas continuously... approximately sixty times more than VRLA. Second, it is an extremely rare circumstance to operate a UPS for weeks on end with no load connected and with no personnel in the vicinity. Third, had the facility had ISX type A or B with batteries installed in the data center instead of a centralized UPS with batteries in a separate room, the batteries would have been removed along with the data center equipment.

The sense of urgency must also be put into perspective. There would be considerable time between the loss of room ventilation and an increase in battery temperature to the point where it would vent hydrogen. Then there would more time before hydrogen could accumulate into significant pockets of concentration. The risk of damage to the electronic equipment in the room will probably be far greater than the hazard presented by battery off-gassing. A ventilation failure alarm circuit would make more sense than a circuit that will interrupt mission-critical operations.

InfraStruXure architecture contains several features that prevent battery gassing, including small batteries; redundant batteries; redundant chargers; temperature sensors in each battery module; temperature compensated charging; intelligent monitors; fail safe chargers; and over-current protection.

Conclusion: InfraStruXure types A and B in a computer room can react to a ventilation failure and prevent off-gassing from batteries without the need of additional circuits.

InfraStruXure – How Much Gas?

Application:	InfraStruXure Type B UPS System
Battery:	One shelf contains (4) Modular Battery Cartridges (MBC) and each MBC contains (8) 7.2 AH VRLA batteries
Battery Description:	Valve Regulated (Sealed, Non-spillable) Lead Acid Battery: 6-cells, 7.2 ampere-hour, nominal 12-volt, high-rate, w/ faston tabs UL Recognized
Vent Pressure rating:	0.1 – 0.5 kg / cm ² (1.42 - 7.11 PSI)
Float Voltage Range:	2.25 – 2.30 Volts per cell
Recombination efficiency at normal float voltage:	approximately 99+ %
Gassing rate at normal float voltage & only 98% efficiency:	0.24 cc / hr
Worst-case charge scenario:	Vent wide open at 2.4 – 2.5 Volts per cell
Recombination efficiency at fast recharge voltage:	approximately 95+ %
Gassing rate at worst case:	0.602 cc/hr per cell
Theoretical maximum hydrogen that could be created by one cell:	413,000 cc
Theoretical time to vent total H ² from one cell at a maximum rate of 0.602 cc / hr:	28,585 days (78 years)
Maximum H ² that can be generated from one battery:	0.602/cell x 6 cells = 3.612 cc / hr
Maximum H ² that can be generated from one MBC:	3.612 x 8 batteries = 28.896 cc / hr
Maximum H² that can be generated from one ISX shelf:	28.896 x 4 MBC = 115.584 cc / hr = 0.00408181 Cubic feet / hr

PRACTICAL APPLICATION

SCENARIO "A"

Assumptions

- InfraStruXure System is installed with 4 shelves of batteries
- Room dimensions: 10 ft. x 10 ft. x 10 ft. = 1,000 cu. ft.
- Approximately 20% of the space in the room is taken up by equipment: 1,000 cu. ft. x .8 = 800 cu. ft.
- 5 battery chargers fail simultaneously; none of them disconnect; temperature compensated charging does not occur; no protection circuits operate
- All batteries open their vents to the maximum (0.602 cc / hr)
- All batteries vent continuously until they dry up

- The room is completely sealed; there is no air exchange; nobody opens a door
- The Lower Flammability Level (LFL) for hydrogen is 4% concentration by volume. 4% of 800 cu. ft. = 32 cu. ft.

gas rate, one shelf

$$= 0.00408181 \text{ Cubic feet / hr} \times 4 \text{ shelves}$$

$$= 0.01632724 \text{ cu. ft. / hr}$$

Time required to reach LFL:

$$32 \text{ cu. ft.} / 0.01632724 = 19,599 \text{ hours}$$

$$= 81.7 \text{ Days}$$