IEEE Guide for Selection of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications

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Abstract: Methods for selecting the appropriate type of valve-regulated, immobilized-electrolyte, recombinant lead-acid battery for any of a variety of potential stationary float applications are described.
Keywords: absorbed electrolyte, dryout, electrolysis, failure mechanisms, float voltage, gelled electrolyte, grid corrosion reaction, hydrogen evolution, oxygen recombination, safety, thermal runaway, valve-regulated lead-acid (VRLA) batteries

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Introduction

[This introduction is not a part of IEEE Std 1189-1996, IEEE Guide for Selection of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications.]

Valve-regulated lead-acid (VRLA) batteries are playing an ever-increasing role in control and power systems, for stationary reserve use in electric utilities, telecommunications, and uninterruptible power systems. In many cases, VRLA batteries are being substituted for vented lead-acid batteries. Their use is also expanding into many other applications where their unique characteristics appear attractive. Both gelled electrolyte and absorbed electrolyte VRLA designs, covering a range of sizes and capacities, are now available for use in many traditional and nontraditional battery applications. This guide fulfills the need within the industry to provide common understanding on VRLA cells and is applicable to all installations and battery sizes.

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IEEE Guide for Selection of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications

1. Scope

This guide describes methods for selecting the appropriate type of valve-regulated, immobilized-electrolyte, recombinant lead-acid battery for any of a variety of potential stationary float applications. Installation, maintenance, sizing, and consideration of battery types other than valve-regulated lead-acid batteries, are beyond the scope of this guide. Design of the dc system and sizing of the dc battery charger(s) are also beyond the scope of this guide.

2. References

This guide shall be used in conjunction with the following publications:

IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).[1]

IEEE Std 485-1983, IEEE Recommended Practice for Sizing Large Lead Storage Batteries for Generating Stations and Substations (ANSI).

IEEE Std 1187-1996, IEEE Recommended Practice for Installation Design and Installation of Valve-Regulated Lead-Acid Batteries for Stationary Applications.

IEEE Std 1188-1996, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications.

3. Definitions

The following definitions apply specifically to this guide. For other definitions, see IEEE Std 100-1992 .

3.1 absorbed electrolyte: Electrolyte in a VRLA cell that has been immobilized in absorbent separators.

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3.2 gelled electrolyte: Electrolyte in a VRLA cell that has been immobilized by the addition of a gelling agent.

3.3 immobilized electrolyte: Electrolyte in a VRLA cell that is retained by using either gelled or absorbed electrolyte technology.

3.4 oxygen recombination: The process by which oxygen is generated at the positive plates and ultimately recombined with hydrogen ions at the negative plates and converted back to water. In this process, hydrogen gas formation and evolution are suppressed. (See annex A for more details.)

3.5 oxygen recombination efficiency: The amount of oxygen ultimately converted to water at the negative plates expressed as a percentage of the total amount of oxygen produced at the positive plates:

$$O_{2eff} = \frac{O_2 \textit{converted to water at the negative plates}}{\textit{total } O_2 \textit{ produced at the positive plates}} \times 100$$

3.6 valve-regulated lead-acid (VRLA) cell: A cell that is sealed with the exception of a valve that opens to the atmosphere when the internal gas pressure in the cell exceeds atmospheric pressure by a preselected amount. VRLA cells provide a means for recombination of internally generated oxygen and the suppression of hydrogen gas evolution to limit water consumption.

3.7 vented cell: A cell in which the products of electrolysis and evaporation are allowed to escape to the atmosphere as they are generated. These cells are commonly referred to as "flooded."

3.8 VRLA cell: *See:* **valve-regulated lead-acid (VRLA) cell.**

4. Technology overview

4.1 Water loss

Water in a vented lead-acid cell is lost during overcharge by a process known as electrolysis. In this process, water is converted to oxygen at the positive plates and to hydrogen at the negative plates. The oxygen and hydrogen gases are allowed to vent out of the cell into the atmosphere, resulting in the loss of water. In VRLA cells, the oxygen recombination cycle limits the water loss.

4.2 Oxygen recombination

In a perfect water-to-oxygen-to-water cycle, all the oxygen produced at the positive plates on float or overcharge would be transported to the negative plates and converted back to water, with no water being lost from the cell. This is the basis for VRLA cell technology (see annex A for more details).

4.3 Oxygen transport between positive and negative plates

The efficiency of the oxygen recombination cycle depends primarily on the ability to transport the oxygen generated at the positive plates to the negative plates. In vented lead-acid cells, the transport process is impeded by the bulk liquid electrolyte, and oxygen is liberated to the atmosphere. The migration of oxygen through liquid sulfuric acid electrolyte is approximately 10000 times slower than it is through air [B1], [B2], [B3][2]. VRLA technology provides voids (gas passages) between positive and negative plates through which oxygen transport is greatly enhanced.

[2]The numbers in brackets preceded by the letter B correspond to those of the bibliography in annex B.

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4.4 Gelled electrolyte technology

Gelled electrolyte cells are designed such that voids develop in the gel. These voids serve as passages through which oxygen transport to the negative plates is enhanced.

4.5 Absorbed electrolyte technology

Absorbed electrolyte cells are designed with an absorbent separator that is approximately 95% filled with liquid electrolyte. The remaining voids provide for optimized oxygen transport from positive to negative plates.

4.6 Hydrogen evolution

It is possible to design VRLA cells in which, under normal float conditions, the oxygen recombination will operate at virtually 100% efficiency. However, even under normal float conditions, some water will be lost by electrolysis. There are reactions that occur at the positive plates whose only possible corresponding reaction at the negative plate is the formation of hydrogen gas. The most familiar of these reactions is corrosion of the lead or lead alloy positive grid to lead dioxide, which results in hydrogen evolution at the negative plates. These reactions cannot be prevented. (See annex A for more details.)

4.7 Pressure regulation valve

The internal cell pressure caused by the evolved gases is regulated by a valve that allows them to escape periodically. This is the origin of the term *valve regulated*. VRLA valves operate over a relatively narrow range, typically within the limits of 0.5–50 psig, depending upon design, allowing the escape of unrecombined gases and preventing the backflow of air into the cell.

5. Comparison of vented (flooded) and valve-regulated technologies

5.1 Reactions

Both technologies undergo the same chemical and electrochemical reactions. The rates of some of these reactions are different (see 4.3).

5.2 Construction materials

Most of the materials used in vented and VRLA cells are the same. Notable exceptions are absorbent separators used in absorbed electrolyte VRLA cells and gelling agents used in gelled electrolyte VRLA cells. Also, flooded cell jars (containers) are typically transparent whereas jars for VRLA cells are usually opaque.

5.3 Failure mechanisms

The familiar failure mechanisms of positive plate corrosion and growth, active material failure, post seal leakage, and jar/cover seal leakage associated with vented cells are also present in VRLA cells. However, in VRLA cells, the effects of leakage at the post and/or jar cover seals are more significant than in vented cells. First, such leakage can contribute to dryout (see 5.3.1) and second, such leaks can allow atmospheric oxygen to enter the cell, which causes discharge of the negative plates.

CAUTION — Electrolyte leakage may lead to ground paths and potential fire/explosion hazards.

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VRLA cells are susceptible to two failure modes that are normally not associated with vented cells. These are dryout and thermal runaway.

5.3.1 Dryout

VRLA cells operate on a precise balance of electrolyte and active material to optimize capacity and oxygen recombination. If the cells are relatively free of oxidizable impurities and the positive grid corrosion rate is not unreasonably high (see 4.6), very little water will be lost through electrolysis. If water is lost, internal resistance increases and performance on discharge degrades. Positive grid corrosion and water loss increase with increasing temperatures. Operation at voltages above the recommended float voltage will also accelerate water loss via electrolysis. Another dryout mechanism that can be significant at elevated temperatures is water loss via diffusion through the jar and cover walls. Dryout by diffusion is highly dependent upon the selection of jar and cover materials., the thickness thereof, operating temperature, and relative humidity of the external environment.

5.3.2 Thermal runaway

When a VRLA cell is operating on float or overcharge in a fully recombinant mode, almost all of the overcharge energy results in heat generation. If the design of the system ands its environment are such that the heat produced can be dissipated and thermal equilibrium can be reached, then there is no thermal runaway problem. However, if the recombination reaction gives rise to a rate of heat evolution that exceeds the rate of heat dissipation, the battery temperature will rise and more current will be required to maintain the float voltage. The additional current results in still more recombination and heat generation that further raises battery temperature, and so on. The net effect can be accelerated dryout and/or melting of the battery. This potential problem is further aggravated by elevated ambient temperatures or by cell or charging system malfunctions. The possibility of thermal runaway can be minimized by use of appropriate ventilation between and around the cells and by limiting the charger output current and voltage such as by using temperature-compensated chargers. In the gelled electrolyte system, the gel has intimate contact with the plates and the container walls and provides better heat dissipation characteristics than the absorbed electrolyte system, but not as good as the vented (flooded) system [B4].

5.4 Electrolyte concentration

By design, absorbed electrolyte VRLA cells have lesser volumes of electrolyte than vented cells of equivalent dimensions. This would normally result in lower long-duration capacities for the absorbed electrolyte cells of equivalent dimensions. Gelled electrolyte cells will usually have the same volume of electrolyte as vented cells. However, the presence of the gel interferes with electrolyte diffusion and convection, which results in reduced high-rate capacities. In both cases, the expected reductions in capacity may be partially compensated for by increasing the electrolyte concentration (specific gravities). Comparing absorbed and gelled electrolyte designs, the absorbed electrolyte system may provide better high-rate performance, while the gelled electrolyte system may provide better deep-discharge rechargeability and heat dissipation.

5.5 Float voltage

The electrolyte specific gravity that is typical of VRLA cells may require higher float voltages. The actual float voltage depends upon the specific gravity of the electrolyte being used. Recommended float voltages are provided by the battery manufacturers.

5.6 Absence of free electrolyte

Designs of VRLA cells are such that the electrolyte should be fully immobilized and thus little, if any, liquid electrolyte should leak from the cell in the event of a jar and/or cover break or crack. The absence of free electrolyte simplifies the handling of VRLA cells.

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5.7 Maintenance

By the very nature of the designs of VRLA cells, specific gravity readings and water additions are not practical. Consequently, the batteries are often referred to as "maintenance free." However, this is true only with respect to the electrolyte. Otherwise, VRLA battery maintenance is similar to that required for vented batteries, and will require special procedures to compensate for the inability to determine the amount and concentration of electrolyte. (See IEEE Std 1188-1996.)

5.8 Orientation in use

Unlike vented lead-acid ceils where the only possible orientation requires that the cell cover be facing upward, certain VRLA cell designs allow for operation in other orientations. Contact the manufacturer for specific instructions.

5.9 Vented gas

In a VRLA cell operating in a fully recombinant mode, there will be a slow buildup of gases. Eventually, the composition of this gas will be essentially pure hydrogen. When the cell internal pressure exceeds the valve release pressure, the gases will be vented into the atmosphere. Adequate ventilation must be provided in order to prevent buildup of hydrogen gas in the area.

CAUTION — When a VRLA cell is charged at voltages above its recombinant limits, potentially explosive mixtures of hydrogen and oxygen are generated within the cell and released at rates similar to those of vented cells. Contact the manufacturer for information on gassing rates and recombination efficiencies.

6. Selecting VRLA batteries

The following factors should be considered in selecting VRLA batteries.

6.1 Temperature

Elevated temperature operation will shorten VRLA battery life. As a general rule, prolonged use at elevated temperatures will reduce the battery life by approximately 50% for every 8 °C (15 °F) above 25 °C (77 °F). For VRLA batteries, optimal gas recombination is a function of operating temperature. Therefore, battery charging voltage must take temperature into consideration in order to maximize battery life. The additional issues of possible dryout and thermal runaway with VRLA batteries should be carefully assessed for elevated temperature operation. Consideration should also be given to "fail-safe" current limits on chargers for elevated temperature applications. In addition, some VRLA battery manufacturers recommend the use of temperature-compensated chargers for those applications where significant temperature variations can be expected.

6.2 Charging limitations

In general, VRLA batteries, because of their higher electrolyte specific gravities, will require a higher float voltage per cell. Therefore, charger capability and system voltage limitations must be considered. Some systems that normally would have been engineered with 24 vented cells may be engineered with 23 larger VRLA cells, thus maintaining capacity while solving the float voltage issue.

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6.3 Space limitations

The ability to orient some VRLA cells in nonconventional orientations permits maximizing battery capacity in certain space-restrictive applications. Also, because of increased electrolyte specific gravity and other factors, VRLA batteries may have greater volumetric energy density than their flooded counterparts, which could provide space savings.

6.4 Environment

Properly designed and operated VRLA batteries emit less gas than vented batteries. This feature should be considered in conjunction with the environment in which their use is intended. As always, the effects of cell or equipment malfunction must also be considered. (See IEEE Std 1187-1996 and IEEE Std 1188-1996.)

6.5 Life considerations

Battery life versus system design life should always be considered in the selection process. In general, VRLA batteries are more sensitive to abusive conditions of temperature, voltage, and current than vented (flooded) batteries. This can result in an operational "window" that is more restrictive than for vented batteries.

6.6 Safety

As with all lead-acid batteries, adequate ventilation must be provided for VRLA batteries. In addition, it is strongly recommended that VRLA cells be equipped with flame arrestor devices. Electrically, VRLA batteries pose the same hazards as vented batteries.

7. Sizing VRLA batteries

There is nothing unique about sizing VRLA batteries for stationary applications as compared to sizing practices applied for vented batteries. Clause 6. (Determining Battery Size) of IEEE Std 485-1983 applies equally to VRLA batteries for stationary applications.

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Annex A Recombination and grid corrosion reactions (Informative)

The following reactions form the basis of VRLA cell chemistry.

A.1 Oxygen recombination reaction

At positive plate:

$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$

At negative plate:

$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

(No water is lost from the system.)

A.2 Grid corrosion reaction

At positive plate:

$Pb + 2H_2O \rightarrow PbO_2 + 4H^+ + 4e^-$

At negative plate:

$4H^+ + 4e^- \rightarrow 2H_2$

(Water is lost from the system.)

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Annex B Bibliography (Informative)

[B1] Armstrong, R. D., and Bladen, K. L., *Applied Electrochem,* vol. 7, p. 345, 1977.

[B2] CRC *Handbook of Chemistry and Physics,* 67th ed., p. F45.

[B3] Gerner, S. D., et al., "Thermal Management of Valve-regulated Lead-Acid Batteries—A Comparison of Gelled vs. Absorbed Electrolyte Technologies," *Proceedings of the 12th International Telecommunication Energy Conference (INTELEC),* pp. 161–164, 1990.

[B4] Gubbins, K. E., and Walker, R. D., *Electrochemical Soc.,* vol. 112, p. 469, 1965.

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