CHARGE CONTROL OPTIONS FOR VALVE REGULATED LEAD ACID BATTERIES

THE MOST COMMON CAUSE OF PREMATURE BATTERY FAILURE IS OVERCHARGING

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Summary:

The paper provides information on the characteristics of batteries, particularly Valve Regulated Lead Acid, environmental aspects and practical system configurations available for system architects designed to provide recharge control in battery backed DC power solutions.

Battery types and background information

Rechargeable batteries, also known as secondary batteries, were developed by French scientist, Gaston Plante. The theory explored by Plante was that primary cell batteries eventually lost all of their electricity when the chemical reactions were spent. In a rechargeable or secondary battery, electricity from another source is introduced to reverse these chemical reactions, restoring the battery's charge. Unfortunately, the science of lead acid batteries had progressed hardly at all since 1859, when Gaston Plante immersed lead plates in diluted sulfuric acid and proved current repeatedly through them.

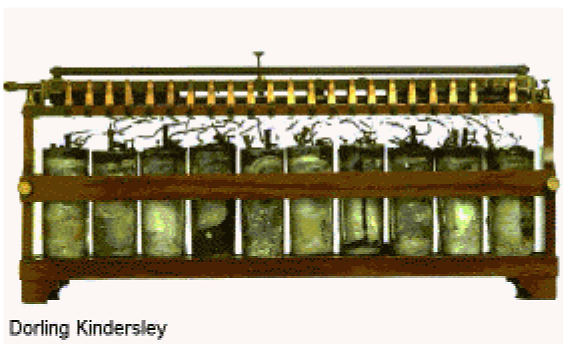

Figure 1: Plante's Lead-acid battery (1859)

Plante's cell used two thin lead plates separated by rubber sheets. He rolled the combination up and immersed it in a dilute sulfuric acid solution. Initial capacity was extremely limited since the positive plate had little active material available for reaction. Plante had positively charged one of his plates, making it lead oxide. The other was simply Lead, which had a negative charge. His breakthrough was to create a flow of electrons from the negative plate, up out of the battery as electricity, then to feed the flow back into the battery, making the world's first rechargeable, or secondary, battery. Lead acid was reliable. But the chemistry of how it charged and discharged had seemed to defy improvement ever since.

The basic Lead Acid battery chemistry is defined as:

$$Pb + 2H_2SO_4 + PbO_2 \quad \xleftarrow{\text{Charging}} \xrightarrow{\text{Discharging}} \quad + PbSO_4 + 2H_2O + PbSO_4$$

Porous lead	+	Sulfuric acid	+	Porous lead dioxide
Active material		Electrolyte		Active material
Negative Plate				Positive plate
	Becomes	^ Charging ^		
		v discharging v		
Lead sulfate	+	Water	+	Lead sulfate
Active material		Electrolyte		Active material
Negative plate				Positive plate

Discharge

During the discharge portion of the reaction, lead dioxide (positive plate) and lead (negative plate) react with sulfuric acid to create lead sulfate, water and energy.

Charge

During the recharge phase of the reaction, the cycle is reversed: the lead sulfate and water are electro-chemically converted to lead, lead oxide and sulfuric acid by an external electrical charging source.

Lead Acid Battery types

This chemistry has been proven for more than 140 years, and batteries of all shapes and sizes, available in sealed and maintenance-free products, are mass-produced today. In their price range, lead-acid batteries provide the greatest energy density (the amount of energy produced) per pound; have the longest life cycle and a large environmental advantage in that they are recycled at an extraordinarily high rate. (97 percent of the lead is recycled and reused in new batteries.) The Lead Acid battery has not really developed in terms of its chemistry since its introduction.

Classic Plante cells

Deep Jars

Thick plates, Pure lead

Flooded cells

Positive pure-lead, large-format plates with a laminated structure, pasted negative plates, large electrolyte reserves and heavy-duty pole and cell connections guarantee an extremely low internal resistance and the best high-power properties. Short and long charging times can be used reliably and safely with a high, stable voltage.

Transparent cell containers in SAN plastic make inspection and maintenance very easy and there is only slight water consumption.

A good charging characteristic enables full charging over a short period with a low charging voltage (5-6 hours at 2.25 V/C).

Equalizing or fast charging is seldom required and self-discharge is low.

The high production quality and the extremely low acid densities ensure a long design life of 20 years or more.

Classic Plante cells

Proven energy suppliers for decades, which captivate in robustness, extreme long design life and reliability

• Very high operationally reliability under rough operating conditions

• Low maintenance due to reduced antimony in the alloy and high electrolyte reserve

• Nominal capacity 50– ~12,000 Ah C10

• 15 years design life at 20°C ambient temperature (80% remaining capacity from C10)

• Also designed for cyclic applications

• Containers made from high-quality transparent plastics

• Tubular plates in block and single cell version

• Also available in dry charged condition with separate electrolyte

• Low gassing due to antimony alloy < 3% (EN 50272-2)

• Electrolyte: diluted Sulphuric acid dN = 1.24 kg/l

• Completely recyclable

Valve Regulated Lead Acid

12 years design life at 20°C ambient temperature (80% remaining capacity from C10)

• Maintenance-free (no topping up) during the whole service life

• Grid plate construction consisting of a lead calcium alloy

• Very low gassing due to internal gas recombination

• Shelf life up to 2 years at 20°C without recharge due to the very low self discharge rate

• Trouble-free transport of operational blocks, no restrictions for

rail, road, sea and air transportation (IATA, DGR clause A67)

• Completely recyclable

Valve Regulated Lead Acid

5 years design life and more at 20°C ambient temperature.

- EUROBAT Classification: Standard Commercial
- Highly resistant against deep discharge and overcharge.

The majority of modern power systems that use a battery system to provide standby power use Valve Regulated Lead Acid type cells.

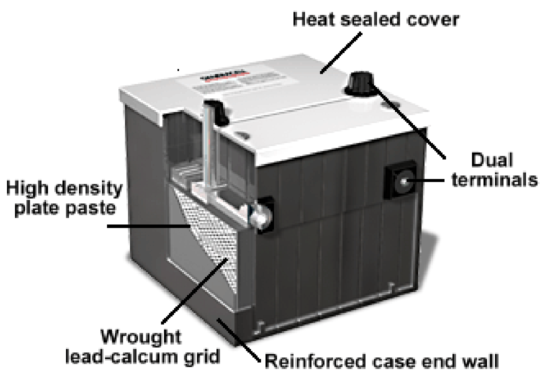

Figure 2: Cut away view of Modern Lead Acid battery

Valve Regulated Lead Acid battery (VRLA) blocks differ from Flooded cells (e.g.: Plante type) in that they are designed to recombine their active chemicals within a sealed container that only vents under special circumstances. Their plate design, size and weight are also different as is the type of container used to hold them. Due to their closed type construction these types of cells are sometimes known as “Maintenance free” or “Sealed”. There are two main types of VRLA battery technology, Absorptive Glass Mat (AGM) and Gel.

The Absorptive Glass Mat (AGM) is much like the flooded battery design because it uses standard plates, but it also has a higher specific gravity of electrolyte. However, as its full name suggests, the AGM has a special glass mat used to absorb and immobilize the electrolyte. Essentially, the mat acts like a sponge. The AGM permits the exchange of oxygen between the plates, thereby making the system recombinant, yet it still provides the electrical separation needed to prevent shorting of the plates. The thicker the glass mat, the greater the ability to store immobilized electrolyte, reduce the effect of dry out over the life of the battery, and prevent shorting of plates. The AGM's safety vent is the second major difference in design. The safety vent/flame arrestor has several purposes. It prevents the release of oxygen during normal operation. It maintains sufficient pressure within the cell for recombination to occur. It acts as a safety device in preventing sparks and arcs from entering the cell (much like flooded designs). And finally, it acts as a safety release vent during abnormal operation.

Gel technology batteries utilize the same plate and separator design as flooded batteries. However, with this battery, a pure form of silica is added to the electrolyte, forming acidic gel. As the gel dries out, cracks are formed. If it were placed in a clear container it would appear similar to a vigorously shaken bowl of gelatin. (Because these cracks would be alarming to a user, all gel designs are in opaque containers.)
These cracks are essential to diffuse oxygen between the positive and negative plates, making the gel technology recombinant.
Like AGM designs, gel batteries have a flame arrestor/safety valve to maintain pressure in the battery, prevent the release of hydrogen and oxygen during normal operation, prevent arcs and sparks from entering the cell, and allow venting during abnormal operation.

Temperature
Aside from changes in the load, the most important factor in the battery's performance is the temperature. Batteries are often installed in mechanical rooms with other maintenance equipment. As a company grows and requires new equipment, it is not unusual for a new boiler, compressor or a pump to be installed in the same room as the battery. All of this equipment generates significant heat, and will cause the room's ambient temperature to rise. The good news is that one can expect higher capacity from the battery with an increase in temperature (*Figure 5*). If discharged at this higher temperature, the battery will deliver more energy. However, what is much more important than this short-term gain, is the long-term loss in life that results from this higher temperature. More specifically, a battery will lose one-half of its life if it is kept at 95°F instead of 77°F (and half again for every 18°F above this). This factor alone is probably responsible for a significant portion of the disappointments in the life of lead-acid batteries. It is critically important to a battery's life to regulate the temperature in its environment. On the other hand, low temperatures are also important to consider, since batteries will experience reduced capacity as the temperature drops. In this case, it is not the average temperature that needs to be considered, but the temperature at the time of the discharge. Because of this relationship, the sizing of the battery becomes questionable if the battery room temperature is allowed to appreciably shift over time from the original temperature. The battery will also be affected if there are changes in the winter heating conditions, or even if the building heat is turned down on weekends for energy conservation reasons.
If the ambient temperature varies by 5 Dec C or more Battery voltage-temperature compensation should be considered.
Typically charge voltage compensation is somewhere in the region of 3-6mV/Cell/Deg C change.

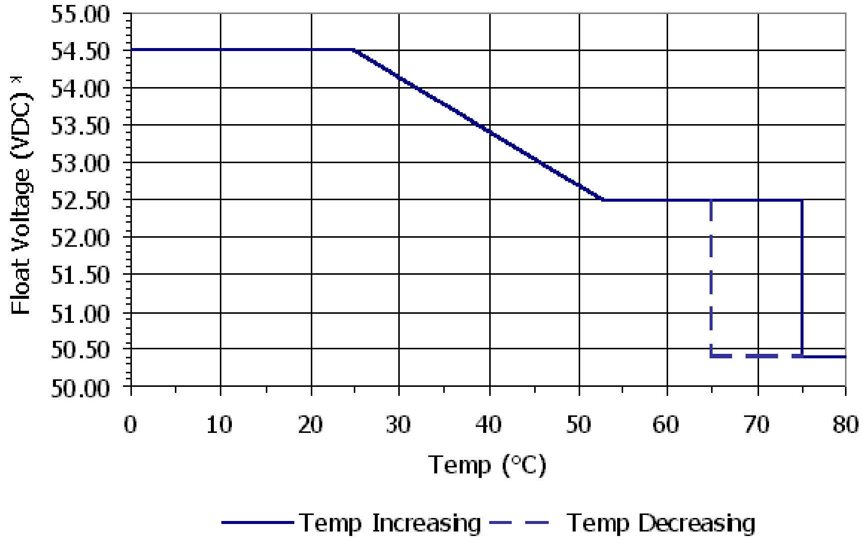

Figure 3: Temperature / Voltage compensation for a VRLA battery

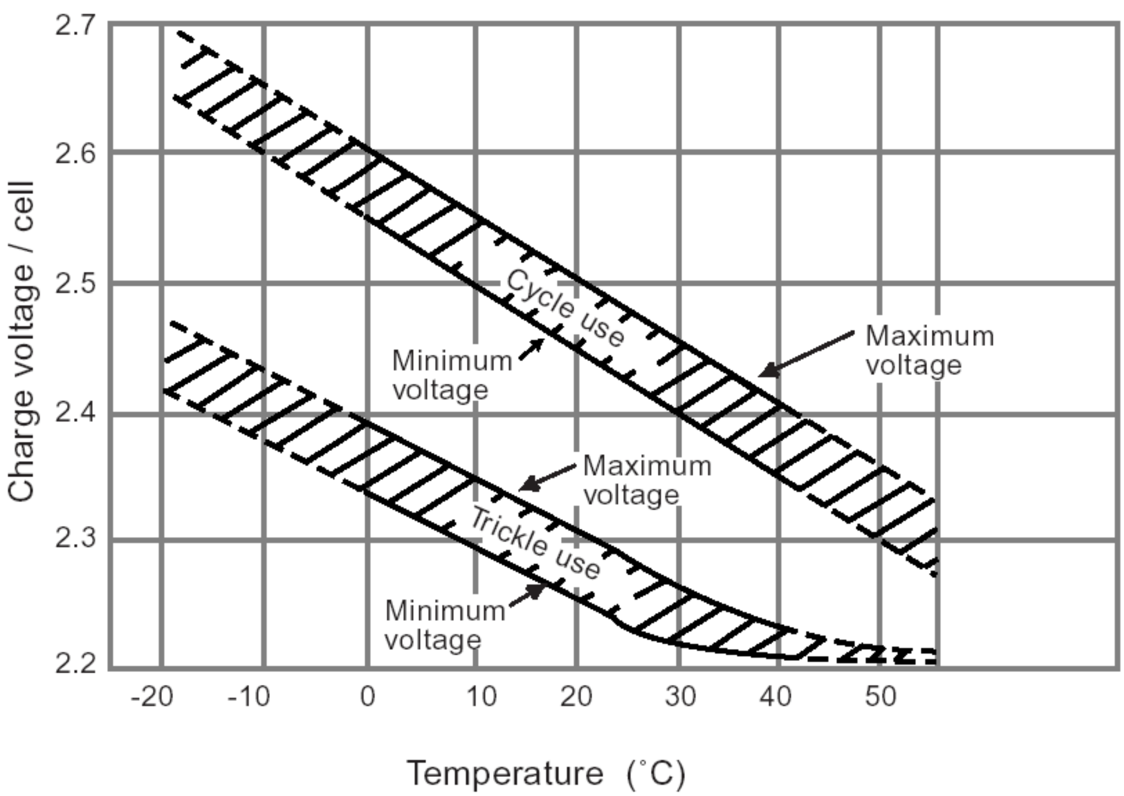

Figure 4: Typical battery compensation

The effect of temperature (AGM type battery) on the battery capacity is shown in the table below

Discharge time (hour)	End voltage (Volt)	Temperature				
		14°F	32°F	50°F	68°F	86°F
		-10°C	0°C	10°C	20°C	30°C
1	1.67	0.39	0.59	0.80	1	1.05
3	1.75	0.55	0.70	0.85	1	1.05
5	1.77	0.60	0.74	0.87	1	1.04
10	1.80	0.60	0.74	0.87	1	1.04

Figure 5: Effect of temperature on battery capacity

Higher Temperature operation

During high temperature conditions, float current increases. This causes more heat and gassing, and therefore more release of hydrogen and increased water loss. In addition, positive grid corrosion rate is accelerated and is the basis of temperature derating (for example, 50% reduction in life for each 15 F increase in temperature over 77 F). Loss of water due to high-temperature operation accelerates the drying out and further shortens the life of both AGM and Gel VRLA products.

Much of today's newer charging equipment includes temperature compensation and even fold-back capability to reduce the effects of higher temperatures, excess gassing and thermal runaway. Provisions for airflow between cells allows for more uniform thermal distribution from cell to cell.

Thermal Runaway

The result of *not* compensating the float voltage on flooded batteries that operate at high temperatures is excessive gas evolution, greatly increased water loss, excessive shedding of positive active material and increased positive grid corrosion – all factors in low capacity and early life failures. VRLA batteries that are not charge-compensated for high temperatures are at an even greater risk of failure. VRLA batteries normally operate at higher temperatures internally than a flooded battery due to the internal heat of gas recombination, the lower thermal mass of the acid-starved element and the reduced heat transfer (as compared to a flooded battery container). Should temperature rise without the voltage being lowered to compensate, the battery will be forced to generate additional gas, which will recombine and add more heat to an already warm battery. Should the battery reach the point where more heat is generated internally than can be dissipated to the surrounding air, the batteries will reach a point of thermal runaway. At this point, the batteries will almost certainly be damaged beyond repair, and may generate enough heat to damage surrounding equipment. This is an extreme example, but it is important to consider the ramifications of allowing a battery room’s temperature to climb, while not compensating the float voltage.

Voltage Regulation

While we're on the subject of temperature, it is important to note voltage regulation. If the temperature of the battery room is allowed to drift either higher or lower after installation, it is critical to compensate the charge voltage. A flooded, lead-calcium battery that was originally sized for 77°F and is later kept at 87°F, should have its charge voltage reduced by 0.028 volts per cell, or 2.8 millivolts per degree F per cell (or 5mV/°C per cell). A VRLA cell should be compensated in the same manner by 0.002 volts per degree F per cell (or 3.6mV/°C per cell). For a total battery, this actual voltage change can be significant, as shown in *Table 3*.

example:	180 cells	
	flooded, lead-calcium	
	1.215 specific gravity acid	
	float voltage:	
	at 67°F	401.0 volts
	at 77°F	396.0 volts (nominal)
	at 85°F	392.0 volts
	at 90°F	389.4 volts

Table 3. *It is critical to compensate the charge voltage if the temperature drifts in the battery room.*

For Maximum service life it is a general rule of thumb that the charge current should not exceed 10% of the C_{10} rated capacity (commonly written as $0.1C_{10}$). In practice the recharge current should not exceed $0.3C_{10}$. If the application guarantees a depth of discharge of >40% of the C_{10} capacity, through the use of a battery Load disconnect device, then the charge current limits itself and the charge limitation may be removed.

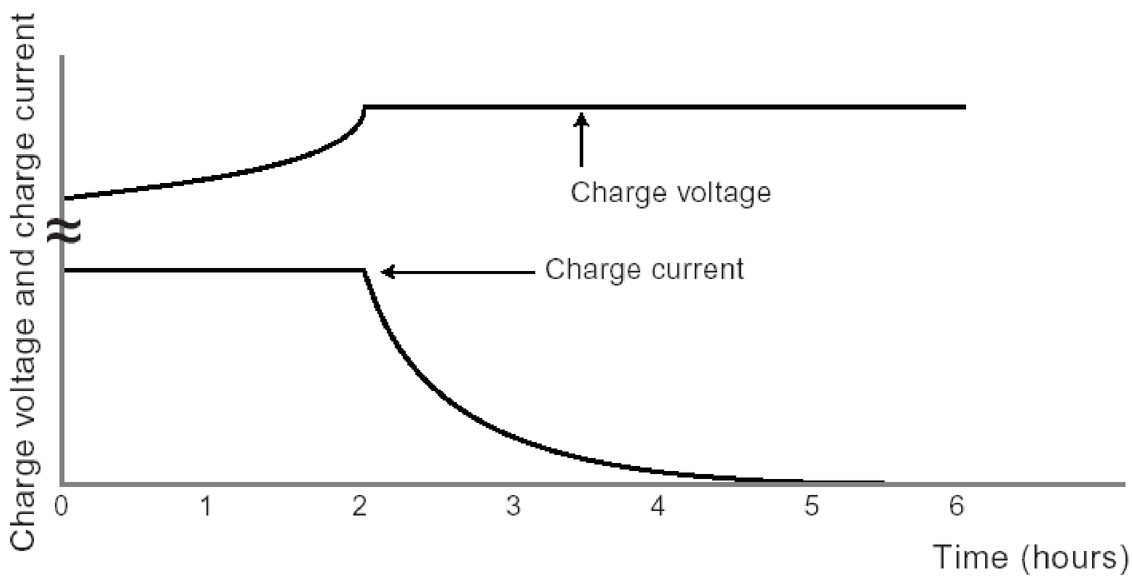

Figure 6: Constant Voltage, constant current charge characteristics

Charge current Limiting Practical solutions

Option 1. Equipment sizing / Application engineering.

Possibly the simplest way to control the battery recharge current in a simple power system is to correctly size the power supply (or supplies) such that the total available current is ideally matched to the sum of the maximum load current and the calculated value of $0.1C_{10}$

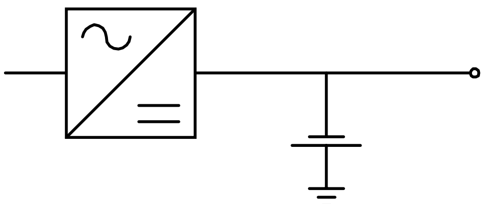

Figure 7: Simple charger / battery system

Example:
Load: 10A
Battery Capacity, C_{10}: 20Ahr
Power Supply rating (at current limit): 12A

In this example our power system is ideally matched to the battery in relation to the recharge requirements, with a load of 10A, the battery can only demand 2A or $0.2C_{10}$ from the power source.

Option 2. Trickle charge

Typical low power charger systems employ a timed high output feature that drops to a trickle charge after a predestined time period. This type of charge control is not usually employed on large or standby type applications.

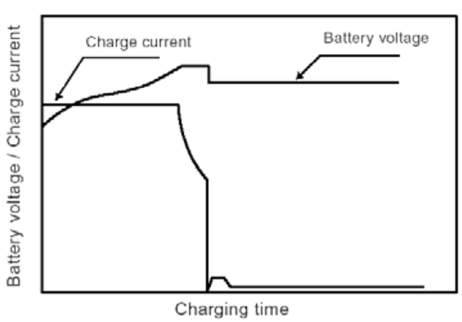

Figure 8: Simple charger output characteristic with boost/trickle modes

Option 3. Output voltage control with external "controller"

The Power system is equipped with a system controller that provides battery management functions. These functions include the control of the battery Low Voltage Disconnect contactor and output voltage control of the rectifier modules for charge control and battery temperature / Voltage compensation.

The control of the charge current to the battery is part of a feedback loop made by measuring the current through a shunt in the battery cabling, this measurement is "processed" by the system controller and a corresponding instruction provided to the rectifier modules to alter their output voltage level. By altering the rectifiers output voltage, the current drawn by the battery system will be controlled. With the concurrent requirement for battery temperature / Voltage compensation a microprocessor based controller is typically used.

Note that the system output voltage during charge control operation will vary (typically between ~48.5V dc and 54.5Vdc, i.e. the battery nominal voltage to the FLOAT voltage) during this mode. Calculation of the number and power rating of the rectifiers used in the system is made in the normal way.

Example:

System load, I_{Load}: 200A

Battery Standby: 2 hrs, Battery Capacity required: 210Ahrs

Battery Charge $I_{Battery\ Charge}$= 21A (i.e. $0.1C_{10}$)

Total System Load = $I_{Load} + I_{Battery\ Charge}$ = <u>221A</u>

Rectifier module size is 25A per module

N+0 rectifier modules required is 9, N+1 rectifiers is 10.

Note: typically where the battery recharge current requirement is less than the rating of a single rectifier module the redundant rectifier is typically designed to provide redundancy AND the battery recharge capacity. This may have an effect on the systems overall AVAILABILITY and should be considered during the initial sizing exercise.

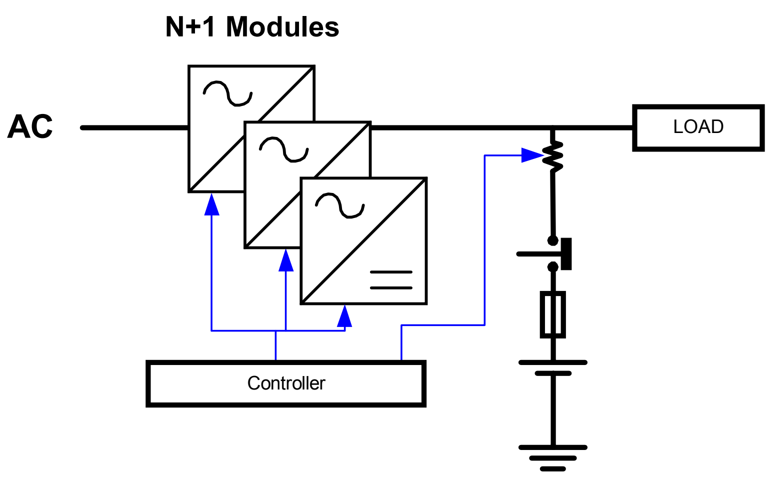

Figure 9: Power system with µProcessor controller.

Option 4. DC power system with "parallel" battery charging specific rectifiers

Providing the battery with a dedicated set of rectifiers and isolating those dedicated rectifiers from the main load powering units provides an interesting alternative to the controller method discussed previously. For systems where overall battery capacity is static and load current levels are not unreasonably high, providing rectifiers that are dedicated to the battery recharge eliminates the need to monitor battery current and control the entire bus voltage to regulate the charging current

Example:

System load, I_{Load}: 200A

Battery Standby: 4 hrs, Battery Capacity required: 420Ahrs

Battery Charge $I_{Battery\ Charge}$= 42A (i.e. $0.1C_{10}$)

Total System Load = $I_{Load} + I_{Battery\ Charge}$ = <u>242A</u>

Rectifier module size is 25A per module

Modules required to power the Load N+0 = 8, N+1 rectifiers is 9.

Modules required to charge the battery = 1

Note: While this system provides simple method to limit the battery charge current the method also has two inherent design limitations:

i. *The addition of the charge control diode provides a single point failure to the system; an open Diode would disconnect the battery. System architecture must take this into account*

ii. *Without redundant battery charging rectifier modules (with the blocking diode in place) a failure of the battery charge module removes ALL charging capability from the system.*

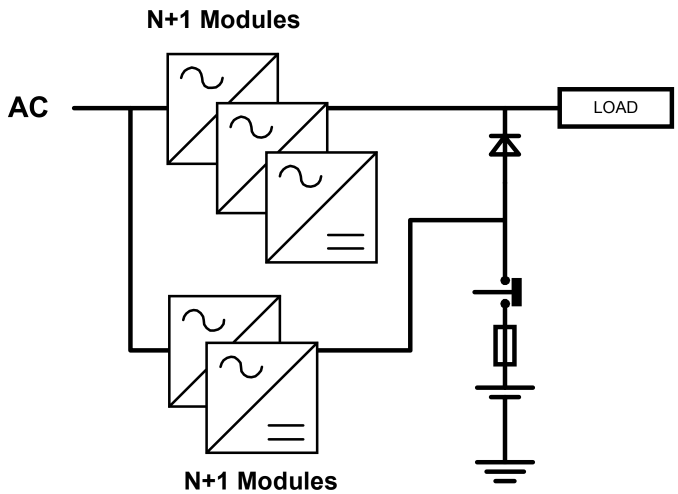

Figure 10: Power system with dedicate modules for battery charging

Acknowledgements:

Portions of this text were taken directly from the various battery manufacturers web sites including Exide Technologies, Panasonic Batteries, C+D and Hawker Batteries.