



Charger Output AC Ripple Voltage and the affect on VRLA batteries

*Please Note: The information in this technical bulletin was developed for C&D Dynasty 12 Volt VRLA products.
While much of the information herein is general, larger 2 Volt VRLA products are not within the intended scope.*

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Charger Output AC Ripple Voltage and Affect on VRLA Batteries

The operating temperature is a major factor in the determination of a VRLA battery's service life. The battery temperature is a function of both the temperature of the operating environment and the heat generated within the battery. Heat will be generated within the battery due to exothermic electrochemical reactions within the cells and current, both DC and AC, passing through the resistive components of the cells (I^2R_i).

During float charging of the battery with a pure DC voltage (no AC ripple), the total energy input to the cell is expressed in watts and calculated as the float charging voltage (V_f) multiplied by the float charging current (I_f). For example, if a fully charged VRLA battery was accepting 0.2 amperes while float charged at 13.8 vdc it would be consuming 2.76 watts ($\text{Watts}_{dc} = V_f \times I_{fdc}$) from the charger.

The self-discharge rate of the VRLA battery is very small and only about 2% of the float current will be consumed in offsetting the self-discharge reactions. Under normal conditions, another 2% to 3 % is consumed in the overcharge grid corrosion and gassing reactions. The bulk of the float charging current or power (up to 96%) is consumed in the oxygen recombination cycle. The oxygen recombination cycle is an exothermic reaction and it generates heat in addition to that resulting from the passage of the float current through the resistive components of the battery. Therefore, it is safe to assume that up to 95% of the float charging DC power is consumed and dissipated as heat – so the watts dissipated as heat would be:

$$\text{Watts}_{dc} = V_f \times I_{fdc} \times 95\%$$

DC Float Voltage, Float Current and Heating

The DC float current is actually quite small and will naturally vary with the charging voltage as is shown in Figure 1. Note that the float current varies with not only the float voltage but also with the type of VRLA battery technology (AGM vs. gel). This reflects in large part the differences in the efficiencies of the oxygen recombination cycle of the two technologies. For example, a 100 Ah AGM VRLA battery draws 200 milli-amperes (0.2 amperes) when charged at 2.30 volts DC per cell while the gel VRLA equivalent battery will only draw 100 milli-amperes. As a result, the heat generated by the AGM battery will also be greater.

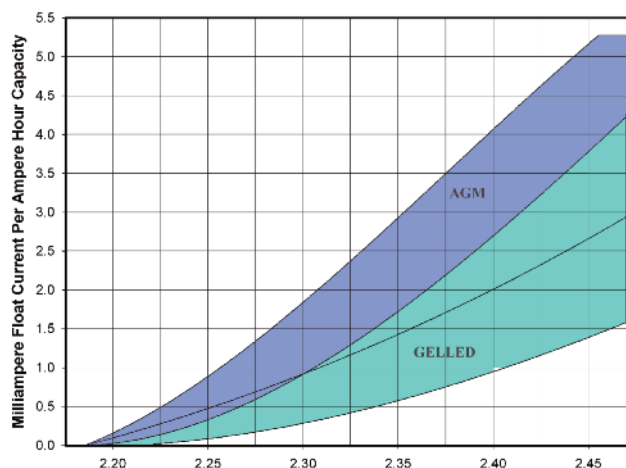


Figure 1 - VRLA battery float current vs. voltage

The 100 Ah capacity AGM battery, drawing 0.2 amperes with a charging voltage of 13.8 vdc would develop as a maximum, 2.6 watts (0.2 amperes x 13.8 vdc x 95%). In contrast the 100 Ah gel VRLA battery drawing 0.1 amperes could only generate 1.3 watts (0.1 Amperes x 13.8 x 95% vdc) of heat.

Heat is generally expressed in terms of British Thermal Units (BTU's) which is the amount of heat required to heat one pound of water from 59°F to 60°F. One watt of heat will generate 3.4129 BTU's of heat per hour. Therefore:

- (AGM) 2.6 watts x 3.4129 BTU per hour/watt = 8.87 BTU per hour per 12 volt battery
- (Gel) 1.3 watts x 3.4129 BTU per hour/watt = 4.437 BTU per hour per 12 volt battery

Lead Acid Battery and Direct Current Flow

The lead acid battery is an electro-chemical device that produces a constant polarity and amplitude of voltage resulting in a constant direct flow of current (DC or direct current) in a single direction when applied to a resistive load.

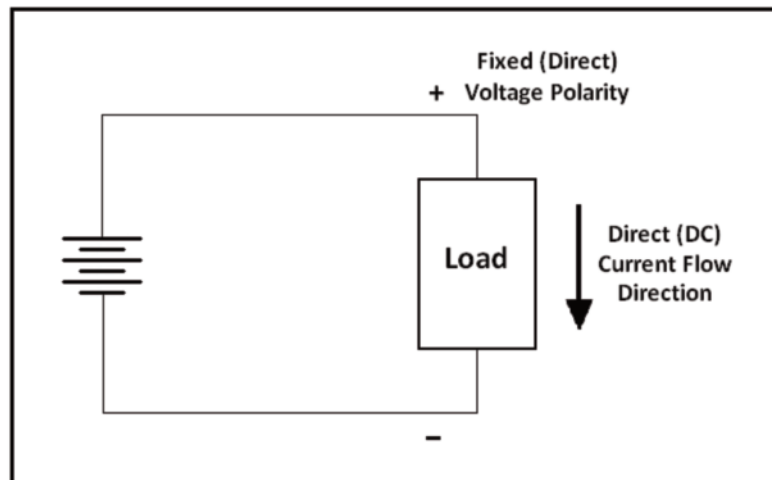


Figure 2 - Direct Current Flow from a Battery

The lead acid battery produces a DC voltage and current on discharge as noted in Figure 2. Likewise, it requires a DC voltage and current for recharging. However, the DC power required for charging is normally generated by converting the commercial AC power to an acceptable form of DC power.

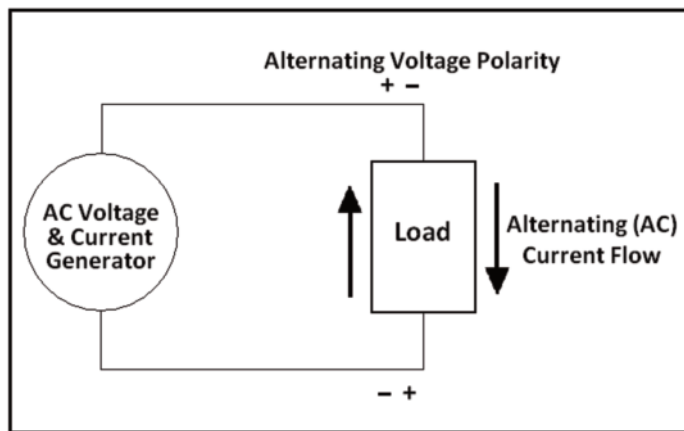


Figure 3 - Alternating Current Flow from a Generator

AC Voltage and Current

The commercial AC power is generated electro-mechanically in the wire windings of the rotating armature of a large generator. This will produce an output voltage, which varies in amplitude and polarity about a neutral point as the generator armature spins. The frequency at which the polarity changes is a function of the armature speed of rotation and is usually 50 or 60 times per second. This is referred to as 50 or 60 cps (cycles per second) or Hertz (Hz) power.

As a result of the voltage polarity changes, the resulting current flow to a load will also change direction and vary in amplitude at the same frequency – hence the name alternating current or AC.

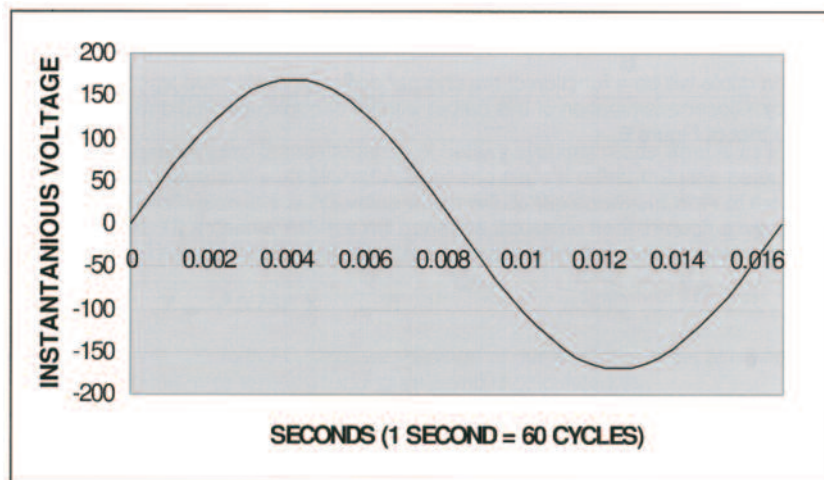


Figure 4 – 120 VAC (rms), 60 Hz (cps) Waveform

Conditioned AC Power for Charging and Ripple Voltage

Commercially available power is AC and as such, it must be rectified to pulsating DC, regulated to the correct amplitude and filtered with capacitors too minimize any remaining AC, thus providing pure DC for charging of VRLA batteries. This may be done via several different techniques however, that of Figure 5 illustrates a typical approach.

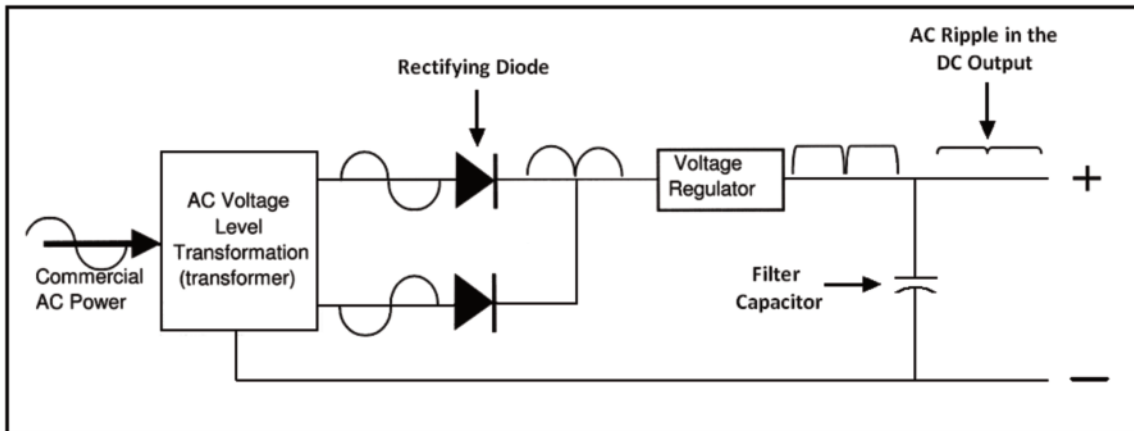


Figure 5 - Battery Charger / Regulated Power Supply

While the rectifying diodes convert the AC power to pulsating DC, the voltage regulator will clip the peaks to the appropriate level for charging of the battery. The filter capacitor will then store power during the peak regulated voltage period to be released during the valleys between cycles, thus "smoothing" the output and minimizing the AC ripple.

As noted in Figure 5 there may be a slight residual AC ripple in the output voltage of the charging system. The total heat dissipated by the battery will be the sum of that generated due to the DC float charging current and any remaining AC ripple current supplied by the charger and flowing through the battery.

The frequency of the ripple will be a function of the charger design and will have less impact the higher the frequency. Closer examination of this output with an oscilloscope would reveal a waveform similar to that of Figure 6.

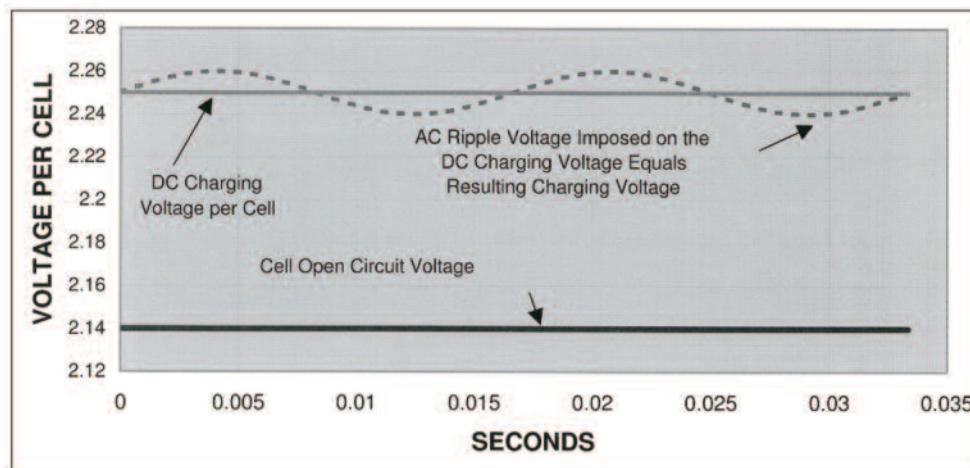


Figure 6 – DC Float Voltage with 0.9% p-p AC Ripple

If this charger output, having an AC ripple voltage of .020 volts peak to peak (p-p) per cell as shown in Figure 6, is applied to a 2 volt cell having a resistance of 0.001 ohms, an AC ripple current of 20 amperes p-p will flow through the cell (20 amperes p-p = 0.020 volts p-p/0.001 ohms) resulting in an additional heating effect.

Rms vs. P-P AC Voltage and Current

Most test equipment used in maintenance of battery systems reads what is called the rms (root mean squared) value of the measured voltage and current rather than the peak to peak (p-p) values. The "rms" value is that AC value which will do the equivalent work of the same DC value. As an example, 10 amperes AC rms will generate the same heat through a resistance, as will 10 amperes DC. The relationship between the rms value and the peak to peak (p-p) value is:

$$Y_{rms} = 0.707 \times (Y_{p-p}/2)$$

For example, the 120 volts AC (rms) we measure at our electrical outlet at home is actually 338 volts peak to peak (p-p) as shown in Figure 4 and is calculated as:

$$120 V_{rms} = 0.707 \times (338 V_{p-p}/2)$$

AC. Ripple Current and Battery Heating

In the preceding example, the 0.02 volts p-p ripple voltage per cell would be measured as 0.007 V_{rms} per cell. This would be 0.3% of the per cell float voltage of 2.25 vdc (0.007 $V_{rms}/2.25v/c$). The resulting AC ripple current would be 7 amperes rms (0.007 $V_{rms}/0.001$ ohms). Note that the ripple voltage is within the typically recommended maximum of 0.5% (rms) of the DC float voltage. However, the ripple current of 7 amperes rms does exceed the normally recommended maximum of 5 amperes rms per 100 Ah rated capacity. This ripple current of 7 amperes will create heating within the 6-cell 100 Ah battery of 0.294 watts ($I_{rms}^2 R_i$). This is in addition to the 2.6 watts created by the electro-chemical float charging reactions within the battery and the $I_{fdc}^2 R_i$ losses. Obviously, excessive amounts of AC ripple current can have a major impact on battery internal heat generation and service life.

The impact of battery heating due to AC ripple current on the service life of a 31 Ah VRLA gelled battery is illustrated in Figure 7.

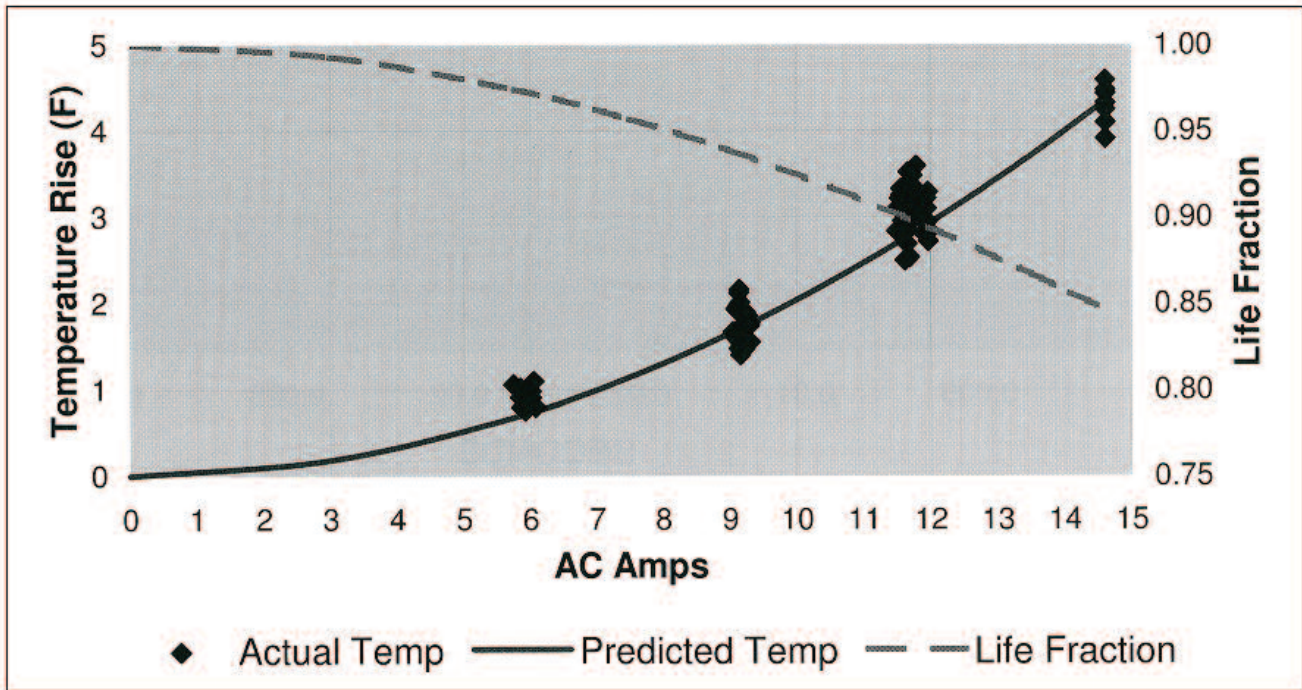


Figure 7

The AC ripple current (I_{AC}) is driven by the AC ripple voltage (V_{AC}) from the charger and will be a function of the cell (battery) internal resistance (R_i) in accordance with ohms law, $I_{AC}=V_{AC}/R_i$.

As can be seen in the equation, $I_{AC}=V_{AC}/R_i$, the AC ripple current will increase with increasing AC ripple voltage from the charger. Also, note that the AC ripple current for a given AC ripple voltage will vary with the internal resistance of the specific battery. For example, a high rate AGM type of cell with a very low internal resistance will experience a greater AC ripple current than that experienced by a higher resistance gelled electrolyte cell with the same applied AC ripple voltage.

AC Ripple Voltage and Battery Gassing

Beyond the concern for heating due to excessive AC ripple current there is the additional concern for battery gassing and dryout due to excessive charging voltages. Consider that the VRLA battery may start to gas at about 2.35 v/c, and that the maximum recommended DC float voltage is 2.30 v/c. It becomes obvious that the ripple voltage should never exceed +/-0.05 v/c (0.1 v/c p-p) or 4.3% p-p (1.5% rms) of the float voltage or the peak voltage would be above the gassing voltage and this will result in electrolyte premature dryout.

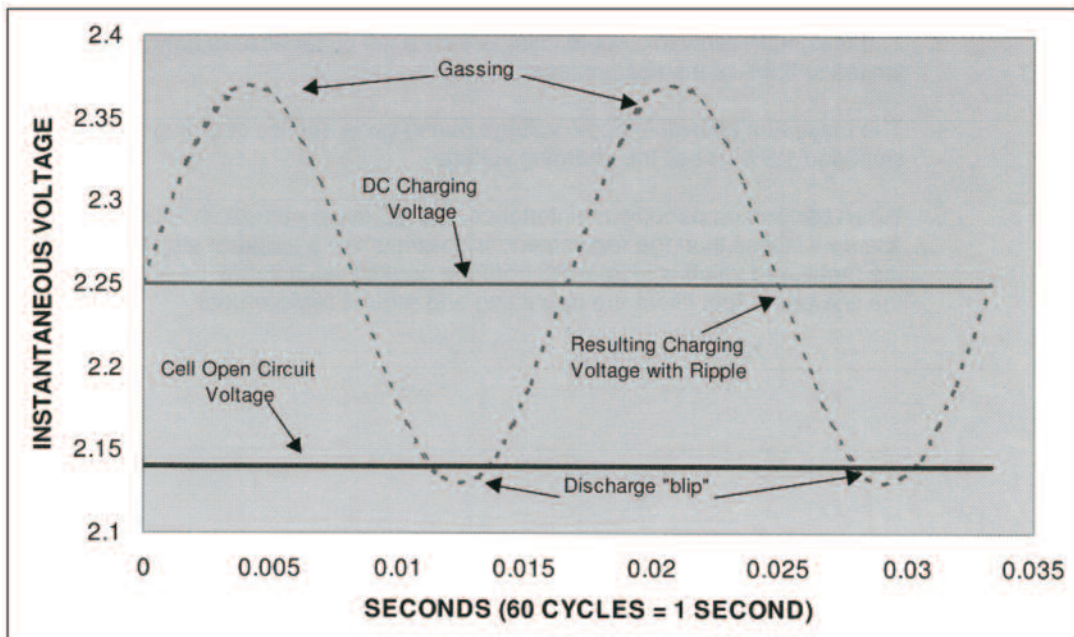


Figure 8 – Extreme AC Ripple Voltage of 9.9% p-p of V_f

AC Ripple Voltage and Battery Cycling

The open circuit voltage of the VRLA battery with $SG = 1.300$ is 2.14 volts per cell. Obviously the charging voltage should not go below this value or the load, which is connected in parallel with the charger and battery, will discharge the battery during that portion of the cycle.

With a float voltage of 2.25 v/c, the ripple voltage must never exceed ± 0.11 (0.22 v p-p) or 9.9% of the float voltage. Should this occur the battery will actually be cycled at the ripple frequency as the resulting charging voltage periodically dips to below 2.14 vdc ($2.25 \text{ vdc} - 0.11 \text{ vdc}$). Again, this would result not only in extreme heating due to the excessive AC ripple current passing through the battery but also rapid deterioration of the plate active material and grid due to cycling.

Recommendations for Optimum Service Life

Based on the preceding comments it is obvious that ideally, there would be no AC ripple in the DC charging voltage. Realistically, this is not always practical from an economic standpoint or even necessary. However, to obtain optimum service from the VRLA battery the following recommendations should be adhered to:

1. The AC powered float charger design should be such to minimize the AC ripple current that will be drawn by the battery during the float phase of charging to less than 5 amperes per 100 Ah of rated battery capacity. This may demand that output ripple voltage be less than the maximum allowed due to the low internal resistance of the specific types of batteries to be float charged.
2. The maximum allowable ripple voltage during the bulk phase of charging should be limited to 1.5% rms of the float voltage and to 0.5% of the float voltage during the float phase.

3. The maximum allowable ripple voltage during the float phase of charging should be limited to 0.5% of the float voltage.
4. The maximum allowable ripple voltage during cycle service charging should be limited to 1.5% rms of the charging voltage.
5. When performing periodic maintenance, the AC ripple current should be measured to assure it is less than the recommended maximum of 5 amperes rms per 100Ah. If the measured value is increasing from the original value it may be an indication that the charger output filters are degrading and require replacement.

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