Effects of AC Ripple Current on VRLA Battery Life

EMERSON™
Network Power

Introduction

Given the importance of battery life to UPS system users and the fact that battery life is negatively impacted by elevated battery temperature, many IT and data center managers are concerned about the internal heating effects of battery ripple voltage and current present in UPS systems. Data reported by critical power engineering consultants and service personnel indicate that some UPS systems may generate ripple current above the battery manufacturer's recommended levels.

Research into ripple current effects shows that while battery ripple current may exceed the battery manufacturer's guidelines, as long as the ripple current is not excessive (more than 3 to 4 times the recommended level) the resulting internal heating effects are minimal, and reduce the statistical expected life by only a few percentage points.

Ripple voltage

Battery manufacturers recommend that under normal float charge conditions, battery ripple RMS (Root Mean Square) voltage must be limited to <0.5 % of the DC voltage applied to the battery.

$$\text{Ripple Voltage (E)} < 0.5\% * \text{normal float charge conditions } (V_{float})$$

This ensures that the instantaneous cell voltage will not fall below the open cell voltage or rise above the maximum float charge voltage. It also eliminates the consequential battery heating that would occur from constantly cycling the battery through discharging and recharging states.

Ripple current

It is a misconception that as long as the battery ripple voltage specification is adhered to, then the ripple current created by this voltage must also be acceptable. This is not necessarily true since by Ohm's law, the ripple current is a direct function of the ripple voltage applied to the battery, as well as the internal cell resistance of the battery.

$$I = E / R \text{ (Ohm's law)} \rightarrow \text{ripple current (I)} = \text{ripple voltage (E)} / \text{cell resistance (R)}$$

Because batteries have internal impedance or resistance, ripple current flowing into a battery at normal float charge conditions can cause heating due to simple power dissipation heating (based on $I^2 R$ losses). Battery manufacturers typically recommend that the ripple current into a VRLA (sealed lead-acid battery) jar be limited to a value of the 20 hour discharge rate Amp-Hour Capacity divided by 20 (C/20 @ 20hr rate). As an example, the maximum ripple current for a typical AGM (absorbent glass mat) 12 volt 100 Ah VRLA battery (@ 20hr rate) would be 100/20 or 5 amps (I).

Ripple current power dissipation

This type of battery may have an internal impedance of 2.5 milliohms (R), so the power dissipation would then be:

$$I^2 R = (5 \text{ amps})^2 * 0.0025 \text{ ohms} = 0.062 \text{ watts}$$

According to battery manufacturers, this level of ripple current will not cause any appreciable battery heating.

As previously stated, the level of ripple current present in a particular battery depends not only on the ripple voltage present, but also on the internal cell resistance of the battery. For example, using the 12 volt 100 Ah battery example above and assuming some nominal battery string wiring and connection impedance of 0.5 milliohms, if the maximum ripple voltage (0.5% of the recommended float voltage of 13.5 volts per jar) is applied to this battery, the resulting ripple current would be:

13.5 volts * 0.5 % / (0.003 ohms [internal + interconnect impedance]) = 22.5 amps

This is well above the 5 amps (C/20) recommended maximum ripple current for this battery.

This brings the discussion to the issue the level of ripple current seen in UPS systems. For a typical 540 volt DC bus system, depending on the rectifier and inverter topology employed, the ripple voltage present on the UPS DC bus has been observed to be as much as 2 volts RMS. While this is well below the maximum ripple voltage specified (540 * 0.5% = 2.7 VRMS max.), it can result in battery ripple current in excess of the recommended level.

Assuming a 40 jar battery string (13.5 volts float voltage * 40 jars = 540 volts DC bus) with the same battery example being used above, the ripple current would be:

(2 volts / 40 jars) / 0.003 ohms = 16.6 amps (≈ 3 times the recommended 5 amps max)

So, the question becomes, what is the result of exceeding this specification? What is the magnitude of the cell heating effect and how does it impact battery life?

Predicting the heating effect of ripple current

As discussed previously, the amount of heating caused by ripple current is directly related to the magnitude of the current and the internal impedance of the battery (I^2R losses). At sufficiently high levels of ripple current, Faradaic (electrochemical) heating can also occur, but as long as the ripple current does not cause the cell voltage to exceed the maximum recommended float voltage or fall below the open cell voltage at which discharging occurs (2.14 V), then this effect is insignificant. According to a paper published by C&D Technologies [1], at float conditions, battery heating is almost solely due to ohmic (resistive heating) rather than electrochemical heating.

Therefore, using basic thermodynamic principles, an equation for calculating internal battery temperature rise as a function of battery ripple current can be derived. Starting with the basic equation for heat conduction:

$$h \text{ (watts)} = H \text{ (heat transfer coefficient)} * A \text{ (area)} * \Delta T$$

Where:
h = heat generated by the I^2R losses in the battery
    (I = AC ripple current, R = battery internal resistance)
H = heat transfer coefficient of the battery
A = effective surface area of the battery jar or case in meters^2
ΔT = temperature rise of battery above ambient, T battery - T ambient

Taking a specific battery as an example, the manufacturer's battery specification data sheet for the C&D UPS12-490MRLP battery shows the internal resistance to be 0.0023 ohms and the case dimensions to be 323 x 166 x 213 mm. The heat transfer coefficient for this battery is approximately 4.6 W/m2/ °C [2].

Rearranging the above equation to get an equation for temperature rise as a function of ripple current:

$$\Delta T = I^2 R / (A * H)$$

For the UPS12-490MRLP battery (and converting °C to °F):

$$\Delta T = I^2 * 0.0023 \,/\,(0.315 * 4.6) * 1.8 \text{ °F/ °C} \approx 0.0028 * I^2 \text{ °F}$$

Summarizing, the temperature rise in degrees F will be 0.0028 times the RMS ripple current squared.

Using this equation and the rule of thumb for battery life vs. temperature (50% reduction for 10 °C, or 18 °F rise) based on the Arrhenius equation[3], a curve can be generated showing temperature rise and predicted battery life as a function of ripple current.

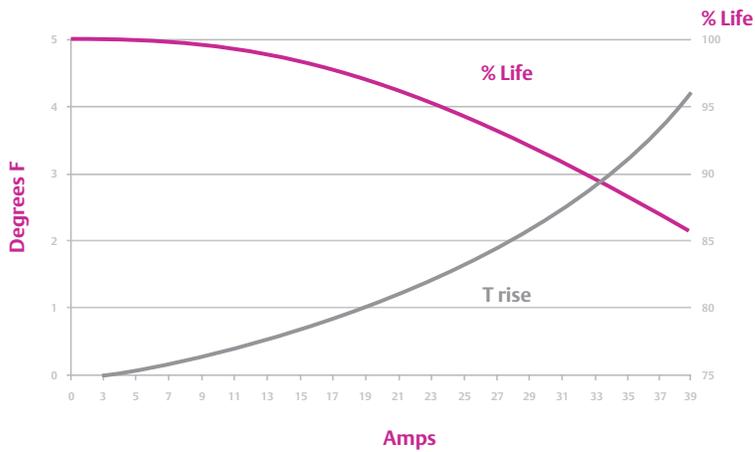Figure 1 shows the curve generated for ripple current values of 1 through 40 amps.

% Life

% Life

Degrees F

T rise

Amps

Fig. 1 Ripple Current vs. Temperature Rise and % Expected Life Remaining
C&D UPS12-490MRLP Battery

The curve predicts that at 17 Amps (more than 3 times the recommended C/20 ripple current) there is less than 1 ° F battery heating. This reduces battery life by approximately 3%.

Figure 2 demonstrates that the results of lab testing for the UPS12-490MRLP battery verify the calculated values from the chart of figure 1. The internal battery heating for this battery at greater than 17 amps ripple current was 0.44 °C, or approximately 0.8 °F. Similar results were shown and documented[4, 5, 6] for extensive tests on additional battery samples. Shown below in figures 3 and 4 are example results for other battery models and manufacturers. These batteries have similar ratings, so similar temperature rise values would be expected.
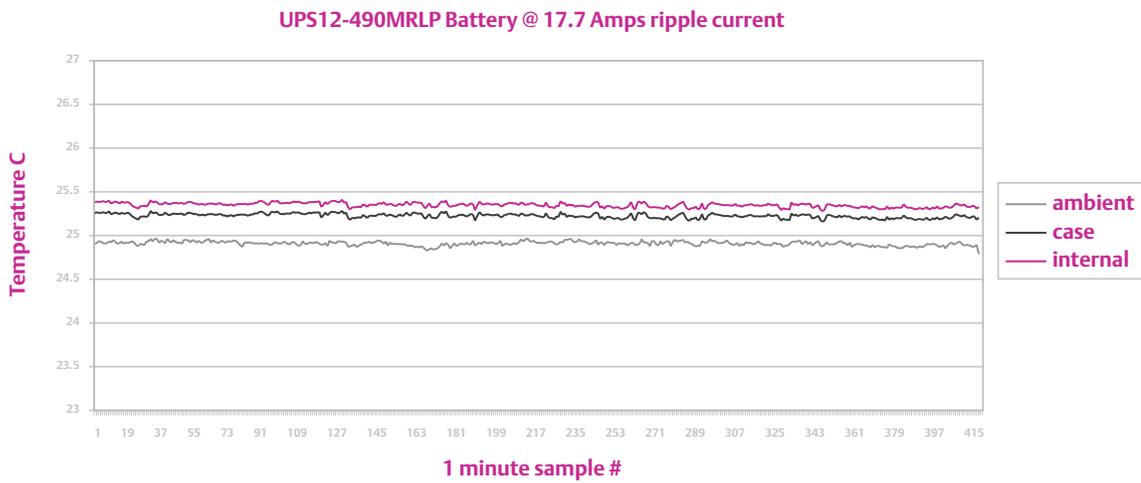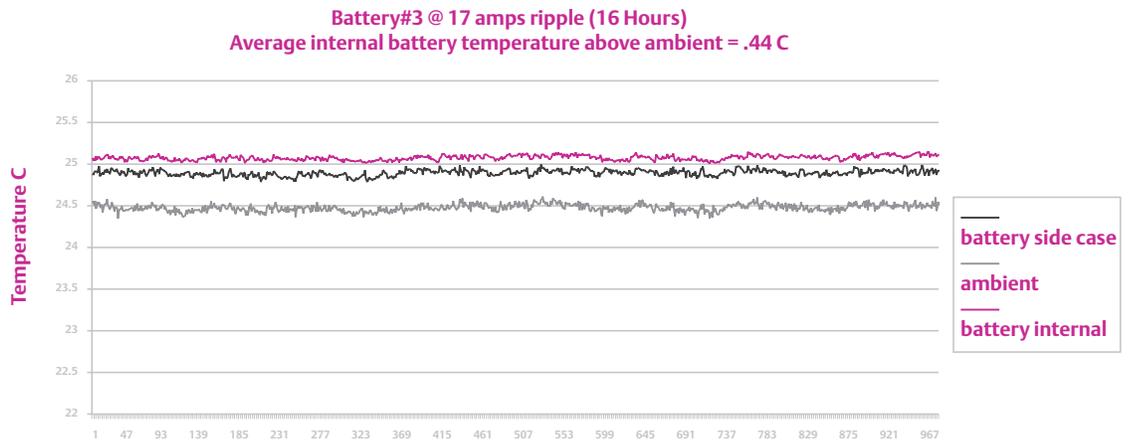

UPS12-490MRLP Battery @ 17.7 Amps ripple current

Temperature C

ambient
case
internal

1 minute sample #

Fig. 2 C&D UPS12-490MRLP Battery

Battery#3 @ 17 amps ripple (16 Hours)
Average internal battery temperature above ambient = .44 C

Fig. 3 C&D UPS12-400MR Battery

Enersys Battery @ 17 amps ripple (6 hours)
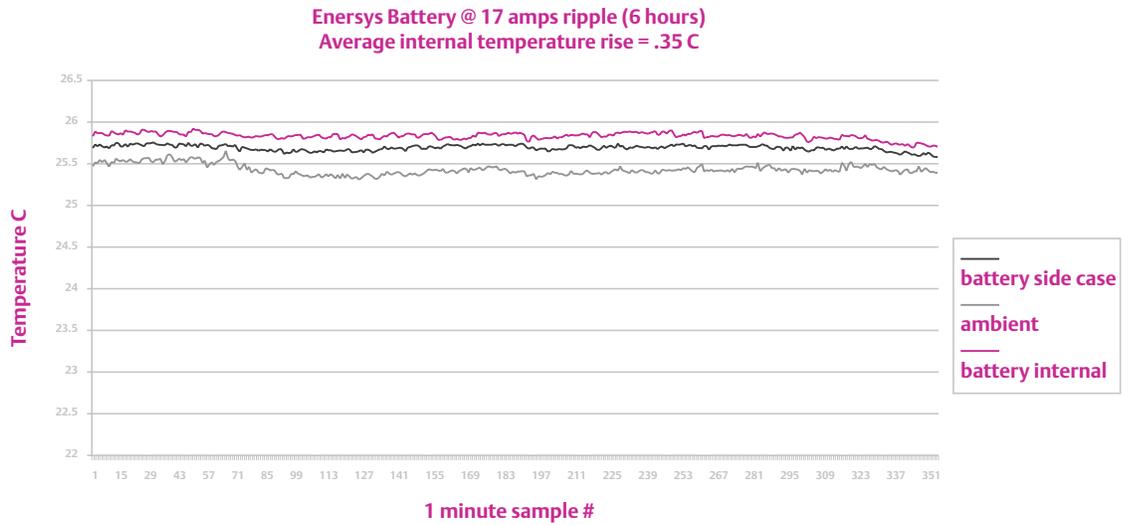**Average internal temperature rise = .35 C**

Fig. 4 EnerSys 12-HX505-FR Battery

The analysis method also applies to other VRLA battery Amp-Hour ratings with a similar minimal temperature rise expected at proportional ripple currents for the battery rating. Naturally, higher rated batteries would have higher recommended ripple current values, and since power varies with the square of current, far more potential heat generation would be expected. However, the internal impedance (thus the power dissipation at a given current) varies inversely and the physical dimensions (thus surface area and heat transfer capability) vary proportionally.

These two facts tend to counter the significantly different temperature rise that would otherwise be created by higher ripple current. For a given ripple current to battery Amp-Hour rating ratio, the net result yields a slightly higher temperature rise for larger batteries and smaller temperatures rise for smaller batteries. Table 1 shows predicted temperature rises for size of batteries other than those for which detailed analysis was outlined in this report.

C&D Battery Model #	20 Hr rating	Predicted Temp rise @ 3 times recommended ripple
UPS12-100MR	26.0 Ah	0.26 °F
UPS12-150MR	34.6 Ah	0.41 °F
UPS12-210MR	53.8 Ah	0.56 °F
UPS12-300MR	78.6 Ah	0.84 °F
UPS12-350MR	93.2 Ah	0.78 °F
UPS12-400MR	103 Ah	0.74 °F
UPS12-490MR	141 Ah	1.02 °F
UPS12-540MR	149 Ah	1.18 °F

Table 1 Predicted Temperature Rise for C&D High Rate Max Series

Conclusion

Analysis and subsequent battery testing demonstrates that the heating effects of battery ripple current can be predicted. Furthermore, at battery ripple current level of approximately 3 times the recommended, the heating effect is minimal, typically less than 1 ° F. This results in less than a 3% impact on battery life.

It may be noted that a 1 degree change in battery temperature is most certainly within the temperature variation that would occur in battery cabinet ambient temperature; even in a well controlled environment. Informal site surveys have shown that it is not uncommon for battery room temperature to vary as far as 3 degrees above the recommended 77 ° F.

Applicability of Analysis

The analysis contained in this report applies to VRLA batteries, which are similar in design and construction and have internal impedance characteristics equivalent to those such as the UPS High Rate Max series manufactured by C&D Technologies or the DataSafe HX series manufactured by EnerSys. These types of batteries employ absorbent glass mat technology, are constructed in thermoplastic cases, and typically have an upper capacity range limit of approximately 600 watts/cell.

References

1. S. Gerner, T. Ruhlmann (Dynasty Division, C&D Technologies), "Effect of AC Ripple on VRLA Battery Performance.
2. S. Gerner, G Brilmyer, D. Bornemann (Specialty Battery Division, Johnson Controls, Inc.), "Thermal Management of Valve Regulated Lead-Acid Batteries. A Comparison of Gelled vs. Absorbed Electrolyte Technologies", Intellec Conference Proceedings, 1990.
3. The Arrhenius equation relates temperature to chemical reaction rates, basically stating that the rate of a chemical reaction process (for example, a lead acid battery) will double for every 10 °C rise in temperature. See "Battery Life and How to Improve It"
   @ www.mpoweruk.com/life.htm
4. Ripple Current Testing on C&D UPS12-490MR/490MRLP Battery
   Liebert Corp (10/9/2009)
5. Ripple Current Testing on C&D UPS12-400MR Battery
   Liebert Corp (12/15/2009)
6. Ripple Current Testing on EnerSys 12HX505-FR Battery
   Liebert Corp (1/13/2010)

Emerson Network Power.
The global leader in enabling Business-Critical Continuity™.   **EmersonNetworkPower. com**

- AC Power
- Connectivity
- DC Power
- Embedded Computing
- Embedded Power
- Monitoring
- Outside Plant
- Power Switching & Controls
- Precision Cooling
- Racks & Integrated Cabinets
- Services
- Surge Protection