EAGLE EYE TECHNICAL NOTE

Title	**Lead-Acid Batteries and Ripple Voltage and Current. Is There a Problem?**
Document No.	**TN-082222-1**

Revision History

Date	Revision	Change Description	Author(s)
08/22/22	0	Original document	JAB

First of all, a definition.

Ripple is the AC component of a system's charging voltage imposed on the DC bus. It can also be reflected from load equipment. It could be caused by poor charger design, poor inverter design, failing capacitors, or by the interaction of load equipment connected to the DC bus. The result is a ripple current flowing into the battery. The amplitude of the ripple is primarily the result of the rectifier/charger design, charger output filtering, and the type and magnitude of the load placed in parallel with the battery.

What are the concerns?

Ripple voltage and the resulting ripple current imposed on a battery DC bus could have an adverse effect on the battery and electronic equipment connected to the battery. Consequently, this ripple should be taken into consideration when maintaining, testing, and monitoring a battery. Ripple is not to be confused with noise.

Some history.

In 1986, a paper was published in the *Journal of Applied Electrochemistry* titled "Influence of Superimposed Alternating Current on Capacity and Cycle Life for Lead-Acid Batteries."[1] The paper stated that "Capacity and cycle life have been measured for commercially available lead-acid batteries by superimposing an AC upon the charge and discharge DC to clarify the influence of an AC invasion into the DC system on battery performance in an electric power storage system." "…Thus, it was clarified that the influence of the AC superimposition on battery capacity and cycle life is practically negligible for lead-acid batteries."

Well, things have changed a little bit since then. For a start, the tests were carried out on Vented Lead-Acid (VLA) batteries and not the somewhat smaller capacity Valve-Regulated Lead-Acid (VRLA) batteries, which could be more susceptible to ripple effects and are more predominant today. As battery manufacturers, maintenance companies and individuals started looking into the failures of VRLA batteries, the question of possible effects of ripple began to arise.

At the Intelec conference in 1988, a paper was presented by David Wilson of C&D Charter Power Systems titled "The Measurement of Ripple Current in Battery Plants."[2] In the paper, the author stated that "Recently the users of UPS have become concerned with the wear-out of battery systems." It mentions a Draft Standard for the Selection of Batteries in UPS Applications and states that "While many papers are written about battery plants, ripple voltages, cycling, and applications, no information was available on ripple currents. The draft standard mentioned was to become IEEE Std 1184-1994.[3]

Moving fast forward to 1995. There was a *High Frequency Power Conversion Conference* in Santa Rosa, CA. and under the banner of a *Battery Systems Engineering Forum*, there was a session on "Analysis of Battery Field Failures." This author was a member of the panel that looked at battery failure, particularly with UPS applications, and presented a paper that examined the perceived extension of battery life on a UPS battery when using a charging topology that involved switching the charger off when the battery was fully charged and only switching it on again when the battery voltage had decayed to a predetermined level.[4]

This conference was quickly followed in 1995 by a *Power Quality Conference* in Long Beach California[5] where there was a heated discussion on VRLA battery failures (this conference was one of the catalysts in the founding of the Batttcon Conference).

In the late 1990's, the battery manufacturer C&D Technologies came out with a pamphlet on ripple. This was titled *Charger Output AC Ripple Voltage and the Effect on VRLA Batteries*.[6] This was followed up at the Battcon Conference in 1999. A paper titled "Effect of Ripple on VRLA Battery Performance" was presented by the Dynasty Division, C&D Technologies.[7] It stated that "Superimposed AC ripple on lead-acid batteries used in float service has the potential to produce battery heating, depending upon the AC magnitude and frequency. Battery service life is roughly halved the life for every 10ºC increase in temperature. To date, few actual test results have been published to equate the magnitude of AC ripple with the resulting temperature rise and actual impact on service life. In this paper, we present actual VRLA product responses to AC ripple and discuss the potential impacts on life."

At the same time, the IEEE, in what was then the IEEE Power Engineering Society Standards Coordinating Committee 29, opened a Provisional Authorization Request (PAR) 1491 with the objective of writing a guide to battery monitoring which would include ripple current and voltage.[8]

At the 2004 Battcon Conference, a paper was presented by Polytronics Engineering, Inc. titled "Electrical Noise in Battery Installations." It stated that "AC presence across the battery significantly complicates the extraction of the battery conditions from on-site voltage and current measurements. Battery monitoring equipment, in particular, is prone to this problem especially since the frequency, phase and amplitude of the AC is not known before installation and may change with time."[9]

Again, at a Battcon Conference, this time in 2007, a paper titled "AC Ripple Currents in UPS DC Links" was presented by GE Zenith Controls, Inc.[10] It stated that "Most people point to the rectifier as the source of the AC ripple currents in the DC link. However, the inductance of the DC filter blocks most of the ripple current from the rectifier. Unless the rectifier has a malfunction, such as a missing drive signal, the current from the rectifier to the DC link will be smooth with very little ripple. The majority of the AC ripple current actually comes from the inverter as it converts the DC power into AC power. Balanced linear loads (loads with sine wave currents and no harmonic currents) produce the least ripple in the DC link current."

So, what is the current position of the various codes and standards, manufacturers, testers and maintainers?

The IEEE and Ripple Voltage and Current.

In 1994, the IEEE released IEEE Std 1184, *IEEE Guide for Batteries for Uninterruptible Power Supply Systems.*[11]

The current edition in section 6.2.2 AC Ripple Current, states:

"AC ripple currents can cause overheating in VRLA batteries and may also have detrimental effects on VLA and, to a lesser extent, Ni-Cd batteries. UPS applications can place unusual conditions on a battery. Typically, UPS battery design seeks excellent short-term, high-rate current characteristics, which, in turn require the lowest possible internal cell resistance. This low resistance allows a lower impedance path for the ripple current coming out of the rectifier stage of the UPS than the filter capacitors in the output of the rectifier.

In addition, the inverter stage of the UPS requires large transient currents as it builds AC power from the parallel rectifier/battery combination. With a (high impedance) AC power source, short-term, instantaneous load current changes will be drawn from the lower impedance battery. These factors may result in a relatively high AC component in the battery. At present, manufacturers place no warranty penalties on VLA cells operating in a high ripple current environment, but some manufacturers do publish maximum allowable ripple for VRLA. Ripple is an important consideration in affecting design life and it is advisable to maintain the rectifier filters as prescribed by the manufacturer."

The IEEE also developed IEEE 1491, *IEEE Guide for Selection and Use of Battery Monitoring Equipment in Stationary Applications*

Section 6.8 deals with ripple voltage. Under the headings of Purpose of Monitoring and Indications and Interpretations, it currently states that "Monitoring can detect the presence and indicate levels of ripple voltage. Significant levels of ripple voltage would indicate the need for corrective action within the system's electronics. High ripple voltage could also lead to damage of the battery cells from either heating, gassing, or cycling." And "The normal level of ripple voltage for each system must be individually determined by initial and ongoing measured values. Consult the battery manufacturer for the upper limit of ripple voltage. Monitoring the exact value of this parameter is not as important as trending the value as the system ages. Escalating ripple voltages can cause higher than normal water usage in VLA cells and premature dry-out in VRLA cells. Higher than normal ripple voltages can often indicate a failure in the dc filter assembly or a defective semiconductor in the rectifier bridge."

Section 6.9 deals with ripple current. It basically follows the statements in 6.8. but goes on to say that "All of the adverse effects of ripple current are not fully understood other than the heating effect, gassing, and high frequency cycling of the battery, which will result in a reduced life expectancy."

An informative annex on the subject of Ripple Voltage and Current was also written for IEEE 1491. This is currently Annex A. In the Overview it states that "Ripple voltage and the resulting ripple current imposed on a battery DC bus can have an adverse effect on the battery and electronic equipment connected to the battery. Consequently, this ripple should be taken into consideration when monitoring a battery. Ripple is not to be confused with noise."

There is a wealth of information in this annex, and it deals separately with Telecom, UPS and Utility applications. In the conclusion it states that "All of the adverse effects of ripple current are not fully understood other than the heating effect, gassing, and high frequency cycling of the battery which will result in a reduced life expectancy. Some battery manufacturers specify the maximum permissible ripple only in the form of the permissible ripple voltage. However, the user should use this limit with caution in that the resulting ripple current and resulting heating will be a function of the internal impedance of the battery. A lower internal impedance will result in higher ripple current, and a higher impedance will result in lower ripple current. The user should use this information with the understanding that although the battery may tolerate a certain degree of ripple voltage, the load may not. For instance, in telecommunication systems, the load may not tolerate a ripple voltage higher than 0.1%, whereas the battery might not be affected by a ripple voltage even five times greater."

Manufacturers and Users perspectives.

In 2010, Emerson Network Power (now Vertiv) published an excellent white paper titled *Effects of AC Ripple Current on VRLA Battery Life.*[12] It mainly addresses the heating effect of ripple because, as it stated, "…many IT and data center managers are concerned about the internal heating effects of battery ripple voltage and current present in UPS systems."

With regard to battery manufacturers point of view it stated, "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." It goes on to say that "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 (Ohm's law) → ripple current (I) = ripple voltage (E) / cell resistance (R)."

"Battery manufacturers typically recommend that the ripple current into a VRLA (sealed lead-acid battery) jar (sic) 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)." According to battery manufacturers, this level of ripple current will not cause any appreciable battery heating."

In its conclusion, the white paper states that "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."

A summary of the contents of the Emerson White Paper and other contributions regarding ripple voltage and current were the subject of a special tutorial session that was part of the IEEE Power Engineering Society Winter Meeting in Tucson, AZ.[13] This author was the chair of that session and can certainly recommend that the contents be researched for some excellent information.

The North American Electric Reliability Corporation's (NERC) Reliability Standard PRC-005 in the section applicable to batteries makes no mention of ripple voltage or current.[14]

Conclusion.

The IEEE does not recognize the measurement of individual cell ripple voltage and current as an indication of battery state-of-health. It does; however, recognize that AC ripple can be detrimental to the performance of a battery. Some manufacturers do publish maximum allowable ripple for VRLA batteries. It is not known if there is a battery manufacturer that will accept ripple measurements as a standalone means of submitting a warranty claim. One manufacturer, for example, makes the following statement:

"Ripple is the poor man's impedance measurement. It is only effective when there is a very high signal (bad power) and very degraded batteries (lug corrosion or similar open type failure modes). In addition, one very bad battery may absorb all the ripple voltage – when that is taken out there may be other batteries that then spike. It can be used as an indication further testing is needed; however, warranty cannot be based on it."

The views on the effect of ripple on stationary batteries are still being debated, especially in the UPS sector. This author, in engaging in a conversation with a well-respected subject matter expert (SME) was told by the SME that,

"The views on ripple are still changing. Ripple current and voltage is worthless for telling you about the state of health of a battery today. In times past, when the load current was reflective in current pulses from the UPS, and loads did not vary by the hour, it might have told you something. Ripple today is more directly related to UPS design and health than battery health. Worse so, we have found it is completely unrepeatable. Take a meter or analyzer to measure ripple and come back in a day and measure again. The values vary by such a significant value that you can neither baseline nor set alarm points. We do 70,000+ inspections a year at my company, always measuring ripple. It tells us something about the UPS and capacitors, but zero about the batteries."

This author’s contribution to that conversation was as follows,

“I seem to remember back in the early days of UPS's that measuring ripple was deemed by one company (I think it was his company) that measuring battery ripple voltage and current was a good way of estimating battery state-of-health. However, I think that notion was dispelled by many in the battery community. It is often used by battery maintenance companies as a down and dirty way of performing maintenance without using a good battery testing device such as an impedance, resistance, or conductance meter. I think that the ripple values measured can be very misleading. The IEEE Power and Energy Society's Stationary Battery Committee has debated the issue extensively."

It is known that most battery manufacturers do not accept ripple measurements as a basis of warranty claims. If there is a manufacturer out there that does, the author would like to hear from them.

This is basically Eagle Eye Power Solutions' position on the subject. Any warranty claim submitted based on ripple measurements should show trending data and should also be accompanied by voltage and ohmic measurement data. A battery load test may also be necessary.

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