Technical Note

PowerDesigners

Negative Pulse Charging: Myths and Facts

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Introduction

Fast charging of industrial batteries is poised to become a main stream charging technology due to the operational savings and the increased productivity and safety that this technology offers. Users are realizing the benefits of fast charging as fast charge systems are already buzzing at manufacturing plants and distributions centers all around the US.

Some of the fast charging systems presently available incorporate negative pulse fast charging algorithms that claim to have great benefits to batteries including reduced recharge time, lower temperature rise, full recharge capabilities, as well as shorter equalization times. These claims are not new and this paper will shed some light on the history and realities of negative pulse fast charging techniques and attempt to separate fad from reality.

I. Negative Pulse Charging Defined

Negative pulse charging schemes generally consist of the one or more of the following charging sequences:

- A positive charging pulse
- A rest period (no charging)
- A discharge pulse (burp)

The sequencing, duration, and the repetition rate of each of the above sequences can vary (Fig. 1). Many patents and claims have been filed in this field since the late 1960s, so this is by no means a new discovery.

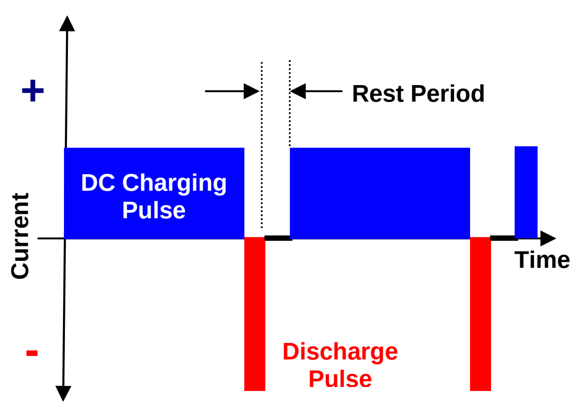

Fig. 1: Generic Negative Pulse Charging Scheme

II. Brief History of Negative Pulse Charging

The concept of applying a short discharge pulse during the charge cycle sometimes referred to as "reflex charging" or "burp charging" started with patents 3,597,673 “Rapid charging of batteries” W. Burkett & J. Bigbee in 1971 and 3,614,583 "Rapid charging of batteries" in 1971 by W. Burkett & R. Jackson [1].

After the first patent was awarded, the patent holders took it to General Electric, then the leading Ni-Cd manufacturer in the US, where it was analyzed in detail. **After extensive testing, GE could not find any conclusive evidence that the negative pulse offered any advantage** [1].

With the expiration of the original patents, many continued to make similar claims and many users bought into these claims. General Electric, confronted by battery customers who had bought into the Burkett scheme of charging, tested and retested the concept as each new variation was presented. The results were the same in each instance. **It has never been demonstrated to have any advantage over conventional charging, either on charge efficiency, the performance or the life of the battery.**

While many claims have been attributed to this technique, **none have ever been substantiated in the laboratory**. Fortunately it does not harm the battery in any way and since the concept makes for a rather **elegant marketing concept**, it has been adopted as a way to promote the sale of charging systems by numerous companies in which marketing dominates technology.

III. Selected Issued Patents in this Field

Since Burkett original patent, many patents have been issued claiming variations of his original patent. These patents differ in the following:

- Make up of the charging sequence, i.e. whether discharge pulses are incorporated or not
- The amplitude and durations of each sequence
- The repetition rate

The following table lists some of the patents issued in this regard.

Table 1: Selected Pulse Charging Patents

US Patent #	Issued	Inventor	Main Features
3,597,673	1971	Burkett et. al.	♦ Rapid Charging < 15 min ♦ Discharge pulses incorporated (100% of nom. rating), < 5µs ♦ Stabilize / rest periods may be incorporated between charge and discharge pulses
3,614,582	1971	Burkett et. al	♦ Rapid Charging < 1 hour ♦ Discharge pulses incorporated (100% of nom. rating), < 5µs ♦ Stabilize / rest periods may be incorporated between charge and discharge pulses
4,499,415	1985	Itoh (Minicam Research Corporation)	♦ Rapid Charging (NiCd) < 1 hour ♦ Pulse charging with rest periods (5% duty cycle) ♦ Terminate during rest period
4,829,225	1989	Podrazhansky et. al.	♦ Rapid Charging < 1 hour ♦ Charge pulses 0.1-2 seconds ♦ Discharge pulses (1C), 0.2%-5% duration ♦ Rest periods after discharge pulses
5,304,611	1993	Nor et. al. (Norvik / Edison)	♦ Rapid charging < 1hour ♦ Charge pulses ~ 1 second ♦ Stabilize / rest pulses of zero current (0.05C - 0.2C) ~ < 500 msec ♦ Determining resistance free voltage
5,680,031	1997	Nor et. al. (Norvik / Edison)	♦ Rapid charging < 1hour ♦ Charge pulses ~ 1 second ♦ Stabilize / rest pulses of non-zero current (0.05C - 0.2C) ~ < 500 msec ♦ Determining resistance free voltage
5,905,364	1999	Ookita (Brother Kogyo Kabushiki Kaisha)	♦ Rapid charging < 1hour ♦ Charge pulses ~ 1 second ♦ Stabilize / rest pulses ~ 100 msec ♦ Battery Voltage sensed during rest mode
5,998,968	1999	Pittman et. al. (Ion Control Sultions)	♦ Rapid charging < 1 hour ♦ Charge pulses ~ 100 msec ♦ Stabilize / rest pulses ~1 msec ♦ Discharge pulses (1C) ~ 2 msec ♦ Determining resistance free
6,388,425	2002	Petrovic, V. (Accelrate)	♦ Rapid Charging 1-2 hours ♦ Charge pulses (0.6C) 2 minutes ♦ Discharge pulses (0.05C) 15 sec ♦ No Communization (!)
6,841,974	2005	Dykeman; S. (HDM Systems Corp)	♦ Rapid charging ♦ Charge pulses ~ up to 2 seconds ♦ Discharge pulses ~ 20 msec ♦ Requires monitoring

IV. Negative Pulse Charging Claimed Benefits: The Research Approach

In the scientific / research field, where I come from, scientific research methods are used to establish any claims made. This is how we separate fads from reality and this is how claims are accepted by scientists and researchers world wide. Given the above, and in order to establish the claimed benefits of any negative pulse charging scheme, one has to establish experiments with clearly measured performance parameters that can be easily repeated.

One approach to establish the benefit of any negative pulse charging scheme is to run a controlled experiment where all the parameters are controlld except for the test parameters. For example, if one wants to establish the benefit of negative pulse charging (burp charging) on the battery, one need to do the following:

- Start with two batteries of the same age, model, capacity and voltage
- Establish the same operating conditions for the batteries (same loading, temperature, watering, …)
- Charge the two batteries using the same charger, same charging algorithm with one having the discharge pulse incorporated while the other without
- Cycle the two batteries through significant portion of their life cycles. Ideally, the test should run through the battery life cycle to establish distinct performance benefits
- Establish test criteria, such as capacity tests every 50 or 100 cycles, to assess any performance improvement with one charge cycle versus the other

One of the products that PowerDesigners developed is a battery equalizer, which equalizes series connected battery strings, used the above stringent research method to establish the benefits of such technique. You can refer to our white paper on this at: http://www.powerdesigners.com/pdf/PowerCheq%20Paper%20-%20Motive%20Power.pdf.

Unfortunately, since the first concepts of negative pulse charging were introduced, **there has been no scientific study conducted to establish any benefits and thus there has been no conclusive evidence to the any of claimed benefits.** Much of the data in circulation today show data with respect to nothing or comparing the performance of such algorithms with that of conventional chargers (**the typical case of comparing apples to oranges**).

On the scientific end of it, **there have been a number of studies concluding the negative, i.e. no benefits of any of these schemes**. A major study was conducted by Jung-Chieh Cheng for his Masters Thesis work at the National San-Yat Sen University, in Taiwan in 2002 [2]. Jung attempted to test various pulse charging schemes with and without discharge pulses and their impact on charging efficiency and charging rates. The following is a excerpt of the abstract of his thesis:

> *Unfortunately, the experimental results reveal that **charging efficiency is not obviously affected by pulse amplitude, duty ratio or frequency**. Instead, **charging rate is dominantly influenced by average charging current**. These results indicate that **pulse charging scheme is not superior to constant current charging**. To compare these two charging schemes further, a series of experiments are carried out to discuss the effects of each operating variables. Unfortunately, no evidence from the experimental results can prove the superiority of pulse charging to constant current charging as formerly documented.*

Another paper by a scientific team in New Zealand show very little improvement in charging efficiency [3]. The following is a excerpt of the abstract of the published paper:

> *The inclusion of a small discharge pulse gives a **slight improvement in charging efficiency** without reducing the charging time, despite the initial lower average current.*

The above study was conducted on a sealed lead acid battery and after some discussions with the lead researcher, he pointed out that the **tests were neither complete nor conclusive**. In addition, the study was only conducted over few charge cycles and didn't extend to show any improvement over the battery life cycle.

V. Negative Pulse Charging Myths & Facts

The following is a list of all myths related to pulse charging algorithms with the clarifying facts:

Myth 1:

Negative pulse charging algorithms result in **faster recharge rates compared to constant current charging**

Fact 1:

There has been no substantiated scientific evidence to prove that. In fact, the Masters Thesis referenced in [2] **conclusively found that the recharge rate is a function of the charging current and nothing else**.

Myth 2:

Negative pulse charging algorithms result in **lower temperature rise compared to constant current charging.**

Fact 2:

Temperature rise is a function of many variables including:

- The charging rate (% of capacity)
- Gassing voltage
- Temperature compensation
- Run cycle characteristics (note fast charge operated battery operates at elevated temperatures due to the lack of rest time)

A controlled charging process with temperature compensation **can achieve very low temperature rise**. Add to that, **there has been no established evidence that negative pulse charging have lower temperature rise compared to constant current charging using the same charging criteria**.

Again, many tend to compare their pulse charging method, which may have controlled temperature profile, with standard chargers without any temperature controls. This is no evidence of the benefits.

Myth 3:

Negative pulse charging can recharge a battery up to 100%. No need to stop at 80%

Fact 3:

All charging schemes can bring a battery to 100%. The only difference is that **above 80% - 85% the charging process needs to be controlled to allow the battery to accept proper charge**.

In flooded batteries the main side reactions are oxygen evolution at the positive electrode

$$H_2O \rightarrow \tfrac{1}{2}O_2 + 2H^+ + 2e^-$$

and hydrogen evolution at the negative electrode.

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

Oxygen gas appears at the positive electrode at about 85% SOC and Hydrogen gas appears at the negative electrode at about 90%-95% SOC. As a result, the charging process becomes less efficient due to the evolution of oxygen at 85% SOC and hydrogen at 95%. An equivalent circuit model of a lead acid battery is shown in Fig. 2.

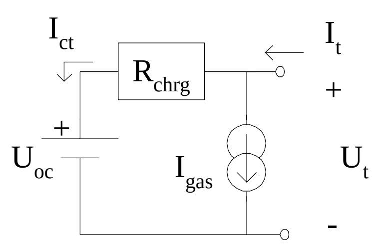

Fig. 2: Battery Equivalent Circuit

If high gassing voltages are applied to accelerate the charging process, the evolution of hydrogen and oxygen from the electrodes accelerates. This gassing reaction is very lossy and causes the interface region to heat up. Unfortunately, the presence of more heat often accelerates the gassing reaction, thus causing excessive pressure and temperature build up

The one thing that many seem to not realize is **pushing power into a battery doesn't mean storing energy**. One can continue high charging rate even above 80-85%. However, most of that energy will be wasted in the gassing process and will not be stored.

One last note, although all fast chargers used today have the ability to take the battery to full state of charge (100%), the reason why **80%-85% was chosen is primarily to limit gas evolution**. This is critical due to the fact that with fast charging, there **are no battery rooms and no ventilation** (chargers are distributed throughout the plant) and as such the charger needs to minimize hydrogen evolution. **Recharging the battery to 100% every fast charge cycle will result in unnecessary hydrogen generation and can pose a hazard. Add to that the additional time it takes to bring a battery to 100%, which is not readily available during work days.**

Myth 4:

Negative pulse charging can achieve 100% recharge in 2 hours or less.

Fact 4:

Well, the math doesn't even add up. Most fast chargers available today can charge at **0.4·C to 0.7·C** due to the power limitations and the maximum temperature rise projected. Using a charging rate of 50% (0.5C), which is quite typical, one can think that you can bring a discharged battery (20% SOC) to 100% in less than two hours: 2 * 0.5·C = 1·C. This is far from being true. These are the facts:

- The **high charging rate can be sustained up to the gassing voltage**, which is normally reached at **50% to 60% state of charge**. As such, this will take approximately less than one hour (~50 minutes using the 0.5·C rate)

- While in constant voltage, the charging rate drops and cannot be sustained as the battery dictates the charging rate. In fact, the charging current drops anywhere from 0.1·C-0.2·C at 80-85% SOC. A such, it may take another 20-30 minutes to reach 80-85% SOC. Totally time is 1-1.2 hours.

- **Above 80%-85%, the gassing reactions start**. The charging rate is greatly reduced to ensure proper acceptance of charge. Typical finish rates start at 5% to 10%. As such, it will take 1.5-3 hours to finish charge the battery. Total time: 3+ hours.

Many also underestimate the specific gravity of the battery at the end of a charge cycle. Industrial flooded motive power batteries that are fully charged will have typical specific gravities of about 1.280 to 1.285 for a flat plate design and 1.300 to 1.310 for a tubular plate design. Many seem to misunderstand the basic concept of charging, namely the restoration of the battery's specific gravity. Even small variations in specific gravity translate into large changes in state of charge. **A 1.260 specific gravity is simply not 100% but rather 85% to 90%**.

Myth 5:

Fast charging schemes employing pulse charging techniques **can equalize the battery during a fast charge cycle. No need for a fully blown equalization cycle.**

Fact 5:

It seems that engineers are talking and not chemists. Engineers treat the battery as a black box and assume it is an ideal energy storage system with little understanding of the chemistry inside. As such, they become quite innovative thinking that this black box can do winder.

The reality is that an equalization cycle is needed with and without fast charging. Fast charging doesn't change the basics of battery chemistry. **The basic principles of temperature rise and its impact on batteries, specific gravity, the need to equalize do not simply change once one switches to fast charging**. We are still dealing with the same battery chemistry. The process of charging doesn't alter the basic battery chemistry.

An equalization cycle is an extended overcharge cycle that is necessary to:

- Break and prevent battery sulfation

- Mix the electrolyte to prevent stratification

- Balance the voltage between the cells of the battery

Normally equalization is performed over a 3-6 hour time interval (or even longer) using a low charge rate of 3-5 A / 100Ahrs. Although the name indicates that this is an overcharge cycle, but it is dearly needed and can't be avoided. Claims have been made that many pulsing schemes can eliminate the need for an equalization cycles since pulsing schemes can prevent sulfation. Even if that is the case, although again there has been no scientific proof to that, equalization is still needed to prevent stratification and **more importantly balance the cells**. Other than individually charging each cell independently, which will be cumbersome in an industrial battery, **one has to overcharge the entire battery to ensure that lower state of charge**

batteries come to full state of charge. This can only be accomplished with an extended overcharge cycle at low charge rates.

Conclusion

In summary, negative pulse charging schemes have been with us for more than 30 years and although numerous claims have been made to the benefits of these techniques, there has been **no scientific conclusive evidence** to any of such benefits as compared to standard constant current charging schemes.

References:

[1] Negative Pulse Charge, or "Burp" Charging: Fact or Fiction? http://www.rcbatteryclinic.com/burp.html

[2] Jung-Chieh Cheng, “Investigation on Pulse Charging Characteristics of Lead-Acid Batteries”, Master's Thesis, 2002, National San-Yat Sen University, Kaohsiung, Taiwan, http://etd.lib.nsysu.edu.tw/ETD-db/ETD-search/getfile?URN=etd-0616103-100019&filename=etd-0616103-100019.pdf

[3] J. J. Wilkinson, G.A. Covic, “A New Pulse Charging Methodology for Lead Acid Batteries”, IPENZ Transactions, Vol. 25, No.1/EMCh, 1998.

[4] Pulse charging of batteries - controlled deposition of metal? http://www.basytec.de/uect/uect97.html

[5] A collection of battery questions and the replies from Red Scholefield, a battery engineer: http://www.vencon.com/index.php?page=support_art3