Dismantling the Myths of the Ionic Charge Profiles

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Introduction

Lead acid batteries were first invented more than 150 years ago, and since then, engineers and scientists have developed various methods of recharging these batteries. Many patents were filed disclosing various charging algorithms and claiming various benefits. In addition, many patents were filed disclosing methods for assessing the battery state throughout the charge process in an attempt to deliver optimal charge cycles. This white paper will shed some light on some of these charging and assessment methods–namely the ionic charge profile–and discuss the claims made by these methods. The paper also showcases how ACT's Quantum Charger and BATTview monitoring technologies achieve optimal battery charging and battery assessment.

Battery Charging Basics

Battery charging is a complex electrochemical process in which the discharged electric energy must be replenished. The quality of the charging process is critical to the health and longevity of batteries. As such, battery chargers need to be fitted with advanced controls to optimize charging and prolong battery life.

In principle, a battery charger is a power supply with controllable voltage and current limits. Typically, battery chargers have two tasks to accomplish. First, and most importantly, is to restore discharged capacity as quickly as possible. Second to this is the task of maintaining capacity by compensating for battery inefficiencies, self-discharge, and temperature variations. These tasks are normally accomplished by controlling the output voltage and current of the charger in a preset manner, namely, using a charging algorithm.

The most basic charging algorithms for lead acid batteries involve constant current and constant voltage charging.

- In constant current charging, the charging current is held constant while the battery voltage is allowed to increase. This method is often used in deep cycle applications, as it recharges the battery in a relatively short time.
- In constant voltage charging, the voltage across the battery terminals is held constant while the level of charge current is determined by the battery state of charge. The charging process is normally terminated after a certain time limit is reached. Constant voltage charge is most popular in float mode applications.

There are many variations of the two basic methods where a succession of constant current and constant voltage charging is utilized to optimize battery charge acceptance. Fig. 1 shows an example of a typical charge profile for recharging a lead acid battery.

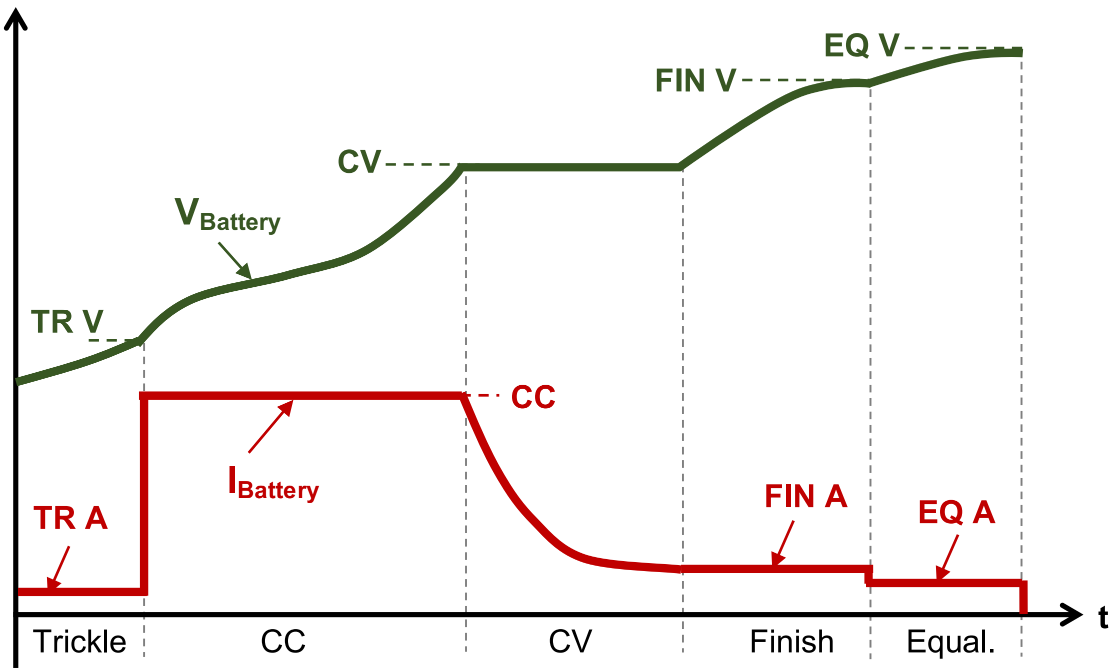

Fig. 1: Typical charge profile for lead acid battery

The characteristics of each charging phase is discussed below.

Trickle Charge Phase

When a battery is deeply discharged or the battery temperature is very low (cold storage), a trickle charge mode can be used. A trickle charge is a low constant current charge (typically 5% or C/20) aimed at ramping up the battery voltage to a safe level before high current charging is applied.

Constant Current (CC) Charging Phase

During the CC charge phase, the charge current is held constant and the battery voltage is allowed to increase. The CC rate depends on the charge regimen employed, namely conventional, opportunity, or fast, and varies between 17% to 40% in most applications. This phase ends when the battery voltage reaches the target gassing voltage (CV).

Constant Voltage (CV) Charging Phase

During the CV charge phase, the battery voltage is held constant at the target gassing voltage level (CV). The charge current during this phase begins to drop as the battery state of charge increases. The gassing voltage limit depends on the charging regimen employed and can vary from 2.37VPC to 2.42VPC in most applications. This phase ends when the battery current reaches the finish charge current (FIN A).

Finish (FIN) Charging Phase

During the FIN charge phase, the battery current is held constant at the finish rate (FIN A) while the voltage is allowed to increase. The finish rate is typically set to 5% (C/20). The finish charge mode is terminated based on various conditions, namely based on a timer, reaching a finish target voltage (FIN V), or based on a preset *dv/dt* (change in battery voltage over time). The aim of the finish charge phase is to bring the battery to 100% SOC. The finish target voltage (FIN V) can range from 2.55VPS to 2.6VPC.

Equalize (EQ) Charging Phase

A periodic (weekly) equalize charge is recommended for flooded lead acid batteries. An equalize charge phase is a deliberate overcharge aimed at removing sulfate crystals that build up on the plates over time as well as reversing acid stratification, where acid concentration is greater at the bottom of the battery than at the top.

During the EQ charge phase, the battery current is held constant at the EQ rate (EQ A) while the voltage is allowed to increase. The equalize charge rate is typically set to 3% – 5%. The equalize charge mode is typically terminated based on a timer (3 – 6 hours) or based on reaching the target equalize voltage (EQ V).

Temperature Compensation

In order to achieve optimal charge of lead acid batteries, the battery temperature must be measured and accounted for. The temperature highly effects both the gassing and the effective charging resistance of the battery. These changing characteristics require the use of temperature modifiers for best results. Temperature compensation involves adjusting the target voltage set points (CV, FINV and EQ V) based on the measured battery temperature.

Lead acid batteries have a negative temperature coefficient, where as the battery temperature increases, the internal resistance of the battery drops and the charging reactions become more efficient (Fig. 2). As such, the target voltage set points need to be decreased in order to prevent unnecessary overcharge.

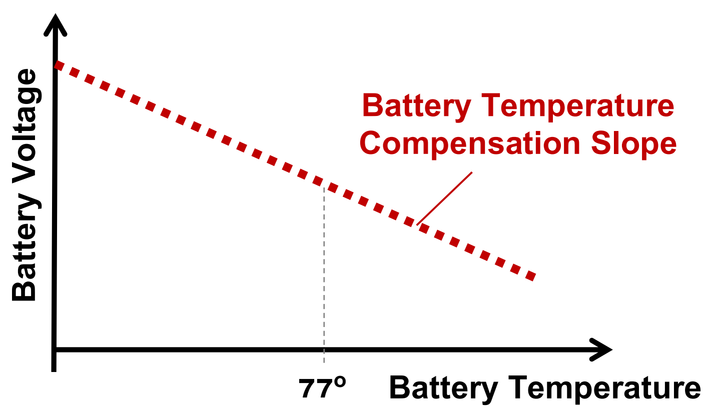

Fig. 2: Lead acid battery voltage versus temperature

In summary, the basic trade-offs of constant current and constant voltage charging are:

- Higher current levels reduce recharge times (assuming the battery can accept charge at high rates).
- Voltage limits reduce excessive gassing at end-of-charge, and prevent dry-out.

- Modified voltage and current limits as a function of temperature reduce gassing and electrode damage.
- Equalize charging is necessary to help achieve full charge status and a degree of cell equalization.

The Ionic Charge Profile

The Ionic Charge Profile is a battery testing and assessment method developed mainly for sealed or AGM battery and aimed at determining the battery state of charge, residual capacity, and possibly battery size prior to charging and throughout the charging process. Fig. 3 shows a typical battery current and voltage during an ionic profile phase.

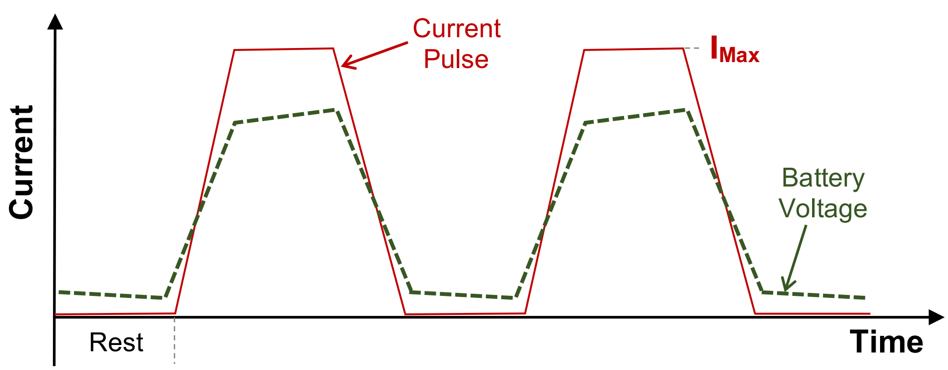

Fig. 3: Battery voltage and current waveforms during an ionic profile phase

According to the ionic charge profile claimed method, several current pulses (conditioning pulses) are first applied at the start of the charge process in an attempt to assess the battery capacity (C) and the state of charge (SOC). The applied pulse charging current have variable ramp-up and ramp-down rates followed by rest periods[1]. Various measurements of battery voltage and change in voltage due to change in current are made to assess the battery capacity. The method employs the simplified equivalent circuit model of a lead acid battery as shown in Fig. 4, where V_{OC} is the battery open circuit voltage, R_{Batt}, is the battery internal resistance, and V_{Batt} is the battery terminal voltage, which is typically what gets measured. The calculated capacity uses preset experimental weighted coefficients derived for lead acid batteries. Based on the calculated capacity, the charge rates is set to C/4 to C/7, depending on the state of charge of the battery (14% to 25%).

[1] US Patent 6,577,107 B2

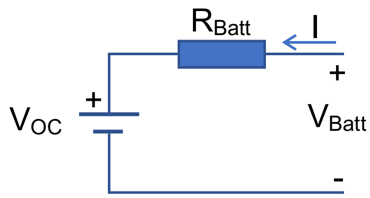

Fig. 4: Battery Equivalent Circuit

The frequency of the ionic pulses varies throughout the charge cycle.

- During the initial charge phase, the frequency of the ionic profile is set to ~6 minutes to continually assess battery capacity, SOC and make needed adjustments.
- During the bulk charge phase, the frequency of the ionic profile is increased to ~20 minutes to continually assess battery capacity, SOC and make needed adjustments.
- At or above 80% SOC, the frequency of the ionic profile is reduced back to ~6 minutes.
- During the finish charge phase, the frequency of the ionic profile is reduced back to ~6 minutes, along with pulse charging (referred to as Electromix) aimed at reducing overcharge.

Ionic Charge Profile: Separating Fads from Facts

Below is a summary of the claimed features of the ionic charge profile versus the facts as it relates to flooded lead acid batteries.

Flooded Batteries are Different than Sealed Types

The nature of the ionic charge profile is that it is guessing the battery parameters at best. This is due to the fact that it only uses battery voltage and temperature to assess battery capacity of SOC. While these may be the relevant variables for sealed batteries, flooded lead acid batteries have additional variables that can impact the assessed battery capacity and SOC.

- <u>Battery temperature can greatly affect the battery's internal resistance and can result in an erroneous assessment of battery capacity</u>. This is especially of concern when charging cold or hot batteries. For example, in cold storage applications, the internal resistance of the battery will be quite high leading to an erroneous estimate of the battery open circuit voltage and thus battery capacity. In addition, although the ionic charge profile claims to reduce battery temperature, unless temperature feedback is available, this cannot be achieved. If battery temperature is available through a monitoring device, then the need for the ionic charge profile diminishes as the monitoring devices will also report the battery capacity as well as other battery parameters.

- Deeply discharged or sulfated batteries can cause errors in the estimated SOC.
- Electrolyte (water) level can also impact the estimated SOC, as dry batteries will have a higher specific gravity (SG) leading to errors in estimating SOC.
- Battery aging can also impact the estimated SOC, as batteries typically lose 3%-4% of their capacity annually over their lifetime
- Battery build, condition, and maintenance can also affect the estimated SOC. Relatively higher intercell resistances can cause errors in the estimated SOC.

In summary, many variables need to be accounted for, making the task of having a reliable detection algorithm impossible.

Battery Monitoring is Becoming Common and is Cost Effective

One of the basic premises of the ionic charge profile is the lack of battery intelligence (i.e. battery monitoring). This was made clear in the disclosed ionic profile patent, where it argued that the cost of battery monitoring is prohibitive. This is no longer the case today.

Battery monitoring is becoming the status quo in many industrial battery charging applications and are available from multiple suppliers. Battery monitoring and ID devices store the battery nameplate parameters (voltage, capacity) as well as measure runtime parameters (temperature, current, and voltage). Advanced battery monitoring devices also calculate SOC and amp-hour usage and communicate with the charger throughout the charge cycle. There is no need for guess work in estimating battery capacity at the start of the charge cycle, as the capacity can be simply communicated to the charge nor there is a need for continuous estimating of battery SOC as these parameters may be readily available.

Today's Chargers are Smart

Another premise of the ionic charge profile is the assumption that battery chargers are dumb (not smart) and use rudimentary controls (e.g. timers) to control the charge process. This was probably the case more than 10 years ago, but definitely not the case today. Most of today's battery chargers incorporate microprocessor controls that adjust the current and voltage throughout the charge process to ensure optimal charge cycles. In addition, many of today's chargers also communicate with installed battery monitoring devices to read battery parameters (such as temperature and state of charge) throughout the charge cycle and adjust the charging process to ensure optimal charge and limit overcharge. As such, there is no more need for guess work.

Pulse Charging (or Electromixing) is NO Different than a Controlled Finish Rate

As discussed in another white paper, no reputable studies have established measurable benefits of pulse charging schemes. While some chargers incorporate pulse charging during the latter stage of the charge cycle (finish phase) as a way to reduce overcharge of sealed lead acid batteries, the benefits to flooded batteries are almost negligible. Unlike sealed batteries, flooded batteries require an overcharge to prevent sulfation and reverse stratification. The goal here is to optimally terminate the finish charge phase once the nameplate specific gravity is restored. This can be achieved with a controlled constant current charge phase and proper termination conditions.

Quantum Chargers' and BATTview Monitors: Delivering Intelligent and Optimal Charge Cycles

The Quantum charger, ACT's flagship product, is the industry's first smart industrial charger appliance that features many advanced energy efficiency and energy management capabilities as well as communication and smart grid integration (Fig. 5).

Fig. 5: ACT Quantum chargers: Industry's first smart charging appliance

The BATTview battery monitor, another ACT flagship product, transforms industrial batteries in smart appliances (Fig. 6). Unlike conventional battery monitors on the market, the BATTview not only monitors battery performance data but also controls the charge process and continuously communicates with the charger as well as the ACTview cloud application to optimize battery life and performance.

Fig. 6: ACT BATTview battery monitors: Transforming industrial batteries into smart appliances

The combination of Quantum charger and BATTview battery monitors offer the industry's first smart battery-charger systems that optimizes battery performance through the life of the battery. These include:

- The Quantum charger and BATTview incorporate PLC communication allowing BATTview to only report many battery settings (e.g. capacity, voltage), but also upload the preferred charge parameters to the charger. These charge parameters allow each battery to receive the most optimal custom charge profile for that battery. Unlike the ionic profile that makes best guess estimates of the battery capacity and delivers a generic charge profile to all batteries, the Quantum/BATTView combo uses 100% accurate battery settings and optimal charge prolife for each battery.

- The BATTview data continuously reports the battery temperature and SOC throughout the charge cycle, allowing the charger to adjust the charge algorithm to minimize heat build-up and properly terminate the charge cycle. Again, no guess work is involved.
- The Quantum/BATTview combo incorporate data integration functionalities that allow for more extensive data communication and reciprocal cycle and record saving capabilities between Quantum and BATTView. The data integration allows both the Quantum chargers and the BATTview units to make better decisions in optimizing charge cycles, scheduling and delivering precise equalization cycles, and tracking charge cycle termination conditions. This allows for better diagnosis of charger and battery performance issues.

Conclusions

The claimed benefits of ionic charge profiles are no longer valid or relevant today. While an ionic charge profile may provide best guess estimates of battery capacity and state of charge, the nature of lead acid batteries makes this task quite difficult. In addition, the advent of cost effective industrial battery monitoring technologies obsoletes the need for ionic charge profiles since the exact battery parameters can be simply provided by the battery monitoring devices.

ACT's Quantum/BATTview charger/monitor combo offers the most advanced battery charging system on the market, as it tailors the charge process to every battery individually ensuring optimal battery life and performance.

References:

[1] US Patent US657710, Method of testing a lead battery for the purpose of charging it under optimal conditions, 2003.

[2] Hawker Power Source LifePlus brochure, https://www.hawkerpowersource.com/uploadedFiles/HPS/Content/Chargers/LifePlus%20MOD3%20Brochure_Rev1.pdf

[3] Enersys Enforcer Impaq and Impaq+ brochure, http://www.enersys.com/WorkArea/DownloadAsset.aspx?id=25769804045