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New accelerated charge methods using early destratification applied on flooded lead acid batteries

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ABSTRACT

A traditional charge process for flooded lead acid batteries (FLABs) lasts generally from 8 to 14 h. Nowadays, many applications of FLABs require reduction of the charge duration, for instance, a 4 h-charge for FLABs in grid energy storage or 1 h-charge for FLABs in electric buses. These are called accelerated charge and fast charge. Such reductions of charge time imply the use of a new charge process. One way to reduce the charge duration is to perform an early destratification step without waiting for the end of charge. The new charge method proposed in this paper (early destratification method – ED) focuses on the reduction of the charge time for FLABs using early destratification, which is performed and controlled using charge acceptance measurement during the charge. Laboratory experiments presented here aim first to develop charge acceptance measurements followed by an ED charge method compared to an IUi traditional charge process.

1. Introduction

In practice, a charge process has to answer three principal conditions: reasonable or desired charge durations, a sufficient state of charge and acceptable electrolyte homogeneity.

Electrolyte stratification is a common problem of vented lead acid batteries, in which the electrolyte on the bottom tends to be more concentrated than at the top [1–13]. The stratified battery, exposed to accelerated aging process, loses its capacity prematurely. One way to homogenize the electrolyte is to provoke a sufficient gas circulation to mix the electrolyte by a forced convection.

It is known that gas evolutions due to water electrolysis always occur at the same time with charge reactions in lead acid batteries. They increase with the increase of the charge voltage, and become noticeable beyond a gassing point, called gassing voltage. At this gassing voltage, charge current contributes mostly to proper charge reactions, or in other words the battery is charged with its charge acceptance. The definition of the charge acceptance used in this paper is the current response of the battery at a gassing voltage (cf. Section 2.1). Therefore, a noticeable gas flow can be produced by applying a current superior to the charge acceptance, or by applying a voltage that exceeds the gassing value; this is called the destratification phase. The destratification by gassing is necessary for battery longevity, but the current of gas evolution, called here gas current, has to be controlled to prevent the shedding of active materials, the depletion of the electrolyte and the excessive hydrogen evolution, which increases the flammability risk. The work of Alzieu and Robert [14] shows in Fig. 1 that for a flooded battery, beyond about 8% of overcharge (8% of electrical quantity obtained during the previous discharge), the electrolyte is almost homogeneous and independent on the overcharge rate.

A typical charge of lead acid batteries is composed of three phases, usually called IUi charge (cf. Fig. 2). The first phase is a constant current phase (A) in which the major part of the charge is accomplished. During this phase, the battery voltage increases up to gassing voltage. The second phase (B) is performed at constant gassing voltage. During this phase, the current, called battery charge acceptance decreases asymptotically to a low value. The third and last phase is the destratification phase (C). In this phase, in general a constant current, called overcharge current, whose value is higher than the charge acceptance, is applied.

In this classical charge process, which lasts in general from 8 to 14 h, the destratification phase is achieved at the end where the charge acceptance is sufficiently small to be negligible, so that the current of gas evolution (gas current) is roughly assimilated to the applied current. This makes the evaluation of gas current easier, as well as the global management of the charge. In practice, as the electrical quantity (Ah) used during the previous discharge is usually unknown, a 10–20% of the total electrical quantity accepted during the two previous charge phases (cf. Fig. 2) is applied at the

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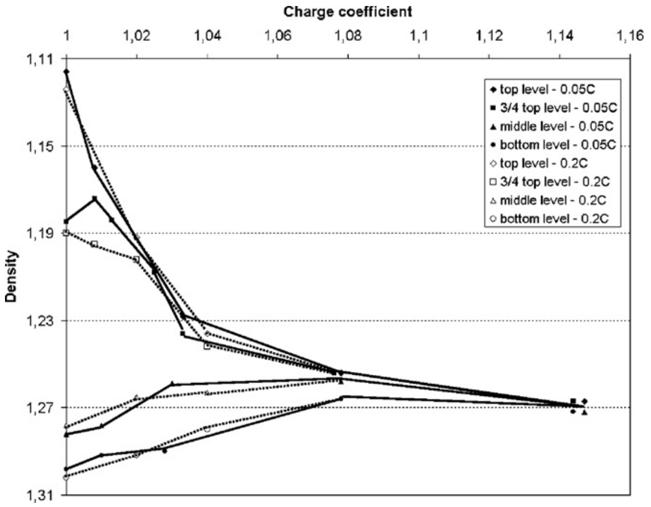

Fig. 1. Electrolyte density measured at 4 levels of the cell and as the function of the charge coefficient evolution during overcharge phases at 0.05 C or at 0.2 C. Beyond 8% of overcharge, the electrolyte is almost homogeneous without depending on the overcharge rate [14].

end of the charge process to destratify the electrolyte. In commercial battery chargers, the current generally does not exceed the 0.2C (C/5) rate during the (A) phase and the 0.05C (C/20) rate during the (C) phase. As the gassing current is part of the (C) phase current, its value never exceeds the C/20 rate.

New applications of lead acid batteries require, in general, a reduction of the charge duration, e.g. 4 h or less. Such short charges do not include a final phase just for destratification. All along the charge, charge acceptance remains too high to be neglected. Final destratification by gassing has to be thus carried out in parallel with the proper charge. Here we call this overcharge phase "early destratification".

In this paper, a new charge algorithm is developed applying early destratification. Charge acceptance measurements are achieved in order to evaluate and control gas currents.

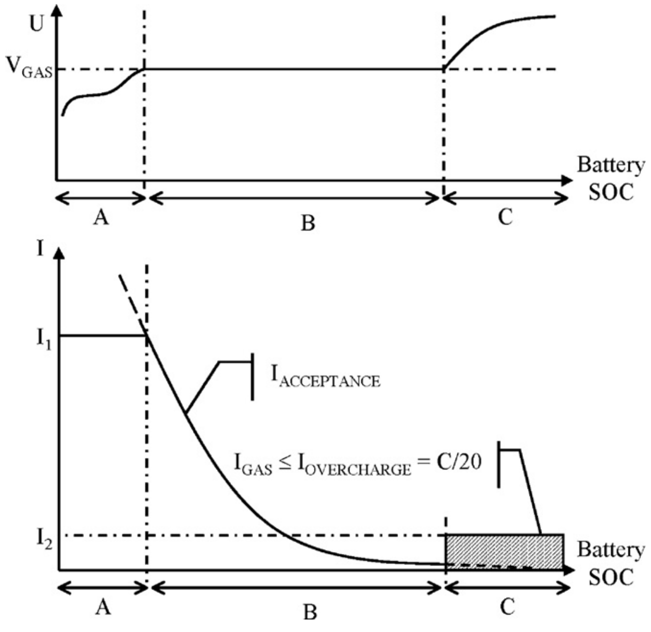

Fig. 2. IUi charge of lead acid batteries: (A) constant current phase, (B) constant voltage phase at gassing value V_{GAS} and (C) overcharge or destratification phase at constant overcharge current C/20.

2. Charge acceptance measurement method

2.1. Charge acceptance definitions

Several definitions of the charge acceptance, in term of a current, of a flooded lead acid battery can be found in the literature [15–20].

Berndt defines the "acceptance" as *the share of the current that actually is "accepted" by the battery and could be retrieved by subsequent discharge* [20]. Indeed, the charge current is partly involved in side reactions, mainly gassing. According also to Berndt [20], charge acceptance is determined by the balance between the kinetic parameters of the main charge current and the gassing current. In other words, it depends on the rate of the main and side charge reactions. This definition is difficult to use in practice because this "acceptance" cannot be directly measured, but only evaluated, by taking into account the losses through side reactions. This definition of the charge acceptance is associated to faradic efficiency (r_{Faraday}) as the following:

$$r_{\text{Faraday}} = \frac{I_{\text{ACCEPTANCE}}}{I_{\text{CHARGE}}} \qquad (1)$$

In which: $I_{\text{ACCEPTANCE}}$: charge acceptance, I_{CHARGE}: charge current.

Charge acceptance may also be defined as the maximum current a battery can absorb for its main charge reaction. This corresponds to the maximum value that can be reached in the case of the first definition. Although this concept is easily understandable, measurement of such a charge acceptance is very difficult.

A very different definition is the total charge current (main and side reactions) under a constant charge voltage. The result can widely vary with the chosen voltage value. This includes for instance charge currents under float charges (charge with very low rates to maintain the charge of stationary batteries).

Gassing becomes noticeable when voltage is above a threshold value, called here gassing voltage. The gassing voltage depends on temperature, charge rate, alloy quality, battery age and history. Moreover, as "noticeable" is subjective, it depends also on the observer appreciation. The gassing voltage is statistically situated between 2.3 and 2.6 V/cell. In this paper, the charge acceptance of the flooded lead acid battery is assumed to be the charge current passing through its electrodes at a gassing voltage. Thele [17] has used a similar definition for modeling the charge acceptance of flooded lead acid batteries.

2.2. Experimental

In order to control the gassing current, assuming that during an overcharge phase, the supplied current ($I_{\text{OVERCHARGE}}$) is the sum of charge acceptance ($I_{\text{ACCEPTANCE}}$) and gas current (I_{GAS}), we have to find a way to measure the charge acceptance during the overcharge phase (C) so that the gassing current can be calculated as follows:

$$I_{\text{GAS}} = I_{\text{OVERCHARGE}} - I_{\text{ACCEPTANCE}} \qquad (2)$$

As defined above, the charge acceptance ($I_{\text{ACCEPTANCE}}$) that has to be measured is the charge current at a gassing voltage (V_{GAS}).

The charge test to measure charge acceptance called here early destratification charge test (ED charge test), is carried out as follows: at the first phase like in the case of a traditional IUi charge process, battery charge acceptance is high and the charge current is limited by the charger maximum current. During this phase, the battery voltage increases to reach V_{GAS}. Prolonging the charge beyond V_{GAS} with a constant current ($I_{\text{OVERCHARGE}}$) would increase the share of gassing, I_{GAS}, which is beneficial for destratification, overcharge step. $I_{\text{ACCEPTANCE}}$ can be measured when reducing periodically the battery voltage back to a chosen V_{GAS} for a very short time, called measurement step; at this V_{GAS} value, charge accep-