Available online at www.sciencedirect.com
SCIENCE DIRECT®
Journal of Power Sources 144 (2005) 346–351
JOURNAL OF POWER SOURCES
www.elsevier.com/locate/jpowsour

Optimization of charge parameters for lead–acid batteries used in photovoltaic systems

D. Benchetrite, M. Le Gall, O. Bach, M. Perrin, F. Mattera*

Laboratoire Stockage ElectroChimique, Commissariat à l'Energie Atomique de Cadarache, Saint Paul Lez Durance, France

Abstract

The lead–acid batteries used in the photovoltaic (PV) systems are subjected to penalizing operating conditions. The recharge is badly controlled since it depends on the weather conditions. These particular operating conditions induce unusual degradations of the active material compared to more traditional applications like SLI batteries. Consequently, when used in PV applications, lead–acid batteries show a shorter lifetime than they could reach.

The management of the recharge of the photovoltaic lead–acid batteries is a major issue for the optimization of their lifetime. Today, complex methods of end of recharge, such as complements of recharge using current pulses, are increasingly widespread. Many parameters can be adjusted (frequency, duty cycle, voltage threshold for beginning the pulsed phase . . .) but no reliable data are available in the literature.

The study that follows deals with the experimental optimization of these various parameters (under well defined operating conditions). In the same time, a specific software has been developed in our laboratory and helps to understand why these pulses increase the charge acceptance of the lead–acid battery.

Keywords: Lead–acid battery; Photovoltaic systems; Charge; Battery management; Pulsed current; "Hard" sulphation

1. Introduction

Lead–acid batteries integrated into photovoltaic (PV) systems suffer from a lack of reliability leading to heterogeneous lifetimes (going from 3 to 14 years). In the more penalizing cases, the battery must be replaced frequently and the storage system corresponds to half the global system cost after 20 years of service. Outstanding and durable lead–acid battery management is then necessary to obtain reliable storage function and thus, reliable PV systems.

Battery management concerns both the charge and the discharge of the battery but most efforts concern the charging phase and lots of charge management strategies can be observed in the literature. Most of the time, they come from the automotive application, which working conditions strongly differ from PV applications. These managements must then be optimized to PV range, both for the daily and periodic managements for rehabilitation. The daily management, which is the purpose of this work, is mainly divided into two kinds: the ampere-hour management and the voltage management.

The ampere-hour management consists in calculating the number of ampere-hours needed to fully charge the battery. This management is the less widespread strategy [1,2], in so far as it is necessary to set an overcharge coefficient to balance the gassing reaction, the overcharge coefficient depending on the battery technology and ageing.

The voltage management assigns predefined voltage thresholds, which cannot be exceeded, in order to limit specific degradations of corrosion and drying out at high voltage and "hard" sulphation at low voltage. The main voltage managements are the on/off [3–6], floating [7–9] and pulse width modulation (PWM) [10–14] strategies.

The PWM management appears to be an effective alternative compared to other strategies and tends to spread. It is more and more studied for PV applications and seems to

* Corresponding author. Tel.: +33 442252113; fax: +33 442257365.
E-mail address: florence.mattera@cea.fr (F. Mattera).

0378-7753/$ – see front matter © 2004 Published by Elsevier B.V.
doi:10.1016/j.jpowsour.2004.11.015

be really attractive for the charge of lead–acid batteries in so far as the accumulators would be better charged with this strategy. However, even if some studies try to explain the phenomena induced in such a case [15], the electrochemical reasons of the gain obtained and the characteristic parameters of such a management are still undefined.

The purpose of this paper is then to present a new kind of management, which can be described as a "combined" strategy of pulsed current associated to ampere-hour management, in order to obtain the benefit of these two kinds of strategies.

The present paper shows how the "combined" management we propose is favorable to the lead–acid battery both in a physical and a chemical way and explains why we observe benefits in terms of restored capacity and "hard" sulphation amount.

2. Experimental

The experiments are performed on battery elements, consisting of one positive tubular electrode and two negative prismatic electrodes separated by a Daramik® separator. The different components are provided by CEAC-EXIDE and were conditioned by charge/discharge cycles until reaching a constant initial capacity value. After being submitted to the cycling procedure described afterwards, an optical study was performed on the positive active material as well as a chemical quantification of the sulphate content of the positive active material.

Table 1
Parameters of the pulsed current phase and comparison with PWM charge procedure

	PWM	Pulsed current phase
Voltage	Constant	Free
Height of the current pulses	Constant	Constant (I_{10})
Frequency (F)	Fixed	Variable (1–500 Hz)
Duty cycle (r)	Variable	Variable (0.5–0.875)
End of charge	Imprecise	Number of ampere-hour

2.1. Cycling procedure

The "combined" procedure, formerly described in [16,17] and summarized here in Fig. 1 is then applied to the elements. A reference cell is also realized with the same electrodes. The reference experiment consists in applying the same phase A (stopped when U equals U_s), and a phase B, where the current is constant and equal to I_{10}, until reaching 0.15 time the initial capacity (C_{init}) of the cell. Five parameters were identified as possible parameters to modify and study during the pulsed current phase of this "combined" procedure. Table 1 shows these five parameters, the ones chosen for optimization and the main differences with a classical PWM strategy. Only two of them were studied here: the frequency of the pulses (noted F) and the duty cycle (r) corresponding to the duration of the pulses (t_{ON}) multiplied by the frequency F.

The range of frequency studied is from 1 to 500 Hz and the range of the duty cycle varies from 0.5 to 0.875.

The restored capacity is measured after 20 cycles with the "combined" charge procedure.

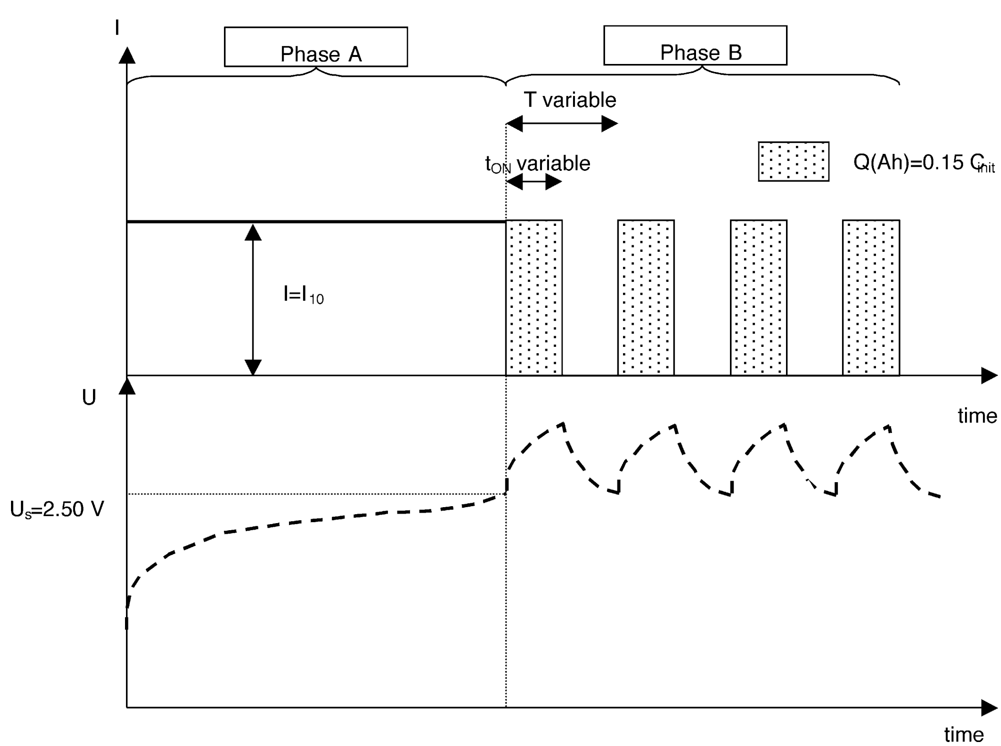

Fig. 1. Description of the "combined" procedure proposed in terms of voltage (dashed line) and current (full line).