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Influence of the charge regulator strategy on state of charge and lifetime of VRLA battery in household photovoltaic systems

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Abstract

By simulating real working conditions of household photovoltaic system, the effects of overcharging on lifetime of valve-regulated lead-acid (VRLA) battery in solar home systems have been investigated; and the influences of three kinds of charge regulator strategies on state of charge and lifetime of VRLA battery have also been studied by experiments. A quantitative analysis of the VRLA battery behaviour under different charge regulator strategies was carried out. It is found that the temperature compensation of the end-of-charge voltage is necessary for VRLA battery, particularly in hot climates. The linear temperature compensation for the end-of-charge voltage keeps VRLA battery the best state of charge compared with other charge regulator strategies. Based on our results, the design engineers can choose a cost-effective regulator according to the details of photovoltaic system and local climate, and can estimate working state of VRLA battery installed in a system correctly, so as to extend VRLA battery lifetime in solar home systems. The clarification of the performance difference of VRLA battery under different regulators may be an important issue for determining life-cycle costs and servicing requirements.

Keywords: Photovoltaic; Regulator; Charge strategy; VRLA battery

1. Introduction

A typical household photovoltaic system includes a solar array, VRLA battery, regulator and load. In such a stand-alone photovoltaic system, VRLA battery provides storage energy, which is delivered at the time the solar radiation is low, that is, in cloudy periods or at night-time. The battery is often considered as being the "weak point" of a photovoltaic system, in terms of cost, lifetime and reliability (Spiers and Rasinkoski, 1995; Potteau et al., 2003). It was demonstrated that the failure of photovoltaic systems was firstly induced by the damage of VRLA batteries, and it was concluded that about 85% of VRLA batteries used in photovoltaic systems were damaged by irreasonable regulators from the results of reliable analysis of lots of photovoltaic systems

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Nomenclature

VRLA	valve-regulated lead-acid battery
SOC	state of charge
I_{10}	a 10-h discharge current
PWM	pulse width modulator
LVD	low voltage disconnection

(Yang et al., 2003). Most VRLA batteries used in household photovoltaic systems will have a service lifetime which is less than that of the photovoltaic modules because of inherent characteristic. The irreasonable regulator will shorten the VRLA battery much more, and the reliability of the system depends on the performance of the VRLA battery as well as on its good behaviour and expected lifetime. So the VRLA battery lifetime is an important factor in the calculation of life-cycle costs and also when planning future maintenance requirements.

Irregular VRLA battery operation causes a variety of degradation mechanisms: excessive gassing; corrosion; sulfation; loss of water; and active mass. In this sense, the compatibility between battery requirements and the associated charge controller seems to be, and is in practice, a decisive point to extend battery lifetime. However, this is not always taken into account when designing PV systems. At present, it is very frequent in PV solar handbooks and technical specifications linked to PV rural electrification programs, that the charge regulator and batteries are specified separately, including setpoint voltages. The battery and charge controller combined with performance is still not well coordinated, with important consequences not only on battery duration, but also on the short-term energy supply to users.

In photovoltaic systems, it is nearly always the temperature-dependent corrosion process that limits the battery lifetime, and not the cycle life (Spiers and Rasinkoski, 1996). The battery working temperature depends on not only ambient temperature, but also overcharging, which makes the working temperature of battery high. The battery working temperature is different under different regulators at the same ambient temperature, but few people found the importance of overcharging and temperature compensation of VRLA battery in a household photovoltaic system, so it is very important to analyze the performance difference of the VRLA battery under different regulators.

Although the VRLA battery lifetime in a household photovoltaic system is important in determining life-cycle costs and servicing requirements, unfortunately, it is not calculated with any certainty yet. Some authors (Armenta-Deu, 2003; Ross and Markvart, 2000; Guasch and Silvestre, 2003) have presented a simple model for estimating photovoltaic battery lifetime, but they did not consider the difference of battery lifetimes caused by different regulators. Because some experiments for modeling the VRLA battery in household photovoltaic systems are complicated, they predicted the battery behaviour of stand-alone photovoltaic system using mathematical approaches only.

In this paper, we combine the charge controller with the VRLA battery, and analyze the influence of three kinds of charge regulator strategies on state of charge and lifetime of the VRLA battery in household photovoltaic systems by experiments. And a quantitative analysis of the VRLA battery performance under different charge regulator strategies is given for the first time.

By analyzing the effect of the charge regulator strategy on state of charge and lifetime of the VRLA battery in household photovoltaic systems, technical recommendations for charge regulation of VRLA batteries are given. According to the details of photovoltaic system and local climate, the design engineers can choose a cost-effective regulator, and estimate working state of the VRLA battery installed in a system correctly. The experiments can also help the battery industry to choose and develop appropriate VRLA batteries for photovoltaic applications according to the actual operating conditions of solar home system. The clarification of the performance difference of the VRLA battery with different regulators may be an important issue for determining life-cycle costs and servicing requirements.

2. Real working conditions for household photovoltaic system

2.1. Solar irradiation

Solar irradiation that reaches solar modules is variable due to the apparent motion of the sun with seasons. Fig. 1 shows the daily average irradiation of 20 years on an inclined surface in Xi'an as a function of the month. The panel inclination is close to the value which maximizes the energy input during the ‘‘worst month’’. The mean value is 3.54 kWh/m^2 day. At present, sizing a photovoltaic system is according to the mean solar irradiation, so as to reduce the overall system costs. So, for a correctly designed and operated household photovoltaic system, it can be concluded that overcharging happens for six months in a year from a distribution of the year-round solar irradiation, particularly in summer,