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Improvement of safety, longevity and performance of lead acid battery in off-grid PV systems

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ABSTRACT

In a renewable energy system, in order to ensure continuous production, batteries associated to a charge controller are always necessary whenever the source of charging is solar, wind, or hydraulics. For photovoltaic (PV) systems, an excessive energy produced by solar cells during intense sunlight peak conditions could damage the batteries. A charge controller is therefore used to maintain the suitable charging voltage to the batteries so that, as the input voltage from the PV module rises, the charge controller regulates the process, thus, preventing any overcharging. This paper presents a practical solution for off-grid PV systems using standard commercial elements. A detailed analysis is carried out based on experimental results of the battery charge control allowing a long-life and a high safety of the autonomous storage and production systems. The experimental work was performed with a solar battery (24 V-55 Ah) charged by a 175Wp PV module, through a Maximum-Power-Point-Tracking/Three-Stage-Charging-Cycle (MPPT/TSCC) charge controller. The benefits of the Three-Stage-Charging-Cycle (TSCC) control as well as the Maximum-Power-Point-Tracking (MPPT) have been thus proven for the efficiency of the recharge, both qualitatively and quantitatively.

Introduction

Operating a power system from renewables, such as wind or solar, is constrained in many instances by the variable and intermittent nature of their inputs and output. This calls for practical application and management of energy-storage systems [1]. One of the most promising, innovative and efficient solutions of electrical energy storage is the solution based on integration of batteries directly in renewables power systems [2]. Within this solution, during low consumption period, the extra energy produced is stored in the battery and during peak consumption period or to compensate the intermittence of the renewable sources, the stored energy is used

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to supply the energy demand. Batteries are commonly referred to as one of the weakest components in off-grid photovoltaic (PV) systems in the field and the criteria for the selection of solutions for the storage of renewable energy are still under debate [3,4]. A complex set of parameters has to be considered in the choice of the storage system being associated in the renewable power generator as technical, economic and environmental ones [5–8]. Hydrogen-based storage systems are sometimes coupled with renewable energy sources and a lot of study on possibilities of improving efficiency of electrolysers coupled with renewables [9–13]. Nevertheless, more mature solutions associate photovoltaic panels or wind turbines with for renewables, standard or specially designed lead-acid batteries to store the intermittent produced energy in off-grid systems [14,15].

Usually, even in standard functioning conditions but worst when intermittent possibilities of charging are only possible, the lifetime of the storage elements is very often below expectations and therefore a regular replacement is required, which consequently increases the overall cost of the renewable energy sources [16,17]. The lifetime of a battery is not only influenced by the internal electrochemical and construction parameters, but also by operating parameters [18,19]. Therefore, battery management systems in PV applications have the task to operate the batteries at conditions that will not reduce their lifetime. Additionally, it is possible to maintain and optimize the performance, while increasing the lifetime of a battery by special operation regimes of charge and discharge.

Once in operation, any battery has to work within a controlled and limited power range in order to satisfy lifetime expectancy. Excessive overcharge and deep discharge conditions must be avoided by appropriate charge regulation, according to the battery type and characteristics. Compatibility between battery requirements and the associated charge controller seems to be, and is in practice, a decisive point to extend battery lifetime [17]. For lead acid batteries, whatever the type, most solar battery manufacturers recommend a Three-Stage-Charging-Cycle (TSCC) even if other technics exist [20–22]. Indeed, the TSCC represents the best and most efficient way to return full capacity to the battery and extend battery lifetime [14–18]. In fact, current battery charging technologies, the so-called "smart chargers", rely on microprocessors to recharge using three stages regulated charging: bulk, absorption, and float. Qualification or equalization is sometimes considered as another stage, a two-stage unit is bulk and float stages.

Charge control, therefore, clearly appears as a keystone of any autonomous PV system. The objective of this publication is to highlight the function of a MPPT/TSCC controller in the operation management of an off-grid system based on PV and batteries, not only for the control of safety limits of battery operating parameters (overcharge, deep discharge, …) and self-discharge, but also for high energy efficiency both by reducing the fluctuation of the solar power and fitting the Maximum Power Point (MPP) voltage of the PV module to the battery charging voltage.

The experiment is conducted on a real PV system installation, and the charge controller is additionally featured with a tracker. Indeed, mainly two types of TSCC controllers stand out from others. Using traditional Pulse Width Modulation (PWM) charge controllers, the PV module is directly connected to the battery, which then sets the operating voltage. Therefore, charging power remains lower than if the controller was directly connected with the PV module. The use of MPPT charge controllers has many advantages, but the most relevant argument is certainly that it is increasingly difficult to find a suitable PV module for direct battery charging. Low cost grid injection PV modules are generally utilized, but these cannot be associated with a conventional controller because of their voltage. MPPT controllers yield at least 15% more power supply as compared to conventional PWM controllers [19,23–27]. The one used in the present work is the MPPT/TSCC Victron BlueSolar Charge Controller.

Experimental set-up and methodology

The aim of this work is to experiment and analyze, in real operating conditions of off-grid PV systems, the charge control of a lead acid battery with a TSCC and MPPT charge controller. Fig. 1 shows the experimental setup of the study.

The PV module is taken from the actual installation of the experimental PV station of the laboratory, meeting the local

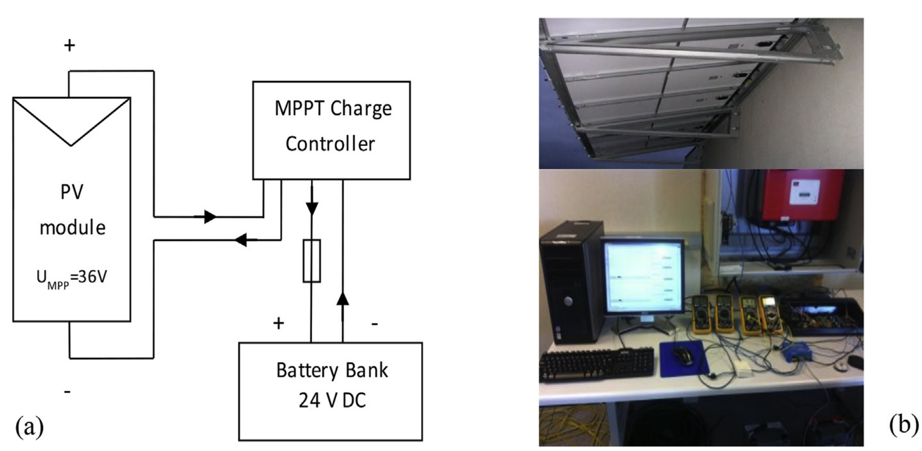

Fig. 1 – (a) Electrical scheme (b) A view of the experimental setup.