INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 38 (2013) 13702–13716

Available online at www.sciencedirect.com

SciVerse ScienceDirect

journal homepage: www.elsevier.com/locate/he

Economic impact of performances degradation on the competitiveness of energy storage technologies – Part 2: Application on an example of PV production guarantee

B. Guinot [a,*], Y. Bultel [b], F. Montignac [a], D. Riu [c], I. Noirot-Le Borgne [a]

[a] CEA-LITEN/DTBH/L2ED, 17 rue des Martyrs, 38054 Grenoble Cedex 9, France
[b] LEPMI, UMR 5279 CNRS–GINP–UdS–UJF, BP75, 38402 Saint Martin d'Hères Cedex, France
[c] G2Elab, UMR 5269 CNRS–GINP–UJF, BP46, 38402 Saint Martin d'Hères Cedex, France

ARTICLE INFO

Article history:
Received 13 June 2013
Received in revised form
1 August 2013
Accepted 4 August 2013
Available online 5 September 2013

Keywords:
Solar energy
Lead-acid batteries
PEM hydrogen chain
Simulation
Optimization
Aging

ABSTRACT

In this paper, the newly developed techno-economic assessment platform Odyssey introduced in Part 1 of this two-part series of papers is applied to an application example: the call for tenders from the French Energy Regulation Commission on PV installations greater than 250 kWp. In this context, two storage systems are studied: a bank of lead-acid batteries and a PEM hydrogen chain (PEM electrolyzer, H_2/O_2 PEM fuel-cell, H_2 and O_2 storages under pressure at 30 bars). The objective pursued in the study of this application case is to assess the economic value of these two energy storage technologies and to focus on different influencing factors. Therefore, in the context of this application case, it is shown how a suitable control strategy can considerably help in improving economic results. The influence of the reference meteorological year is also investigated showing that the variations of economic indicators between two different years are greater than the variation of the annual insolation. Furthermore, the investigation on the influence of the simulation time step shows that the use of large time step (30 min, 1 h) may lead to unsuitable sizing and inaccurate estimations of economic performances. Finally systems sizing have been optimized considering different aging modeling which has shown that the influence of aging on the optimal sizing may be important.

1. Introduction

In Part 1 of this two-part series of papers, a newly developed platform Odyssey has been introduced. This simulation-optimization platform has been elaborated to perform comprehensive techno-economic assessments of energy systems comprising renewable energy sources and energy storage units. The objective of this paper (Part 2) is to illustrate the platform's strengths on an application example: the call for tenders from the French Energy Regulation Commission on PV installations greater than 250 kWp. This paper is structured in two sections. The first section deals with the presentation of the call for tenders, highlights the objective pursued in the study of this application case and describes the modeling used with the corresponding hypothesis. The second part presents techno-economic

* Corresponding author. Tel.: +33 438 786 023.
E-mail address: benjamin.guinot@cea.fr (B. Guinot).
0360-3199/$ – see front matter
http://dx.doi.org/10.1016/j.ijhydene.2013.08.023

results obtained from different simulations. They have been performed during the study of different influencing factors. These factors are the meteorological year taken as reference, the simulation time step and the consideration of components aging.

2. Description of the call for tenders and the corresponding modeling

The objective of this part is to describe the specifications of the call for tenders and to describe the realized modeling.

2.1. *Call for tenders specifications*

The call for tenders which is used as an application example is relative to new PV installations greater than 250 kWp and situated on a French island (Corsica, Guadeloupe, Réunion, etc.). For these PV power plants an energy storage system must be used in order to store the produced PV energy and to control the power injection to the grid. Every day, the injected profile should be of a trapezoidal shape as illustrated by Fig. 1 and must follow three phases: power increase, constant power and power decrease. For each of them, technical constraints must be respected and are summarized in Table 1. A full description of the call for tenders can be found on the French Energy Regulation Commission website (Ref. [2]).

The daily injection profile must be known in advance (the day before) by the grid operator and the producer shall respect it in order to get paid for the injected energy. Any non-respected constraint mentioned in Table 1 leads to a non-payment of all supplied energy during the hour when the fault has been observed. The need to announce the profile the day before means that a PV production forecast for the day D+1 is necessary on day D. This forecast is indeed required as an input in the elaboration of the injection profile of day D+1 (contractual load profile). In reality, the PV energy producer is allowed to modify during day D the contractual load profile of the same day as long as these changes are notified early enough to the grid operator. In this study, this flexibility is not considered and the contractual profile of day D+1 must be announced on day D and must be strictly respected.

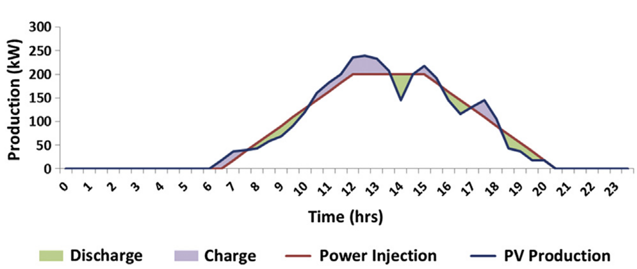

Fig. 1 – Example of daily PV power production and grid power injection. Description: This figure illustrates an example of a daily PV power production and the corresponding power profile injected to the grid.

Table 1 – Summary of the technical constraints of each power injection phase. Description: This table illustrates the technical constraints to be respected for the three injection phases.

Phase	Technical constraints
Power increase	During this phase power injection shall remain constant or shall increase at a rate not greater than 0.6% of the PV installed capacity per minute.
Constant power level	During this phase power injection shall remain constant and shall not exceed 40% of the PV installed capacity. Power injection fluctuations are allowed as long as they remain within a band of ±2.5% of the PV installed capacity around the constant power level value.
Power decrease	During this phase power injection shall remain constant or shall decrease at a rate not greater than 0.6% of the PV installed capacity per minute.

2.2. *Objective pursued in the study of this application case*

The objective of this example is to assess impacts of several influencing factors on the economic value of different energy storage technologies in the context of this call for tenders. The complete PV-storage plant is modeled and its operation is simulated. Techno-economic indicators are then computed based on simulation results. Influencing factors discussed here are: the selected year for meteorological data, the simulation time step and the aging consideration approach. These last three factors are indeed rarely discussed in publications but may be of a great influence. In order to compare the different cases studied in this paper, a comparison indicator must be used. As mentioned in Ref. [1], the Levelized Cost of Energy (denoted LCE – €/MWh) is widely used as an indicator to estimate the cost of supplied energy. In this case study, all supplied energy is not necessarily remunerated (if the technical constraints described in Table 1 are not respected) which means that the standard LCE is not suitable. This is why the use of a new indicator, the Levelized Cost of Paid Energy (denoted LCPE – €/MWh), has been preferred and is defined as the ratio between the total levelized system costs and the levelized supplied energy for which the producer has been paid Eq. (1). For the comparison, values of the LCE are given as an example in paragraph 3.1.

$$\mathrm{LCPE} = \frac{\sum_{y=1}^{n} \frac{C_{Tot}(y)}{(1+d)^{y-1}}}{\sum_{y=1}^{n} \frac{P_{PaidInj}(y)}{(1+d)^{y-1}}} \quad (1)$$

where n is the number of operating years (20), d is the discount rate (8%), $C_{Tot}(y)$ are the total annual costs of year y (€) and $P_{PaidInj}$ is the annual injected energy of year y for which the producer has been paid (MWh). $C_{Tot}(y)$ include all investment costs the first year ($y=1$) and includes replacement costs at the year of replacement.

2.3. *Systems architectures and power control strategies*

2.3.1. Systems architectures

The global system studied in this paper is composed of a PV power plant and an energy storage system. The PV plant has