Applied Energy 183 (2016) 1075–1085

Contents lists available at ScienceDirect

Applied Energy

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

The economic viability of a feed-in tariff scheme that solely rewards self-consumption to promote the use of integrated photovoltaic battery systems

Giovanni Brusco, Alessandro Burgio *, Daniele Menniti, Anna Pinnarelli, Nicola Sorrentino

Department of Mechanical, Energy and Management Engineering, University of Calabria, Rende 87036, Italy

HIGHLIGHTS

- A FIT scheme for grid-connected integrated PV-battery systems is discussed.
- The FIT tariff scheme solely rewards self-consumption.
- An optimization problem minimizes the tariff and it sizes the integrated systems.
- The saving on bill is approximately 50%, the end user attains 25% self-sufficiency.
- The self-generation is 50% at least, the self-consumption is 80% at least.

ARTICLE INFO

Article history:
Received 6 June 2016
Received in revised form 31 August 2016
Accepted 2 September 2016

Keywords:
Battery storage
Economical analysis
Feed-in tariff
Optimal sizing
Photovoltaic system
Support policy

ABSTRACT

With reference to an integrated photovoltaic battery (PV-BES) system for grid-connected end users, a feed-in tariff scheme is discussed in this article. This scheme solely rewards self-consumption. Zero is the generation price paid for the generated renewable energy, and zero is the export price paid for the renewable energy delivered to the grid. This feed-in tariff scheme, referred to as S-FIT, also excludes the net-metering service and the possibility that the grid recharges or discharges the batteries.

To calculate the incentive tariff, an optimization problem is adopted. The problem returns the minimum value of the tariff so that the subsidy given to the end user is equal to the difference between the instalments paid for the integrated PV-BES system and the savings obtained from the electricity bill. The period during which the end user has secured this grant is ten years.

The S-FIT scheme is applied to the case of the Italian Public Administration from 2011 to 2015. Consequently, the real values of temperature, irradiation, and energy consumption are measured every 15 min, and the real electricity prices over the period 2011–2015 are considered. The optimal solution returned by the optimization problem allows for a significant reduction of the electricity bill by 49.56%; moreover, the self-produced energy is equal to at least 50%, whereas the self-consumed energy is equal to at least 80%.

The optimal solution that is calculated using 2011 data is applied for 2012–2015. Although the electricity prices were subject to a radical change during this period, the optimal solution still allows for a significant reduction of the electricity bill; in particular, this reduction is equal to 44.98% when the PV-BES system is adopted, whereas it is equal to 33.65% when only the PV system is adopted. In both cases, the optimal solution ensures self-produced energy of at least 50% and self-consumed energy of at least 80%.

This article ends with an assessment of the impact of the integrated PV-BES system on the load profile from the grid perspective and the satisfactory degree of self-sufficiency achieved by the end user.

1. Introduction

Among the contributions in the literature concerning the study and the economic viability of integrated photovoltaic and battery energy storage (PV-BES) systems for industrial or dwelling applications, including those benefitting from an incentive policy, Ref. [1] stands out among the many studies because the conclusion is the

* Corresponding author at: University of Calabria, via bucci, 42C, 87036 Rende, CS, Italy.

E-mail address: alessandro.burgio@unical.it (A. Burgio).

http://dx.doi.org/10.1016/j.apenergy.2016.09.004

opposite of the majority of the contributions. In 2012, McKenna et al. state that in the UK, the PV-BES combination is not economically efficient because even in the presence of the incentive feed-in tariff policy, there is no economic convenience when adopting lead-acid batteries even if ideal batteries with an optimistic life expectation are considered. In addition, based on well-formulated considerations, McKenna et al. claim that this conclusion, *batteries in the UK do not pay*, is also valid for the case of Germany and the Australian States of Queensland, Victoria and Western Australia.

Three years before, in 2009, the study of PV-BES systems on the German FIT policy was already being addressed in Ref. [2]; in this reference, Braun et al. present a PV-BES system developed within a French-German project called Sol-ion. They conclude that the adoption of the Sol-ion system is a profitable operation for lithium-ion battery system prices below 350 €/kW h.

One year later, Ref. [3] arrived at the same conclusion; Hoppmann et al. state that in 2013, investment in storage batteries in Germany was economically viable for small PV systems even when not considering feed-in policies or demand-side management. The authors conclude that a promotion policy of battery storage will be necessary only in the short term.

In 2014, the study of PV-BES systems on the German FIT policy is again addressed in Ref. [4]. Like many other academics, Weniger et al. also seek to identify the storage system price at which residential PV-BES systems become economically sustainable. In reality, the authors question which factor primarily influences the break-even price and conclude that the main factor is the rate of interest, followed by the PV system price, the retail price of electricity and the feed-in tariff. Consequently, Weniger et al. suggest evaluating the profitability of PV-BES systems and focusing on the future development of retail electricity prices instead of the development of new feed-in tariffs. The authors state that the integration of PV systems with batteries will be the most economical solution in a long-term scenario.

A further contribution to the study of PV-BES systems on the German FIT policy was made in 2015 by [5]. In the reference, Linssen et al. show that the use of realistic load and production profiles is mandatory to allow for reliable statements concerning both the technical parameters and economic feasibility. The authors also conclude that the break-even price for the integrated system is approximately 900 €/kW h without a battery energy storage support scheme and approximately 1200 €/kW h when considering the German support scheme. Linssen et al. conclude by underlining that the individual taxation of revenues can significantly lower the break-even costs.

The study of PV-BES systems on the German FIT policy in commercial applications is addressed in 2016 in Ref. [6]; in the reference, Merei et al. focus their attention on this sector due to the significant opportunity for economic savings. Indeed, commercial buildings usually have ample space for the installation of photovoltaic panels, and their load profiles have a high correlation with the generated solar energy. A supermarket in Aachen with yearly electricity consumption of 238 MW h is the case studied in the reference; in this commercial application, the authors conclude that battery storage significantly increases the self–consumption of PV produced energy, but even with unrealistic battery prices of less than 200 €/kW h, batteries cannot offer an economic solution.

The German incentive system was used as inspiration in Ref. [7]; in this reference, Mulder et al. affirm that since 2012 in Belgium, the use of lead-acid batteries up to 5 kW h is also affordable without subsidies, regardless of the increase in the cost of electricity. In view of the gradual decrease of the cost of lithium batteries, this latter technology will be attractive in the short term. Specifically, if the price of electricity increased by 4%, 4 kW h lithium batteries will be an attractive option in 2017 even without subsidies.

Currently, Italy does not have a specific FIT policy for battery energy storage systems; the only concession to customers for the installation of batteries is a tax deduction equal to 50% of the investment costs spread over 10 years. All residential and commercial customers can install BES systems, which do not necessarily have to be integrated with a PV plant. In the case of batteries integrated with PV systems, the installation of a bidirectional electric meter is required to prevent the annulment of the incentives, where they exist, for the PV system. An analysis of the costs/benefits of the PV-BES system in residential applications is reported by the Italian total public-controlled Research into Electrical Systems company in Ref. [8]. The results presented in the reference show that in the case of an existing PV system subsidized by a feed-in tariff, the adoption of a BES system further increases the annual economic benefit of approximately 150 euros. In the case of a PV system that is not subject to a feed-in tariff, the additional annual economic benefits increase to approximately 170 euros. The calculated annual benefit is estimated net of the costs of the initial investment.

In most of the articles cited above that are mentioned in the noteworthy review presented in Ref. [3], the analysed incentive schemes already exist; therefore, these schemes include input data in the economic-financial evaluation of an integrated PV-BES system, like solar radiation or user load profiles. On the contrary, a proposal for a new incentive scheme for PV-BES systems on the Greek island of Corvo is presented in 2011 in Ref. [9]. Two diesel generators of 120 kW and two of 160 kW serve the island and its approximately 400 inhabitants. To calculate the subsidy for remunerating the adoption of PV-BES systems, Krajacic et al. estimate the fuel savings achieved from the adoption of batteries; they conclude that for a residential battery storage system with a capacity of up to 40 kW h mounted with a 4 kW inverter, the feasible remuneration scheme is a fixed tariff of 53.8 €/kW h, multiplied by the storage capacity.

Two further proposals for a new incentive scheme for PV-BES systems in Australia are presented in 2014 in Refs. [10,11]; in these references, Ratnam et al. study 145 residential customers who were randomly selected from customers located in the low voltage Australian distribution network operated by the Ausgrid distributor.

For these customers, the authors assume the use of a photovoltaic system mounted on a rooftop and a battery storage system with a capacity initially fixed at 10 kW h. The authors also propose a role and the respective algorithm that efficiently manages the batteries to grant economic benefits to the residential customer and simultaneously alleviate the utility burden associated with peak demand and reverse power flow. The economic benefits are derived from the proposed FIT schemes. One of these schemes consists of a generous constant FIT of 0.4 $/kW h; this value is higher than peak load price but is lower than the FIT offered in 2010 by the New South Wales Government, which paid a generation price of 0.6 $/kW h. The proposed FIT schemes enable an overall average savings of $350/yr and $100/yr per user.

Four algorithms for the battery storage system operation are also proposed in Ref. [12], where the residential storage at the local and grid levels for Portugal is analysed. In the reference, Santos et al. use these algorithms to implement four rules and achieve the same number of different objectives. The first objective is to minimize the energy exchange between the grid and the customer, i.e., the grid zero role; the second and third objectives aim to reduce the peak demand from the grid and the peak energy injected into the grid, respectively. The last objective is to facilitate the integration of wind power from the grid. Each storage role is studied with respect to the four scenarios that represent the incentive for the customer to adopt the battery storage system. The authors concluded that the grid zero scenario is better able to