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ScienceDirect

Energy Procedia 73 (2015) 48 – 58

Energy Procedia

9th International Renewable Energy Storage Conference, IRES 2015

Optimal sizingof electrical energy storage systems using inventory models

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Abstract

This paper adopts a single-period newsvendor model with supply uncertainties to be used for optimally sizing an electrical energy storage system (EESS) for an apartment house with a photovoltaic (PV) system. Hence, typical inventory cost components and supply chain characteristics are translated to the EESS application. The results show that inventory management and energy storage can be aligned. The optimal size of the EESS takes into account the total cost of the storage system including energetic losses as well as the costs for energy supply from the own energy systems and from the energy supplier.

Peer-review under responsibility of EUROSOLAR - The European Association for Renewable Energy

*Keywords:*energy storage; PV home storage; sizing; newsvendor model; inventory model

1. Introduction

Along with the increase of renewable energies in power supply, there is a rising demand for storage capacities [1]. Even for small households withphotovoltaic PV, an electrical energy storage system (EESS) can be profitable if it increases the self-consumption of the building. With a higher penetration of renewable energies in the power grid, EESSs will be necessary to provide valuable grid services in addition to their main task [2,3]. Following the

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1876-6102
Peer-review under responsibility of EUROSOLAR - The European Association for Renewable Energy
doi:10.1016/j.egypro.2015.07.559

increasing use of EESSs, the need for an EESS-sizing-procedure has recently started to attract the attention of researchers and practitioners alike. The approach proposed in this paper is based on analogies between inventory management in classical supply chains and the energy storage process. These applications show strong parallels in terms of the basic assumptions and general conditions.

In contrast to the field of EESSs, a plethora of methodologies have been developed for cost-efficiently planning inventories within a supply chain. This paper adopts such a methodology to optimally size an EESS for an apartment house with a PV system as the building's own source of energy with respect to different cost parameters. Before we explain this methodology in detail, we give an overview of procedures which are currently used to size EESS, shortly elaborate on the fundamentals of inventory management and present areas of interdisciplinary research which have already capitalized on the use of inventory models (Section 2). In Section 3, we define requirements which the operation of an EESS imposes on the model. Based on these requirements, we select a model and adjust it accordingly. In Section 4, we present a numerical analysis of the developed model, and Section 5 concludes the paper.

Nomenclature

α	self-discharge ratio for 24 hours in $\%$
C	optimal capacity of the EESSin kWh
c	purchase price in $€/kWh$
$c_{Generation}$	cost for generating solar energyin $€/kWh$
$c_{Storage}$	cost for storing energyin $€/kWh$
c_o	overage costin $€/kWh$
c_u	underage costin $€/kWh$
D	demandin kWh
$E_{D,i}$	discrete amounts of energy demandin kWh
$E_{D,mod,i}$	modifieddiscrete amounts of energy demandsin kWh
$E_{S,i}$	discrete amounts of energy supplies in kWh
η	single-sided conversion efficiency in $\%$
F_w	cumulative distribution function of w
f_D	density function of D
p	sales price in $€/kWh$
Q^*	optimal order quantity in kWh
S	order-up-to levelin kWh
S^*	optimalcyclical order quantityin kWh
v	salvage valuein $€/kWh$
w	random yield in kWh

2. Literature review

2.1. Existing EESS-sizing procedures

Since energy storage systems of different types have been in operation for centuries,severalmethods have been developed in the past that support finding suitable storage systems for different applications. Most of these methods use search heuristics or optimization algorithms based on input parameter variations to identify the appropriate dimensions (power and energy) of the EESS. Examples of such approaches can be found in [4], [5] and [6]. An example for an analytical approach, where the objective function can be solved for the dimensions of the EESS, can be found in [7]. The intermittent character of most demand and production profiles has led to promising stochastic approaches. Examples can be found in [8], [9] and [10]. Yet, to the best of the authors' knowledge, none of these procedures make use of well-studied inventory models to size and optimize an EESS.