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Life cycle cost analysis for BESS optimal sizing

Beatrice Marchi*, Marco Pasetti, Simone Zanoni

Department of Mechanical and Industrial Engineering, Universita degli Studi di Brescia, via Branze 38, Brescia 25123, Italy

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Abstract

The increase of renewable energy sources (RES) installations all over the world during the past decades leads to a more sustainable energy scenario, however some drawbacks still persists and hinder the complete replacement of traditional fossil fuels. One of the main challenging issue is related to the intermittent production that generates serious problem in the power grids operations. Battery energy storage systems (BESS) represent one of the most promising technology which can help to overcome this issue, revolutionizing the way in which electrical power grids are designed and operate. The main aspects of these devices are related to the grid energy management, increasing the host capacity of RES, the system reliability and the users’ self-consumption. However, even energy storage systems present several pitfalls. They should be correctly maintained over the lifetime and they cannot be completely recycled at the end of their life, in addition, maintenance, decommissioning and disposal costs represent a significant share of the total cost. So as to consider these aspects in a holistic model the present work proposes a life cycle cost (LCC) model, which take into account all the most relevant cost components during the entire operation of the system.

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Keywords: batteries; energy storage systems; optimal sizing; life cycle cost analysis; maintenance; disposal

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1. Introduction

Renewable energy sources (RES) has been characterized in the last few years by a huge increase of the installed power capacity [1], leading to a more sustainable energy scenario. Recent reports, published by the International

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* Corresponding author.
E-mail address: b.marchi@unibs.it

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Energy Agency (IEA), predict that the share of total renewable energy generation will present remarkable shifts in a very limited period of time, growing worldwide from 22 % to over 26 % in the time period 2013–2020 [2], and from 21.4 % to 43.8 % by 2035 within the EU [3]. In spite of the great benefits introduced, RES sources still cannot totally replace traditional fuels, since almost every renewable source is characterized by intermittency, unreliability and non-programmability of the energy output, causing relevant drawbacks in the supply. Energy storage system (ESS) is considered one of the most promising technology in overcoming RES's limits and in achieving the EU energy targets by 2020 and 2050 [4], revolutionizing the way electrical power grids are designed and operate and supporting distributed generation (DG) [5]. The main applications of storage devices are related to energy management, leading to reduced time shifts and increased host capacity of RES, system reliability and self-consumption. Besides stabilizing RES's output energy, storage devices generate other several benefits at different stage of the network grid: for example, they can reduce the energy price through price arbitrage [6], shift electricity from low-demand periods to the peaks [7], limit surplus energy production and reduce the users' contractual power. Energy in the form of electricity is not storable, thus it is necessary to convert it into other forms of energy, such as chemical, kinetic, gravitational potential energy, or electrical/magnetic fields. Among the different technologies already mature for electrical energy storage, batteries energy storage system (BESS) is currently considered the most suitable technology for the integration with RES [4]. On the other hand, BESS present several pitfalls too: they should be correctly maintained over the lifetime in order to have good performance until the end of their life and they cannot be completely recycled once disused. Consequently, maintenance, decommissioning and disposal costs represent significant topics and should not be omitted from economic considerations. For this reason, a life cycle cost (LCC) model should be considered for the evaluation of the benefits and costs introduced by BESS, in order to judge whether it represents a profitable investment and to compare competing energy storage devices. In recent years, a wide spectrum of studies has been performed on energy storage systems. This interest has been mainly focused on the classification of the EES technologies [4, 8–11], on energy and economic analysis in order to find the optimal size of energy storage devices [12–16] and on models describing the physical and chemical processes in batteries [17]. Some other works consider environmental aspects applying the life cycle assessment approach [18–20] and economic aspects through LCC or levelized cost analyses [20–22]. To the best of the authors knowledge, in literature very few LCC models applied to BESS consider both maintenance and disposal costs in addition to the traditional investment and operational costs, and the ones that consider them do not show the disaggregated impact of the different costs. Moreover, these models consider given storage size for comparing different technologies and do not find the optimal value of capacity storage. The aim of the present work is thus to find the economical optimal size of the BESS technology minimizing the life cycle cost, taking into account all the most relevant cost components at a user stage of the network grid. This paper is structured as follows: in Section 2 we describe the energy balance model; in Section 3, the LCC model is presented, detailing the different cost components considered; in Section 4, we present a numerical example considering a real user context and, finally, in Section 5 the concluding remarks are outlined.

2. Energy balance model

The algorithm that regulates the energy balance of the integrated system and thus the charge and discharge power rates of the storage system and the related state of charge (SoC) is defined in Fig. 1: when the power generation of the RES is higher than the energy requested from the loads and the storage system is not full, the battery can be charged; conversely, when the energy requested by the loads is higher than the RES production and the storage device is not empty, the battery can be discharged. In the other cases, the energy storage system is in stand-by mode and it is subject to self-discharge losses. Eq. (1–7) describe the behavior of the energy storage in charge condition, Eq. (4–6) in discharge condition, while Eq. (7) describe the system in idle mode.