A linear programming approach for battery degradation analysis and optimization in offgrid power systems with solar energy integration

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A B S T R A C T

Storage technologies and storage integration are currently key topics of research in energy systems, due to the resulting possibilities for reducing the costs of renewables integration. Off-grid power systems in particular have received wide attention around the world, as they allow electricity access in remote rural areas at lower costs than grid extension. They are usually integrated with storage units, especially batteries. A key issue in cost effectiveness of such systems is battery degradation as the battery is charged and discharged.

We present linear programming models for the optimal management of off-grid systems. The main contribution of this study is developing a methodology to include battery degradation processes inside the optimization models, through the definition of battery degradation costs. As there are very limited data that can be used to relate the battery usage with degradation issues, we propose sensitivity analyses to investigate how degradation costs and different operational patterns relate each others. The objective is to show the combinations of battery costs and performance that makes the system more economic.

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1. Introduction

Storage technologies and storage integration are currently key issues in energy systems research, particularly due to the need to integrate high renewable energy capacities. Diagrams presented in Ref. [1] show the increasing penetration of renewable sources both in industrialized and developing countries between 1980 and 2010. The International Renewable Energy Agency IRENA discusses different technologies of battery storage for renewables in the report [2], where four main application areas are identified: islanded systems with off-grid rural electrification; households with solar photovoltaic; demand shifting; short-term electricity balancing in ancillary markets.

Off-grid power systems in particular have received wide attention around the world as further analyzed in Ref. [3]. They can bring electricity to remote rural areas at lower costs than grid extension. As described in Ref. [4] they are typically based on one or more renewable energy sources (e.g. solar photovoltaic or wind) together with a conventional power generator to provide backup when necessary.

Storage units, such as batteries, can be integrated in offgrid systems as they represent an alternative capacity source to the conventional generator which has high operational costs due to fuel consumption in addition to CO2 emissions [5]. Especially in offgrid applications like the one presented in Ref. [6], batteries perform several important tasks such as reducing intermittence of the renewable resources, extending the electrical service hours to night time periods, and allowing the system to run for extended periods without any power generation.

Optimization techniques and technical economic analyses has been widely used in literature in order to investigate smart operational management approaches both in distributed energy systems and islanded systems. Examples can be found in Ref. [7] where linear programming is used for distributed energy system operational optimization, and in Ref. [8] where comparisons between
As outlined in Ref. [9], the economics of a hybrid energy system depend both on the size of the selected components and on the dispatch strategy. With regard to the latter, a key issue in cost effectiveness of such systems is battery degradation as the battery is charged and discharged [10]. Hence a question that arises is how dispatch strategy. With regard to the latter, a key issue in cost fuel-based systems and smart renewable-based systems are such systems become economic. 

The available literature in the field of batteries can be classified into two main approaches, experimental studies and the mathematical analytical studies. The first focuses on chemical analyses and laboratory tests to increase knowledge of degradation processes. Examples of this approach can be found in Ref. [12] where authors discuss a method to diagnose electrode-specific degradation in commercial lithium ion (Li-ion) cells [13]; which presents a diagnostic technique which is capable of monitoring the state of the battery using voltage and temperature measurements in galvanostatic operating modes [14]; where authors describe life experiments performed on lithium polymer cells to investigate the cell life dependence on the depth of discharge; and [15] where a review on methods to mitigate battery degradation is presented. 

On the other hand, the mathematical analytical approach is focused on computational simulations and optimization analyses.
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