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Robust Design of Microgrids using Component Models with Different Level of Accuracy

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Abstract. Robust design of microgrids is a complex optimization process requiring multiple simulations in order to integrate uncertainty variables associated with the system environment or design models. In this context, having sufficiently accurate models that are compatible with the optimization algorithms and associated computational costs represents a real challenge. In this paper, we illustrate this through the robust design of a simple microgrid with electrochemical storage. Based on battery models that couple energy efficiency and aging, we develop an approach for choosing the right level of precision to match the microgrid's optimization criteria or constraints.

Keywords: Integrated Optimal Design, Robust Design, Microgrids, Battery Storage, Aging

INTRODUCTION

The techno-economic optimization of electrical microgrids represents a real challenge since it requires integrating both the energy efficiency of components and their aging, as well as the uncertain nature of certain parameters (production or consumption scenarios, value of operational and capital expenditure costs, model fidelity) [1,2]. In this context, the development of suitable robust design approaches takes on its full meaning. The complexity of such approaches requires the use of simplified models ensuring a good compromise between accuracy and CPU time in compliance with the optimization techniques used. In this paper, we show in particular how to determine in microgrid design the right level of model accuracy, using the example of battery models that include energy efficiency and aging.

ROBUST DESIGN FORMULATION

The robust optimization problem associated with the microgrid design is defined as:

$$\min_{d \in D} \sum_{s \in S} \frac{NPV(d, s)}{\text{card}(S)} \quad \text{s. t.} \quad \sum_{s \in S} \frac{\delta_{\varphi}(RES(d, s))}{\text{card}(S)} \geq \beta \quad \text{with } \delta_{\varphi}(x) = \begin{cases} 1 & \text{if } x \geq \varphi \\ 0 & \text{otherwise} \end{cases}$$

It consists in finding the microgrid design within a space design D which minimizes the NPV (Net Present Value) on average over all considered scenarios S of PV production and load consumption, while ensuring a level φ of self-sufficiency for a least a fraction of β scenarios. The NPV is obtained by adding investment and operating costs over the microgrid lifetime. This is a conditional value of risk (CVaR) formulation [3], which incorporates uncertainties while providing flexibility in self-sufficiency and robustness.

CASE STUDY

The case study is a small microgrid including PV production, electrochemical storage and load consumption, connected to a main grid. Production and consumption data are generated by Markov models based on the Ausgrid data from [4]. The electrochemical storage can be represented using two energy models and four aging models with varying levels of accuracy/complexity.

A simple heuristic is implemented for the energy management, charging the battery in case of PV surplus, discharging it in case of PV deficit and using the main grid only in extreme cases (i.e. battery fully charged or empty). The robust sizing of this simple microgrid is investigated using a Sobol sequence [5] for the PV and battery sizes lying in the respective ranges of [0, 100 kWp] and [0, 160 kWh]. A number of $S=16$ scenarios is considered in the robust design formulation with a threshold of $\beta=15/16$ for ensuring robustness.

The figure 1 illustrates a comparison of microgrid sizing results for different levels of self-sufficiency using two battery models: a non-linear reference model based on a variable efficiency according to the C-rate coupled with aging (including calendar aspects, Rainflow cycling and Solid Electrolyte Interface degradation [6]) is compared with a coarse linearizable model considering a fixed efficiency and an aging based on exchanged energy. In particular, the results show the importance of taking into account the degradation of battery parameters during aging (especially the loss of battery capacity) and enable us to identify a linearizable model that can be easily used without loss of accuracy in MILP (Mixed Integer Linear Programming) optimization processes.

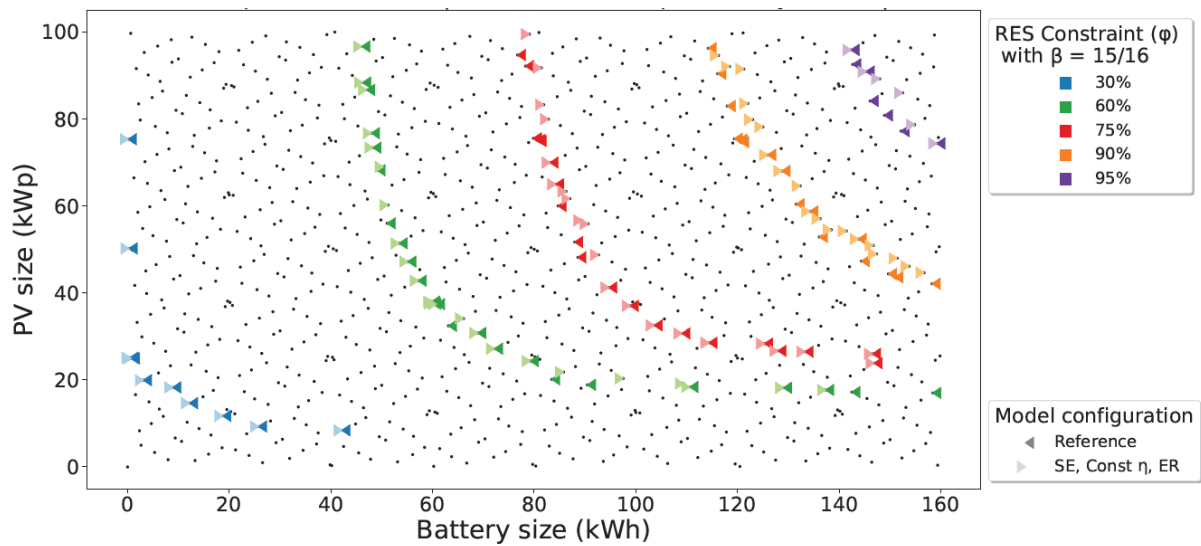


Figure 1: Constraint satisfaction front line comparison. The results show a good agreement between the fine battery model coupling energy efficiency and aging (leftward triangles) with a coarse linearizable one of lower complexity (rightward triangles)

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