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METHOD FOR THE DESIGN AND CONTROL UNDER UNCERTAINTIES OF A SIMPLE DISTRIBUTED ENERGY SYSTEM

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Abstract. This paper focuses on the integrated design and control under uncertainties of a distributed energy system (DES): the future energy demand and production as well as the electricity tariff are not perfectly known while sizing and operating the system. To address this question, a two-stage stochastic programming model is implemented where uncertainties are modelled as random variables and the quality of the solutions is assessed on a common “out-of-sample” simulator. The results show that the method provides designs which are consistent with a given risk measure (expectation, worst case, etc.).

Keywords: design, stochastic programming, Markov chains, energy systems, energy planning

INTRODUCTION

With the growing integration of renewable energy sources into the conventional system, the concept of distributed energy systems has emerged. The design of such systems has been widely studied in the literature and is oftentimes expressed in the form of optimization problems [1]. To tackle long computation times, uncertainties are usually ignored assuming perfect foresight over the system lifetime. However, this simplification could lead to underestimation of the total system cost with overestimated performance of the DES [2]. To address this shortcoming, a two-stage stochastic programming model is implemented and the quality of the solution is assessed on a common “out-of-sample” simulator. The DES remains voluntary simple as the objective is to focus on the design methodology rather than the system complexity. In the first section, the problem is formulated and the scenario generation approach is presented. Then, the resolution method is introduced and some results are depicted in the last section.

1. MATHEMATICAL FORMULATION AND SCENARIO GENERATION

The future electrical ($p_h^{ld,e}$) and heating ($p_h^{ld,h}$) demands, the normalised solar production (p_h^{pv}) and the electricity tariff ($c_h^{g,+}$) are the uncertainties of the problem as their values could not be predicted with perfect accuracy. They are modelled as random variables over a sample space Ω . The charged/discharged power in the battery ($p_h^{b,-}$ and $p_h^{b,+}$), the curtailed solar power (p_h^c) and the heater electrical power ($p_h^{ht,e}$) are the decision variables for the operation of the DES (see figure 1). They have to be made at an hourly time step in order to supply the energy demands while considering technical limitations of the assets. As the decisions depend on the uncertainties, they are also random variables. The objective of the design procedure is then to determine the optimal PV peak power ($p^{pv,max}$) and the battery capacity ($E^{b,max}$) in order to minimize the sum of both the annualised investment and operating expenditures (1). As operation decisions are random variables, the conditional value at risk (CVaR) is introduced as a coherent risk measure in the objective [3]. Note that for the sake of simplicity, no electricity could be sold to the grid.

$$(1) \quad \min_u \underbrace{\gamma^{pv} \cdot c^{pv} \cdot p^{pv,max} + \gamma^b \cdot c^b \cdot E^{b,max}}_{\text{Investment cost}} + \underbrace{\text{CVaR}_\beta \left[\sum_{h=1}^H c_h^{g,+} \cdot p_h^{g,+} \right]}_{\text{Operating cost}}$$

Furthermore, a self-sufficiency ratio (between 0 and 1) is also introduced as a “soft” constraint also depending on the CVaR measure. It represents the percentage of the total consumption “self-supplied” by the local solar production. In order to solve the stochastic problem, synthetic scenarios are generated to build the sample space Ω . The generation method is based on Markov chains and the approach will be detailed in the presentation. From a residential measured dataset, 2000 scenarios of one year at an hourly time step are generated to fairly represent the stochastic process. Then, the scenario pool is split in two parts: one will be used for the design (Ω_d) and the other for the “out-of-sample” assessment (Ω_a) for performance evaluation.

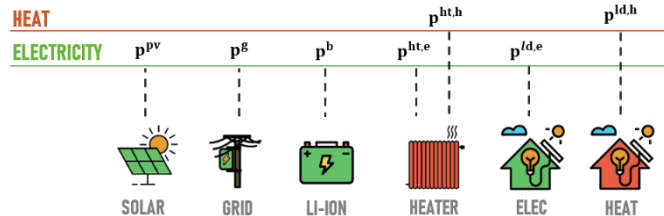


Figure 1: Schematic view of the DES

2. RESOLUTION, ASSESSMENT AND RESULTS

The linear two-stage recourse model is solved using stochastic programming technique by formulating the *deterministic equivalent problem* on a finite set of scenarios from Ω_d [4]. Then, each design solution is assessed on a common “out-of-sample” simulator by Monte Carlo simulation over the sample space Ω_a . Unlike the design phase, uncertainties are revealed step by step and operation decisions are only made with past and current information. Figure 2 shows the results for an isolated DES case (self-sufficiency equal to 1) where the consumption is only supplied by solar panels. The first 3 cases (“S1”, “S179” and “EVP”) are deterministic results to be compared with the stochastic results (“EXPECT.” and “WORST”) where the risk measure is the expectation and the worst case, respectively. As depicted in the figure 2, the statistical distribution of the self-sufficiency could not be controlled with the deterministic formulation and the result will depend on the scenario selected for optimization. On the contrary, the stochastic method provides designs which are consistent with a given risk measure: the higher the risk aversion, the higher the equipment sizes and the higher the total cost of the system (see table 1). Sensitivity over the self-sufficiency ratio and risk measure will be depicted in the presentation.

Table 1: Design values and total annualized cost.

	PV [kWp]	Battery [kWh]	Cost [k€/y]
S1	141	469	27,8
S179	62	383	18
EVP	91	311	18,2
EXPECT.	163	476	29,9
WORST	189	551	34,7

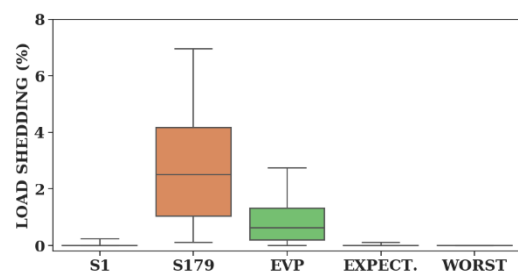


Figure 2: “out-of-sample” distribution for the load shedding ratio

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