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Optimal design of distributed energy system in a neighborhood under uncertainty

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ABSTRACT

Distributed energy systems (DES) are widely accepted as the future generation of the energy systems. The number of studies in all related fields corroborates the assertion that these systems are in their infancy and need to develop more in terms of efficiency and economizing. Admittedly, these systems are hardly lucrative and poor planning is one of many hurdles standing in the way of their profitability. Disregarding uncertainty as an innate characteristic of the real world seems one of the improper simplifications of this planning. To cover this gap, the paper is mainly focused on designing an energy system in a neighborhood including its pipeline network under demand uncertainty concerning data insufficiency. Therefore, a new model for planning in a neighborhood is presented and then reformulated to its robust counterpart. Various technologies like PV array, chillers, boiler, storage tank, and CHPs are considered in order to meet the cooling, heating and electrical demands. The probable consequences of the demand uncertainty are studied to the length. The outcomes reveal that the unit sizes and pipeline network are highly dependent on the decision maker's level of conservatism.

1. Introduction

An energy system could be regarded as a supply chain consisting of production, conversion, and transmission to the end-users [1]. Conventionally, energy is produced in large power plants operating in central locations and all the produced electricity is transmitted through distribution networks to the long distances. About a decade ago, distributed energy system (DES) was introduced as a new concept on energy generation as the opposite of centralized energy system. A distributed generation network refers to small-scale producers which are located near to end-users.

One of the main challenges for designing an energy system is the degree of decentralization. Studies have discussed energy systems in different degrees of decentralization. Some of them bounded the scope of the study to a building while others discussed the energy system in a district.

Undeniably, despite all advantages of distributed energy systems, there are some barriers which make an applicatory plan a necessity. All the mentioned studies in the literature shared a common assumption. They all proposed the mathematical model in a deterministic environment and it is highly probable that the outcomes are distorted by the ignored uncertainties which it may jeopardize the profitability of the whole project. As it is obvious from Table 1, some studies considered energy system planning of a single building under inherent uncertainty while to the best of our knowledge; this planning is never conducted in any studies in the scale of a neighborhood.

This paper is mainly focused on designing an energy system in a neighborhood under demand uncertainty. Literature review reveals the lack of attention to the field of energy system planning in a neighborhood while the quality of studies in a single building seems quite satisfying. For filling this gap, a mathematical model for investment planning of the energy system in a neighborhood is proposed and then for overcoming the uncertain environment, the robust counterpart of proposed model is obtained.

In the proposed deterministic model, a wide range of technologies is considered. The buildings could also exchange heat via pipeline network which its existence depends on the model's preferences. A combined cooling, heat and power (CCHP) unit by assisting a back-up boiler, solar thermal cells and a heat storage tank could supply both heating and electricity demand and meanwhile, both electric and absorption chillers are considered for meeting the cooling demand. Moreover, some environmentally friendly technologies like Photovoltaic arrays (PV) are considered. It

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Table 1
Review of studied uncertainties in a building's energy system (Source: adopted from Ref. [5] and updated).

Author	Uncertainty							Solution approach
	Demand	Supply	Fuel cost	Other costs	Electricity price	Interest rate	Others	
[13]	•							Robust optimization
[12]	•							Probabilistic theory (simulation-based optimization)
[10]	•	•						Stochastic optimization
[4]	•							Fuzzy programming
[14]	•							Fuzzy programming
[11]			•		•	•		Combined mathematical programming and Monte Carlo simulation
[15]	•							Sensitivity analysis
[16]	•							Monte Carlo simulation and optimization
[17]	•							Robust optimization (Based on maximum regret rate)
[18]				•			•	Interval programming
[19]			•					Stochastic optimization
[20]			•					Stochastic optimization
[21]	•		•	•				Stochastic optimization and interval programming
[22]	•	•			•			Probabilistic programming
[23]				•				Fuzzy programming
[5]	•		•	•	•			Robust optimization
[24]	•							Stochastic optimization
[25]	•		•				•	Stochastic optimization
[26]	•		•		•		•	Stochastic optimization
[27]			•		•			Stochastic optimization

should be noted that both CHP and boiler use natural gas. The objective function also consisted of multiple criteria namely investment costs, operation and maintenance costs, Carbon emission costs and revenues.

The paper is assembled in eight sections. In Section 1, an introduction to distributed energy systems (DES) are presented and then concerns of this paper is highlighted. A generic mathematical model is presented at Section 3 and later in Section 2, a comprehensive review on literature is provided. In Section 4, the mathematical model consisted of the objective function and constraints discussed thoroughly. In Section 5, the robust model is explained and in Section 6, the test problems are described. Consequently, the outcomes are discussed to the length in Section 7. Finally, the remarks are concluded in Section 8.

2. Literature review

In this paper, the previous studies in the context of energy system planning are classified into two main groups. The first group is focused on researches that aimed to plan the energy system in a *sole* building while in the second group the studies are concentrated on planning the energy system *several* buildings.

2.1. Energy system planning in a building

There have been numerous efforts focused on the planning of the energy system in a building like Ref. [2]. The remarkable point is a majority of the studies in this group are conducted in a hospital or commercial buildings which could afford to finance in their energy sector. For instance, Ref. [3] did the feasibility study of a hospital in Parma, the case study of [4] was a hospital in Athens, Ref. [5] studied on a hospital in Iran. As it is obvious, there is a focus on hospitals. Ref. [6] concluded that due to simultaneous and flat loads of hospitals, distributed generation systems are more efficient in the hospitals.

To begin with, Ref. [7] proposed a new method consisted of a genetic algorithm for the purpose of planning an energy system even if the problem is non-linear. The outcomes suggested that the model could be applied to the complex energy systems. In Ref. [8] a mixed-integer linear programming (MILP) model is proposed for unit sizing of candidate technologies in a hypothetic hotel in China. The results suggested that an optimal configuration of DES with various technologies is more efficient than the conventional centralized energy systems as well as distributed combined cooling, heating and power systems. The proposed mathematical model of [9] intended to manage the daily operation of smart polygeneration microgrid (SPM) in the university of Genoa and results demonstrated the efficiency of the model.

It is probable that a minor perturbation in coefficients distort the results and adversely affect some of the determinant factors like Return of Investment (ROI).

In Ref. [10], a two-stage stochastic programming model is implemented in a hospital for the purpose of planning under both demand and supply uncertainty. A decomposition-based solution strategy and a Monte Carlo method are applied for first and second stage respectively. The outcomes illustrated the slight difference between stochastic and deterministic design and due to the computational efficiency of the deterministic one, this model is suggested to implement in the energy system planning. In Ref. [4], a fuzzy programming model is proposed for the purpose of investment planning under demand uncertainty in a hospital in Athens. The outcomes illustrated that the uncertainty of objective function could be effectively tackled by implementing fuzzy programming approach. In Ref. [11], an integrated framework consisted of mathematical programming and Monte Carlo simulation is implemented in order to manage the risk of some volatile parameters in the objective function such as fuel costs and interest rate. This study is also conducted in a hospital in Athens. In Ref. [12] the demand's uncertainty is modeled using probabilistic theory and stochastic programming. A simulation-based optimization is implemented and the outcomes illustrated the better cost performance of FTL (following thermal load) strategy in comparison with other alternative configurations. Also, by increasing demand uncertainty, the amount of CHP and absorption chiller decreased while the capacity of the boiler and electric chiller increased. In Ref. [13], for tackling the demand's volatility a robust optimization method is implemented. Also in Akbari et al. [5], for facing multiple uncertainties (for instance carbon emission costs, electricity prices and demand) a robust optimization method is applied.

2.2. Energy system planning in a neighborhood

This section is devoted to energy planning studies that are conducted in the scope of several buildings or a neighborhood.