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Optimization approaches in district heating and cooling thermal network

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ABSTRACT

Modelling, simulation and optimization of an isolated building separated from the district in which they operate is no longer of interest as a view point of improved efficiency, economic benefits and exploitation of renewable energy resources. Instead, district energy systems have the capacity to obtain several benefits, regarding the practical, environmental and safety by taking advantage of large poly-generation energy conversion technologies. The use of optimization techniques to design such high-efficient systems is strongly motivated by minimizing of the cost for the required infrastructures, minimizing emission, and maximizing the generation or efficiency but is particularly challenging because of the technical characteristics and the size of the real world applications. In this paper, different types of optimization problems, constraints and techniques as well as the optimization tools used in district energy systems are discussed.

Contents

1. Introduction

A district energy system is able to simultaneously satisfy the demands of local buildings by providing on-site electricity, heating, and cooling[1]. The adoption of district energy systems exhibits several benefits. It allows for a reduced transmission losses through on-site generation, increased conversion efficiency, utilization of waste heat, reduction in constructing large generation plants, mitigation of emission problem and associated economic profits, and exploitation of renewables [2–4]. These systems may split into two categories: decentralized and centralized [5]. In the former, which is most suitable for large-scale areas, energy conversion technologies are integrated in almost every building and then is distributed among various buildings in an area. In the latter, which is better for relatively small, energy conversion technology is adopted outside the buildings and then the energy flows towards the buildings via a distribution network [6]. The rational design and planning of district energy systems have a pivotal role to achieve maximum energy saving/efficiency and maximum economic benefits of implementa-

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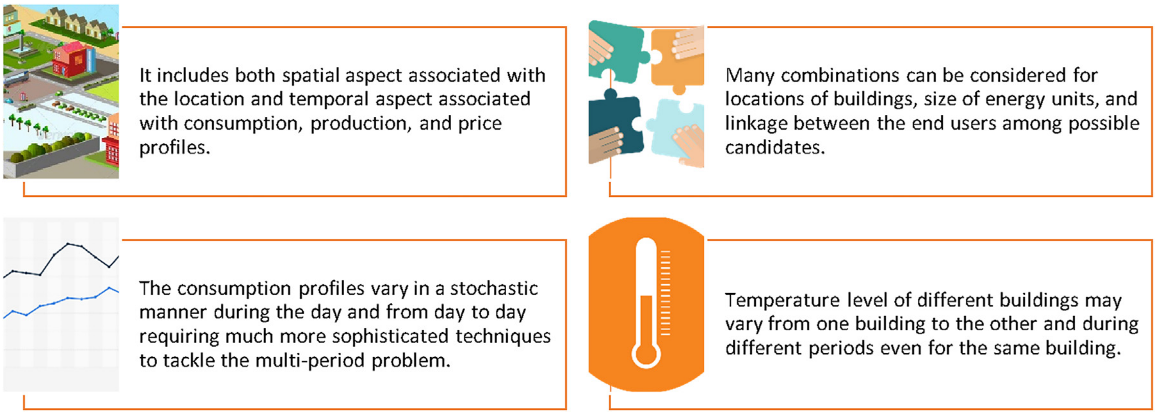

Fig. 1. Four main challenges faced by optimization at district level.

tion of such systems [7]. However, as Fig. 1 shows, achieving these goals is a complex task for several reasons [8].

Allegrini et al. [9] presented a review on simulation approaches and tools for energy systems at district level. Olsthroom et al. [10] reviewed the integration of renewable energies into district heating and storage technology. Lake et al. [11] reviewed the implementation of district heating and cooling in real case studies. Lund et al. proposed the concept of 4th generation district based on integration of smart thermal grid and its role in future networks [12,13]. In contrast to previous reviews on district heating and cooling, current study deals with the optimization of such systems. The paper first gives an overview of the mathematical approaches of the problem, and it then discusses different areas of applications at district level, and the constraints used in the formulation of the problem. Finally, it briefly discusses the existing optimization tools used in this area.

2. Overview on the mathematical approach

Considering more than one objective function at the same time may result in conflict between them. For example, minimization of the cost and pollutant emissions are usually conflicting [14]. Table 1 shows most popular types of optimization objectives used at district level and their conflicts. Mathematical programming methods have been employed in wide range to make decision regarding the optimum design, planning and operation of district energy systems. Mathematical models for optimization usually lead to structured programming such as Linear Programming (LP), Mixed Integer Linear Programming (MILP), Non-Linear Programming (NLP), and Mixed Integer Non-Linear Programming (MINLP) [19,20,15].

If the objective function and the constraints are linear, the problem is said to be linear. Otherwise, the problem is called a nonlinear problem [16]. Mixed-integer linear and nonlinear programming involves both continuous and discrete variables arise in many applications of engineering design. Roy et al. [17] investigated the characteristics and details of each algorithm for engineering design. However, the detailed description of each algorithm is beyond the scope of the present paper. Direct search techniques choose the best solution at each iterative by comparing the results and move to the next step based on the current results [18,16]. The techniques are typically efficient, however, they may find local solutions instead of the global one. In some cases, for example when the objective function (cost function) is not convex and not smooth in terms of the decision variables [21], typical gradient-based optimization methods fail to solve the problem. Therefore, evolutionary algorithms are required which are based on the Darwinian principle to remove the poorest solutions in each generation. Common operators are employed to make new generations of solutions. Genetic Algorithms (GA) [21,20,22–24] are widely used especially to optimize subsystem building blocks of a district. The most popular implementation for multi-objective problems is NSGA-II [25]. It is a popular option to establish the optimal heating/cooling distribution configuration, by randomly generating many network designs for the entire district. Other popular method within the optimization of energy systems is to employ more than one technique in a hybrid optimization [26,27]. A near optimal solution is found by applying a global-search technique and the result helps another technique to find the local optimum solution. Both single and multi-objective studies are included in the literature [28,29]. A well-known method to tackle the multi-objective problems is to rewrite the several objectives in the form of only one function using constant weights [32,33]. One main drawback of the method is that the results of the optimization is not uniform. Another drawback is that the method fails in non-convex regions [30]. As the engineering viewpoint, the weighted sum approach is an efficient and easy-to-use method, however it calls for an expert in the field to identify the weight factors and compromise between the functions [31].

Within the time frame, district optimization problems may be split into two groups: (1) short-term problems which the operational management of the system is analyzed within a given period (typically one day/week/year); (2) long-term problems in which the formulation and analysis is carried out over the whole life cycle [34]. Decision variables represent the degrees of freedom in the optimization model. They include both binary and continues variables. Binary variables defines existence of a component or its operation status (on/off) [35]. A general framework of the optimization procedure at district level is given in Fig. 2. This overview is applicable to a wide range of district configurations and framework conditions which can be represented by a group of input parameters.

3. Recent optimization studies at district level

The scientific literature for optimization approaches at district level can be classified into four main topics as illustrated in Fig. 3. In the following sections, the most recent publications regarding each category is discussed.

3.1. Distributed integration

Distributed integration deals with the connection of energy resources to the district energy system to provide reliable, sufficient, economic and environmental-friendly power generation. The complexity of the integrated system associated such as CHP or heat pump [36] with the energy planning within the district calls for optimization analysis. Two major aspects recently draw attentions