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ScienceDirect

Energy Procedia 122 (2017) 541–546

Energy Procedia

www.elsevier.com/locate/procedia

CISBAT 2017 International Conference - Future Buildings & Districts - Energy Efficiency from Nano to Urban Scale, CISBAT 2017 6-8 September 2017, Lausanne, Switzerland

The Ehub Modeling Tool: A flexible software package for district energy system optimization

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Abstract

Effective planning and control of district energy systems must account for numerous complexities and uncertainties, requiring advanced computational tools. This paper introduces the Ehub Modeling Tool, an open source software package for preliminary design optimization of district energy systems. Using automated code generation techniques that directly translate raw data descriptions of a given district into executable optimization code, the tool simplifies and accelerates the process of developing and executing district energy system optimizations, and visualizing/interpreting results. Example applications of the tool in research and education are described.

Peer-review under responsibility of the scientific committee of the CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale

Keywords: District energy systems; Energy hubs; Modeling; Optimization; Software tool

1. Introduction

District energy systems can be an efficient means of enabling the integration of renewable and low-carbon energy sources into the built environment. However, effective planning and control of such systems must account for numerous complexities and uncertainties, including the intermittent availability of renewable energy sources, electricity market dynamics, multiple energy carriers, technical constraints, policy/price uncertainty and other factors. Advanced computational tools are necessary to account for the complex interactions of these diverse factors and dynamics.

This paper introduces the *Ehub Modeling Tool*, an open source software tool for preliminary design optimization of district energy systems. Based on the energy hub concept [1], the tool optimizes the selection, sizing and operation of energy conversion and storage technologies in a manner tailored to the characteristics of a given district and project. Key advantages are its ability to capture important complexities in district energy system design/operation and the ease with which the tool can be adapted to different cases and different types of problems. Using automated code generation techniques that directly translate raw data descriptions of a given district into executable optimization

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1876-6102
Peer-review under responsibility of the scientific committee of the CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale
10.1016/j.egypro.2017.07.402

code, the tool simplifies and accelerates the process of developing and executing district energy system optimizations, and visualizing/interpreting the results.

This paper describes the structure and capabilities of the Ehub Modeling Tool, and provides examples and sample results from application of the tool in research and education. The following section introduces the theoretical basis for the tool and the research/knowledge gap being addressed. Motivation, features and limitations of the tool are introduced, and a set of application examples is provided. Finally, plans for the further development, validation and adaptation of the tool to meet industry needs are described.

2. Energy hub modeling

The mathematical formulations underlying the Ehub Modeling Tool are based on the *energy hub* concept – a conceptual model of multi-carrier energy systems used to represent the interactions of multiple energy conversion and storage technologies [1]. The energy hub concept serves as a basis for developing mathematical models to optimize the operation and design of multi-carrier energy systems at different scales, often with the objective of minimizing total costs or carbon emissions. Energy hub models have been used extensively to identify optimal designs and control regimes for building, district and urban energy systems [2–4]. Most state-of-the-art energy hub models are formulated as mixed-integer linear programmes (MILPs), which offer an advantageous balance of solution efficiency and accuracy. Other formulations have also been implemented, including bi-level formulations, which link a MILP with a genetic algorithm [5], machine learning formulations [6] and nonlinear formulations [7].

Typical objectives of energy hub models are to minimize (operational and/or capital) costs or carbon emissions. Optimized variables include the dispatch schedules, installation and sizing of various energy conversion technologies (e.g. heat pumps, CHP units, solar photovoltaics) as well as the charging/discharging schedules, installation and sizing of various energy storage technologies (e.g. boreholes, batteries). Key constraints in energy hub model formulations include: *load balance constraints* which ensure that energy supply matches energy demand at each timestep (Equation 1); *capacity constraints* which ensure that energy conversion and storage technologies do not exceed their defined capacities in operation (Equation 2); *storage continuity constraints* which ensure that energy stocks and flows from storages balance across time steps (Equation 3); and *carbon or cost constraints*, which cap the total allowable costs or carbon emissions over the specified time horizon. Numerous additional constraints are included in different energy hub formulations, depending on the characteristics of the case, the purpose of the study and the assumptions underlying the analysis. For a more comprehensive overview of energy hub model formulations, the reader is referred to [8].

$$L_k(t) + X_k(t) = P_{k,g}(t) + Q_{k,out}(t) - Q_{k,in}(t) \quad (1)$$

where $L_k(t)$ refers to the demand for energy type k at time t, X_k refers to the energy k exported from the system, P_g refers to the output of generator g, and $Q_{k,dis}$ and $Q_{k,ch}$ refer to the quantity of energy charged/discharged from storages.

$$P_{k,g}(t) <= P_{max,k,g} \quad (2)$$

$$E_k(t) = E_k(t-1) - D_k(t-1) + \eta_{k,ch} \cdot Q_{k,in}(t) - (\frac{1}{\eta_{k,dis}}) \cdot Q_{k,out}(t) \quad (3)$$

where $E_k(t)$ refers to the state of charge of storage k at time t, $D_k(t-1)$ refers to the standing losses from the storage in the previous timestep, and $\eta_{k,ch}$ and $\eta_{k,dis}$ refer to the efficiency of storage charge and discharge, respectively.

An important hindrance to the application of energy hub models in practice is the required time, effort and expertise necessary to develop model formulations which effectively balance accuracy of system representation and solution efficiency. Aggravating this, different cases/projects and different types of problems may demand very different model formulations, limiting the degree to which existing models can be reused. This points to the need for a flexible modeling tool that may be adapted to the demands of different cases and problems, and which reduces the resources needed to implement, execute and analyze the results of energy hub models.