Abstract

This work suggests a methodology to assist the designer during the planning phase of microgrids and eco-districts. A mixed integer linear programming model is designed to mathematically describe the different energy systems and the physical relations among them. Given the different electrical/thermal demand profiles, the micro grid’s topology and a set of boundary conditions, the model can identify the optimum mix of (poly-)generation units and energy storage systems, as well as the necessary district heating/cooling infrastructure. Both economic and energetic cost functions are defined to explore the problem from different perspectives. The described tool is applied to study an actual district of the NTU campus in Singapore, comprising 5 multi-purpose buildings and a district cooling network supplied by centralized electrical chillers. The planning tool was run to assess the optimal configuration that minimizes the overall cost (initial investment and O&M); the outcome results presented a layout and a mix of energy systems different from the present one. In particular, the optimal configuration results to be a district cooling system served by a mix of electrical chiller plant, trigeneration distributed energy system and sensible cold thermal energy storage.

Keywords: Micro grid design, energy mix optimizaion, techno-economic analysis; eco-district; polygeneration
1. Introduction

Electricity generation, transmission and distribution systems have been changing dramatically in the last 20 years. Everywhere in the world, the diffusion of renewable driven distributed generation is posing new challenges to the national grids. This trend is eventually going to threaten the entire distribution system in terms of reliability, costs and service quality. Micro grids have a critical role in this scenario. Micro grids can locally manage the combined generation of multiple useful products like power, heat and cooling energy. Being made by the integration of several energy distribution systems and storage technologies, they are complex entities to design [1-2] and manage [3-4]. The goal of obtaining the optimal design for the energy system for a micro grid has been widely analyzed both in the literature, with authors concentrating on an optimal distribution of heat pumps [5] or on interactions between different users [6]; but also in already available software tools. Most of these tools mainly focus on electricity generation and consumption: that is the case of H.O.M.E.R (Hybrid Optimization Model for Electric Renewable) [7] and Sandia Labs MDT (Microgrid Design Toolkit) [8]. The planning tool presented in this paper aims at designing polygeneration systems considering all the energy networks usually involved in a microgrid and eco-district: other than electricity, thermal (district heating) and cooling (district cooling) energy.

1.1. Novelty and Goals

The goal for this work was then to obtain a framework for the design of microgrids which could take into account the different kinds of energy vectors aligned with the microgrid needs, therefore consisting in electrical and thermal demand; where the latter is made up of both heating and cooling. A model was built, simulating the operation of a microgrid for a year in which both electrical and cooling/heating demand had to be satisfied; the demand can be centralized or dislocated in multiple sites. The outputs of the simulation are the optimal mix of energy systems to install and the associated costs, including the ones for district cooling/heating networks.

2. Methodology and mathematical model

2.1. Test Case Description

The case study of this work is part of the campus of the Nanyang Technological University (NTU) in Singapore. The part of the campus under study, consists of five sites and presents a peak demand for cooling of around 21.5 MWc. At the present time, each building has its chiller plant room in order to meet its own cooling demand. Table 1 shows the actual configuration of the electric chillers in the five sites of the NTU campus under study.

<table>
<thead>
<tr>
<th>Campus Site</th>
<th>Boiler (kW)</th>
<th>CHP/Genset (kWe)</th>
<th>Absorption Chiller cooling capacity (kWe)</th>
<th>Electrical Chiller cooling capacity (kWc)</th>
<th>Electric Storage (kWh_e)</th>
<th>Thermal Storage capacity (kWh_h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3600</td>
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<td>-</td>
</tr>
<tr>
<td>U2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>8000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>U3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1600</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>U4</td>
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<tr>
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<td>-</td>
<td>-</td>
<td>7000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>23500</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Actual configuration of the cooling power installed on each site

The campus has been modeled as a series of 5 sites, where each one represents a User with its own power/cooling demand; on each site there is the possibility to install different kinds of energy systems such as Boilers, CHP units, Electrical and Absorption Chillers and thermal storages. The sizes to take into consideration for each energy system
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