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The energy hub concept applied to a case study of mixed residential and administrative buildings in Switzerland

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Abstract

The concept of Energy Hub (EH) is getting popular as a method to integrate non-dispatchable energy sources at building and neighbourhood scale with the support of energy storage and grid. It is interesting to study the effectiveness of EH concept to integrate solar energy and wind energy at both building and neighbourhood scale considering the real-time price and curtailments in the grid. This paper presents a case study conducted to evaluate the effectiveness of EH in integrating solar energy in the SwissTech Convention Centre (STCC) and Quartier Nord on the EPFL campus in Lausanne considering both building and neighbourhood scale. The results depict that EH is more effective when both compared to standalone operation and grid integrated mode (considering grid curtailments and RTP) in the process of integration of renewable energy sources. Interacting with the grid seems to be more economical when compared to storage. Grid curtailments cause the storage to operate more frequently in both charging and discharging cycles.

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1. Introduction

Energy requirements in urban areas are rising very fast and this trend is expected to continue with the increase in the urban population (70% by 2050). New buildings are built according to more and more stringent norms which can make them either net-zero or energy positive buildings. Decentralized urban energy systems are hence drawing a lot of attention from the research and industrial community as a possibility towards more sustainable urban areas responding to stringent limitations for fossil fuel based power generation and global concern on greenhouse gases (GHG) emissions.

The stochastic nature of both demand and solar photovoltaics (SPV) energy potential makes SPV integration into buildings more challenging. The concept of Energy Hub (EH) [1]–[5] is getting popular as a method to integrate non-dispatchable energy sources at building and neighbourhood scale with the support of energy storage and grid. In a previous study, a district on the EPFL campus, Switzerland [6], [7] was analysed to implement renewable energy. However, the analysis did not account for the various energy vectors that could be considered and integrated in order to increase the autonomy of the energy system. There have been no studies on the effectiveness of energy hub (EH) to integrate solar energy and wind energy at both building and neighbourhood scale considering real-time price (RTP) and curtailments in the grid. This study presents a case study conducted to evaluate the effectiveness of EH in integrating solar energy in the SwissTech Convention Centre (STCC) and Quartier Nord on the EPFL campus in Lausanne considering both building and neighbourhood scale.

In the next section we describe the models used in the current study. We then show the results obtained and discuss them. In the final section we conclude on the most important findings in this study and give a few perspectives to further develop the concept of implementation of decentralized energy systems.

Nomenclature

EH	Energy hub
EPFL	Ecole Polytechnique Fédérale de Lausanne
GHG	Greenhouse gases
ICG	internal combustion generator
RTP	Real time price
SPV	Solar photovoltaics
STCC	SwisstTech Convention Centre
ToU	Time of Use

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2. Methodology

2.1. Brief description of the CitySim software

CitySim [8] is a large-scale dynamic building energy simulation tool developed at the EPFL. The tool includes an important aspect in the field of simulating multiple buildings: the building interactions (shadowing, light inter-reflections and infrared exchanges). Furthermore, CitySim is based on simplified modelling assumptions to establish a trade-off between input data needs, output precision requirements and computing time. It also takes into account the occupancy profile and thermal comfort of the occupants throughout the year.

2.2. Overview of the energy system

The EH consisting of wind turbines, SPV panels, battery bank, internal combustion generator (ICG) operating connected to the main grid is considered in this study (see Fig. 1). Global solar irradiation on horizontal surfaces and wind speed are taken into account on an hourly time scale. The computational model is described in Ref. [9]–[12]. Energy demand for multiple energy services (heating and electricity) is taken from Citysim, and standard occupancy profiles are used. The electricity price in the grid is taken based on the Time of Use (ToU) scheme. Grid

curtailments were introduced when selling and purchasing electricity from the grid. The interactions with the grid, energy storage and ICG are determined using a bi-level dispatch strategy [4]. At the primary level the Fuzzy Takagi-Sugeno method is used to derive the operating load factor of the ICG. State of charge of the battery bank, mismatch in demand and generation as well as price of grid electricity are considered when deriving the load factor of the ICG. Subsequently, interactions with the grid and battery bank are determined based on the energy management system using finite automata theory. The operating state of the system is determined based on the all the aforementioned factors and the grid curtailments for selling and purchasing electricity to and from the grid.

Thereafter, the energy system is optimized considering grid integration level and levelized energy cost as objective functions. An evolutionary algorithm is used to obtain the optimum set of solutions. Decision variables related to both system design and operation strategy are considered in the optimization. Loss of load probability is considered as a constraint in the optimization.
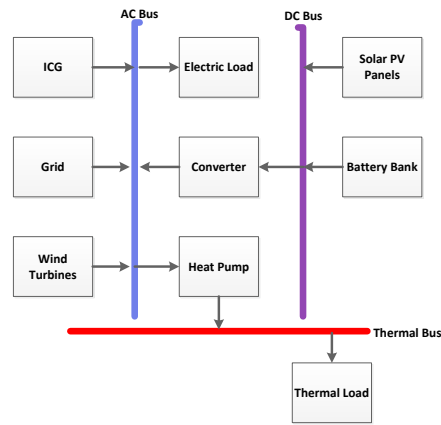

Fig. 1. Overview of the Energy Hub

3. Experiments

CitySim was run over one typical year using data from Meteonorm software [13]. The study case is located in Ecublens, VD/Switzerland. The district is composed of the STCC and student housing on the EPFL campus (see Fig. 2). The complex was built in 2013 and the HVAC system installed is mainly composed of a heat exchanger using waste water from the EPFL campus to meet the heating and cooling demand. For the simulation, the temperature set point for both buildings are set to Tmin = 20°C and Tmax= 22°C.

Fig. 2. Representation of the Quartier Nord (EPFL campus, Switzerland)

The results (heating and cooling demand), along with techno-economic data for system components, meteorological data of the location are used as the input data. An Enumerative method is used in the optimization process where the system configuration is optimized considering cash flows throughout the life cycle. Three configurations are selected to access the scenario i.e. stand-alone operation mode, grid-integrated operation mode and EH configuration to optimize the system. Sensitivity of ToU and RTP scheme on optimized results are subsequently analysed.

4. Results and discussion

Fig. 3 shows the annual short wave irradiation received on each surface of the district. The solar irradiation received is used in the calculation of the energy balance of the different buildings.
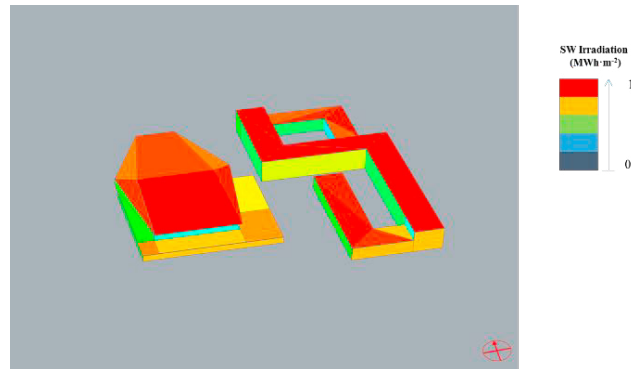

Fig. 3. Short wave irradiation

Fig. 4 shows the heating and cooling demand simulated with CitySim for a typical year. It can be seen that one of the housing buildings has a higher energy consumption as compared to the other ones while the STCC has a quite low demand. One of the reason for this is the high glazing ratio that optimizes the solar gain in the building.
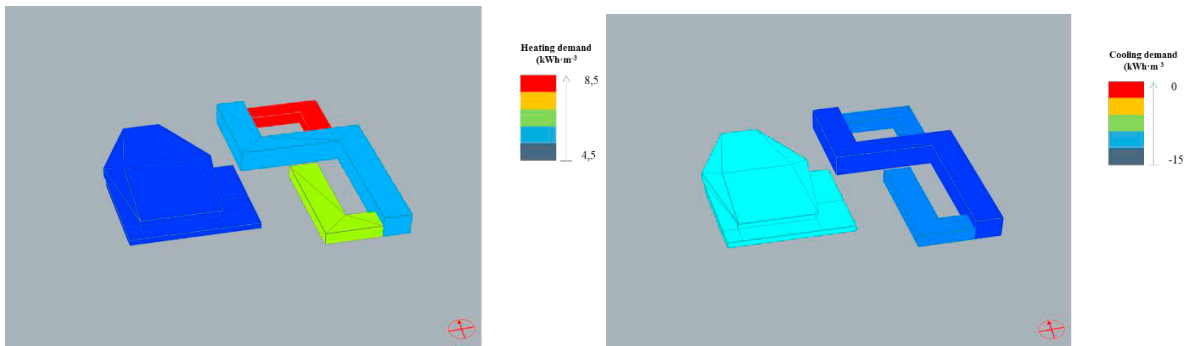

Fig. 4. Yearly heating demand (left) and cooling demand (right)

However, the cooling demand of the district is quite high and this is also very likely to be due to the high glazing ratio in the different buildings. Besides, the temperature set point that has been used is quite low for the housing and could be a reason for such a high cooling demand, but this corresponds to the temperature usually prescribed for the STCC as obtained from real data.

   The Pareto front obtained considering grid integration level and net present value is presented in Fig. 5. A notable reduction is LEC is observed when integrating the grid interactions. When analyzing the results, it is prudent to say that an energy autonomy of 55% for the system can be reached when considering the purchasing of electricity from the grid, which tends to be a notable improvement when considering the present context. However, lifecycle cost notably increase when reaching the stand-alone state. When analyzing the renewable energy integration process, it can be noted that power generation using renewable energy technologies can reach up to 45% of the total demand, which is quite significant. However, when considering the lowest cost option, the level of renewable energy integration is less than 10%.
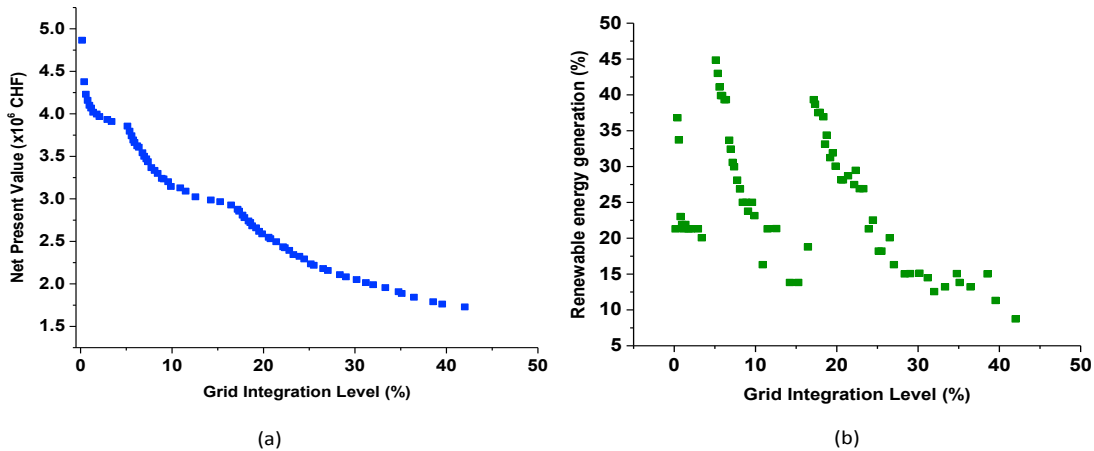

(a) (b)

Fig. 5. Pareto front considering the grid integration level (a) net present value and (b) renewable energy integration level.

5. Conclusions

   This study focuses on the potential of the energy hub concept to integrate renewable energy technologies at neighborhood scale. An energy hub consisting of renewable energy components, energy storage and a dispatchable energy source operating connected to the grid is considered. Obtained results show that an autonomy level of up to 55% can be reached for the energy system using the energy hub while the contribution of the renewable energy sources can reach up to 45 %. However, the minimum cost scenario does not correspond to the maximum renewable energy integration scenario.

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