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Energy flexibility from the consumer: Integrating local electricity and heat supplies in a building

Yang Zhang[a,*], Pietro Elia Campana[a,b], Ying Yang[b], Bengt Stridh[b], Anders Lundblad[c], Jinyue Yan[a,b,*]

[a] Division of Energy Processes, KTH-Royal Institute of Technology, SE-10044 Stockholm, Sweden
[b] School of Business, Society & Engineering, Mälardalen University, SE-72123 Västerås, Sweden
[c] Division of Safety and Transport/Electronics, RISE Research Institutes of Sweden, SE-50462 Borås, Sweden

HIGHLIGHTS

- Electricity and heat supplies are integrated in a building.
- Electrical grid and district heating network are connected via the building.
- The net present cost for energy demands is reduced by 22%.
- Great flexibility can be provided to the electrical grid.

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ABSTRACT

The increasing penetration level of renewable energy requires more flexibility measures to be implemented in future energy systems. Integrating an energy consumer's local energy supplies connects multiple energy networks (i.e., the electrical grid, the district heating network, and gas network) in a decentralized way. Such integration enhances the flexibility of energy systems. In this work, a Swedish office building is investigated as a case study. Different components, including heat pump, electrical heater, battery and hot water storage tank are integrated into the electricity and heat supply system of the building. Special focus is placed on the flexibility that the studied building can provide to the electrical grid (i.e., the building modulates the electricity consumption in response to the grid operator's requirements). The flexibility is described by two metrics including the flexibility hours and the flexibility energy. Optimization of the component capacities and the operation profiles is carried out by using Mixed Integer Linear Programming (MILP).

The results show that the system fully relies on electricity for the heat demand when not considering the flexibility requirements of the electrical grid. This suggests that district heating is economically unfavorable compared with using electricity for the heat demand in the studied case. However, when flexibility requirements are added, the system turns to the district heating network for part of the heat demand. The system provides great flexibility to the electrical grid through such integration. The flexibility hours can be over 5200 h in a year, and the flexibility energy reaches more than 15.7 MWh (36% of the yearly electricity consumption). The yearly operation cost of the system slightly increases from 62,273 to 65,178 SEK when the flexibility hours increase from 304 to 5209 h. The results revealed that flexibility can be provided from the district heating network to the electrical grid via the building.

1. Introduction

The penetration level of renewable energy is increasing rapidly [1,2]. Many countries have set ambitious goals towards carbon-neutral societies [3], and thus, an increased amount of variable renewable electricity is expected in future electrical systems [4]. However, as the electrical systems require a balance between supply and demand over time, the variability and uncertainty of renewable energies pose a growing challenge to the stable and secure operation of electrical systems. The ability of an electrical system to cope with uncertainty and variability is usually regarded as the

* Corresponding authors at: Teknikringen 42, SE-100 44 Stockholm, Sweden.
E-mail addresses: yaz@kth.se (Y. Zhang), pietro.campana@mdh.se (P.E. Campana), ying.yang@mdh.se (Y. Yang), bengt.stridh@mdh.se (B. Stridh), anders.lundblad@ri.se (A. Lundblad), jinyue@kth.se (J. Yan).

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Nomenclature

Symbol	description [Unit]
$C_{DH,y}$	district heating cost at year y [SEK]
$C_{DSO,y}$	electricity cost charged by the DSO at year y [SEK]
$C_{ER,y}$	electricity cost charged by the Energy Retailer at year y [SEK]
$C_{O,y}$	yearly operation cost [SEK]
$C_{R,y}$	replacement cost at year y [SEK]
$C_{M,y}$	maintenance cost at year y [SEK]
Cap_i	capacity of component i [–]
COP_t	coefficient of performance at t [1]
ELP_t	electricity spot market price at t [SEK/kWh]
Inv_i	investment cost for component i [SEK]
$P_{c,t}$	battery charged electricity at t [kWh]
$P_{d,t}$	battery discharged electricity at t [kWh]
$P_{EH,t}$	electrical heater electricity consumption at t [kWh]
$P_{ex,t}$	exported electricity at t [kWh]
$P_{HP,t}$	heat pump electricity consumption at t [kWh]
$P_{im,t}$	imported electricity (electricity consumption) at t [kWh]
$P_{L,t}$	electricity demand at t [kWh]
$P_{Net,t}$	net electricity at t [kWh]
$P_{PV,t}$	PV electricity production at t [kWh]
$Peak_m$	monthly peak of imported electricity [kWh]
$Q_{c,t}$	hot water tank charged energy at t [kWh]
$Q_{d,t}$	hot water tank discharged energy at t [kWh]
$Q_{DH,t}$	electrical heater heat output at t [kWh]
$Q_{HP,t}$	heat pump heat output at t [kWh]
$Q_{Load,t}$	heat demand at t [kWh]
R_y	revenue from exported electricity at year y [SEK]
$S_{HWT,t}$	HWT storage state at the end of t [kWh]
SOC_t	state of charge at the end of t [%]

Abbreviations

ASHP	Air Source Heat Pump
CHP	Combined Heat and Power
DH	District Heating
DSM	Demand Side Management
DSO	Distribution System Operator
EH	Electrical Heater
ER	Energy Retailer
GSHP	Ground Source Heat Pump
HP	Heat Pump
HWT	Hot Water Tank
MILP	Mixed Integer Linear Programming
P2G	Power-to-Gas
PV	Photovoltaic
SCR	Self-Consumption Ratio
VAT	Value-Added Tax

flexibility of the system, which though lacks a unified definition. The flexibility of a system originates from a portfolio of different measures that help maintain the balance between supply and demand over time. These measures are usually collectively called flexibility measures, which were summarized and analyzed by Lund et al. [5]. The increase in renewable energies requires more flexibility measures in future energy systems.

1.1. Energy flexibility measures

A schematic summary of the energy systems and flexibility measures is given in Fig. 1. The electrical system, district heating system, and gas system are distinguished by the energy carriers and showed in different colors. The conversion between different energy carriers is achieved by the energy conversion technologies. In each energy system, the supply units and consumers are connected by the distribution network.

The flexibility measures mainly include supply-side flexibility, demand-side flexibility and the integration of energy networks. Supply-side flexibility is achieved by the coordinated operation of various generation, transmission and distribution units, which are controlled to balance the energy systems. Demand-side flexibility is usually achieved

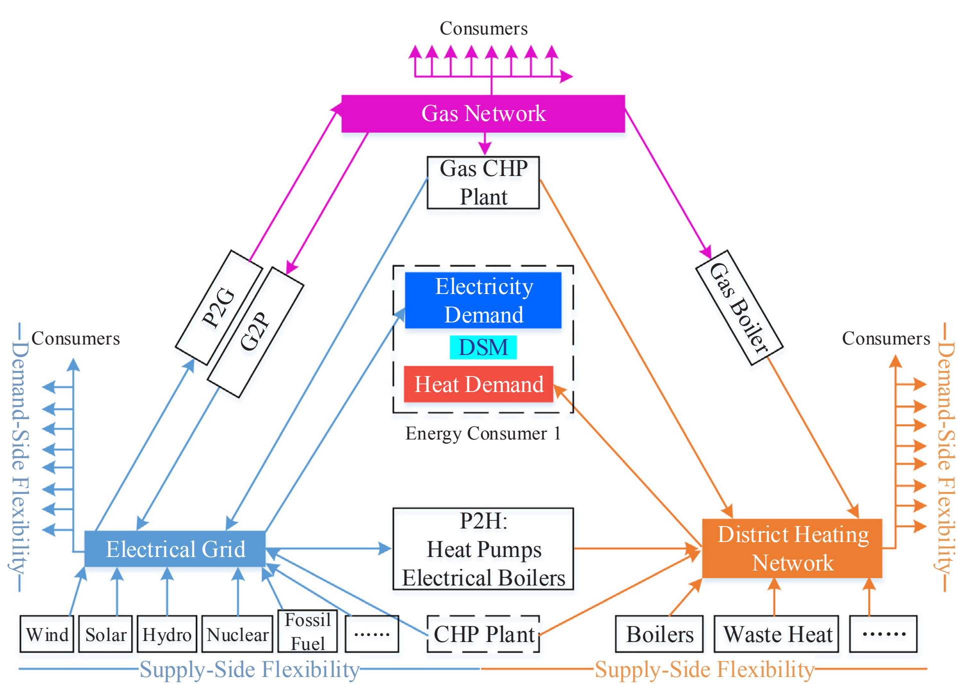

Fig. 1. Flexibility measures in energy systems.