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A comprehensive model for self-scheduling an energy hub to supply cooling, heating and electrical demands of a building

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ABSTRACT

This paper presents an innovative method for modeling energy hubs based on energy flow between its constituent elements. Using this method, modeling of energy hubs with different elements and connections is facilitated. Also, an appropriate mixed integer nonlinear programming model is presented for short term 24-hour scheduling an energy hub, in which, the objective is to fulfill daily cooling, heating and electric demands of a hypothetical building with the maximum profit. Furthermore, in the energy flow based modeling method presented in this paper, energy storage elements are not only used at the output of the hub; but also, are capable of being used as inputs for other elements inside the energy hub. In order to evaluate the performance of the model, simulations have been accomplished for one hot and one cold typical day. Presented energy hub includes various elements such as combined heat and power, electric heat pump, boiler, absorption chiller and electrical and thermal energy storages. Moreover, in the modeling of the proposed energy hub, feasible operation region for combined heat and power system together with technical constraints of energy hub equipment is considered. Analyzing numerical results, flexibility of the energy hub for feeding the required loads of the building, operation of combined heat and power and the effect of electrical heat pumps in meeting cooling and heating loads of the building are evaluated. The numerical results show that combined heat and power operation points and its average electrical and thermal efficiency in hot and cold days are totally different and electric heat pump, regarding its high efficiency, is the main supplier of cooling and heating loads of the building in the studied energy hub.

1. Introduction

Achieving ambitious goals of reducing greenhouse gas (GHG) emissions and optimizing energy consumption, needs specific strategies, not only in electric energy sector; but also, in all other energy sectors as well. A considerable amount of consumed energy in the world is used in domestic and commercial sectors. Namely, in United States in 2013, nearly 40 percent of total consumed energy is used in domestic and commercial sectors; the same amount has been used in the mentioned sectors in Iran too [1,2]. Based on the report of energy information administration in 2011, nearly 30 percent of consumed energy in the world has been consumed in domestic and commercial sectors. On the other hand, cooling and heating demands of domestic sector is almost 65 percent of energy consumption in this sector [3].

1.1. Energy hub

Nowadays, owing to distribution networks for energy such as natural gas and electricity in different urban areas, together with technology developments such as CHP (combined heat and power systems), EHP (electric heat pump), Ab.Chiller (absorption chiller), TES (thermal energy storage) and EES (electrical energy storage) in conjunction with smart control and measurement equipment, integrated operation for energy management is feasible. Concept of energy hub which is firstly introduced by Anderson et al. in 2007 is a functional unit capable of transforming, conditioning and storing of several kinds of energy [4,5]. In fact, using mentioned technologies, the energy hub represents an interface between different energy infrastructures at its input ports, such as EDS (electrical distribution system) and GDS (natural gas distribution system) and

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Acronyms

EHP electric heat pump
EES electrical energy storage
TES thermal energy storage
A.B auxiliary boiler
Ab.Chiller absorption chiller
CHP combined heat and power
EDS electricity distributed system
GDS gas distributed system

Variables

$E(t)$ electricity dispatching at each time period t (kWh)
$H(t)$ heat dispatching at each time period t (kWh)
$C(t)$ cooling dispatching at each time period t (kWh)
$F_{CHP}(t)$ fuel consumed by CHP at each time period t (kWh)
$F_{A.B}(t)$ fuel consumed by A.B at each time period t (kWh)
$F(t)$ total fuel consumed by energy hub at each time period t (kWh)
Income (t) income of energy hub at each time period t (Mu)
Cost (t) cost of energy hub at each time period t (Mu)
Profit profit of energy hub (Mu)
$Cost_{CHP}^{st}(t)$ startup cost of CHP at each time period t (Mu)
$Cost_{CHP}^{shd}(t)$ shut down cost of CHP at each time period t (Mu)
$Eng^{EES}(t)$ Energy stored level in EES at each time period t (kWh)
$Eng^{TES}(t)$ energy stored level in TES at each time period t (kWh)
s (t) binary variable equals to 1 if CHP is on and 0 otherwise
x (t) binary variable equals to 1 if EES is charging and 0 otherwise
y (t) binary variable equals to 1 if EES is discharging and 0 otherwise
u (t) binary variable equals to 1 if TES is charging and 0 otherwise
v (t) binary variable equals to 1 if TES is discharging and 0 otherwise
m (t) binary variable equals to 1 if transmitting energy from EDS and 0 otherwise
n (t) binary variable equals to 1 if receiving energy from EDS and 0 otherwise
l (t) binary variable equals to 1 if EHP operates in cooling mode
b (t) binary variable equals to 1 if EHP operates in Heating mode
f fuel consumption function of CHP

Parameters

EL (t) forecasted electrical load of the building at each time period t (kWh)
TL (t) forecasted thermal load of the building at each time period t (kWh)
CL (t) forecasted cooling load of the building at each time period t (kWh)
SC startup cost of CHP (Mu)
SHC shut down cost of CHP (Mu)
MUT minimum up time of CHP (h)
MDT minimum down time of CHP (h)
$H^{max,\ A.B}$, $H^{min,\ A.B}$ minimum/maximum heating capacity of auxiliary boiler (kW)
$\eta^{A.B}$ auxiliary boiler efficiency
$P^{max,EES}$ power capacity of EES (kW)
$P^{max,TES}$ power capacity of TES (kW)
$SOC^{max,\ EES}$ maximum state of charge of EES (kWh)
$SOC^{min,\ EES}$ minimum state of charge of EES (kWh)
$SOC^{max,\ TES}$ maximum state of charge of TES (kWh)
$SOC^{min,\ TES}$ minimum state of charge of TES (kWh)
η^{EES} charging and discharging efficiency of EES
η^{TES} charging and discharging efficiency of TES
$H^{min,\ EHP}$, $H^{max,\ EHP}$ minimum/maximum heating capacity of EHP in heating mode (kWh)
$C^{min,\ EHP}$,$C^{max,\ EHP}$ minimum/maximum cooling capacity of EHP in cooling mode (kWh)
$C^{min,\ Ab.Chiller}$, $C^{max,\ Ab.Chiller}$ minimum/maximum cooling capacity of Ab.Chiller in cooling mode (kWh)
$COP^{EHP\ cooling/heating}$ coefficient of performance of EHP in cooling/heating mode
$COP^{Ab.Chiller}$ coefficient of performance of Ab.Chiller
CLC cable line capacity (kW)
GLC gas line capacity (kW)
EPr (t) electricity price at each time period t (Mu/kWh)
NGpr natural gas price for heat generation (Mu/kWh)
NGpre natural gas price for electricity generation (Mu/kWh)
Mu monetary unit
a,b,c,d,e,g coefficients of fuel consumption function of CHP

end user's demands, such as electrical, heating and cooling demands at its output ports. In order to have integrated energy operation, concepts such as MES (Multi Energy System) [6], MEC (Multi Energy Carrier) [7] and DMG (Distributed Multi Generation) [8] are used in relation with energy hub. In fact, energy hub structure is based on modeling and analysis using Multi Energy Carrier and Multi Energy System. Convertors inside energy hub not only integrate energy carriers, but also, cause these energy carriers being converted to required energy for consumers from diverse alternative paths [9].

1.2. Literature review

After introducing the energy hub concept by Anderson and colleagues [4], diverse studies have been accomplished in this regard. Operation and planning studies and design of energy hubs and MESs are carried out in different scales. Short term scheduling of residential and commercial energy hubs which is noticed in this paper, has been analyzed from various points of view in recent studies. Diversity of constituent equipment of energy hubs and their technical and economic constraints, diversity of services of these hubs in meeting different loads, environmental effects, reliability and DR (demand response) (DR) are the subjects under study regarding short term scheduling of energy hubs. Some papers have assessed these systems in small scales like a building [10–13] and some others in bigger scales like regions and cities [14,15].

Ref. [11], has focused on the modeling of a home as an energy hub, considering different electrical and thermal appliance. Short term scheduling of energy hub in this paper which is equipped with CHP and plug-in hybrid vehicle (PHEV) is accomplished with the objective of minimization of customer payment. Numerical results of this paper show that home load management in energy hub framework leads to lower customer payment costs. Ottesen et al. [12], has developed a 24-h scheduling model of energy flexibility in buildings. They have utilized this model of energy hub for a Norwegian university college building to minimize the operational cost. Their study shows that the model is able to reduce costs by reducing peak loads and utilizing price differences between periods