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Stochastic optimization of energy hub operation with consideration of thermal energy market and demand response

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ABSTRACT

Multi carrier energy systems or energy hubs has provided more flexibility for energy management systems. On the other hand, due to mutual impact of different energy carriers in energy hubs, energy management studies become more challengeable. The initial patterns of energy demands from grids point of view can be modified by optimal scheduling of energy hubs. In this work, optimal operation of multi carrier energy system has been studied in the presence of wind farm, electrical and thermal storage systems, electrical and thermal demand response programs, electricity market and thermal energy market. Stochastic programming is implemented for modeling the system uncertainties such as demands, market prices and wind speed. It is shown that adding new source of heat energy for providing demand of consumers with market mechanism changes the optimal operation point of multi carrier energy system. Presented mixed integer linear formulation for the problem has been solved by executing CPLEX solver of GAMS optimization software. Simulation results shows that hub's operation cost reduces up to 4.8% by enabling the option of using thermal energy market for meeting heat demand.

1. Introduction

World's energy crisis and its related problems caused a considerable movement into efficient utilization of energy systems. Recently, a new window has been opened in the energy optimization filed by presenting the concept of energy hub [1]. This comprehensive attitude to energy, which presented in the energy hub idea, persuaded the researchers to design future energy systems based on this idea [2]. In the energy hub concept, whole of energy systems are investigated instead of individual management of energy carriers such as electricity, natural gas and so on. The new technologies such as combined heat and power (CHP), which make various energy conversion to each other possible, have formed the energy hub concept and have made it practical. The main question in the optimization of energy hub operation problem is that what is optimum arrangement of energy components in each time for providing demands with minimum cost [2]. In the addition, the energy hub can be defined as the energy utility, which is capable for energy conversion, energy storage and direct connection of multi energy carriers [3].

Energy hub operation optimization [4] has formed considerable percentage of energy hub studies that could be categorized as follows: (1) Energy hub modeling [5], which presents new formulation for hub modeling in optimization problems. (2) Hub designing [6] which searches for optimum design of energy hub with various targets. (3) Energy hub presence impact in smart grids [7]. (4) Energy flow optimization in multi hub system [8], which investigates the flow of energy carriers in integrated systems with considering technical constraints of each system.

Optimization of energy hub operation problem has been developed in different directions with considering additional control variables. The robust optimization technique has been proposed for finding optimal operation point of energy hub in [9]. Integrated view to optimal load management and energy hub operation with considering distribution companies has been analyzed in [10]. Renewable energy sources and energy storage effect on the energy hub operation in the competitive electricity markets have been presented in the [11]. Multi objective optimization of energy hub with considering cost and risk level as objective functions has been studied in [12] in uncertain environment. Electrical vehicle has been implemented to participate as the electrical storage in the system to neutralize the wind turbine intermittent output power without modeling the related uncertainties in [13]. Increasing the energy hub

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Nomenclature

General indices
t time (hour) index
s scenario index

Cost and prices
$\pi^E_{net}(t,s)$, $\pi^H_{net}(t,s)$ electricity price and heat price at time t and scenario s
π^E_{wind} operation cost of wind turbine
π^G_{net} natural gas price
π^E_{op}, π^H_{op} operation cost of electrical storage and heat storage
π^E_{DR}, π^H_{DR} cost of electrical and thermal demand response program

Energy balances
$P^E_{demand}(t,s)$ electrical demand of energy hub at time t and scenario s
$P^H_{demand}(t,s)$ heat demand of energy hub at time t and scenario s
$P^G_{demand}(t,s)$ natural gas demand of energy hub at time t and scenario s
$P^E_{net}(t,s)$, $P^G_{net}(t,s)$, $P^H_{net}(t,s)$ imported electrical, gas and heat power from corresponding networks at time t and scenario s
$P^E_{wind}(t,s)$ imported electrical power from wind turbine at time t and scenario s
$P^G_{netCHP}(t,s)$ natural gas power input of CHP at time t and scenario s
$P^G_{netB}(t,s)$ natural gas power input of boiler at time t and scenario s

Storage systems
$P^E_s(t,s)$, $P^H_s(t,s)$ stored energy level of electrical and thermal storage at time t and scenario s
$P^E_{loss}(t,s)$, $P^H_{loss}(t,s)$ power loss of electrical and thermal storage at time t and scenario s
$P^E_{ch}(t,s)$, $P^E_{dis}(t,s)$ charging and discharging power of electrical storage at time t and scenario s
$P^H_{ch}(t,s)$, $P^H_{dis}(t,s)$ charging and discharging amount of thermal storage at time t and scenario s
$I^E_{ch}(t,s)$, $I^E_{dis}(t,s)$ binary variables representing charging and discharging condition of electrical storage at time t and scenario s
$I^H_{ch}(t,s)$, $I^H_{dis}(t,s)$ binary variables representing charging and discharging condition of heat storage at time t and scenario s

Demand response
$P^E_{up}(t,s)$, $P^E_{down}(t,s)$ shifted up and shifted down electrical power by demand response program
$P^H_{up}(t,s)$, $P^H_{down}(t,s)$ shifted up and shifted down heat power by demand response program at time t and scenario s
$I^E_{up}(t,s)$, $I^E_{down}(t,s)$ binary variables representing shifting up and shifting down condition of electrical demand at time t and scenario s
$I^H_{up}(t,s)$, $I^H_{down}(t,s)$ binary variables representing shifting up and shifting down condition of heat demand at time t and scenario s

Wind farm
$v(t,s)$ wind speed at time t and scenario s
v^c_{in}, v^c_{out} cut in and cut out speeds of wind turbine
v^c_{rated}, P^w_r rated speed and rated output power of wind turbine

remittance with considering integrated electrical and gas demand response programs is discussed in [14].

In [15], cost and emission minimization in the multi carrier energy system, which includes electricity, natural gas, heat and hydrogen, has been followed up with using multi-agent system technique. Energy cost and demand side peak reduction with utilization of reinforcement learning algorithm is the outcome of [16], which resulted in fully automatic control of multi carrier systems. Demand response programs have attracted attentions of the researchers in different areas of power systems as a new sources of system flexibility [17]. The uncertainty sources of system are considered in [18] as main features of energy systems. Authors of [18] has investigated the optimal operation of energy hub in the presence of wind turbine, electrical demand response program (EDRP), electrical and thermal storage systems and electricity market with considering the uncertainty of electrical demand, market price and wind turbine output.

Thermal energy market as a newfound market in recent years, is another condition which has impact on control of the energy hub. Characteristics of this market as a new approach for providing heat demand has been reviewed in [19]. Implementation of thermal energy market in the completely deregulated model in some countries like as Finland and Sweden has been discussed in [20]. Developing this market into single-family houses scale for giving them more freedom in providing their heat load [21] is demonstrator of progressive and bright future of this market. Structuring the thermal energy market like the electricity market method with enabling the price offering system will start competition between heat demand providing methods including thermal energy market, constant tariff thermal energy and electricity based heat producer devices such as heat pump or bio-fuel boilers [21].

This work focused on optimal operation of an energy hub with considering wind farm, electricity market, thermal energy market, electrical and thermal storage systems, demand response programs and uncertainty sources. One of the features of this work is adding the thermal demand response program (TDRP) beside the EDRP. This addition will make the heat demand side more flexible like as the electrical demand and helps in operation cost reduction of energy hub with shifting the load into low price periods. The proposed TDRP can be considered as thermal energy market complementary role with responding to market price fluctuating. In this paper, system uncertainty sources has been considered with the aim of realistic model provision for the problem. All of hub demand side carriers including electrical demand, heat demand and natural gas demand, electrical and thermal energy market prices and wind farm output power are the uncertainties which are considered in this paper. The presented mixed integer linear formulation for energy hub modeling is handled by CPLEX solver of GAMS software, which can guarantee finding global optimum operation point.

Remainder of this paper has been organized as follows: Section 2 presents the assumed energy hub design. Section 4 is dedicated to formulation of optimization problem of energy hub operation. In Sections 5 and 6 the simulation conditions and results have been explored, respectively. Section 7 concludes finding of the paper.