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Optimal scheduling of heating and power hubs under economic and environment issues in the presence of peak load management

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ABSTRACT

Financial issues have been always one of major priorities in scheduling of energy systems. Although these systems are able to serve several types of energy demands but generated emission by these systems is a challenging problem. Since improvement of each one of mentioned issues has negative effects on the other issue therefore a trade-off solution is necessary to be obtained between these issues. In this paper, a multi-objective model has been presented to satisfy both economic and environmental objectives of a hub energy system in the presence of demand response program. In the proposed paper, ε-constraint and max–min fuzzy satisfying methods have been employed to solve and select the trade-off solution. The main reason of implementation of demand response program is to reduce operation cost and improve environmental performance of hub energy system. In fact, demand response program transfers some percentage of load from peak periods to off-peak periods to flatten load curve which leads to reduction of cost and emission. A mixed-integer linear programming has been used to simulate the proposed model and general algebraic modeling system software has been utilized to solve it. A sample hub energy system containing renewable and non-renewable energy resources has been studied and comparison results are presented to validate efficiency of proposed techniques.

1. Introduction

Recently, optimal operation of energy systems capable of supplying different energy demands called multi-carrier energy systems or hub energy systems has been one of major topics in the scheduling of power systems [1]. Various energy resources like combined heat and power systems (CHP) can be employed to enhance efficiency of operating systems [2]. Moreover, heat energy resources like boiler can be exploited to supply thermal demand [3]. In addition to mentioned non-renewable energy resources, renewable generation units can be integrated in hub energy systems to meet several types of loads [4]. It should be noted that utilization of resources burning fossil fuels in hub energy systems has made emission problem of these systems a big challenge for system operators [5].

Operation of hub energy systems with different purposes and applications has been studied within various researches which are summarized in the following: Economic dispatch problem of multiple energy hub system has been investigated through Self-Adoptive Learning with Time Varying Acceleration Coefficient-Gravitational Search Algorithm in [6]. With the aim of gaining maximum profit, hub energy system has been optimally designed in [7]. Influence of optimizing transmission networks on performance of hub energy system has been evaluated in [8]. Using a new approach, optimal power flow problem of hub energy systems has been investigated and the results have been compared with the ones obtained through other approaches in [9]. New formulations have been presented for accurate modeling of hub energy system with taking technical constraints into account in [10]. In order to improve performance of a residential hub energy system in the smart grid, a real-time based model has been presented in [11]. Employing controlling structure called hierarchical control structure, economic operation of a multi-carrier energy system has been evaluated in [12]. Optimal performance of multi-carrier energy system and optimal sizing of resources in this system have been investigated in [13]. Economic performance of multi-carrier energy system subject to uncertain behavior of renewable sources has been studied in [14]. Using evolutionary algorithm in [15], optimal operation of multi-carrier energy system has been investigated. Optimal operation of an on-grid multi-carrier energy system including different types of renewable energy sources has been evaluated in [16]. Using Monte Carlo simulation technique in [17], economic performance of hub energy system has been investigated. Optimal operation of hub energy system has been studied through two types of pricing namely dynamic pricing and time-of-use pricing in [18]. Using dispatch strategy, performance of hub energy system subject to curtailment in grid integration and real time pricing has been

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Nomenclature

Indices

t	time index

Parameters

η_{ee}^{T}	transformer efficiency
η_{ge}^{CHP}	gas to electricity efficiency of CHP
η_{gh}^{B}	gas to heat efficiency of boiler
η_{ee}^{CON}	converter efficiency
η_{ch}^{e}	electrical storage charging efficiency
η_{dis}^{e}	electrical storage discharging efficiency
η_{ch}^{h}	heat storage charging efficiency
η_{dis}^{h}	heat storage discharging efficiency
$\alpha_{\min}^{e}$	coefficient for minimum capacity modeling of electrical storage
$\alpha_{\max}^{e}$	coefficient for maximum capacity modeling of electrical storage
α_{loss}^{e}	coefficient for loss of power modeling in electrical storage
$\alpha_{\min}^{h}$	coefficient for minimum capacity modeling of heat storage
$\alpha_{\max}^{h}$	coefficient for maximum capacity modeling of heat storage
α_{loss}^{h}	coefficient for loss of power modeling in heat storage
A^{NET}	upstream network availability
A^{CHP}	CHP availability
A^{WIND}	wind turbine availability
$C_c^{st,e}$	nominal capacity of electrical storage
$C_c^{st,h}$	nominal capacity of heat storage
EF_{CO}^{CHP}	CO_2 emission factor for CHP unit
EF_{SO}^{CHP}	SO_2 emission factor for CHP unit
EF_{NO}^{CHP}	NO_2 emission factor for CHP unit
EF_{CO}^{B}	CO_2 emission factor for boiler
EF_{SO}^{B}	SO_2 emission factor for boiler
EF_{NO}^{B}	NO_2 emission factor for boiler
EF_{CO}^{L}	CO_2 emission factor for gas consumption in residential section
EF_{SO}^{L}	SO_2 emission factor for gas consumption in residential section
EF_{NO}^{L}	NO_2 emission factor for gas consumption in residential section
EF_{CO}^{Net}	CO_2 emission factor for upstream network power
EF_{SO}^{Net}	SO_2 emission factor for upstream network power
EF_{NO}^{Net}	NO_2 emission factor for upstream network power
$g_{\min}^{net}$	gas network minimum capacity
$g_{\max}^{net}$	gas network maximum capacity
g_t^{l}	gas demand in residential section
$LPF^{shup,e}$	coefficient for increased electrical load
$LPF^{shdo,e}$	coefficient for decreased electrical load
$p_{\min}^{e}$	upstream network minimum capacity
$p_{\max}^{e}$	upstream network maximum capacity
p_c^{T}	transformer rated capacity
p_c^{CHP}	nominal capacity of CHP
p_c^{B}	nominal capacity of CHP
p_r	wind turbine rated power
p_t^{el}	electrical load
p_t^{h}	heating load
wa_t^{l}	water demand
$wa_{\min}$	minimum limitation of water network
$wa_{\max}$	maximum limitation of water network
w_{co},w_{ci},w_r	cut-out, cut-in and rated speeds of wind turbine
$w(t)$	wind speed
x, y, z	coefficients for modeling generation of wind turbine
λ_t^{e}	price of purchased power from upstream network
λ^{wi}	generation cost of wind turbine
λ^{g}	gas price
λ^{wa}	water price
λ_s^{e}	operation cost of electrical storage
λ_s^{h}	operation cost of heat storage
λ^{DR}	cost of demand response

Variables

$Cost$	total operation cost of hub energy system
$C_t^{st,e}$	available energy of electrical storage
$C_t^{st,h}$	available energy of heat storage
Em	total emission generated in hub energy system
g_t^{CHP}	gas consumption of CHP
g_t^{B}	gas consumption of boiler
g_t^{net}	total purchased gas from gas network
$I_t^{ch,e}$	binary variable, 1 if electrical storage is in charging mode; otherwise 0
$I_t^{dis,e}$	binary variable, 1 if electrical storage is in discharging mode; otherwise 0
$I_t^{ch,h}$	binary variable, 1 if heat storage is in charging mode; otherwise 0
$I_t^{dis,h}$	binary variable, 1 if heat storage is in discharging mode; otherwise 0
$I_t^{shup,e}$	binary variable, 1 if electrical load is increased; otherwise 0
$I_t^{shdo,e}$	binary variable, 1 if electrical load is decreased; otherwise 0
p_t^{e}	purchased power form upstream network
$p_t^{ch,e}$,$p_t^{dis,e}$	charge/discharge power of electrical storage
$p_t^{ch,h}$,$p_t^{dis,h}$	charge/discharge heat of thermal storage
$p_t^{loss,e}$	loss of power in electrical storage
$p_t^{loss,h}$	loss of heat in heat storage
$p_t^{el,DRP}$	electrical load in the presence of DRP
$p_t^{shup,e}$	increased electrical load
$p_t^{shdo,e}$	decreased electrical load
p_t^{wi}	produced power by wind turbine
wa_t^{net}	purchased water from water network

Abbreviations

CHP	combined heat and power system
DRP	demand response program
GAMS	general algebraic modeling system
MILP	mixed-integer linear programming
TOU	time-of-use rates of demand response program

investigated in [19]. Considering uncertainty modeling of wind, price and load, optimal operation of hub energy system has been investigated in [20]. Using a heuristic technique called Time Varying Acceleration Coefficient Gravitational Search algorithm, optimal performance of hub energy system has been evaluated in [21]. With the aim of minimizing total cost, optimal operation of hub energy system considering uncertainty of renewable sources has been studied using stochastic programming in [22]. A paradigm has been presented to optimize operation of interconnected multi-carrier energy systems in [23]. Employing teaching–learning based optimization algorithm, energy flow problem of multi-carrier energy system has been evaluated in [24]. Optimal dispatch strategies and coordinated operation of a hub energy system have been investigated in [25]. Using multi-agent systems approach, optimal operation of hub energy system has been evaluated

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