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Heating hub and power hub models for optimal performance of an industrial consumer

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ABSTRACT

In addition to economic objectives that has always been considered to be the first priority in the scheduling and planning of power systems, concerns over emission of greenhouse gases due to energy consumption of industrial consumers have made policy makers consider environmental issues in the scheduling of such systems. In this paper, a multi-objective framework has been proposed for environmental and economic performance of large consumer in the presence of demand response program (DRP). In order to solve proposed multi-objective model, weighted sum technique is employed and trade-off solution satisfying conflicting objective functions is selected using fuzzy satisfying approach. DRP is employed to shift load from peak periods to off-peak periods to reduce total operation cost and emission. In order to model the proposed problem, a mixed-integer linear program has been employed and GAMS software has been utilized to solve it. Different case studies have been studied and the results have been presented to validate the effectiveness of proposed methods.

1. Introduction

Large consumers are usually energy consumers with different types of loads to be supplied. Integration of distributed energy resources like photovoltaic system [1], fuel cell [2] and battery storages [3] can help these consumers decrease their dependency on the upstream network to meet their energy demand. Also, global focus on the reduction of greenhouse gases has led to scientific researches in this field [4–6].

In order to participate in energy market, large consumer needs to be equipped to some tools. These tools as well as the reason of participation in energy market is discussed in [7]. It essential for any energy consumer including large consumer to be robust against uncertainty of various parameters available in the power systems and this issue is studied through information gap decision theory in [8,9]. Using mean–variance approach, cost of energy procurement for a local distribution company is minimized considering cost-exposure constraint from bilateral contracts and pool in [10]. In order to be capable of employing energy management tools, some necessary info and data are needed which are taken from consumers experiences using smart metering equipment in [11]. In order to handle uncertainties of market price, load management program has been used in [12]. A new approach based on robust optimization model has been developed for energy consumption scheduling of a large consumer in [13]. Detail evaluation of the effects that time-of-used rates of demand response program can have on the load curve as well as costs of consumers is presented in [14]. Robust performance of large consumers against uncertainty is investigated in [15]. Optimum purchase allocation problem with considering uncertainty of two energy markets is investigated in [16]. Using mean–variance technique, risk-based participation of large consumer in the energy market with uncertain prices is evaluated in [17]. Participation of large consumer in bilateral and pool markets with no consideration of load and price uncertainties is studied in [18]. The benefits that load management tools can provide for large consumers in energy market are discussed in [19]. Optimum trade-offs to the local distribution company are obtained between procurement cost and risk in [20]. A theory-based framework has been proposed to decide which forward-contract purchase minimizes cost of energy procurement of a local distribution company in [21]. Market price is a parameters which has its own elasticity and in order to consider this issue as well as consumer benefit, demand response programs are economically modeled in [22]. Mid-term scheduling problem of large electricity consumer has been studied with considering uncertainty of price and units

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Nomenclature

Indices

h	time index

Parameters

η_{ch}^{b}	battery storage charging efficiency
η_{dis}^{b}	battery storage discharging efficiency
η_{in}^{st}	heat storage charging efficiency
η_{out}^{st}	heat storage discharging efficiency
δ	loss of energy coefficient for battery storage
ζ	loss of energy coefficient for heat storage
η_{e}^{fc}	electrical efficiency of fuel cell unit
η^{bb}	backup burner efficiency
α	inverter efficiency
A	Area for PV installation
β	PV efficiency
$DRP_{\max}^{e}$	Maximum participation of customer in DRP
$E_{\min}^{bat}$	Minimum limit of battery
$E_{\max}^{bat}$	Maximum limit of battery
H	Hours in a day
$H_{capacity}^{st}$	Nominal capacity of heat storage
HE_{ratio}^{fu}	Heat to electrical ratio of fuel cell unit
$H_{capacity}^{bb}$	Nominal capacity of backup burner
M	A constant number
N	A constant number
P_{h}^{l}	Electrical load with no DRP consideration
$P_{capacity}^{fc}$	Nominal capacity of fuel cell unit
ρ_{h}^{grid}	Price of net electricity
ρ_{h}^{gas}	Gas price
ρ_{sale}^{pv}	selling price of PV system
R_{h}	Solar irradiation

Variables

$Cost^{total}$	total cost of large consumer
$Cost^{grid}$	cost of imported power from upstream network
$Cost^{gas}$	cost of imported gas
E_{h}^{b}	energy level of battery
H_{h}^{l}	heat demand
$H_{h}^{st,out}$	released heat from thermal storage
H_{h}^{st}	heat level of heat storage
$H_{h}^{st,in}$	heat input of thermal storage
H_{h}^{fu}	heat generation of fuel cell
H_{h}^{bb}	heat generation of backup burner
$P_{h}^{grid,ch}$	provided power by upstream network to charge battery
$P_{h}^{grid,l}$	provided power by upstream network to supply load
$P_{h}^{fc,l}$	provided power by fuel cell to supply load
$P_{h}^{fc,ch}$	provided power by fuel cell to charge battery
$P_{h}^{pv,s}$	selling power of PV system
$P_{h}^{pv,l}$	provided power by PV system to supply load
$P_{h}^{b,dis}$	discharge power of battery
$P_{h}^{pv,ch}$	provided power by PV system to charge battery
$P_{h}^{l,DRP}$	electrical load with DRP consideration
P_{h}^{TOU}	increased/decreased load
$Sale^{pv}$	profit gained by selling power to the upstream network
$u_{h}^{b,ch}$	binary variable to for charging state of battery
$u_{h}^{b,dis}$	binary variable to for discharging state of battery
$u_{h}^{grid,pur}$	binary variable for purchasing power from upstream network
$u_{h}^{grid,s}$	binary variable for selling power to the upstream network

availability in [23].

In this paper, a multi-objective optimization model has been developed for a large consumer to satisfy its economic and environmental goals. In order to solve the proposed multi-objective optimization model, weighted sum method has been used. Also, the best solution providing win-win strategy for both conflicting objective functions is selected by fuzzy satisfying technique. Shifting load from peak time periods to off-peak time periods, DRP reduces total cost and improves environmental performance of large consumer. For more clarification, the contributions and novelty of proposed paper are summarized below:

- A multi-objective optimization model considering both conflicting economic and environmental objective functions is proposed for large consumer.
- Pareto solutions are obtained for the proposed multi-objective model using weighted sum method.
- Max-min fuzzy satisfying technique is used to select the trade-off solution satisfying conflicting economic and environmental objective functions.
- Time-of-use rates of DRP is employed to reduce total cost of large consumer.
- DRP is employed to improve environmental operation of large consumer through reducing total generated emission.
- A mixed-integer linear program is employed that guarantees global optimal solution.

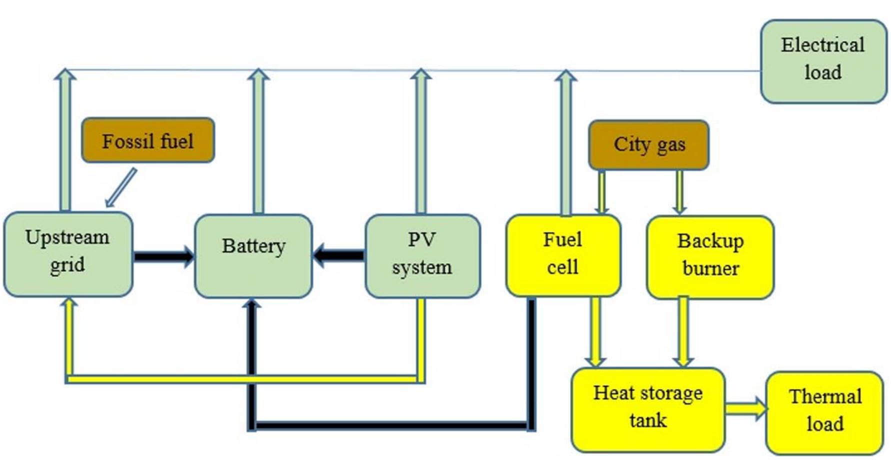

Fig. 1. Heating and power hubs model schematic diagram.