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Heating and power hub models for robust performance of smart building using information gap decision theory

Afshin Najafi-Ghalelou, Sayyad Nojavan*, Kazem Zare

Faculty of Electrical and Computer Engineering, University of Tabriz, P.O. Box: 51666-15813, Tabriz, Iran

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ABSTRACT

One of the big challenging issues for the operators of smart home is optimal scheduling of these homes within various uncertainties that can lead to increase or decrease of the operation cost of smart home. In this paper, information gap decision theory (IGDT) is proposed for robust scheduling of apartment smart building in the presence of price uncertainty. IGDT approach doesn't depend on the size of model. So, the operators of apartment smart building which are known as small scale loads can use IGDT to make more informed decisions against the price uncertainty. IGDT method contains two functions i.e. robustness function and opportunity functions. Robustness function is used to model the negative impacts of market price uncertainty while the opportunity function is used to model positive effects of market price uncertainty. By comparing the obtained results from robustness function of IGDT, it can be found that by taking risk-averse strategy and analyzing one of the obtained strategies, operation cost of apartment smart building is increased 26.18% while robustness of apartment smart building against increase of market price is increased up to 51.87% which means that the apartment smart building has become robust against increase of market price. On the other hand, according to the obtained results from opportunity function of IGDT, by taking risk-seeking strategy and analyzing one of the obtained strategies, due to 56.92% reduction of market price, the operation cost of smart home is reduced 3 £ which is 26.18% of total operation cost of apartment smart building. In fact, these strategies obtained from robustness and opportunity functions help home energy management system to take appropriate decisions to handle various possible outcomes of uncertainty. The proposed IGDT-based sample model is solved using General Algebraic Modeling System (GAMS).

1. Introduction

Smart home technology promises to make living space more comfortable, convenient and secure. One of the equipment in the smart home is home energy management system which is used to monitor and control residential energy consumption [1]. One of the important issues in optimal scheduling of smart home is seeking strategies to meet the heat and electricity demands within uncertainty and minimum operation cost [2,3]. IGDT is one of the powerful tools to find the optimal scheduling strategy of smart home in the presence of market price uncertainty [4–6].

1.1. Literature review

Literature review about optimal energy management of smart homes has been investigated as follows: In order to provide trade-off between minimization of peak demand and total operation cost of the smart home, a multi-objective algorithm has been proposed in [7] for optimal scheduling of electrical and thermal appliances along with optimal management of distributed energy sources. In order to manage the operation of electrical appliances, a novel control algorithm and system architecture has been provided in [8]. The perceived benefits and risks of smart home technologies and social barriers to the adoption of smart homes from the multiple perspectives have been characterized and reviewed in [9,10]. In order to avoid the problem of high peak demand and reduce the electricity cost, a home energy management algorithm based on the time-of-use pricing has been developed in [11]. The optimal scheduling of smart home's energy consumption has been provided in [12] to reduce peak demand and operation cost of smart home. In order to minimize the operation cost of smart home, a mathematical formulation has been developed based on the lexicographic min-max method in [13]. In order to tackle the uncertainty of photovoltaic output power and optimal management of smart home, a robust load scheduling approach has been presented in [14]. The economic operation of a smart residential multi-carrier energy system has been optimized in [15] considering demand forecast error. In order to

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* Corresponding author.
E-mail addresses: afshin.najafi95@ms.tabrizu.ac.ir (A. Najafi-Ghalelou), sayyad.nojavan@tabrizu.ac.ir (S. Nojavan), kazem.zare@tabrizu.ac.ir (K. Zare).

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Nomenclature

Sets

t	time step
j	index of smart home in the apartment smart building
i	index of smart appliances
θ	operation time index of each smart appliance

Parameter

δ	time interval of simulation (hour)
λ^{Gas}, λ^{Sell}	gas price and cost of selling power to the upstream grid (£/kW h)
η^{CHP}, η^{Boiler}, $\eta^{Battery}$, $\eta^{Thermal}$	CHP generator, boiler, battery storage system and thermal storage system efficiencies (%)
$BCC^{Battery}$, $TCC^{Thermal}$	maintenance cost of battery/thermal storage system (£/kW h)
$\lambda_t^{Market\ Price}$, $\hat{\lambda}_t^{Market\ Price}$	real/forecasted market price (£/kW h)
γ^{CHP}	power to heat conversion ratio in CHP generator
$P_{i,\theta}^{App}$	consumption power of ith smart appliance (kW)
P_i	length of operation time of ith appliance (hour)
L^{CHP}, L^{Boiler}, $L^{Battery}$, $L^{Thermal}$	CHP generator, boiler, battery storage system and thermal storage system capacities (kW h)
$LC^{Battery}$, $LD^{Battery}$	charge/discharge limit of battery storage system (kW)
$LC^{Thermal}$, $LD^{Thermal}$	charge/discharge limit of thermal storage system (kW)
$M^{Battery}$, $M^{Thermal}$, M^{Grid}	maximum capacity of battery storage system, thermal storage system and purchased power from upstream grid (kW)
$T_{j,i}^{Start}$, $T_{j,i}^{Finish}$	earliest starting/latest finishing time of ith appliance related to the jth smart home (hour)
C_R, C_W	critical costs for the robustness and opportunity functions (£)

Variable

$P_{j,t}^{CHP}$, $Q_{j,t}^{Boiler}$	output power of CHP generator/boiler related to the jth smart apartment at time t (kW)
$P_{j,t}^{Import}$, $P_{j,t}^{Export}$	imported/exported power from/to the upstream grid related to the jth smart home at time t (kW)
$TC_{j,t}^{Thermal}$, $TD_{j,t}^{Thermal}$	charge/discharge rate of thermal storage system related to the jth smart home at time t (kW)
$BC_{j,t}^{Battery}$, $BD_{j,t}^{Battery}$	charge/discharge rate of battery storage system related to the jth smart home at time t (kW)
$BS_{j,t}^{Battery}$, $TS_{j,t}^{Thermal}$	state of charge of battery/thermal storage system related to the jth smart home at time t (kW h)
$BTS_t^{Battery}$, $TTS_t^{Thermal}$	total state of charge of central battery/thermal storage system at time t (kW h)
$BVS^{Battery}$, $TVS^{Thermal}$	initial state of battery/thermal storage system (kW h)

Binary variable

$X_{j,t}^{Grid}$	binary variable; equal to 1 if electricity is bought from upstream grid by the jth smart home; equal to 0 if electricity is sold to the upstream grid by the jth smart home at each period of time
$X_{j,t}^{Thermal}$	binary variable; equal to 1 if thermal storage system is charged at time t; equal to 0 if thermal storage system is discharged at time t
$X_{j,t}^{Battery}$	binary variable; equal to 1 if battery storage system is charged at time t; equal to 0 if battery storage system is discharged at time t
$\omega_{j,i,t}^{App}$	binary variable; equal to 1 if the ith appliance related to the jth smart home is active; otherwise 0

Functions

$\hat{\alpha}(C_R)$, $\hat{\beta}(C_W)$	robustness and opportunity functions

decrease household payment, an optimal and automatic residential load commitment framework has been presented in [16]. In order to incorporate the priority of operating different appliances in the optimization model of an energy management system, a price-based home energy management framework has been provided in [17]. In order to minimize the operation cost of smart home and maximize the comfortable lifestyle, a multi-objective mixed integer nonlinear programming model has been provided in [18]. Optimal day-ahead scheduling of CHP units in the presence of electrical and thermal storage systems has been presented in [19] to maximize the benefit during scheduled period. Lighting system for a smart home has been designed with effective and efficient daylight harvesting capability in [20]. In order to minimize the value of stochastic forward looking operation cost of smart home, the scheduling problem of energy resources and day-scale and hour-scale deferrable appliances of the smart home has been studied in [21]. In order to evaluate demand response in the presence of solar photovoltaic and flexible loads, an optimization-based generic model has been presented in [22].

Optimal energy management of IGDT-based models has been investigated as follows: The optimal bidding strategy problem has been studied in [23] with modeling the uncertainty of day-ahead market price using IGDT. A hybrid approach based on the modified particle swarm optimization and IGDT has been used in [24] to maximize the profit of generation station in the presence of market price uncertainty. IGDT technique has been provided in [25] to minimize the operation cost of microgrid with considering the load uncertainty. IGDT technique has been presented in [26] to assess different procurement strategies for large consumer in the competitive electricity market. IGDT approach has been provided in [27] to handle the optimal self-scheduling of wind power producers problem in the presence of wind speed and market price uncertainties. A risk-averse decision making tool based on IGDT approach has been provided in [28] to help the smart distribution network operators in short-term operational activities under severe uncertainties. An IGDT based model has been provided in [29] to maximize profit of thermal unit producers considering the market price uncertainty. Finally, IGDT approach has been employed to optimize unit commitment problem considering the uncertainty of wind speed in [30]. In order to incorporate congestion free reserve and energy procurement from smart buildings in distribution system, a conventional distribution locational marginal price approach based on robust optimization method has been provided in [31].

1.2. Differences of IGDT and robust optimization approach

Robust optimization approach has been widely employed in power system fields to model uncertainty of parameters [32–34] like market price. This approach is similar to IGDT and both mentioned approaches are categorized in the interval optimization methods. One of the similarities of both methods is that the worst case of uncertainty parameter can be modeled by both methods. But, one of the big differences between two mentioned methods is related to their inputs parameters. In IGDT method, the desired value of cost function which should be guaranteed is considered as an input parameter while in ROA approach the minimum and maximum amounts of electricity market prices determined based on the historical data (the actual price intends to fall with the pre-defined intervals) are considered as input parameters. In