A multi-objective HEM strategy for smart home energy scheduling: A collaborative approach to support microgrid operation

Tohid Sattarpour, Daryoush Nazarpour⁎, Sajjad Golshannavaz

Electrical Engineering Department, Urmia University, Urmia, Iran

ARTICLE INFO

Keywords:
Home energy management (HEM)
Cost minimization
Flattened load profile
Multi-objective approach

ABSTRACT

Contributing to a flattened load profile by smart home owners could effectively assists the microgrid operator (MGO) in coping with technical hurdles and assuring an economic operation. To attain such functionality, a home energy management (HEM) approach is proposed which interrogates two objectives, sequentially. The first objective assures a minimum energy payment cost of home appliances, as the main purpose of the home owners. In the sequel, the obtained minimum cost is assigned as an optimization constraint and the minimum load profile deviation is pursued. Besides the fixed-load and shiftable appliances, plug-in hybrid electric vehicle (PHEV), small-scale energy storage system, and renewable energy resources are also contemplated. Efficient linearization techniques are applied to avert non-linear nature of the established model ending to a linear one. Detailed simulation studies are conducted to assess performance of the proposed approach. Results are discussed in terms of reduced energy payment costs of home owners and a flattened load profile.

1. Introduction

1.1. Motivation

The soaring energy demands and restricted supply capacity of generators could stimulate to severe electricity price spikes. On the other hand, customers who have been treated with fixed prices are now capable of controlling their load profiles in response to time varying prices. Technically speaking, this task is fulfilled by home energy management (HEM) system without any human interference. This system is now a significant part of smart grid infrastructure which plays a vital role in successful implementation of demand side management (DSM) concepts say as demand response (DR) programs and economic operation of smart homes (Gholami, Shekari, Aminifar, & Shahidehpour, 2016; Javadi et al., 2017). DSM encourages end-side consumers for optimum energy consumption based on two-way flow of both electricity and data (Gholami, Aminifar, & Shahidehpour, 2016; Siano, 2014). As well, it is interlinked with HEM system to transfer time of use (TOU) tariffs and coordinate the electricity consumption in response to network constraints and reliability requirements. In this context, participation of responsive loads (i.e. shiftable appliances) in smart homes is recognized as a promising opportunity to improve the efficiency of microgrid operation (Shakouri G. and Kazemi, 2017; Zakariazadeh, Jadid, & Siano, 2014a).

Shedding more lights on HEM systems, it manages home appliances and infield small-scale distributed energy resources (DERs) to enhance the energy consumption patterns, minimize energy payment cost, and optimize scheduled energy generation. In this task, HEM considers consumer’s comfort and electricity tariff (Yu, Jia, Murphy-Hoye, Pratt, & Tong, 2013). As shown in Fig. 1, HEM system launches bi-directional interactions with home appliances based on home area network (HAN). A similar connection is established with the microgrid operator (MGO) based on local area network (LAN). HEM system receives electricity tariff from LAN. As well, it is made informed of home load profile, plug-in hybrid electrical vehicle (PHEV) status, energy storage system (ESS) specifications, and renewable energy resources such as roof-top photovoltaic (PV) panel information. Afterward, it executes a strong mathematical model to release commitment patterns of shiftable appliances and DERs scheduling commands. More obviously, HEM tries to shift the consumption to low price intervals to attain a higher monetary saving. It should be noted that if no attention is paid on resultant load profile, severe peak loads are prone to occur at off-peak intervals when the electricity price is low (Teng, Luan, Lee, & Huang, 2013). This situation although grants an efficient economic record for home owners, introduces technical challenges for MGOs and reduces the supply reliability.

1.2. Literature review

Several studies are carried out focusing on different types of HEM...
systems developed for optimal operation of appliances and DERs. In (Clastres, Ha Pham, Wurtz, & Bacha, 2010), a PV-based energy management is proposed within the smart home environment. In this study, the impact of PHEV charging/discharging is not considered in peak-load clipping, valley filling, and lowering the total payment cost. A HEM system has been developed in (Rajasekhar and Pindoriya, 2015) considering existence of solar PV and battery energy storage. Similarly, the impact of PHEV is not taken into account. Moreover, the established mathematical model is a multi-objective mixed-integer nonlinear programming (MINLP) which is confronted by computational challenges. An optimal approach has been established in (Rastegar, Fotuhi-Firuzabad, & Aminifar, 2012) for smart home load commitment purposes and PHEV and ESS scheduling task. However, the proposed model does not accommodate renewable energy resources. Besides, minimizing the payment cost instigates new peak load records at low price periods. In (Marzband, Alavic, Ghazimirsaeidd, Uppala, & Fernando, 2017), a HEM strategy is developed considering different types of appliances aiming at reducing day-ahead operation cost and improving energy efficiency based on mixed-integer linear programming (MILP). Responsive loads and ESS are present in the proposed strategy; however, the impact of PHEV is not taken into account. In (Apaydin Ozkan, 2016), an optimal approach is devised for home appliance commitment which excludes the interconnection of DERs. Siano and Sarno (2016) investigated an innovative technique for assessing the influence of residential DR on environmental concerns and wholesale electricity transfer. Although an efficient approach is established, it could be further improved in terms of PHEV connections. Siano, Sarno, Straccia, and Marrazzo (2016) proposed an approach to organize DR by residential customers in a smart grid. However, different scheduling strategies of appliances and operating modes of local energy resources could be further interrogated. The proposed model in (Elma and Selamogullari, 2015) modifies the peak load demand and enhances home energy efficiency. The proposed algorithm is based on voltage control notions to reduce the power consumption of controllable appliances. Adoption of DERs could contribute to an impressive impact in energy management and voltage control strategies. Authors in (Safdarian, Fotuhi-Firuzabad, & Lehtonen, 2016) have developed an approach which not only considers a minimum operation cost, but also takes into account the load profile and tries to make it uniform. The proposed model could be improved by considering the ESS and PHEV discharging effects. Moreover, the effect of renewable-based DERs has not been considered.

1.3. Contributions

Contributing to the outlined context, the ongoing study aims at presenting an optimal multi-objective HEM strategy to not only minimize the home owner’s operation cost but also to support the upstream MG operation. The distinctive features of the presented model can be listed as follows:

- Different DERs including ESS, PHEV, and rooftop PV panel are integrated in the proposed model. Charge/discharge capabilities of ESS and PHEVs enable a higher economic saving by shifting the load demand toward low-tariff intervals.
- The proposed model develops a multi-objective HEM being assessed in a sequential manner. In the first step, commitment of shiftable appliances and DERs is performed to assure a minimum operation cost. Then, satisfying the obtained operation cost within the constraints, second step pursues minimum load profile deviation to assist the MGO with a flattened load profile. Thus, the risk of new peak load generation is averted.
- Efficient linearization techniques are deployed to avert the non-linear nature of the established model. Hence, a computationally-efficient approach is developed.
- Outline of the Manuscript

This paper continues as follows. Section 2 portrays an illustrative representation of the proposed HEM strategy. Mathematical modeling of the proposed approach is addressed in Section 3 wherein multi-objective analysis of the established approach and linearization techniques are also addressed. Simulation studies are thoroughly explored in Section 4. Eventually, the concluding remarks are reflected in Section 5.

2. Conceptual representation of the established HEM strategy

The data transfer between the MGO, HEM system, and home equipment is displayed in Fig. 2. As can be seen, at first level, HEM...
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