Sustainable Cities and Society 40 (2018) 440–453

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Load serving entity interactions on residential energy management strategy: A two-level approach

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ARTICLE INFO

Keywords:
Load serving entity (LSE)
In-home energy management (iHEM)
Energy cost minimization
Load profile deviation

ABSTRACT

A massive motivation has been made on in-home energy management (iHEM) strategies aimed to cooperate with each other in integrated residential areas. Such an approach could make sense in satisfying the objectives of load serving entity (LSE), too. To make such concepts, residential energy management (REM) approach, in interaction with LSE, is proposed pursuing two objectives. The main goal of these objectives is to modify microgrid day-ahead load profile by considering the minimized total daily energy costs of homes. In this regard, in the first level, the objective pursues a minimum energy cost for each home. In the second level, the minimum load profile deviation for microgrid is tracked. Moreover, the obtained homes minimum costs which are achieved in the first level are assigned as running constraints of the second level optimization. In the present study, in addition to existing fixed-loads, iHEM systems are responsible for adjusting shiftable appliances commitment, charging/discharging intervals of plug-in hybrid electric vehicles (PHEVs) and energy storage systems (ESSs), and roof-top photovoltaic (PV) panels. Efficient linearization methods are considered to avert non-linear nature of the established model to a linear one. To investigate the efficiency of the proposed approach, the obtained simulation results are explored carefully.

1. Introduction

1.1. Research background

Energy management in the houses has gradually become more and more significant and a common global issue in all of the countries. An intelligent microgrid can be considered as a future microgrid which motivates the expansion of smart in-home energy management (iHEM) system. The iHEM system which is placed in customers' premises and is in association with smart meter can play a vital role in providing demand response (DR) schemes efficiently to smart homes (Zhang, Li, Sun, & O'Neill, 2016; Shafie-khah and Siano, 2017). Residential energy management (REM) system is an implemented demand response (DR) which manages energy consumption of homes in residential areas to decrease the energy costs according to electricity price. REM not only improves the technical aspects of microgrid, but also motivates consumers to have active interactions with load serving entity (LSE) in demand side management (DSM) programs (Celik, Roche, Suryanarayanan, Bouquain, & Miraoui, 2017). A main wireless external communication related to iHEM system for cost-efficient REM is LSE which is operating and monitoring the microgrid. In response, DSM is designed to encourage customers for optimal energy consumption in terms of two-way flow of both electricity and data (Liu, Gao, Wu, & Tang, 2017). Therefore, participation of homes in DSM has a key role for improving the efficiency of intelligent microgrid (Good, Ellis, & Mancarella, 2017; Jin, Baker, Christensen, & Isley, 2017). Briefly, an iHEM is a DR tool which optimally manages appliances and the existing distributed energy resources (DERs) to enhance the energy consumption, minimize energy payment cost, and optimize the scheduled energy transfer in smart home by considering consumer's comfort, electricity tariff, and also LSE constraints (Amrr, Saad Alam, Jamil Asghar, & Ahmad, 2018). Moreover, iHEM systems must react in response to time-differentiated price signals in a coordinated manner with REM strategies.

Fig. 1 shows the fundamental integrated REM strategy and LSE. As shown in this figure, the iHEM systems can be connected with the home appliances by home area network (HAN) infrastructure and with the LSE through local area network (LAN) infrastructure. Through these two infrastructures, iHEM systems receive data such as historical information about solar power production and the pricing data from LAN. Besides, appliances, plug-in hybrid electrical vehicle (PHEV), and energy storage system (ESS) information have been achieved from HAN to improve the commitment of shiftable appliances and DERs together. iHEM systems also retain data to the LSE about consumption of the

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https://doi.org/10.1016/j.scs.2018.04.013
Received 26 November 2017; Received in revised form 31 March 2018; Accepted 6 April 2018
Available online 26 April 2018
2210-6707/

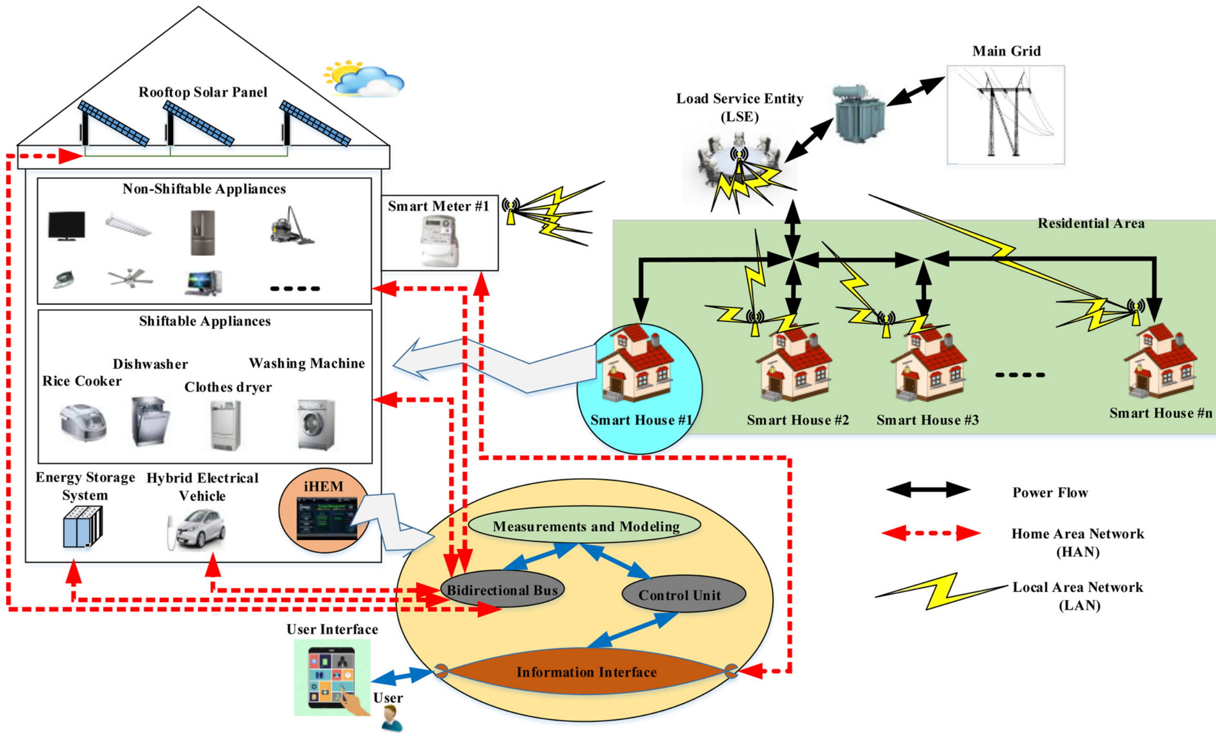

Fig. 1. Integrated REM strategy and LSE.

appliances through smart meters, and also generation patterns of installed DERs in the household. Hence, iHEM systems have bi-directional interaction with LSE and home appliances. Moreover, in this strategy, the houses are in energy interactions with each other by LAN in residential area. Also, as shown in this figure, home appliances in terms of their specification can be divided into two main groups: dishwasher, washing machine, clothes dryer, and rice cooker are shiftable appliances while TV, refrigerator, and etc. are non-shiftable appliances. To minimize the payment cost and enhance the energy consumption, shifting energy consumption in the homes from peak to off-peak intervals is preferable. Moreover, using the existing energy in PHEV and ESS for peak-power shaving and the valley-filling of power demand can be a potential application for REM strategy. If REM system works without considering load profile, it is likely to have severe peak loads at off-peak intervals when cheaper electricity is available (Teng, Luan, Lee, & Huang, 2013). Therefore, for balancing the power consumption and reducing the peak demand economically, REM systems must apply diverse set of programs to modify the microgrid load profile flatter by considering minimized homes energy payments. The economic savings related to these managements are fairly divided between the LSE and home owners through a signed contract.

1.2. Literature review

So far, several contributions on optimal REM, related control strategies, and also about iHEM systems have been made. Since the advent of energy management, few studies have been gradually done upon LSE. Accordingly, it is meaningful and necessary to study the DSM strategy of smart residential areas. Clastres, Ha Pham, Wurtz, and Bacha (2010) proposed a PV-based energy management for a smart home. This study explained how the proposed system could be applied to offer ancillary services. As clarified here, PV manufacturers could benefit by taking part in the markets for balancing power or ancillary services. Nevertheless, the impact of including PHEV charging/discharging process which can be helpful for peak clipping, valley filling, and lowering the total electricity price are not assessed. Also, HEM strategies which can cooperate with each other to reach an optimal operating strategy have not been considered in this study.Rajasekhar and Pindoriya (2015) considered a HEM system based control of smart home with solar PV and battery energy storage. However, the impact of PHEV is not taken into account. Similarly, it was not considered in Clastres et al. (2010) either. In this study, a multi-stage optimal scheduling method has been studied that implements the management strategies for home appliances and installed resources. This study is a multi-objective non-linear problem with equality and inequality constraints which has computational challenges. Therefore, linear based formulations to reduce the computation burden of the problem have not been considered. REM approach, considering different types of household which is in interaction with LSE, is not considered also. Rastegar, Fotuhi-Firuzabad, and Aminifar (2012) advanced a smart home load commitment approach considering possible operating methods of PHEV and ESS, but ignored the power of PV-based distribution generation at home that is credible to be suitable for energy management. In this paper, a framework is proposed to achieve the household minimum payment for day-ahead scheduling. As will be discussed, minimizing the payment cost creates new peak load at low price periods. The modified load profile has been neglected in the objective function. Also, the works mentioned above did not study the conditions of scheduling the complete residential area which involves a set of households. Javaid et al. (2017) presented HEM system considering different types of appliances with the aim of reducing day-ahead scheduling electricity cost and improving energy efficiency on the basis of four heuristic algorithms. ESSs and PHEVs are not considered in HEM strategy. Nevertheless, this study has considered nonlinear programming and also does not contain the circumstances which covers multiple kinds of loads and local resources. Ozkan (2016) also introduced appliance based control without considering local energy resources for power management in household. In this study, manageable appliances and their operation principles are presented. Moreover, energy saving of manageable appliances compared to non-manageable appliances are investigated. Silvente and Papageorgiou (2017) presented a mixed integer linear programming (MILP) formulation to optimally manage energy and heat generation, storage and demand for optimal control of an integrated homes and microgrid. Also, a practical framework is proposed for