Electric Power Systems Research 133 (2016) 27–35

Contents lists available at ScienceDirect

Electric Power Systems Research

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

Dynamic residential load scheduling based on adaptive consumption level pricing scheme

Haider Tarish Haider[a,b,*], Ong Hang See[a], Wilfried Elmenreich[c]

[a] Department of Electronics and Communication Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia
[b] Department of Computer and Software Engineering, University of Al-Mustansiriyah, 10001 Baghdad, Iraq
[c] Institute of Networked & Embedded Systems/Lakeside Labs, Alpen-Adria-Universität Klagenfurt, 9020 Klagenfurt, Austria

ARTICLE INFO

Article history:
Received 10 August 2015
Received in revised form
23 November 2015
Accepted 8 December 2015
Available online 5 January 2016

Keywords:
Smart grids
Residential demand response
Load scheduling
Dynamic pricing
Information and communication technologies

ABSTRACT

Demand response (DR) for smart grids, which intends to balance the required power demand with the available supply resources, has been gaining widespread attention. The growing demand for electricity has presented new opportunities for residential load scheduling systems to improve energy consumption by shifting or curtailing the demand required with respect to price change or emergency cases. In this paper, a dynamic residential load scheduling system (DRLS) is proposed for optimal scheduling of household appliances on the basis of an adaptive consumption level (CL) pricing scheme (ACLPS). The proposed load scheduling system encourages customers to manage their energy consumption within the allowable consumption allowance (CA) of the proposed DR pricing scheme to achieve lower energy bills. Simulation results show that employing the proposed DRLS system benefits the customers by reducing their energy bill and the utility companies by decreasing the peak load of the aggregated load demand. For a given case study, the proposed residential load scheduling system based on ACLPS allows customers to reduce their energy bills by up to 53% and to decrease the peak load by up to 35%.

1. Introduction

Currently, residential electricity demand accounts for 20% to 40% of the total electrical energy used all over the world [1–3]. Residential loads often contribute significantly to seasonal and daily peak demands [4]. To meet these occasional peak demands, utility companies have been required to increase their generation capacity to match the required demand at all times. Generally, about 20% of the power generation capacity is latently available to meet the peak demand that occurs for approximately 5% of the time [5,6]. However, this capacity level is becoming less practical because of the cost of new power plants and the level of greenhouse gas emissions [7,8]. Managing the peak power consumption helps drive significant energy conservation by shifting or curtailing the peak load to achieve smooth customer energy usage [9,10]. Both, utility companies and customers benefit from achieving optimal load management during peak periods [11]. Furthermore, residential homes are becoming smarter because of the integration of the information and communication technologies to connect all household appliances and sensors in a home area network (HAN) for easier monitoring and intelligent control. Meanwhile, smart homes are being faced with varied pricing tariffs where flexible DR schemes are being implemented in many countries all around the world. Therefore, a great opportunity for the residential sector to improve its energy usage load scheduling through smart home techniques under flexible pricing schemes [12–15]. However, residential customers cannot be expected to invest time and obtain knowledge to manage all the smart home devices on their own. Thus, a dynamic load scheduling system is expected to help customers arrange the load scheduling optimally to save energy and cost [16,17].

Recent literature includes several studies that refer to the need to address customer load scheduling in DR systems. In [18], a cooperative game theory model was proposed to optimize the peak load by scheduling the customer appliances. A time-of-use (ToU) DR program was used in the study. The results showed that the customer energy cost was reduced by 18%. In [19], an intelligent home appliance scheduling solution was illustrated on the basis of the ToU program. This solution attempted to optimize the customer constraints and the ToU price change of utility companies to obtain a decision-support system for forecasting the electricity demand and to save energy with an efficient appliance scheduling

* Corresponding author at: Tenaga Nasional Universiti, Electronics and Communication, P13-B-07-06, Sri Cempaka, Jalan Sepakat Indah 2/2 Taman Sep, Kajang 43000 Selangor, Malaysia. Tel.: +60 183262643.

E-mail addresses: haiderth@ymail.com (H.T. Haider), ong@uniten.edu.my (O.H. See), wilfried.elmenreich@aau.at (W. Elmenreich).

http://dx.doi.org/10.1016/j.epsr.2015.12.007
0378-7796/

Nomenclature:

Abbreviation

DR	demand response
DRLS	dynamic residential load scheduling system
CL	consumption level
ACLPS	adaptive consumption level pricing scheme
CA	consumption allowance
HAN	home area network
ToU	time of use
DLC	direct load control
PIB	price-invariant band
CA+	positive consumption allowance
CA−	negative consumption allowance
BC	British Columbia
PR	price rate
R	the currency of South African, that is ZAR or rand

Variables

d^t	the total load at each time slot
t	time slot
d_p^t	one-slot energy consumption for appliance p
D^t	the total load of all appliances at time slot t
C_t	the pricing function
a_t, b_t, c_t	parameters of quadratic cost function
L_t	the customer consumption level in each time slot
S_t	the starting operation time of an appliance
E_t	the ending operation time of an appliance
OS_t	the optimal starting time of appliance operation
OE_t	the optimal ending time of appliance operation

Parameters

T	total number of time slots
P	set of household appliances
p	one household appliance
d_p	the total energy consumption of appliance's p
r_1, r_2, r_3	the constant parameters of the ACLPS cost function
B	the daily energy cost
B_{Ds}	desired daily customer energy consumption cost
B_{AC}	actual daily customer energy consumption cost
Ex	extended energy consumption
T_D	time duration

system. However, the simulation result covered only a few types of customer appliances. Furthermore, customer privacy and load synchronization were not addressed in the study. In [20], a scheduling of actual customer load types was presented using a mixed-integer nonlinear optimization model based on the ToU pricing program. The result achieved approximately 25% cost reduction. A dynamic load scheduling system for a smart home during demand response events was proposed in [21]. In this system, load curtailment and scheduling were adapted every minute to ensure adequate comfort levels during peak periods. Load priorities were fed into an optimization module to determine the least important load at each instant. Another dynamic load scheduling system that incorporated both intelligent smart meter and an aggregator that autonomously scheduled the appliances and storage devices, was proposed in [22]. According to the historical data on the operation of customer appliances, the smart meter learns and predicts the power consumption behavior of the appliances to generate the expected appliance scheduling automatically. The average savings attained by the customers were 20.39%. In [23], a multi-objective genetic algorithm was proposed to optimize the time allocation of domestic load operation while minimizing the costs associated with energy purchase and end-user dissatisfaction. The system showed three extreme solutions to address energy purchase cost, end-use dissatisfaction, and compromise solution. The cost reductions of these three solutions were 24%, 22%, and 23%, respectively. In [24], a mathematical formulation for load scheduling was proposed for optimal cost saving considering the electrical vehicle to home discharging capability. The system investigated different time-varying DR programs (ToU, inclining block rate, and a combination of them) to show the effect of these programs on the results. The results indicated approximately 22% cost reduction. In [25], dynamic load scheduling was proposed on the basis of the theory of optimal portfolio selection. The system optimized the load according to the historical data of customer energy consumption to obtain the customer utility for expected price and energy for the next time slot using the optimal portfolio selection theory. The result achieved about 28% cost reduction. In [26], a dynamic-pricing and peak power limiting-based DR strategy with bi-direction electricity utilization for electrical vehicle and energy storage system was proposed. This system achieved a cost reduction of approximately 65%.

These mentioned works generally refer to load modeling and optimization methods to solve customer load scheduling. On the one hand, most of the current studies on load management aim to schedule the customer load based on a price-based DR scheme, specifically for ToU or real-time pricing programs. In a price-based scheme, the customers are offered time-varying rates that reflect the value and cost of electricity at different time periods [27], which means that the price of energy varies for different times in a day and different seasons in a year [28]. The problem arises from the externality effects of the energy usage of a selfish customer that are imposed on the price rate for other customers. Moreover, customers are offered a single price rate for all consumption levels (CLs) in each period. In addition, customers need to be concerned with price changes with respect to time. On the other hand, the load management studies in the literature optimized the load scheduling based on historical data or expected customer consumption limit, which may not be optimal to reduce the energy bill. The methodology proposed in the present paper intends to use dynamic customer load scheduling based on an adaptive CL pricing scheme to achieve optimal load scheduling. This paper first focuses on modeling the residential load according to actual customer preferences in terms of load scheduling. Second, a mathematical formulation for the objective function and constraints is presented based on actual consumption constraints to manage the customer load scheduling optimally for saving energy and cost. Finally, an adaptive consumption level pricing scheme (ACLPS) is introduced as a DR scheme to overcome the externality effect and time constraint of the price-based DR scheme as discussed in Section 2. In addition, the effect of the price-based program and ACLPS are investigated based on the DRLS results. We consider a scenario where the DRLS functionality is deployed inside the smart meter that is connected to not only the utility side, but also to the HAN to achieve optimal management for the customer's appliances. The overall system performance reveals that employing the dynamic residential load scheduling system (DRLS) benefits not only the customers by reducing their energy cost, but also the utility companies by decreasing the peak load of the aggregated load demand.

2. System model

In this section, a mathematical formulation for the representation of the demand response scheme, energy consumption model, and pricing model is provided. According to these formulated aspects, we formulate an objective function to optimize the customer load scheduling in Section 3.