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True real time pricing and combined power scheduling of electric appliances in residential energy management system

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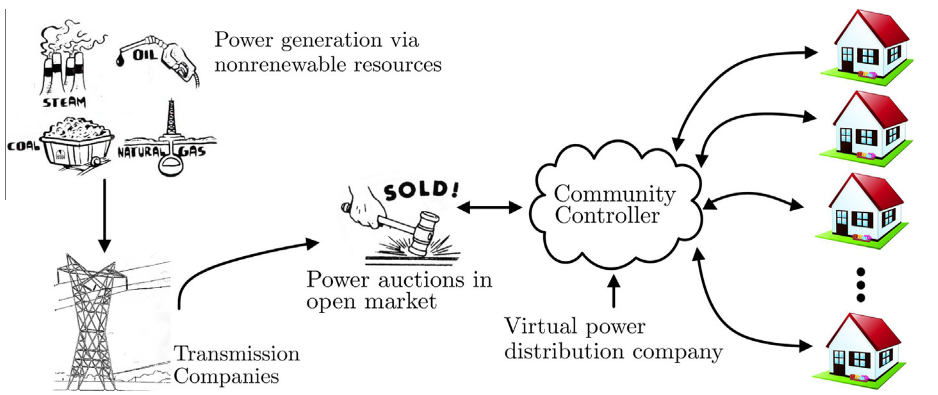
HIGHLIGHTS

- New smart home community architecture is proposed.
- The community controller acts as a virtual power distribution company.
- A true real time pricing scheme is developed that charge at the end of a day.
- A power scheduling algorithm is developed for reduction of power peak to average ratio.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper proposed a new smart home community architecture in power system, in which community controller will acts as a virtual power distribution company. The traditional real time pricing schemes may not be effectively implemented in terms of reduction of power peak to average ratio over the large number of end consumers. To overcome this problem, a true real time pricing between community controller and community end users is developed based on real time pricing and inclining block rates. The proposed pricing scheme implemented in the community is charged at the end of a day according to the combined load of the community. To schedule the electric appliances in a combined way, we have developed a power scheduling algorithm as well. The simulation results have revealed that by applying anticipated technique of pricing scheme in group of households, the consumption cost of end consumers decreases and the overall power peak to average ratio reduces as well which will be beneficial for the utilities.

1. Introduction

Non-renewable energy resources such as oil and coal are continuously decreasing to a point of scarcity to meet the extensive energy supply demands of industrial and residential users. According to a report on non-renewable resources published by WUA, coal and oil will likely experience a permanent global supply shortfall among the other 21 non-renewable resources by the year 2030 [1]. Coal, oil and natural gas are the main contributors for the generation of electricity. Currently, 86% of the electricity needs are provided through these energy resources in Australia and it is much the same all around the world. It is necessary to protect

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Nomenclature

P_t	price at time slot t
T	number of time slots in a day
a_t, b_t, c_t	time of use coefficients
$\mathbb{M}$	number of users in a community
L_t	power consumption of all the users at time slot t
$\mathbf{L}_i$	power consumption of user i in a day
$\mathbf{L}$	power consumption of all the users in a day
x_t, y_t, z_t	price values of inclining block rate
χ_{i_t}	specified power consumption thresholds
ζ_i	threshold pricing constants
κ_i	threshold limiting constants
$\mathbb{E}_i$	set of electric appliances of ith user
$\mathbb{E}$	set of electric appliances of all the users
$\mathbb{N}_i$	number of electric appliances of ith user
$e_{i,j}$	jth electric appliance of ith user
$r^t_{i,j}$	power rating of $e_{i,j}$ in time slot t
$c^t_{i,j}$	cost of $e_{i,j}$ in time slot t
$d_{i,j}$	operating time duration of $e_{i,j}$
$s_{i,j}$	starting operating time of $e_{i,j}$
$f_{i,j}$	finishing operating time of $e_{i,j}$
$\omega_{i,j}$	starting desired time of $e_{i,j}$
$\psi_{i,j}$	finishing desired time of $e_{i,j}$
$\mathbf{C}^{\mathbb{T}}_{\mathbb{M},\mathbb{N}_i}$	total cost of all the users in a day
$\mathbf{C}_i$	individual cost of ith user

Abbreviations

DSM	Demand Side Management
EMS	Energy Management System
PAR	Peak to Average Ratio
HC	Home Controller
ISO	Independent System Operator
RTP	Real Time Pricing
IBR	Inclining Block Rate
TRTP	True Real Time Pricing

these resources as much as possible. In terms of using electricity, one solution is the transferring of electricity generation sources from non-renewable to renewable resources such as to solar and wind powers. However, transferring to renewable resources might be costly and time consuming in terms of their deployment and maintenance. Also, although much effort has been continuously putting for the productive implementation of these renewable resources but it will still take sufficient time to be fully implemented. Meanwhile, the other way to handle these non-renewable resources carefully is by the effective and efficient management of electricity at the consumer's side through the Smart Grid [2,3]. Demand Side Management (DSM) [4,5] whose prime responsibility is to make assure the balance in electricity supply and demand at any time, is the most important functionality of smart grid and a vital need concerning to the careful management of energy resources in Energy Management System (EMS) [6]. EMS which is broaden form of DMS can further be classified as Centralized EMS (CEMS) and Decentralized EMS (DEMS) [7]. CEMS is a hierarchical system having control in a focal and central point. DEMS on the contrary is a collection of small controllers employed in the form of network having more flexibility than the CEMS [8]. The DMS can be achieved by putting extra generation sources at peak times to meet the consumer's demands with the expense of extra cost. However, the effective way of achieving DMS is by motivating end consumers to lower their demands at peak times. This can be done by implementing real time pricing in which prices are forecasted and announced at the beginning of each upcoming time slot. The prices are high at those time slots where the usual previous loads are high. The high prices at these times in fact can motivate end consumers to shift their load to off peak times to reduce the consumption cost. Many researchers and economists argue that real time pricing represents efficient demand response mechanism and thus it should be the focus of policymakers. However, prices announced at the beginning of time slots may decrease the consumption cost of end consumers but might not be effective in terms of reducing power Peak to Average Ratio (PAR) due to the transfer of peak load to off peak times causing peak there. This phenomenon is known as Rebound Peak, reported in [9–11]. The rebound peak is mainly due to the one way communication between the end consumers and system operators. The authors of [9,10] proposed that the reduced peak demand can be achieved by the two way communication. However, with the two way communication, the results are still not satisfactory as presented in [12] which are discussed later in this work. In this paper, we have designed a true real time pricing scheme that will be calculated at the end of a day and directly proportional to the combined load of the community. This direct relationship between cost and load will motivate consumers in the community to schedule their combined load in a uniform and even way. The uniformity in the load will not only reduces the consumption cost but will also lower the power PAR as well.

The power system consist of three major entities of generation, transmission and distribution companies beside Independent System Operator (ISO) and some other market entities. Generation companies sell electricity to distribution companies via auctions or negotiations. The distribution companies then sell electricity to end consumers giving them the options of flat rates or time of use tariffs (same as the real time pricing). In this paper, we have proposed a smart home community architecture in which community controller will acts as a virtual power distribution company and can buy or even sell electricity from the generation companies present in the open market. The proposed system model is based on the combined and collective participation of smart homes in a smart home community as contrary to the previous literature [13,14] which concentrate on DSM of individual smart homes. Fig. 1 shows the overview of the smart home community architecture that consists of small number of users. Each home of community consists of Home Controller (HC), smart meter [15,16], home electric appliances and home display [17,18]. Smart meter, which is situated inside the smart home, capable of reading the consumption data, conveying this information to community controller and transferring the real time pricing signals from community controller to HC for further analysis. HC is a focal point in home, which is an embedded system, responsible for getting information from smart meter (vice versa) and displaying the current status on home display. The operation control of appliances along with the feedback on their energy consumption is done on home display. For the communication of HC with other devices, various communication solutions and protocols [19–21] are present, including ZigBee, Z-Wave and Wi-Fi. This paper attempts to optimize the pricing scheme between smart home community and end users such that the consumption cost and power PAR of the whole community reduces at the same time. An algorithm for combined power scheduling of electric appliances of all the smart homes is also proposed that will assists the pricing scheme in achieving the main objectives.