Electrical Power and Energy Systems 30 (2008) 569–574

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

A hybrid society model for simulating residential electricity consumption

Minjie Xu [a,b,*], Zhaoguang Hu [b], Junyong Wu [a], Yuhui Zhou [a]

[a] School of Electrical Engineering, Beijing Jiaotong University, Beijing, China
[b] State Power Economic Research Institute, Beijing, China

ARTICLE INFO

Article history:
Received 26 July 2007
Received in revised form 15 May 2008
Accepted 15 August 2008

Keywords:
Residential electricity consumption
Multi-agent systems (MAS)
Power price policy
Electricity saving
Social influence model

ABSTRACT

In this paper, a hybrid social model of econometric model and social influence model is proposed for evaluating the influence of pricing policy and public education policy on residential habit of electricity using in power resources management. And, a hybrid society simulation platform based on the proposed model, called residential electricity consumption multi-agent systems (RECMAS), is designed for simulating residential electricity consumption by multi-agent system. RECMAS is composed of consumer agent, power supplier agent, and policy maker agent. It provides the policy makers with a useful tool to evaluate power price policies and public education campaigns in different scenarios. According to an influenced diffusion mechanism, RECMAS can simulate the residential electricity demand–supply chain and analyze impacts of the factors on residential electricity consumption. Finally, the proposed method is used to simulate urban residential electricity consumption in China.

1. Introduction

With rapid development of economy and improvement of the living standard of people, residential power demand is growing rapidly, which creates a strong requirement to develop power resources management schemes. The traditional methods emphasize increasing power supplies, but they do not consider electricity saving, which results in resources waste and pollution problem. However, under the energy shortage condition, promoting the electricity saving awareness of people, changing the habits of electricity using, and improving electricity using efficiency should be taken into account. Policy makers needs to combine "structural" and "nonstructural" methods to consider the potential of electricity saving of the consumers [1,2], the increasing population, and pollution. The "structural" and "nonstructural" methods include social education, power price policy, compensating method, and so on. However, it is difficult to evaluate the influence of these methods on consumer behaviors. On one hand, the consumers have different beliefs, habits, skills and knowledge related to the environment, on the other hand, they interact with their friends, fellows, acquaintances, neighbors, and so on.

According to the similarity between the consumers and the way agents, we adopt a multi-agent social simulation to evaluate the impact of policies in this paper. A hybrid social model for evaluating the impact of electricity saving policies is proposed, and a platform, called residential electric power consumption multi-agent systems (RECMAS), is designed to simulate the residential electricity demand–supply chain. The model benefits from previous works: studies based on econometric model [3] and successful application of agent-based social simulation in water management [4]. RECMAS modifies the traditional econometric models by designing a social simulation layer considering the social awareness on electricity saving policies and social education strategies. RECMAS enables the user to explore the influences of the policies on total residential power consumption, and it facilitates the design, creation, modification, and simulation of different scenarios.

This paper is organized as follows: the next section introduces some applications about multi-agent social simulation. Section 3 proposes the model of residential electricity demand, and puts more emphasis on consumers' social environment for estimating social attribute variables. Section 4 describes the simulation in detail including its architecture, procedure and implementation. Section 5 performs the experiments in six scenarios. Finally, Section 6 concludes the results obtained in this paper.

2. Multi-agent social simulation

Multi-agent systems establish a major research domain in artificial intelligence [5], which was focused on the resolution of problems by society of agents. This field is characterized by the study, design and implementation of artificial agent society, which is the extensive use of computational modeling for real-world applications and social simulations [6]. The method of modeling

* Corresponding author. Address: State Power Economic Research Institute, Integrated Building Room 518, No. 1 Ertiao, Baiguang Road, Xuanwu District, Beijing 100761, China. Tel.: +86 10 6341 6269; fax: +86 10 6341 6779.
E-mail address: 05117299@bjtu.edu.cn (M. Xu).

0142-0615/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijepes.2008.08.005

complex systems by multi-agent social simulations has been used in a wide range of scientific fields, for example, society economy [7], organization theory [8], residential water using management [4], power market simulation [9], and so on.

Multi-agent systems can deal with very different models of individuals, ranging from simple entities to more complex ones. On the other hand, some actual systems may be too complex or too large to be solved by a single agent, and moreover in most cases, they are influenced by the external environment. Hence, multi-agent social simulation is an available way to deal with complex systems. Generally, in a multi-agent social simulation, the society is composed of a number of agents that are able to interact with each other and the environment, and they differ from each other in their habits, skills and knowledge about the environment.

3. Residential electricity demand model

3.1. Influence factors of residential electricity consumption

Residential electricity consumption is influenced by many factors which have been summarized in a number of literatures based on questionnaire surveys or statistical data. Ref. [10] obtained that household incomes, household appliances, area, power prices are related (directly or indirectly) to the total electricity consumption by statistical data, and presented a simplified bottom-up model for forecasting electricity demand. The model can be used to generate realistic domestic electricity consumption data on an hourly basis from a few up to thousands of households. According to the questionnaires, Ref. [11] analyzed residential energy consumption patterns, and presented relationships between electricity consumption and factors, which include power prices, residential incomes, and housing conditions. Ref. [1] examined relationships between the total energy consumption and value patterns or motivation to save energy, and found that the people with the most motivation are willing to save energy, even though the costs are higher and comfort is lower, and the people with the least motivation are not willing to save energy, even though the costs are less and the comfort is higher. As a result, the least motivated group requires more energy than the average and most motivated groups. Results of [2] showed that education of electricity saving plays an important role in implementing and propagating the ideas of energy-efficient behavior and awareness. Ref. [13] presented simulation results about the effects of various dynamic pricing schedules on the average monthly bills for typical single-family houses. The simulation results showed that price responsive load management is an efficient way of peak load management for the residential sector. The influence factors of residential electricity consumption are listed as follows (Fig. 1):

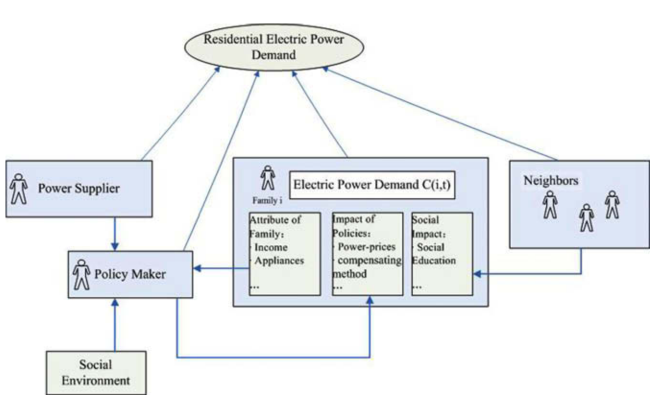

Fig. 1. Influence factors of residential electricity consumption and their relationships.

- Family incomes;
- Housing conditions;
- Household appliances;
- Area and weather;
- Electricity saving technologies;
- Pricing strategies for discouraging inefficient use of electricity;
- Public social education for educating the consumers to change the consumer behavior and to enhance electricity using efficiency; and
- Financial incentive programs for encouraging efficient use of electricity.

3.2. Residential electricity demand forecast model

For estimating electricity demand, a variety of methods and econometric models have been used on the basis of the nature and availability of data. Refs. [13] and [14] summarized four types of parametric econometric models of electricity demand, whose mathematical representations include linear, log-linear, translog, and almost ideal demand systems (AIDS) functional forms. Accuracy and applicability of these models were analyzed by using Bootstrapping method [14] and the Bayesian approach [13]. Each of the parametric functional forms tested performs poorly, suggesting that they may be insufficiently flexible to provide valid results in certain applications. Ref. [3] presented a forecast model of urban residential electricity demand by using OLS method, the model reflects the theory and quantity relationships between electricity consumption and factors, which include urban residential incomes and urban power prices. Electricity demand estimation is usually formulated as a generic model of form $D = f(P, H)$ which relates electricity demand D to power prices P and family attribute H. The residential electricity demand is estimated by using the following equation:

$$D(i,t) = a + bP(i,t) + cH(i,t) + \varepsilon(i,t), \quad (1)$$

where $D(i,t)$ is the electricity demand for consumer agent i at time t; $P(i,t)$ is the vector of price variables; $H(i,t)$ is the vector of consumer attribute variables (i.e., incomes, household appliances, habits of consumer, and so on); $\varepsilon(i,t)$ is the error term; a, b, and c are coefficients to be estimated.

Econometric model can reflect the underlying relationships between the consumption of electricity and explanatory variables such as power prices, incomes, and other factors. However, the model does not reflect function of public social educations, which are tools for educating and informing consumers on how to modify their habits of electricity using and enhance electricity using efficiency [1]. It is usually difficult to evaluate the results of such public social educations. On one hand, public social educations have a direct impact on consumers who participate in them, on the other hand, there is an indirect impact on the other consumers realized by participates who propagate the ideas of electricity saving to their friends, fellows, acquaintances, neighbors, and so on. We can use multi-agent social simulation to obtain the influence results of public social educations in this paper. In order to consider the influence of public social educations, the hybrid social model is formulated as $D = f(P, H, S)$, which describes the relationships between electricity demand D and power price P, family attribute H, and social attribute S. The electricity demand is defined as

$$D(i,t) = a + bP(i,t) + cH(i,t) + dS(i,t) + \varepsilon(i,t), \quad (2)$$

where $S(i,t)$ is the vector of social attribute variables, d is a coefficient to be estimated, and the others are defined as before.

3.3. Residential social environment

In the power demand–supply chain, residents live in a society and interact with each other. To simulate their interactions, we