ORIGINAL PAPER

MODELLING OF HOUSEHOLD POWER CONSUMPTION AND ITS EFFECTS ON LOAD SHIFTING STRATEGIES

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Abstract. *The purpose of this study is to develop models for controlling electricity consumption with the goal of evolving efficiency in the electricity consumption system. The models developed for the electricity consumption problem attempts to investigate the consumption pattern of individual electric appliances in a building to allow for more efficient electricity consumption. The time-based electricity consumption visualizations for appliances used in this research study is carried out to evaluate the level of efficiency in electricity consumption. This paper presents a bottom-up modelling approach for stochastic electricity consumption data profiles in households. By collecting household electricity consumption data, a model is developed for domestic electricity consumption based on daily activity profiles for individual appliances. As a means of validating the model, a statistical comparison is made between measured data collected for appliances over a period in Hamilton, New Zealand and simulated data sets from these measurements. The output of the proposed domestic load model may be designed to meet specific requirements of consumers or integrated into other models.*

Keywords: *Efficiency, Bottom-up model, Stochastic, Simulation, Model validation, Model integration.*

1. INTRODUCTION

Evaluating electricity demand profiles for domestic household is an important prerequisite for analyzing demand side management [1] and the use of household electric appliances varies with time. This knowledge is useful as an input to any domestic energy model, which generates data with statistical characteristics that match original data. Olayiwola [2] developed a computational method based on a variational iteration method (VIM). This is a numeriacal solution of the coupled system of non-linera partial differential equations.

The development of a model for generating residential electricity and hot-water load profiles from time-use data was developed by Widén et al. [3]. This model was used to represent electricity demand and load distributions for individual households. Detailed knowledge about the consumption pattern for individual appliances can be obtained by simulation of energy models. In [4] is presented a simulation of power consumption of individual electric appliances and the development of a domestic load curve model in order to investigate their individual power demand. The research utilized a bottom-up modelling

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method, which considered power consumption for individual appliances to develop a load curve. A more recent study of household power consumption simulation was given by Ortiz et al. [5], where an energy consumption model was developed for generating random profiles of individual appliances as well as to model their peak loads. This model computed the potential savings of high performance electric appliances.

A study of electricity consumption of electric appliances in domestic buildings was carried out to identify the trends in their energy use pattern [6]. In the research, the consumption of different energy user groups (low, medium and high) were investigated, of which low and high power users were identified as contributing to total increase in electricity consumption by appliances. Yao and Steemers [7] discussed a simple method of formulating load profile (SMLP) for domestic buildings in the United Kingdom. The electric appliance load profile and domestic hot water profiles are calculated by gathering input data for the daily average end-use energy consumption and daily average hot water consumption of households respectively. In order to test validity of the data, the study confirms load trend for households is close to the national statistics data. The SMLP method can help electricity suppliers predict the likely future development for electricity demand of households.

The exploratory analysis of domestic electricity profiles recorded at a high time resolution of, taken at one minute time interval was discussed by Wright and Firth in [8]. The paper suggested usage pattern of households varies widely, and very low load consumers mean larger loads requires more energy supply, except when effective storage technologies are developed. The potential of applying information feedback for reducing rates of energy-consumption, thereby saving energy in the home was investigated by Wood and Newborough in [9]. The study focused on collecting data from individual appliances and compared the effectiveness of providing paper-based energy use/saving information with electronic feedback of energy-consumption through the use of specifically designed energy-consumption indicators. The need to provide end-users with accurate energy-consumption and environmental impact information to stimulate energy rational and environmentally sustainable behavior was presented in [10]. The paper focused on identifying energy-use behavior, environmental activities and benefits, ownership levels for certain appliances and their utilization patterns among households.

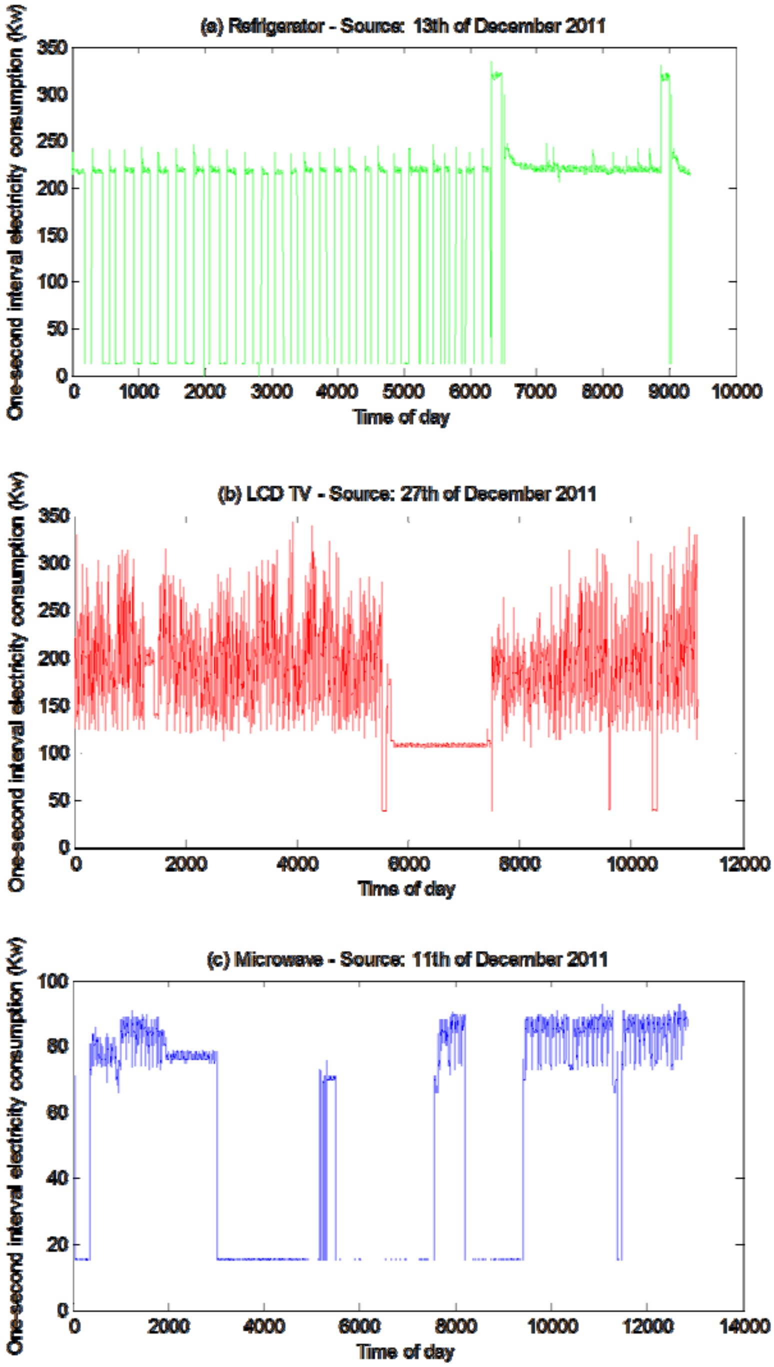
In this paper, a stochastic model based on appliance-specific measurements in households is developed. The stochastic process simulates activity sequences for appliance loads connected to power meters to create power demand data for a variety of end-uses. The aim of this research is to keep the required input data at minimum and the model structure as simple as possible. The model consists of household electricity consumption for some appliances under study. In Section 2, data-sets of domestic load for appliances used in this study are described. Section 3 describes the model validation of load profiles developed for household appliances in the study. Conclusions are drawn in Section 4.

2. MODEL FRAMEWORK

Data-sets of daily, one-second interval load (kW) were collected from a household in Hamilton, New Zealand between August 17, 2011 and March 11, 2016. Data collection was conducted by taking measurements from electric appliances connected to installed power meters in the building. Data quality for the measurements was generally high because appliances were connected directly to the meters and actual readings were taken from them. There were a few gaps in the data, but only complete data-sets were used in the analysis.

The pattern of appliance use for domestic loads in buildings depends on electric appliance use. Some appliances are ‘always switched on’. Other appliances are not always constantly on and depend on occupancy, occupant behavior and weather conditions, which vary between house holds. Electricity consumption by appliances is higher than usual in winter due to heating in homes, and occupancy issues like time spent indoors in winter.

The load profile of energy use of the refrigerator, microwave, play station and the LCD-TV was developed in order to investigate the impact on the electricity network of consumer use of electric appliance during peak and off-peak hours. By developing the load profile of residential sector, showing the consumption for each appliance, it is possible to analyze the contribution of individual appliances to the electricity network. Fig. 1 shows the one-second interval 24 hour load-profile of electricity consumed by different appliances at different periods of time. The data collection period varies between these months and there were gaps among data collected in some cases.



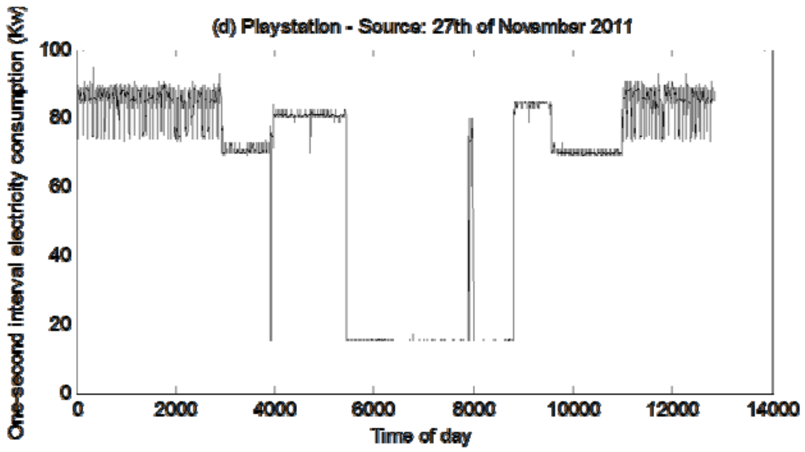


Figure 1. 24 hourly One-second Load Profiles for Appliances.

The load profiles developed for individual appliance gives information about habits of household inhabitants and the use of the appliances at different schedules. In simulating the load profiles of individual appliance, the developed model indicates the shifting of appliance use to certain periods in order to minimize household's electricity bill. Load shifting by consumers enables the electricity network reduce peak demand and increases the reliability of the electricity network, since consumers will have a more active role concerning electricity management.

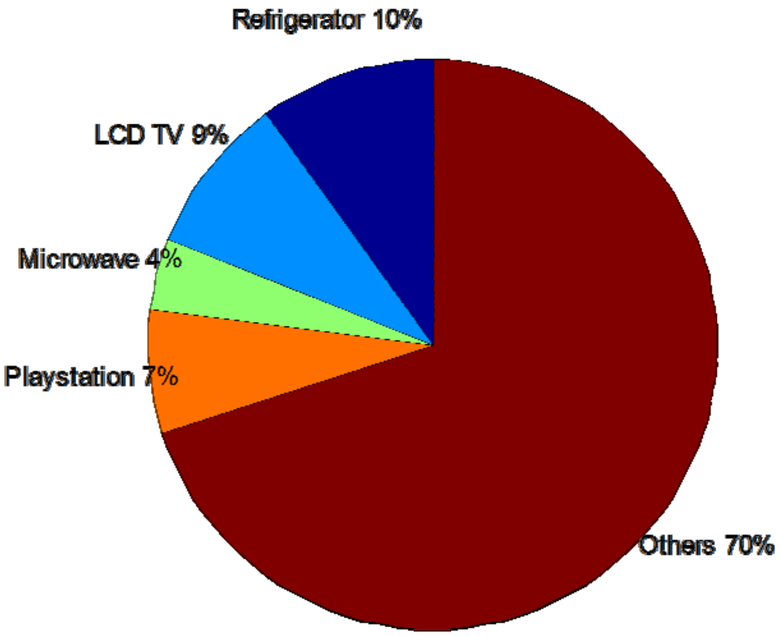


Figure 2. Electricity Consumption for Household Appliances.

Fig. 1a-d represents load profiles for refrigerator, LCD-TV, microwave and the play station and follows an undulating pattern. This indicates the use of appliances more frequently at certain times of the day, especially at periods when electricity costs are low. Consumers tend to use certain electric appliances more when there is a favorable energy plan put in place by electricity companies. This process is referred to as the load shifting technique.

An outline of electricity consumed by individual appliances is shown in Fig. 2. The Fig. 2 indicates a high consumption by the refrigerator (10%) compared to other appliances. There were some fluctuations due to appliance use in peak and off-peak periods. There is more near-constant load for LCD-TV and the play station except when the appliances were in stand by mode. The study indicates that energy use is dependent on the energy plan and the tariff in place because consumers tend to use electric appliances at periods when the tariff is low. In modeling the data collected, there are some outliers noticed in the plots. These could be due to some power outages experienced in households.

3. VALIDITY AND PRECISION OF MODEL

In order to show the modeling precision and validity of the model developed in this study, the percentage change between electricity measurements collected by the installed power meter for whole house electricity consumption and measurements from the electricity network is calculated using the percentage change between the data sets [10]. The deviation between the measurements, referred to as the percentage change is defined as:

$$percentage\ change = \left|\frac{mpm - ment}{ment}\right|\% \qquad (1)$$

where *mpm* = measurements from installed power meter and *ment* = measurement from the electricity network.

As a result of the data collection for the period August 17 2011 to March 11 2016, measurements from installed power meter in the building is 110, 567 kW, and the measurements from the electricity network is 121, 890 kW. Hence, the percentage change as denoted by (1) is given as:

$$percentage\ change = \left|\frac{110{,}567 - 121{,}890}{121{,}890}\right|\% = |0.09\%| \qquad (2)$$

The percentage change is 0.09%, which is a deviation of less than 1 %. This is an indication of the accuracy of the models derived for the refrigerator, LCD-TV, microwave, play station, and other electric appliances in the building.

4. CONCLUSION AND FUTURE WORK

The development of load profiles for individual household appliances will enable consumers use load shifting strategies aimed at reducing energy costs and the optimal management and control of the electricity network. Furthermore, the introduction of energy plans by energy companies to monitor and control electricity consumption will enable electricity households become responsive customers and economically conscious users and participate in the efficient use of electricity, thereby making optimal use of the electricity network.

The introduction of varied and flexible energy plans will allow consumers respond to the dynamism of electricity prices and will induce savings for customers through the optimal use of the electricity network. This will bring about load balancing in the electricity network by redistributing energy demand in the electricity network. There is the need to introduce demand-side management strategies with the main goal of reducing customer’s electricity bill, with the possibility to postpone load operations in addition to optimizing the use of the electricity network.

Further studies would focus on developing load profiles for different group of users based on location, income level and household size. The research will also investigate the effects of load shifting strategies on individual appliances based on these factors.

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