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Domestic electricity load modelling by multiple Gaussian functions

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ABSTRACT

Domestic electricity load profile is essential for energy planning and renewable energy system design. This paper presents analysis of domestic electric load characteristics and a method to model domestic and regional load profile. Multiple Gaussian functions are used to express the load characteristics in the proposed model. This is done by associating the Gaussian function parameters with the peak load changes, e.g. changing height parameters to reflect the peak magnitude. The result of the load curve represented with multiple Gaussian functions allows the model to generate a regional load profile using the number of homes, the number of bedrooms (Nr) and the number of occupants (Np). The proposed model simulates domestic load profile by its load demand change characteristics instead of its appliance ownership and use pattern, etc. Data requirement for the proposed method is significantly lower than the previous top-down and bottom-up approaches. Seasonal change is not included in the present paper, but the method is capable of including seasonal changes if each season's load demand changes in relation to Np and Nr is available. A demonstration of modelling England and Wales's national hourly load profile in 2001 and 2011 is presented in this paper. Comparison is made of the proposed method with two other published domestic load profile models. Results show that the proposed method improves the mean percentage errors by at least 5.7% on average hourly load profile.

1. Introduction

The growing interest in renewable energy and determination to reduce carbon emission has brought much attention to distributed generation and renewable system. Knowledge of domestic electricity load profile is essential for distributed generation system operation, renewable system design and energy planning. Domestic electricity load profile data is also required for planning low voltage networks in residential areas. The traditional domestic load modelling method often requires many input data to carry out modelling of the diversity of domestic load profile, e.g. time use of individual appliances. However such data may not be available or may be difficult to obtain at times. This paper presents a method using multiple Gaussian functions to express the load characteristics in order to reduce the data requirement for regional domestic load profile modelling.

In general, two approaches have been used in load profile modelling, Top-down and Bottom-up approaches. The Top-down approach works with macro situations and tries to attribute a load profile to its modelling target with regard of its characteristic [1], e.g. load change in relation to income level, household size, etc. The Top-down approach was also called Conditional Demand Analysis by Aigner [2] and Parti [3] in 1980s. Aigner used 24 regression equations to represent each hour in a day, five scalar variables (number of bedroom, internal temperature, etc.) and nine dummy variables (presence and absence). The energy demand of appliances is used to complete the model. The key issue with Top-down models is that they do not provide indication of variation within family and home types, resulting in a lack of detail on individual load characteristics. This is due to lack of consideration of domestic load changing characteristics in relation to scalar variables.

On the other hand the Bottom-up approaches are built up from data on a hierarchy of disaggregated components that are then combined according to estimation for their individual impact on energy usage [4]. The most commonly cited examples of the Bottom-up models are Capasso [5], Paatero [6], and Yao [7]. These models use data on ownership of appliances, individual appliance energy demands, and appliances usage time, to model the energy demand for a single household. As the authors addressed, the challenge of such modelling methods is the detailed data requirement in the range of households being considered, especially time of use of individual appliances: a complex and unpredictable human behavioural factor. Later models, e.g. Richardson [8] and Widén [9], use Time Use Survey (TUS) data to study behaviour factor in

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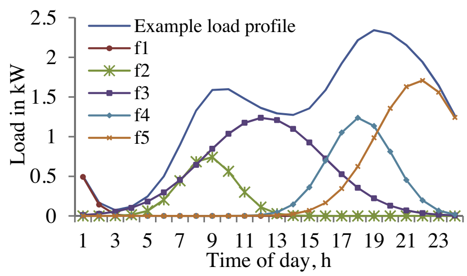

Fig. 1. An example of using multiple Gaussian functions (f1-f5) to model electricity load profile.

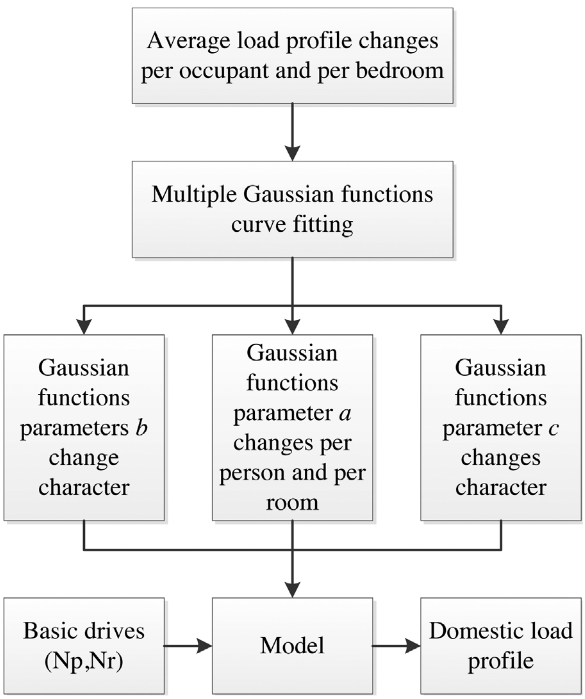

Fig. 2. Flow chart of the proposed modelling process.

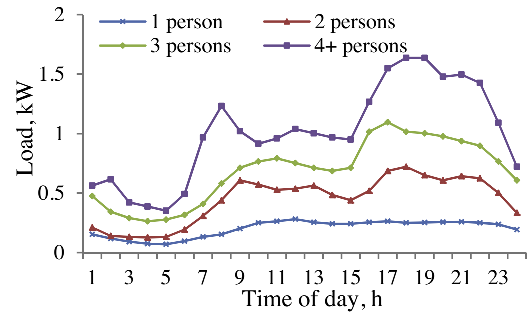

Fig. 3. Average domestic electricity load profile as a function of number of occupants.

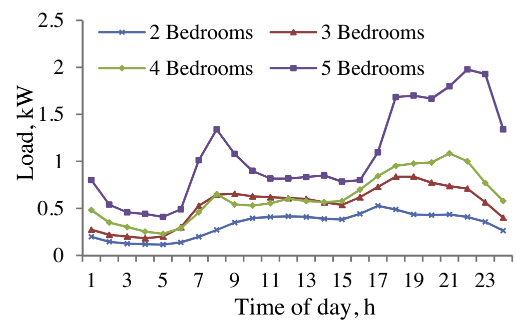

Fig. 4. Average domestic electricity load profile as a function of number of bedrooms.

households. However, nation-wide TUS are conducted very rarely even in the developed countries, e.g. Richardson's model in year 2008 was based on year 2000 TUS report, which could result in inaccurate information being studied.

For practical regional load profile modelling, where thousands of households need to be considered at once, the model must appropriately represent each type of household accordingly. It is, however, almost impossible to obtain detailed information and usage of every single household's appliances when dealing with large numbers of homes. Some domestic load profile models attempt to overcome the issue associated with input data requirement by generating domestic load profile from similar past load profiles, based on synthesising [10] and clustering [11] techniques. Such methods may not be able to model the future load changes, since they are purely based on past load profiles. Furthermore, the synthesising and clustering methods disconnect domestic load profile from behaviour and characteristics of domestic households, e.g. occupancy time, size of households. The methods may be suitable for certain applications, but they will not provide a better understanding of domestic energy consumption behaviour. Therefore, it is important to find a method to reduce data requirement on appliance ownership and use pattern for regional domestic load profile modelling.

This paper presents an alternative view on domestic load profile modelling, where morning and evening peak load have been considered as the most important characteristics of the domestic load profile. The model uses Gaussian function's bell shape to synthesise the morning and evening peak load profile. Instead of finding each appliance's impact on peak demand, the model considers number of household occupants (Np) and number of bedrooms in the house (Nr) as the two main drives of peak demand variation. Nr represents the impact of house size on peak load demand and Np considers how the number of occupants influences the peak load demand. Three Gaussian function parameters are associated with three aspects of peak load, where height parameters (a) are used to synthesise peak magnitude, position parameters (b) are used to synthesise peak load times, and width parameters (c) are used to synthesise the peak duration.

The multiple Gaussian function model presented in this paper is based upon Yohanis's domestic electricity load characteristics study [12], where a household load profile was found to change with the number of persons and rooms. These factors are used to analyse domestic load characteristics.

2. Methodology and model structure

2.1. Domestic electricity usage characteristics

Yohanis's load characteristics study involved measurement of over 200 domestic households over a year. A sample of 27 households is selected to represent the whole population. The household types include detached, semi-detached, terraced homes and bungalow; the household size in terms of occupants includes 1–4+; household size in terms of bedrooms includes 2–5 [12]. The study found that, although the magnitude of the average daily electricity load varied, the load profiles had very similar shapes for all measured households. The minimum load occurs during the night, between 2:00 and 4:00 a.m.; a minor (morning) peak