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Application of smoothing techniques to solve the cooling and heating residential load aggregation problem

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Abstract *The main objective of this paper is to obtain the duty-cycle probability forecast functions of cooling and heating aggregated residential loads. The method consists of three steps: first, the single loads are modelled using systems of stochastic differential equations based on perturbed physical models; second, intensive numerical simulation of the stochastic system solutions is performed, allowing several parameters to vary randomly; and third, smoothing techniques based on kernel estimates are applied to the results to derive non-parametric estimators, comparing several kernel functions. The use of these dynamical models also allows us to forecast the indoor temperature evolution under any performance conditions. Thus, the same smoothing techniques provide the indoor temperature probability forecast function for a load group. These techniques have been used with homogeneous and non-homogeneous device groups. Its main application is focused on assessing Direct Load Control programs, by means of comparing natural and forced duty-cycles of aggregated appliances, as well as knowing the modifications in customer comfort levels, which can be directly deduced from the probability profiles. Finally, simulation results which illustrate the model suitability for demand side – bidding – aggregators in new deregulated markets are presented.*

Introduction

Nowadays, the electric power industry is moving towards a deregulating framework in a number of developing countries. These deregulations should benefit the environment and the economy, as well as the supply security. During the last decade, the European Union (EU) restructuring and liberalization on the supply-side of the electricity – and gas – market has been accelerated by a lot of European Commission directives. In this change to a deregulated market, residential consumers have a choice to reduce their energy bills among competing providers and, perhaps, a way to participate in demand and supply bidding, if they get the flexibility to make changes in their normal load demand profiles. A way to achieve this objective is through Demand-Side Management (DSM) programs. It is not a new tool in Electrical Energy Systems, but in this change to a deregulated framework, the first casualty of utility restructuring has been the demise of utility founded DSM programs; for example, in USA from \$1.65 billion in 1993 to \$0.91 billion in 1998 (Faruqui *et al.*, 2001). In this way, it will be necessary for a certain minimum level of investment for energy efficiency and Demand-Side programs – in some studies for EU, a 2 per cent level of the total net revenue in Member States from electricity is recommended-. The new electricity market will not be complete before full economic and environmental efficiency is achieved, including end-use energy efficiency, fuel switching, load management and new tools as demand-side bidding (DSB). In order to help Demand-Side Technologies reach their full market potential, it is necessary to evaluate load response during control periods, energy and demand savings, and customer comfort through well developed load response models at the elementary and aggregate levels, the main objective of this paper.

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State-of-the-art

The use of elemental load models and aggregation techniques applied to DSM policies have had a parallel development in the last two decades, considering initially the aggregated demand as a simple addition of individual loads. Notice that an aggregation can correspond to a physical location in the network – e.g. specific bus in a given substation – as well as to a defined subset of demand – e.g. water heater demand.

Different aggregation methods have been developed through these last two decades, as an answer to specific problems in electrical power systems. In most of them, the random character of the loads has explicitly been considered mainly in residential demand profile studies. In the first works on the topic, the individual demand, y_i, was defined as the product of an elemental potential demand factor, c_i, an elemental utilization factor, u_i, and an elemental error correction factor, e_i, obtaining the aggregated demand profile as a simple aggregation of elemental powers within the utility network (Ihara and Schweppe, 1981).

$$y_i(t) = c_i(t)u_i(t)e_i(t) \tag{1}$$

$$Y(t) = \sum_i y_i(t) \tag{2}$$

Another approach corresponds to the development of a *load-diversification model*, in which the diversity effects are modelled through two factors: a