Scheduling of Electrical Household Appliances with Price Signals

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1 Introduction

Due to the increasing competition in liberalized electricity markets, a succesful customer retention as well as a cost efficient allocation of electric energy become more and more important. Therefore, new, innovative strategies are sought, which promise on the one hand a long-term customer retention and assure, on the other hand, a more cost-efficient provision of electric energy.

Against the background of the rising cost awareness of customers, caused by the latest increases in electricity prices, price signals could be considered as an adequate instrument for this purpose (cf. e.g. [1], [2]). In this context, price signals can be defined as time-dependent rates for electricity, which are adjusted by power companies depending on the current or expected load.

The objective of this paper is to present a model development to analyse the influence of price signals on power demand as well as the results of its application to a rural area.[4] For this purpose, it was assumed that in a model area consisting of about 1000 households, hourly prices are transmitted to the customers by their power suppliers one day in advance. Based on these prices, the customers decide whether to use their appliances at the usual time, or to reschedule the usage.

2 Modelling Approach for the Optimization of Households' Power Demand

In this paper an adequate modelling approach to analyse the influence of price signals on households' power demand is presented. It is assumed that households

[4] The paper presents inter alias an abstract of the project "Analysis of the effect of price signals of the load behaviour of selected consumers", which has been conducted on behalf of the EnBW AG (cf. [2]). Besides, the modelling approach is enhanced in the project SESAM, supported by the BMBF (cf. e.g. [3], [4]).

minimize the costs and therefore react on the price signals by rescheduling the use of their electric household appliances. To begin with, all big household appliances are considered, that is washing machines, dryers, dish washers, and cooking appliances. It is assumed that all appliances are switched on and off manually. Besides, an automatical load management system for refrigerators and freezers is assumed. In the following section the mathematical description of this problem will be given. After this, some of the most essential aspects of the modelling approach will be adressed, that is the modelling of the households' individual load and preference curves as well as the time-dependent electricity tariffs.

2.1 Mathematical Description of the Optimization Problem

When households decide about the scheduling of their household appliances, they make a trade-off between the savings they might realise in rescheduling their appliances and the loss in comfort. In the optimization problem this consideration is realised via a weighted sum of preference and price. Consequently the objective function of the optimization problem consists of two parts (for nomenclature please cf. Table 1):

$$Min \sum_{i \in A} \sum_{j=t_i}^{t_i+k_v(i)+k_s(t_i,i)} (p_{el}(j) \cdot (d_v(i) + d_s(t_i,i)) \cdot \alpha + r(i,t) \cdot (1-\alpha)) \qquad (1)$$

The first part is the cost related part, where the time-dependent electricity tariff $p_{el}(j)$ is multiplied by the power demand of the appliance. This power demand consists on the one hand of the regular demand of the appliance $d_v(i)$. Besides an additional demand $d_s(t_i,i)$ might occur, if the appliance is rescheduled. The second part of the objective function represents the preferences of the household, where $r(i,t)$ expresses the preference of the household to schedule an appliance i in t. The shape of $r(i,t)$ will be descriped in section 2.3. The weight of the price is α, the weight of the preference is $(1-\alpha)$. All considered appliances are subject to the following constraints:

1. All household appliances have to be scheduled.

$$\forall i \in A \qquad g_i \leq t_i \leq e_i \qquad (2)$$

2. Temporal restrictions are considered.

$$\forall i \in A \qquad e_i + k_v(i) + k_s(t_i,i) \leq t_i \qquad (3)$$

3. Dependencies between individual appliances are considered. For an appliance j $\in A$ which has to be scheduled after an appliance i $\in A$ applies:

$$i \stackrel{before}{\rightarrow} j \qquad \Rightarrow \qquad t_i + k_v(i) + k_s(t_i,i) < t_j \qquad (4)$$

Besides, for the automatic scheduling of refrigerators and freezers applies:

1. The output per timeslot is limited to the capacity of the appliance.

$$0 \leq b_{cold}(t) \leq y(t) \cdot b_{KG}^{max}(t) \qquad (5)$$