AN ASSESSMENT OF DEMAND-RESPONSE FLEXIBILITY ON HOUSEHOLD LEVEL

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ABSTRACT

Within a future smart grid context consumers are expected to play an active role by adapting their electricity consumption behaviour to support the introduction of a higher share of renewable electricity production units. This paper focuses on the demand-response potential by residential consumers by making an assessment of the flexibility in electricity consumption on household level. Three types of flexible devices are considered in the household: an electric hot water boiler, a dishwasher and a washing machine. A software tool was used that is able to calculate the energy cost if these flexible devices are used in the most optimal, cost-effective way. This paper presents the results of the simulations and discusses the saving potential for the household under three different contract options: single, double and hourly tariff structure.

INTRODUCTION

In a situation where the share of renewable energy resources in the overall electricity production-mix increases, the question is brought about whether it is possible to adapt the loads to the increasing renewable intermittent supply. To be able to shift or delay the electricity demand of certain loads might become an added value in future electricity markets [1]. Within this demand-response context it is not always clear how much flexibility needs to be offered in order to create an added value, and what the economic value of offering this flexibility is.

In this work, we focus on the value that can be created by using the flexibility of electric appliances on household level from the viewpoint of the household. The amount of money that a specific household can save on its electricity bill by making use of the flexibility not only depends on the amount of flexibility each appliance has, it also depends on the timing when the flexibility is available, as well as the tariff structure of electricity usage for the household.

In order to determine the added value of having and using flexible devices, simulations were done to calculate the benefits under different tariff structures and for different scenarios concerning the available flexibility.

The paper is structured as follows; First, the assumptions and choices that were made in the simulations are explained; Secondly, the results of using flexibility under different tariff structures are shown; Next, the effect of increasing the flexibility of the devices on the gained profit is discussed. The paper ends with conclusions.

ASSUMPTIONS AND SIMULATIONS

The analysis focuses on the flexibility for one specific household with three flexible devices: a dish washer, a washing machine and an electric hot water boiler. The electric boiler has a thermal storage capacity and therefore has some flexibility in its electricity consumption. The dish washer and washing machine are shiftable loads since their starting time can be postponed. The electricity consumption of the remainder of the loads is considered as fixed, and thus non-flexible.

Modelling of devices

In order to determine the energy usage of the non-flexible load, measurements were done on one specific household during one week, both on household and flexible device level. The energy usage of the non-flexible load is then the overall energy consumption of the household minus the energy consumption of the flexible devices.

The washing machine and dish washer are appliances that perform their function (washing) through a working cycle. It is assumed that their working cycle cannot be interrupted at intermediate phases. The energy usage of both the washing machine and dish washer is based on measured consumption cycles. It is assumed that the user runs both devices every day. The earliest start time of these appliances is set by the user to be 20h00 each day, and both devices should have ended their cycle by 06h00 the next day. The washing machine takes 1h30' to complete its cycle, the cycle of the dishwasher takes 1h15' to complete. The electric boiler is used to heat the total hot water demand of the household. The household is assumed to have a daily hot water demand of 100 litres/day, the hot water demand profile is a standard profile taken from [2]. The electric boiler is assumed to have a heating power of 2 kW, and a thermal storage capacity of 100 litre. The model of the thermal storage tank is based on a storage tank model available in the energy systems simulation tool TRNSYS. The flexibility of the electric boiler originates from the decoupling of the hot water demand from the electric power demand of the boiler through the thermal storage tank.

Figure 1 shows the electricity consumption of both the non-flexible as well as the flexible loads for one weekday for the benchmark situation (when their flexibility is not used).

Tariff structures

In Belgium residential consumers can currently choose between two types of electricity tariffs: a single or a double tariff (day-night tariff). Within this analysis, the existing tariff options are compared with a more flexible tariff structure, namely an hourly tariff structure. Price differences allow end users to save on their electricity bill

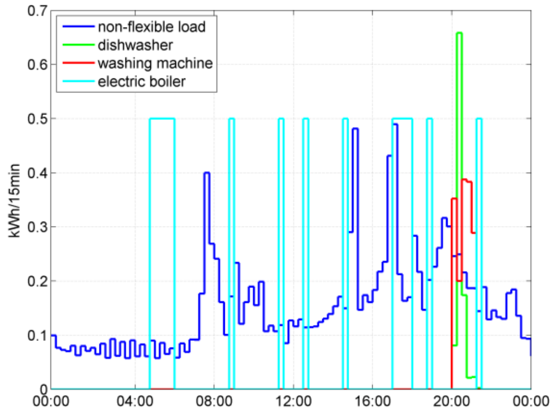

Figure 1: Electricity consumption of non-flexible load, dishwasher, washing machine and electric boiler during one weekday (Thursday) for the benchmark situation.

by shifting flexible consumption during the day.

Electricity prices consist of different components: energy cost, distribution and transmission fee, contributions and taxes. To determine the energy cost for the single tariff structure, the energy cost of an offer of a specific Flemish retailer for a fixed contract for 2 years for December 2010 was used. The distribution fee was calculated as the average single distribution fee of the different Flemish Distribution System Operators. The other fixed elements of the electricity tariffs (transmission fee, contribution and taxes) were added.

Within a double tariff structure, both the energy component and the distribution component are different during night and day hours. For the energy component, the day and night energy costs of an offer of the same retailer as for the single tariff were used. The distribution fees were calculated as the average day and night distribution fees of the different Flemish Distribution System Operators. The other fixed elements of the electricity tariffs (transmission fee, contribution and taxes) were added as well. The night tariff is assumed to apply between 22h00 and 7h00 on weekdays, and during the whole day in the weekend.

The hourly tariff structure was developed by rescaling wholesale prices to consumer levels. First, average Belpex day-ahead prices for the year 2009 for each hour of the day were determined [3]. Then, a rescaling factor was applied to these average prices based on a Synthetic Load Profile (SLP) for residential consumers in Belgium as published by the federation of Distribution System Operators in Belgium (Synergrid) [4]. The same rescaling factor was used for each price, so that a consumer with a consumption pattern like the SLP would have an identical electricity cost within the single and hourly tariff structure.

Figure 2 shows the variation of the three different tariff structures over one day.

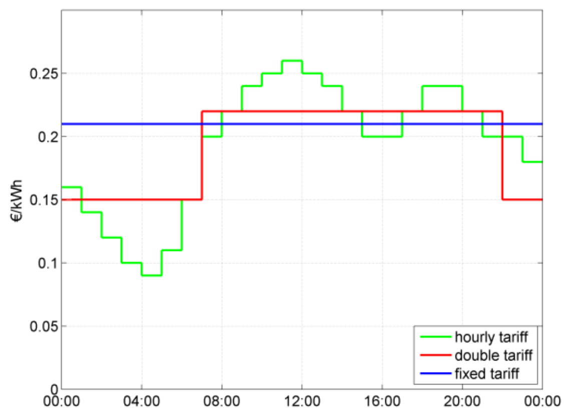

Figure 2: The variation of the different tariff structures over one weekday.

SIMULATION RESULTS

In order to determine the economic value of the flexible loads, a software tool was developed that is able to calculate the energy cost under different tariff structures, if the flexibility within a cluster of devices is used in the most optimal way. The simulations do not take into account the effect of an actual coordination mechanism, but rather calculate what can maximally be gained when the flexible devices are used optimally, under the assumption that all tariff information is known in advance. All simulations are done for one week, with a time resolution of 15 minutes.

Comparison of tariff structures

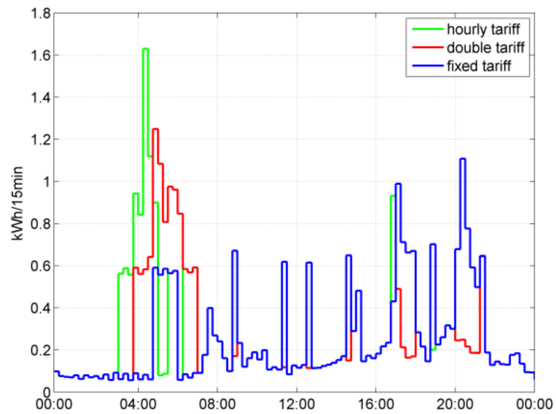

Figure 3: Comparison of the electricity consumption within the three different tariff structures during one weekday (Thursday).

Figure 3 shows a comparison of the overall electricity consumption profile of one specific day for each tariff structure. When comparing the different profiles, a few trends can be seen. When the double tariff is applied, part of the consumption is shifted from day to night hours. In this case the consumption is postponed as much as possible towards the end of the night period, which ends at 7h00.

Within the hourly tariff structure, consumption is shifted as much as possible from expensive price periods to lower price periods: a clear consumption peak is visible when prices are the lowest (between 3h00 and 6h00).

The flexibility of the dish washer and washing machine is valorised by postponing their start time so that their working cycle coincides to the cheapest price periods within the available flexibility window, i.e. the time between the earliest start time (20h00) and latest end time (06h00). For the double tariff structure this is somewhere between 22h00 and 6h00; For the hourly tariff structure, this is between 4h00 and 6h00.

Figure 4 shows the consumption during one day of the electric hot water boiler for each tariff structure. Within the single tariff case, the electric hot water boiler is switched on every time the water temperature within the storage tank falls below a minimal threshold temperature. When applying the double tariff, the buffer is heated as much as possible during night hours. Figure 4 shows that for this day the buffer capacity apparently is not sufficient to bridge a whole day and the boiler needs to switch on twice during the day hours. The electricity consumption of the boiler within the hourly tariff structure is shifted as much as possible towards the cheapest price period (between 3h00 and 7h00); Still two short consumption peaks are needed during higher pricing periods.

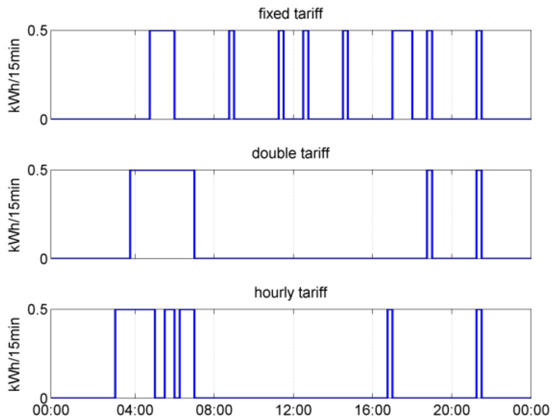

Figure 4: Comparison of the electricity consumption of the electric boiler within the three different tariff structures during one weekday (Thursday).

Figure 5 shows the minimal electricity cost the user has to pay within the three different tariff structures, when using the flexibility of the three appliances in the optimal way for the simulated week. As expected, adding variability to the tariffs allows the consumer to save on his electricity invoice. Within a single tariff structure the consumer cannot save on his electricity cost by shifting consumption and pays 30,05 € for the consumed electricity in the simulated week. Applying a double tariff structure allows the consumer to shift some flexible consumption from day to night hours. In this case the electricity invoice amounts to 25,20 € for the given week and the consumer can thus save 4,85 € at the most compared to the single tariff structure. Within the hourly tariff, the consumer has to pay 24,82 € for the consumed electricity and saves 5,23 € compared to the single tariff structure and 0,38 € compared to the double tariff structure.

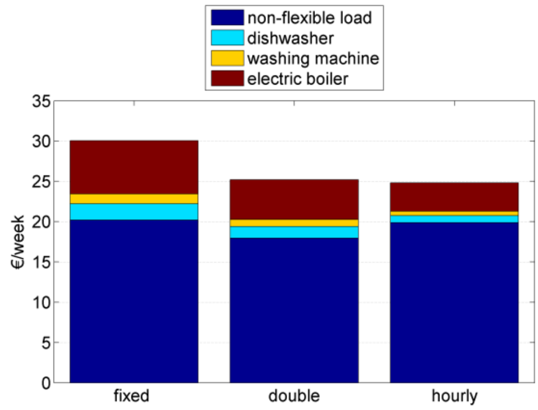

Figure 5: Comparison of the minimal cost of the electricity consumption within the three different tariff structures.

Table 1: The minimal cost of electricity consumption within the three different tariff structures.

	Con-sumption [kWh]	*Fixed tariff [€/Week]*	*Double tariff [€/Week]*	*Hour tariff [€/Week]*
Non-flexible load	96.1	20.19	17.95	19.86
Dishwasher	9.7	2.03	1.45	0.89
Washing machine	5.8	1.21	0.86	0.52
Electric boiler	31.5	6.62	4.94	3.55

In Table 1 the consumption of the flexible devices and the non-flexible load is given together with their respective contributions to the electricity costs under the different contract options for the given week.

From Table 1 and Figure 5, it is clear that the electric hot water boiler has the highest consumption of the flexible devices and its flexibility has the highest saving potential. However, the differences between the double tariff structure and the hourly tariff structure are rather small. During night hours the consumer can save on his electricity costs between 1h00 and 5h00 compared to the double tariff structure. This period corresponds to the lowest price period in the hourly tariff case and the flexible consumption is shifted as much as possible towards these hours (see Figure 3). During day hours there is only a saving potential when hourly prices are applied instead of the double tariff between 7h00-8h00,15h00-17h00 and 21h00-22h00. During these hours the available flexibility is limited since it is only offered by the electric boiler. Furthermore, hourly prices are higher than day-prices between 9h00-14h00 and between 18h00-20h00 and during these hours the non-flexible load is also rather high. The saving potential is thus partly counterbalanced by the size of non-flexible demand during the more expensive hourly tariff hours during the day, resulting in a limited saving capacity. This effect is visualized in Figure 5 by a bigger block representing the cost of the non-flexible loads in the hourly tariff than in the double tariff.

To conclude, switching from a single to a double tariff structure seems the most profitable choice in this case. Introducing hourly prices instead of the double tariff only yields limited profit given the available flexibility of the three devices under consideration for this household. However, if the hourly prices would show more variability or are allowed to change each day, which is probably the case in the future energy market with a higher share of electricity production from renewable sources, it is likely that the gain of using an hourly tariff increases. As no information is available (yet) on probable future hourly tariffs, this was not further assessed.

Effect of increased flexibility

To analyse the effect of increased flexibility, the input parameters of the different flexible devices can be varied.

Increasing the flexibility window of the dish washer and washing machine, will not create any added value. The current flexibility already allows to complete the whole working cycle of both appliances during night hours every day for the double tariff. For the hourly tariff, the total working cycle of both the dish washer and washing machine already falls within the cheapest price period, i.e. between (04h00 and 06h00) every day.

The effect on the electricity cost of an increased flexibility of the electric boiler is not that straightforward. An increased thermal storage capacity from 100 litre, to 150 litre and 200 litre was analysed. By increasing the buffer size, the stand-alone time of the electric boiler increases which leads to a higher potential to postpone switching on the boiler to cheaper periods.

Figure 6 shows the result of the increased flexibility within the double and hourly tariff expressed as the overall electricity cost per kWh for the simulated week. As expected, the lowest cost/kWh is achieved with the largest buffer (buffer size of 200 litre), but the gain of increasing the buffer size from 150 litre to 200 litre is rather small within both tariff structures. This is due to the fact that when the storage tank is large enough to bridge the hot water demand between two low-price periods, adding extra tank capacity will not result in a decreased electricity cost. Thus, an optimal buffer size exists, however, to determine this optimal buffer size, not only the advantages of increasing the buffer size need to be taken into account, the extra investment cost in buffer capacity has to be considered as well.

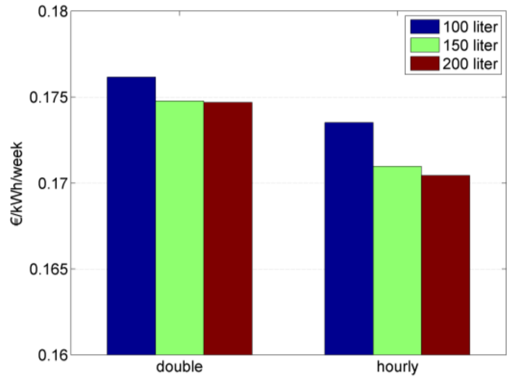

Figure 6: Effect of increased flexibility of electric boiler (buffer size of respectively 100 litre, 150 litre and 200 litre).

CONCLUSIONS

In this study, the effect of using the flexibility of appliances on the electricity cost of a household under three different tariff structures (single, double and hourly tariff) is assessed. The devices that are considered to offer flexibility are a dishwasher, a washing machine and an electric boiler. Applying the double tariff structure allows the household to save 4,85 € at the most compared to the single tariff cost (30.05 €) during one week. Introducing hourly prices yields only limited profit compared to the double tariff, because the counterbalancing effect of the cost of the non-flexible load during expensive hours versus the gain of shifting the flexible loads towards lower pricing periods is considerable. The electric boiler has the highest consumption and flexibility and hence the highest saving potential, however, adding extra flexibility does not necessarily result in a decreased electricity cost.

If we want to employ the flexibility on household level in a real-life setting, some initial investments will be required in intelligent appliances as well as in monitoring and control equipment. The advantages for the household should then be compared with the needed extra investments.

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