ANALYSING HOUSEHOLD CONSUMERS' DEMAND RESPONSE THROUGH BEHAVIOURAL LOAD PROFILES

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Abstract. *The study is devoted to the involvement of residential consumers in demand-side management in the power system. The results of a pilot program involving aggregators of residential consumers in demand response in the UK are analysed, and barriers to its implementation are identified. It is proposed to use a behavioural load profile generator to simulate household participation in demand response. Two typical load reduction strategies for a two-adult household are simulated, and their efficiency is compared. It is estimated that shifting the use of high wattage appliances can reduce the household load by half without discomfort, whereas a mistaken strategy of limiting lighting usage gives three to seven times smaller effect. Thus, it is shown that behavioural load modelling can be used to solve the problem of determining effective strategies for the participation of residential consumers in demand response.*

Keywords: *demand response, energy management, load shifting, peak demand reduction*

Introduction

Demand management plays an important role in ensuring the stability of the energy supply and optimizing the costs of electricity production in the energy system. The application of demand management methods allows for maintaining power balance in the system, reducing peak loads, and lowering prices in wholesale markets. There are many studies on this topic, but they are mainly focused on large industrial consumers [1]. The case of small consumers' participation in demand management programs, especially in demand response through aggregators, is less studied and requires additional research.

An aggregator is an entity that brings together multiple low-capacity consumers such as small businesses or individual households and represents them in energy markets. Aggregators play a key role in demand response programs for household consumers, by coordinating energy consumption, optimizing the aggregated load, providing flexibility to the grid and participating in energy markets.

A recent example of an aggregator's capabilities is the demand response program (DRP) of the Octopus Energy company [1] within the Demand Flexibility Service of the National Grid ESO [**Error! Reference source not found.**] in the UK. This is a program that allows customers to earn m oney by reducing their electricity consumption during periods of high demand on the power grid. It is designed to balance the consumption, which can fluctuate significantly throughout the day. Octopus Energy provides enrolled customers with signals to reduce energy consumption by either turning off appliances or shifting their use to a different time. The program is flexible, allowing customers to choose the amount of energy they wish to save and when to do it. Octopus Energy rewards customers for reducing energy consumption with points that can be redeemed for prizes, donations, or account credit.

In general, there are several ways in which a household can participate in DRPs:

- Time-of-use tariffs: DRP offers time-varying tariffs, which means that the price of electricity varies depending on the time of day;

- Energy storage: households can also participate by installing energy storage systems, such as batteries;
- Behaviour modification: households can participate by adjusting their behaviour, e.g., delaying the use of non-essential appliances such as a washing machine during peak demand or simply turning them off.

Challenges in implementing the demand response

Many residential customers who participated in DRPs reported their positive experiences. They found that by regulating the use of appliances during peak demand, they could significantly reduce their electricity bills. But some participants were disappointed by the slight payback and the great inconvenience of their efforts. As more consumers become aware of the benefits of demand response, it is likely that programs like Octopus Energy's will become more popular and widespread.

DRPs have the potential to offer many benefits to both household consumers and the grid. However, severe challenges may arise when attempting to engage and incentive household consumers to participate in demand response activities. One of the most significant of these is limited consumer awareness. Another problem is the weakness of financial incentives or the difficulty of obtaining them.

Behavioural barriers can hinder the engagement of household consumers in DRP. Despite understanding the benefits, some consumers may be unwilling or unable to change their energy behaviour, such as sacrificing comfort or altering daily routines. Scaling DRPs can also be challenging due to variations in habits among different communities.

Simulation of participation in DRP

Thus, the effective design and implementation of DRP require careful planning, ongoing evaluation and adjustment. Through the load simulation, it is possible to estimate the amount of energy that will be needed during peak demand and the possible output of consumer's response. This can be done using behavioural load profile models such as the Load Profile Generator (LPG) [1].

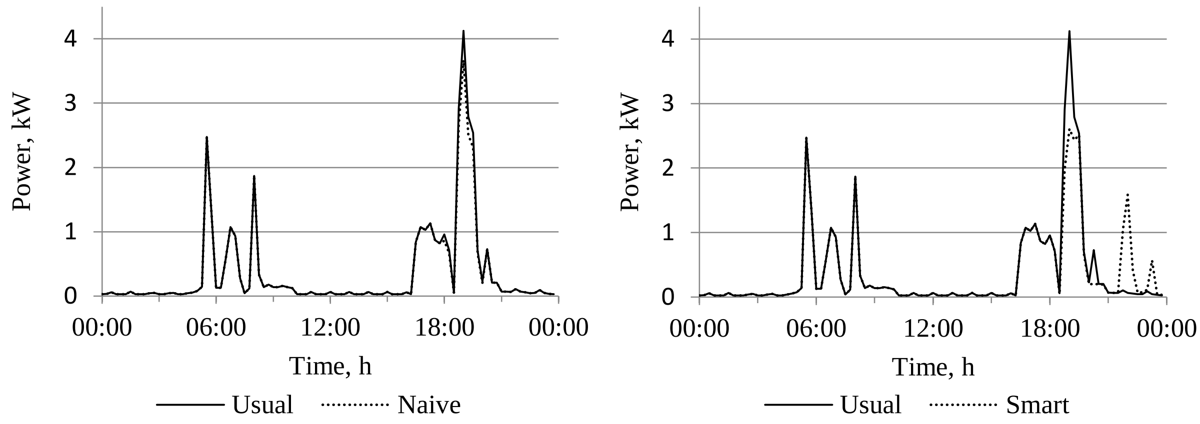
LPG can simulate the energy consumption of a given household or business over a certain period of time, taking into account a number of parameters such as the size of the building, the number of residents or employees, the type of their activities, and more.

In this study, LPG was used to simulate the effect of different strategies of household consumers involved in DRP. The object of the study was a family of two adults who work in an office. Load profiles were generated and investigated for two days when the family used the washing machine in the morning and in the evening. Two different strategies were considered. The first, "Naive" strategy represents inexperienced customers who simply turn off the lights and TV to reduce energy consumption. The second, "Smart" strategy represents customers trying to change the time they use powerful appliances, in this case a washing machine. According to the terms of the DRP, the consumer should reduce consumption during peak load from 8:00 to 10:00 or from 18:00 to 21:00.

Fig. 1, 2 show usual summer working days load profiles. Curves "Usual" show profiles for unlimited power consumption, the other curves show profiles when household participating in DRP under "Naive" (Fig.1a) and "Smart" Fig.1b strategies.

In Fig. 1, evening washing starts at a convenient for the family time from 18:30. A "Naive" consumer simply turns off the appliances in the living room to participate in DRP, while a "Smart" one shifts the start of washing to the night period from 21:30.

The simulation results show that the "Smart" strategy allows to reduce energy consumption during the demand response period (from 18:00 to 21:00) from 4.12 kWh to 2.44 kWh, as well as reduce the peak load by 1.7 kWh or 40%. On the same day, the "Naive" strategy only allows to reduce consumption during demand response period to 3.39 kWh, and reduce the peak load by 0.73 kW or 11%.

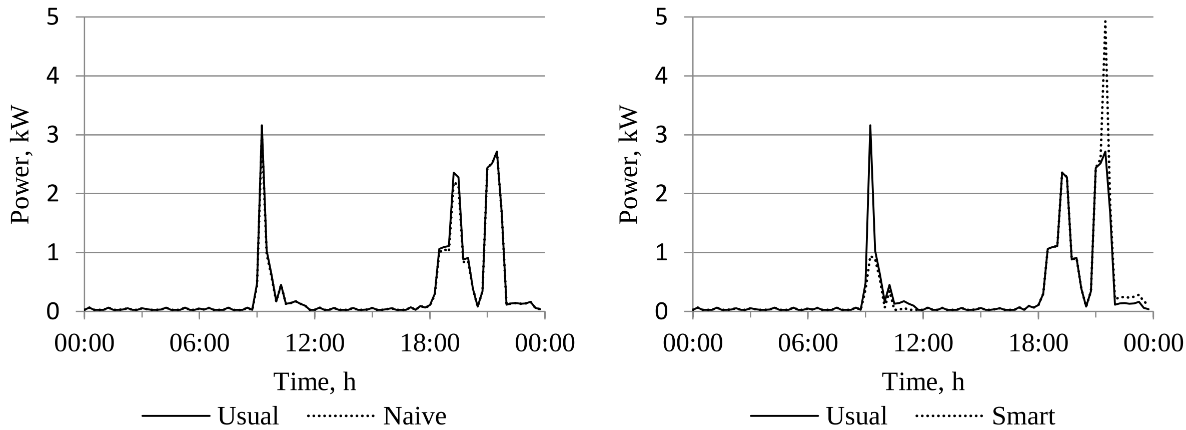


a) **b)**

Figure 1. Load profiles of a household consumer on a working day with washing in the evening

Fig. 2 shows the simulation results for another case where the morning washing starts at 8:30. This time, the consumer is trying to reduce energy consumption during the morning peak from 8:30 to 10:00. Again, a “Naive” consumer Fig.1a) turns off the appliances in the living room, while a “Smart” one Fig.1b) shifts the start of washing to the night period from 21:15.

The simulation results show that the “Smart” strategy allows to reduce energy consumption during the demand response period (from 8:30 to 10:00) from 3.16 kWh to 0.94 kWh, as well as reduce the peak load by 2.21 kWh or 71%. The “Naive” strategy allows to reduce consumption during demand response period to 3.0 kWh, and reduce the peak load by 0.11 kW or 9%.



a) b)

Figure 2. Load profiles of a household consumer on a working day with washing in the morning

These results clearly demonstrate the importance of choosing the right strategies for household consumer's demand response. Shifting washing to the night period almost does not create inconvenience to family, while it provides a 3-7 times greater reduction in consumption compared to almost stopping the use of the living room. It is clear, that the “Naive” strategy makes people uncomfortable, restricts their actions and prevents them from benefiting from the DRP and therefore from being rewarded for participation. Along with this, the chosen “Smart” strategy with similar ones related to other household appliances demonstrates great potential and scalability of residential consumers’ engagement in DRPs [4].

Conclusion

DRP for household consumers can be an effective tool for managing energy demand, but these programs face several challenges, including limited consumer awareness and behavioural barriers. To address these challenges, DRP may rely on load profile simulation to find out household consumers' energy usage patterns and strategies for reducing energy consumption.

This study demonstrates the importance of behavioural approaches in promoting sustainable energy consumption practices through DRP in smart grids. It highlights the need for careful design and implementation of DRP programs that are effective, attractive to participants, and address behavioural barriers. It is shown that such programs can significantly influence consumer behaviour and lead to significant energy savings. The study emphasizes the need for carefully designed and implemented DRP programs that are effective and attractive to households, with education and outreach activities to build awareness and trust. With further and development, behavioural approaches can play a critical role in enhancing the effectiveness of DR programs and promoting a more sustainable energy future.

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