CONSIDERING VARIOUS CONSUMMERS PROFILES IN A SMART GRID

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ABSTRACT

In this paper we address the question of the role of electricity consumers in a smart grid for a day-ahead scheduling. We aim to understand them on a technical but also a socio-economical level. For this purpose, we based our work on a multidisciplinary approach to define involvement profiles among electricity consumers we can then use in a management strategy of a smart grid. Considering that a real consumer behaviour is a combination of various objectives and constraints, the final number of elementary profiles is here limited to five. The goal is to be able to manage the energy efficiently while helping both part (consumer and utility) to reach their objectives, respecting these profiles.

INTRODUCTION

The growing part of renewable energies in the energy production challenges the equilibrium of the entire electrical grid. This results in an increasing complexity for the management of the energy, thus questioning the role of the various actors. The residential consumers, as the most complex grid stakeholders to apprehend, require a special focus to understand and to include it in the grid. To tackle this issue, Demand Side Management (DSM) takes several forms and is increasingly investigated [1]. However, electricity consumers cannot be solely considered under a technical or economical point of view if we aim to have them involved and accept to modify their behaviour. The price is indeed not the only driver for change and disparate objectives and constraints need to be considered [2]. The first step is therefore to understand the various existing profiles among the residential consumers in order to give an adequate framework for both consumers and utility while insuring the reliability of the grid.

To address this problem, we developed the methodology presented on Fig. 1. Each of the three step aims to answer the following questions respectively: 1. What are the exploitable involvement-profiles in terms of electricity consumption in a context of multi-stakeholder energy management? 2. How to model these profiles? 3. How can they then be included in an efficient energy management in the smart grid?

In this paper, we will focus on the first step, where we define the profiles we will model to simulate the interaction between them (step 2 and 3, partially presented here). The proposed approach is first presented, before introducing the contribution of each discipline to the study of consumers' involvement concerning their energy consumption through the grid. The five selected profiles are then presented and the way they can be modelled for the next steps of the methodology. Finally, we discuss the future of this research and the possible improvements in the methodology.

PROPOSED METHOD

Approach

The chosen approach is at the crossroads of electrical engineering, sociology and economics. Each discipline is part of the solution as presented on the Fig. 2, and the final profiles we will use for the energy management in the grid are at the intersection of the three underlying questions: Which profiles exists in terms of energy consumption? Which profiles are we able to observe in a given population? Which profiles are we able to model in a simulation of the interaction of grid stakeholders?

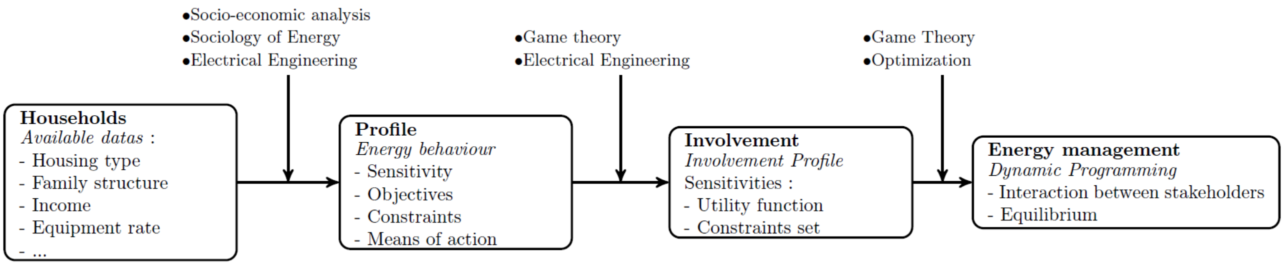

Figure 1: Proposed global methodology for residential consumers

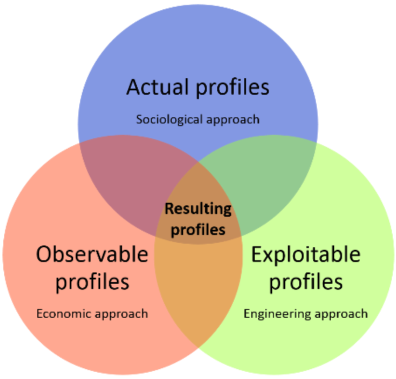

Figure 2: Multidisciplinary interaction for the modelling of consumers' profiles

Actual profiles

The first step of the approach is to understand the existing profiles in terms of electricity consumption. For this purpose, we can rely on the sociology of energy. It brings indeed its formalism to shed light on the constraints faced or imposed by the stakeholder as well as his objectives, which are essential to take into account to have them involved in the smart grid.

The example of the Accenture study [3] (Figure 3), presents the diversity of profiles (a total of six for France in 2010: Proactives, Eco-rationals, Cost-conscious, Pragmatics, Scepticals, Indifferents) for the residential sector. Other studies exists highlighting different segmentation but are consistent about the main objectives and constraints of the users. We therefore sought to model these different commitment levels regarding energy saving behaviour.

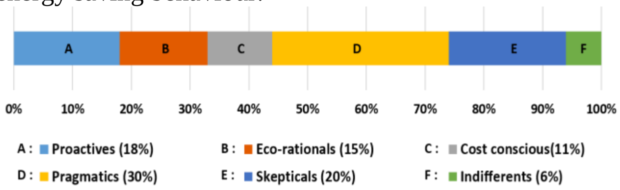

Figure 3: Example of a distribution of residential consumers in France [3]

The sociology of energy allows us therefore to emphasize the involvement profiles, a crucial step of this work. We divide the profiles into three thematic:

- *Objectives*: Understanding the objective of the stakeholder is essential before thinking about the interaction with others, as it is what the modelling will aim to reproduce: Does the stakeholder wants to reduce the expenditure? Does he accept to change his behaviour? etc.
- *Means of action*: To achieve his objective, which possible set of action are available? Not only from a technical perspective but also from a behavioural point of view.
- *Constraints*: The last issue is to incorporate the elements that could reduce the involvement throughout the use of the means of action. Once again from a technical (What does the technique allow?) as well as from a sociological (practices in everyday life) or from an economical (eg limited budget) point of view.

The goal of this part is to list all those parameters, in order to take these informations into account to the greatest possible extent, although the two other steps of the proposed approach will determine the ones that can be included in the final profiles used for the energy management.

It should be noted that the underlying hypothesis is that the smart grid will allow the flow of pertinent information for the consumers. Provided that he accepts to be involved, he will then be able to reach his objectives by being adequately aware of the state of the grid. Moreover, new possibilities and energy practices emerging from this enhanced communication are discussed in [4], and may be included in a future work.

Observable profiles

The second aspect of the study is to be able to find the final chosen profiles in a given population. Therefore, we present in this section the possibility of retrieving consumption profiles based on available socio-economics data in France using the tools of the micro-economy.

The micro-economy helps the study on multiple levels:

- For the understanding and constitution of the of the various profiles, especially for the resident actor, who is the most difficult to define;
- For the modelling of stakeholders' interaction, by investigating the reactions to prices and their evolution.

This discipline considers that the behaviour of a given household is the result of two elements: the marginal profit and the marginal cost related to a change in its behaviour. Behind these two aspects stands the notion of inclination to accept a behavioural modification, which amplitude we aim to measure at the household level. The idea is that there is a statistical link between the inclination to participate in an energy behaviour modification program and the impact of energy consumption on household expenditure. In simpler terms, an effective measure of acceptance of a modification is given by the relationship between energy expenditure and the household's income (relation called *Engel curve* in economics). The prerequisite for using this relation in the search for profiles is the possibility of defining it in a non-linear way, which is possible thanks to recent developments in this field [5]. The recent application of Hicks' work [6] to the definition of demand functions offers a possibility to introduce these nonlinearities in the definition of the curve Engel.

In this study, we use data from the Family Budget Surveys (2005, 2006, and 2011) of the French institute

INSEE. At the time of the writing of this paper the processing of the data is still in progress as it requires a substantial analysis, consequently this will be the subject of a future publication. We therefore focus here on the overall methodology and the contribution of each discipline, as well as their interaction.

Exploitable profiles

The last part is the reflection concerning the modelling, building on the expertise of electrical engineering to manage an electricity grid. Indeed, knowing the different consumers' profiles is useless if they cannot be modelled and embedded in the management strategy. From the literature, various DSM methods are used, such as real time appliances planning using a scheduling algorithm [7], genetics algorithms coupled with dynamic pricing [8,9], or by letting the user decide his consumption by guiding him with a day ahead forecasting [10]. The method adopted in our work is based on the game theory, similar to the approach developed in [11], and will be presented in the next section.

For the management of the energy, from the existing and observable profiles it is only possible to include measurable or disclosable (by the stakeholder) parameters, which can also be processed by the consumer as well as the aggregator or the grid supervisor. From the two previous steps, the three exploitable parameters we therefore chose are: the costs, the environment, the willingness to participate (by differentiating automated or conscious consumption modification). In addition to that, the constraints will also be mathematically modelled thanks to the game theory. Using these three parameters and choosing the set of constraints, the grid will embed the different profiles, while they each will be able to express themselves. Thus, the full communication potential of the smart grid will be exploited, by exchanging the relevant information between all the stakeholders. In the future, using this methodology, more parameters resulting from new energy practices could be included, as mentioned previously [2]. In the first instance, these simple exploitable profiles enable the grid manager to determine the possibilities of flexibility – for the demand side but possibly for the production side by applying the same methodology.

RESULTING PROFILES

Final profiles

Proceeding so, taking each contribution of the three presented perspectives into account, we limited the finale profiles to five, under the assumption that any real profile is a combination of them. In the future, this model can be of course enhanced and even expanded to other stakeholders or other profiles. These profiles are classified along three sensitivities or axis if we imagine them drawn on a 3D diagram: Price, Environment and willingness to be involved (Automated and/or self-behaviour change). The last axis represent the willingness to participate and the difference between the loads than can possibly be controlled by the grid manager (such as the hot water tank like in France) and the loads that requires a specific behaviour from the consumer to be shifted.

Profiles
These five profiles are the following:
• **Eco-sensitive**: Located only on the environmental axis, they aim to limit their environmental impact;
• **Cost-sensitive**: Only driven by the price, their objective is to limit their bill;
• **Indifferent**: They will not participate by themselves but accept a certain control on the automated loads, as long as they do not need to change their behaviour;
• **Proactive**: Technically equipped, they are highly involved in the grid equilibrium;
• **Non-involved**: This last category is considered non-involved, they refuse every form of control and will not change their behaviour. They are therefore considered as a fixed load on the grid.

Constraints
In addition to that, two classes of constraints are also modelled:
• **Power:** Continuous power, on-off controlled power, and power cycle (once started, must complete its entire cycle);
• **Energy**: Amount of energy consumed at a given time (over the considered period as well as at any hour);

Thanks to this approach, we are able to include both technical and usage constraints, while taking into account the various existing objectives among energy consumers. For example, the full charge of an electrical vehicle can be set for a given time, the heating system power may be fixed between specific hours of the day and set loose during others, etc., the floating consumption will then be optimized according to the objectives of the stakeholder. By means of the 3D representation, the sensitivity to each axis can be adjusted, as it is then connected to the parameters used in the corresponding mathematical function presented below.

Profile modelling

As stated previously, we use a game theory approach to model the profiles and the interaction between them. The game theory gives a mathematical framework to ensure the existence of an equilibrium between the various objectives and sensitivities despite the decentralized optimization process we chose with regard to privacy issues. At the present time we work on the power consumption schedule, therefore working on a day ahead supervision. A stakeholder's profile takes the form of a mathematical function called *utility function*, which can be seen as an evaluation function for the different consumption strategies, to choose the most optimal according to the sensitivity. Therefore, this function contains the parameters related to the location of the profile on the three axis and thus including the price, the environmental impact and an image of the involvement. One of the next step of this study is to investigate how to correlate the final profiles with the function's parameter.

Simple example
To illustrate the modelling, we may consider a grid with the overall objective of limiting the power peaks, and consumers' profiles on only one axis, let us take the willingness to participate or not to the grid equilibrium. A *proactive* consumer using an electrical vehicle plugged between 19:00 and 08:00 (usage constraint) with a power limit of P_{Max} (technical constraint) can be therefore simply represented as follows, with x_t the power consumption at the time t, x_t^s the day ahead forecasted power consumption at the time t, $x_{grid,t}$ the total load on the grid (except that of the considered consumer) at t, and m the mean grid load over the considered period:

- The utility function over the studied period of time, with α as the involvement parameter ($\alpha = 0$ means not involved, $\alpha = 1$ means fully involved in the grid objective):
$$u = \sum (x_t - [(1-\alpha).(x_{grid,t} - m) + \alpha . x_t^s])^2$$
- The set of constraints is here limited to:
$$\begin{cases} 0 \le x_t \le P_{Max} \\ \sum_{19:00}^{08:00} x_t = E_{battery} \end{cases}$$

CONCLUSION

This paper proposes a methodology to define involvement profiles for an energy management strategy in a smart grid. The final used profiles result from a three parts approach using humanities and social sciences as well as electrical engineering considering the consumers more broadly than just the traditional technical point of view. The first part involves the sociology of energy to understand the existing profiles in their consumption of electricity, the second one enables us to find the profiles in a given population thanks to the micro-economy, and the third one introduces the framework to use theses profiles from a grid point of view. The adopted five final profiles will be modelled using a game theory approach, enabling us finally to simulate the possible interactions of the stakeholders in the grid. The results of the conducted study using data from France and the interaction simulation will be the topics of future publications. This first step definition is important as it will ensure the success of the implementation of these profiles and their proper use. For the grid manager, the usefulness of this work is to estimate and understand the potential of flexibility in the grid by taking the uses besides technical consideration.

Being able to model real profiles, not exclusively from a technical point of view but also involving other domains such as social sciences, enables us to imagine a new management of the energy taking into account each sensitivity and objectives. In this way, producers, utilities, and consumers will be considered and therefore encouraged to participate. Thus, enabling us to imagine who will take part in which grid services. Such work offers various possibilities in the future smart grids: On the one hand, implementing this methodology together with a learning loop to adapt the parameters of the model enable the utility to predict more efficiently the consumption under the hypothesis of an adequate information exchange. On the other hand, with an appropriate economic model, it is a starting point to define new contracts among consumers, to enable each profile to be considered in a more efficient grid.

REFERENCES

[1] F. Gangale, A. Mengolini, and I. Onyeji, 2013, “Consumer engagement: An insight from smart grid projects in Europe”, *Energy Policy*, vol. 60, 621-628.

[2] G. Verbong, S. Beemsterboer, and F. Sengers, 2013 “Smart grids or smart users? Involving users in developing a low carbon electricity economy” *Energy Policy*, vol. 52, 117–125.

[3] Accenture, 2010, "Understanding Consumer Preferences in Energy Efficiency", *Accenture end-consumer observatory on electricity management*.

[4] J. Naus *et al.*, 2014, "Smart grids, information flows and emerging domestic energy practices", *Energy Policy*, vol. 68, 436-446.

[5] R. Blundell, X. Chen, and D. Kristensen, 2007, “Semi-Nonparametric IV Estimation of Shape-Invariant Engel Curves”, *Econometrica*, vol. 75, 1613-1669.

[6] A. Lewbel and K. Pendakur, 2008, “Tricks with Hicks: The EASI Demand System”, *American Economic Review*, vol. 99, 827-63.

[7] D. Caprino, M. L. Della Vedova, and T. Facchinetti. 2014, “Peak shaving through real-time scheduling of household appliances”, *Energy and Buildings*, vol. 75, 133–148.

[8] N. Shaheen *et al.*, 2016, “Appliance Scheduling for Energy Management with User Preferences Appliance Scheduling for Energy Management with User Preferences”, *Proceedings IMIS Conference*, vol. 10.

[9] T. Logenthiran, D. Srinivasan et T.Z. Shun, 2012 “Demand side management in smart grid using heuristic optimization”, *IEEE Transactions on Smart Grid*, vol. 3, 1244–1252.

[10] D. Geelen, A. Reinders et D. Keyson, 2013, “Empowering the end-user in smart grids : Recommendations for the design of products and services”. *Energy Policy*, vol. 61, 151–161.

[11] H. K. Nguyen and J. B. Song., 2012, “Optimal charging and discharging for multiple PHEVs with demand side management in vehicle-to-building”, *Journal of Communications and Networks*, vol. 14.6, 662–671.