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Categorization of residential electricity consumption as a basis for the assessment of the impacts of demand response actions

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ABSTRACT

In a smart(er) grid context, the existence of dynamic tariffs and bidirectional communications will simultaneously allow and require an active role from the end-user concerning electricity management. However, the residential end-user will not be always available to manage energy resources and decide, based on price signals and preferences/needs, the best response actions to implement or the best usage of the electricity produced locally. Therefore, energy management systems are required to monitor consumption/generation/storage and to make the best decisions according to input signals and the user's needs and preferences. The design of adequate algorithms to be implemented in those systems require the prior characterization of domestic electricity demand and categorization of loads, according to availability, typical usage patterns, working cycles and technical constraints. Automated demand response actions must be tailored and chosen according to this previous analysis of load characteristics. In this paper, a characterization of household electricity consumption is presented and an operational categorization of end-use loads is proposed. The existing potential for demand response to a diversified set of management actions is described and a tool to assess the impact of implementing several actions with different rates of penetration of energy management systems is presented. The results obtained show the potential savings for the end-user and expected changes in the load diagram with a decrease of the aggregated peak electricity demand and a smoothed valley.

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1. Introduction

The increasing penetration of micro-generation has been changing the traditional role of end-users in the residential sector.

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Several end-users are now not only electricity consumers but also producers and this trend is likely to increase [1]. At the same time, new types of loads are emerging, namely electric vehicles. Their expected dissemination among the residential end-users will expectedly induce significant changes in the domestic demand patterns and create new challenges to the low voltage distribution infrastructure [2–5].

On the other hand, the supply-side is also facing some changes: smart embedded systems that combine instrumentation, analytics and control are turning the traditional grid into a more efficient self-diagnosing, self-healing, distributed and bidirectional grid [6,7]. This "smart(er)" grid would further benefit of a more active role from the end-user side if he/she is able to respond to external input signals (e.g. dynamic tariffs) by adequately managing his/her electricity consumption and/or by taking the maximum advantage from micro-generation and storage systems.

From the end-user's point of view, demand response plays a key role by allowing a more efficient and integrated management of resources possibly contributing for reducing the electricity bill. From the power system side, responsive demand will allow an improved management of the grid, mitigating the variability associated with renewable generation and reducing the potential undesirable impacts of electric vehicle charging, for instance the creation of a high local peak demand, besides contributing for an improved load factor, lower losses and increased reliability [8,9].

However, the residential end-user is not always available to manually manage in an optimized way, his/her electricity consumption/production/storage in real-time day by day and hour by hour. There are several decisions that must be done that the end-user is neither prepared nor available to deal with, namely:

- the best scheduling for appliances to be turned on/off (washing machines, clothes dryers, etc.);
- the changes in the thermostats setting points and/or the curtailments to be applied over thermostatically controlled loads, such as air conditioners and electric water heaters or even refrigerators and freezers;
- what to do with the energy produced locally (store/use/sell back to the grid);
- how to manage electricity storage devices.

The aim of this paper is twofold. Firstly, it aims at characterizing and classifying in a detailed way the potentially controllable demand in the residential sector in Portugal, namely the electricity demand originated from:

- washing machines, clothes dryer, dishwashers;
- cold appliances and electric water heaters;
- air conditioning systems.

This analysis provides the foundations for the design of diversified management actions to be implemented over the several types of loads.

Secondly, it aims at assessing the impacts of implementing distinct Automated Demand Response (ADR) actions over some of the controllable end-use loads previously identified. These ADR actions might be carried out by Energy Management Systems (EMS) able to optimally manage the end-user's available energy resources.

A brief description of electricity consumption patterns in Portugal is done in Section 2. The demand characterization and load categorization in face of ADR actions is made in Sections 3 and 4, respectively. These two sections allow for the selection of ADR actions to be used in Section 5. The impact assessment of ADR implementation on the load diagram is presented in Section 5 and the importance of EMS is presented in Section 6. Conclusions are drawn in Section 7.

2. Electricity consumption in Portugal

Electricity consumption in the residential sector in Portugal has been increasing steadily and since 1990 electricity consumption has been rising faster than Gross Domestic Product (GDP) per capita. One of the reasons pointed out for explaining this trend is the increasing rate of ownership of electrical appliances associated with higher living standards [10,11].

Concerning electricity generation, Portugal has been doing remarkable efforts in the deployment of generation from renewable sources with the main aim to reduce the need of fossil fuel imports and therefore external energy dependence [12]. Nevertheless, a significant part of the electricity produced in Portugal is based on fossil fuels. Concerning renewable sources, their contribution has been increasing although it is quite variable and mostly strongly dependent on weather conditions. It is therefore important to be able to deal with the variability associated with each one of these resources in order to maximize their integration into the grid [13].

One of the ways to achieve this aim is the application of demand-side management (DSM) actions [14–17]. However, it is important to have beforehand an adequate knowledge of the disaggregated electricity consumption in the residential sector as well as the typical patterns of usage of the appliances that can be somehow controlled in order to choose the best DSM actions [18]. Technical constraints and end-user's preferences that may frame the way loads can be controlled also play an important role that should be considered. Besides contributing for a more efficient operation of power systems and allowing higher penetration of renewables, smart ADR actions may also contribute for reducing end-user's electricity bills and/or increasing the supplier's profits from selling electricity.

Taking into account the load profile of the residential sector disaggregated by end-uses [19] (Fig. 1), it is possible to analyze and to estimate the contribution of end-use loads to the total electricity consumption and electricity bill (Fig. 2).

The regular time of usage gives information about residential end-users' habits and the potential of using some of the appliances in different schedules. Studies about users' willingness to change behavior concerning the utilization of energy services have already been developed [20–23].

3. Controllable demand characterization

The evolution of Electrical Energy Systems towards Smart Grids is expected to provide the residential end-user with the technological basis and the economic incentives to adequately manage his/her energy resources, including local generation and/or

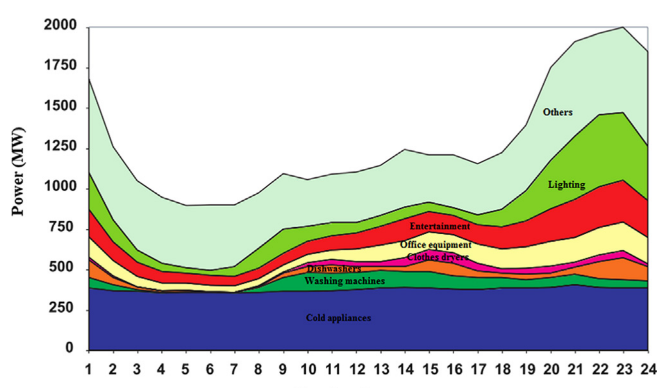

Fig. 1. Load profile of the residential sector [19].