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Methodology to simulate the impact of a large deployment of a residential energy management system in the electricity grid

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ABSTRACT

The purpose of this work is to provide an insight for a possible methodology to implement demand response strategies at a city scale. The objective is to determine a range of values for the energy and power that can be made available through the large deployment of a residential energy management system. This work can help the distribution system operator to assess the impact of the usage of such technology at the grid level.

The paper describes a methodology that identifies the start of operation cycles of appliances and other loads on a given general load diagram, enabling the simulation of load shifting caused by the operation of residential energy management systems.

A simulation of an hypothetical 20% deployment of a residential energy management system on the city of Coimbra in Portugal, was performed. The results show the release of almost 3% of the demand on periods of higher price, but also the occurrence of a pronounced peak during the night period, an occurrence which may need to be dealt with, and for which some solutions are proposed.

1. Introduction

In order to allow decision makers to select local, regional or national end-use energy efficiency policies, it is necessary to assess the technical, economic, environmental and societal effect of replacing or adopting a given equipment, technology or measure.

The deployment of Demand-Response (DR) [1] programs and the recent trend toward combining the use of advanced smart meters with automatic load management capabilities requires assessing their possible aggregated impact and, for that purpose, the knowledge of the household (hh) consumption pattern and its composition in terms of the individual end-uses is fundamental.

The common strategies to load modeling are normally based on top-down or bottom-up approaches, the first kind trying to derive load models from statistical data and the second kind building an aggregated model from engineering models of end-uses. These methodologies can be improved by the growing availability of data from smart-grids and smart-meters, thus taking advantage of these new types of data, as well as reducing costs associated with energy modeling, avoiding the complexity of models and reducing the time required to perform simulations.

This paper presents a methodology proposal to determine the impact of the deployment of a demand response technology such as the Energy Box (EB), a residential energy management system defined by Livengood and Larson [2], assessing the energy and power made available through load shifting on an hourly basis in response to a price signal. The Energy Box is the focus of a research conducted by a team to which the authors belong, as a research project in the framework of the MIT-Portugal Program [3].

The developed methodology assumes some randomness to be associated with the input data, scarce information being available on probability distributions of appliances schedules along the day. Some randomness is also associated to the hourly tolerance of consumers for postponing the starting time of their appliances. This simulation also intends to analyze the outcome of having a certain percentage of consumers from one city, county (or country) with Energy Box devices, using the information regarding the consumption of the area at, and taking a bottom-up approach.

1.1. Load research review

Similarly to what happened in other European countries, several studies regarding electrical energy use (especially consumption)

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have been developed in the past years giving a special attention to the Portuguese household sector. This attention is explainable due to the overall and growing importance of electrical energy consumption in this sector and its share of the total electricity consumption of the country (29.00% in 2010). Portugal accounts for a total of 3,927,733 households with electricity usage (13,946 GWh for 3,769,896 hh in Portugal mainland, 258 GWh for 77,222 hh in the Azores islands and 239 GWh for 80,615 hh in Madeira [4]).

Another reason for the existence of these studies has to do with the alleged homogeneity of the sector in terms of appliances or other equipment, energy usage patterns and energy behaviors, which allowed the development of typical load profiles that intend to represent the energy consumption in households. According to a recent study [4], electricity is the main source of energy used in Portuguese households with a share of 42.6%, clearly surpassing the 15.8% share in 1989 and 27.5% in 1996. The popularity of equipment/appliances that use electric energy increased significantly, contributing to the growing importance of the use of this type of energy in the household sector and motivating researchers to develop studies on the electrical energy usage in dwellings. An extended review of the state of the art regarding this subject was published by the authors in Ref. [5] focusing load studies regarding the Portuguese household sector. Another review with relevance for the present article, covering the simulation methodologies, and including bottom-up and top-down studies, was published in Ref. [6].

1.2. Load management

In order to increase security in energy supply and to reduce greenhouse gas emissions (GHG), Europe made a strong effort to integrate renewable energies (RE) in the electric grid. Several reasons could be pointed out for the European Commission and European Countries to devise concrete objectives for the expansion and integration of RE in the electricity grid, namely, the necessity of having a diversified energy mix, RE potential and several technological breakthroughs. From the available renewable energy sources, the most likely to be used at a larger scale are solar and wind, both of which are intermittent. Using current tools to manage load and supply fluctuations it is possible to deal with the intermittency of renewable energy sources at low levels of implementation. However, an increase of the share of energy supplied by RE of 10–30% requires new resources to balance the fluctuating supply to the also fluctuating load [7].

Another reason for the need to study new tools to balance supply and demand is that transmission networks in Europe, due to new market mechanisms, are becoming a platform to increasing energy flows as stated by the authors of [8,9] and more recently in [10,11].

In addition to this burden, technological advances imply new appliances that require more energy. Thus, the gap between electrical supply and demand is increasing in many countries [12,13].

Conventional approaches to solve the above-referred problems are based on the expansion of the supply resources, even to serve only as idle backup power. These are usually high-investment solutions, planned to work for a very small fraction of the time. An alternative approach is then to manage the energy consumption, in order to compensate fluctuations, avoiding the need of new supply capacity [14–16].

Managing consumption helps controlling the energy production, allows relieving the transmission systems and helps the implementation of decentralized supply structures with small and autonomous energy systems.

Recently an extensive review of load management methods was published in Ref. [17], describing techniques and programs, many used in developed and developing countries. According to Ref. [17], and in the perspective that consumers should adapt their patterns of usage to the actual evolution of the cost of electricity, the tariff that better reflects the present situation of the electricity market is the real time tariff. This tariff has prices announced in advance, e.g., a day ahead, as assumed in the remaining of this article. However, this tariff scheme may require the temporary reduction of quality of service levels and increased needs for granularity of control and telemetry speed [18]. The possible benefit of DR, for the transmission and distribution operators, of deferring investment in network reinforcement or increasing the long-term network reliability stated by Ref. [18] requires comfortable evidence in order to enable a meaningful investment by interested parties.

The need for a methodology as the one described in this paper is also strengthened by the existence of studies [19] that state that DR can cause new demand peaks for electric utilities to deal with, when day-ahead hourly prices are applied. The question remains to know what their relevance is and how to avoid them.

1.3. Comparing load profiles

A methodology to evaluate profiles, aimed at comparing load profiles of the residential sector, with the ability to relate reference studies that developed load diagrams, was published by the authors in Ref. [5]. The general idea consisted in comparing the load profiles approved by the Portuguese national energy regulator (ERSE) with the typical load profiles provided by load research studies.

The profiles provided by ERSE and REN are demand values for each quarter of hour of an entire year in p.u. (kW), also including the power value.

Within this methodology, and considering the underlying concept of the regulator load profile, it was also possible to compare the profiles provided by Refs. [20,21] with the ERSE profile, normalized for the same integral of consumption over the entire period. Since the load profiles have the same sum and average, the maximum positive hourly variation (MPHV), the maximum negative hourly variation (MNHV) and the average variation (AV) are equal to the normalized unitary vector counterparts.

In Ref. [22] the author used the updated ownership rates of appliances published in Ref. [4] to change the hourly end-use impact of the consumption diagram presented in Ref. [20].

Using this information, the household equipment was grouped in three different types of loads, type I, II and III, as in Table 1. Type I loads can be scheduled or simply interrupted, type II the loads that can be interrupted but also allow the changing of settings, and type III are the non-controllable loads [2,23]. It is possible to verify that in average some kind of control can be applied to 48.79% of the loads.

Table 1
Type of load by possibility of control [5].

Type of loads (%)							
Type I			Type II		Type III		
Clothes washer	Dish washer	Clothes dryer	Lighting	Cold appliances	Office equipment	Entertainment equipment	Other applications
3.94	4.05	3.48	10.68	26.65	12.21	9.01	29.98
	11.46			37.33		51.21	