Consumption Management Informatics Solution for Increasing Consumers' Awareness towards Energy Efficiency

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Abstract

The paper presents an informatics solution for increase consumers' awareness towards energy efficiency considering three main aspects: consumption optimization, market segmentation and smart application for monitoring and scheduling electrical appliances and real time billing information.

Key words: energy efficiency; prosumer; analytics; clustering; business intelligence
J.E.L. classification: C88, D47, L94, Q40

1. Introduction

Informatics solutions for demand side management are particularly important in the current context of the European and national regulations regarding large scale implementation of smart metering (SM) systems (European Parliament, 2009, p1), (NARE, 2016, p1), reduction of carbon footprint and improvement of energy efficiency (European Parliament, 2012, p1). In order to implement SM, the National Regulatory Authority for Energy (NRAE) approved national targets for grid distribution operators that should be reached until 2020 (up to about 80% of final consumers should have smart meters, based on cost benefit analysis). Comparing with previous period before SM implementation, the final consumers will play an active role, scheduling and controlling their appliances, charging storage equipment that can be unloaded back into the grid based on the electricity price, consuming or selling electricity produced by their own micro-generation units (photovoltaic panels installed on the roofs or buildings' facades, small wind turbines) also according to the electricity price. These consumers are known as prosumers. The volume of data provided from SM and intelligent appliances (IoT) is significant and currently it is not processed. Compared to conventional electricity meters that are manually read once a month, the SM measure aggregate/individual electricity consumption of IoT appliances at configurable time intervals (5, 10, 15, 30 min). In this area, at international level there are researches and studies for data management described in (Bughin et al, 2010, p1), (Rusitschka et al, 2010, p1), but at national area there are no tested or validated solution. Also, prosumers profiles are described in (Rathnayaka et al, 2012, p1), (Guo et al, 2012, p1), (Dedrick, 2012, p1), but due to national aspects (legislation, market requirements, consumer's necessities, demographic and infrastructure constraints), these solutions cannot be directly applied in Romania. As for the demand optimization models, there are several approaches at national level (Mujescu et al, 2012, p10) and international level (Zhi et al, 2012, p1) , (Yang et al, 2008, p1), (Mohsenian-Rad et al, 2010, p1) and some electricity consumption forecasting models are described in (Mohamed et al, 2017, p1), (Moller, 1993, p1), (Huang et al, 2012, p1), (Quadrelli et al, 2012). However, these solutions require advanced customization and investments in order to be directly applied in Romania.

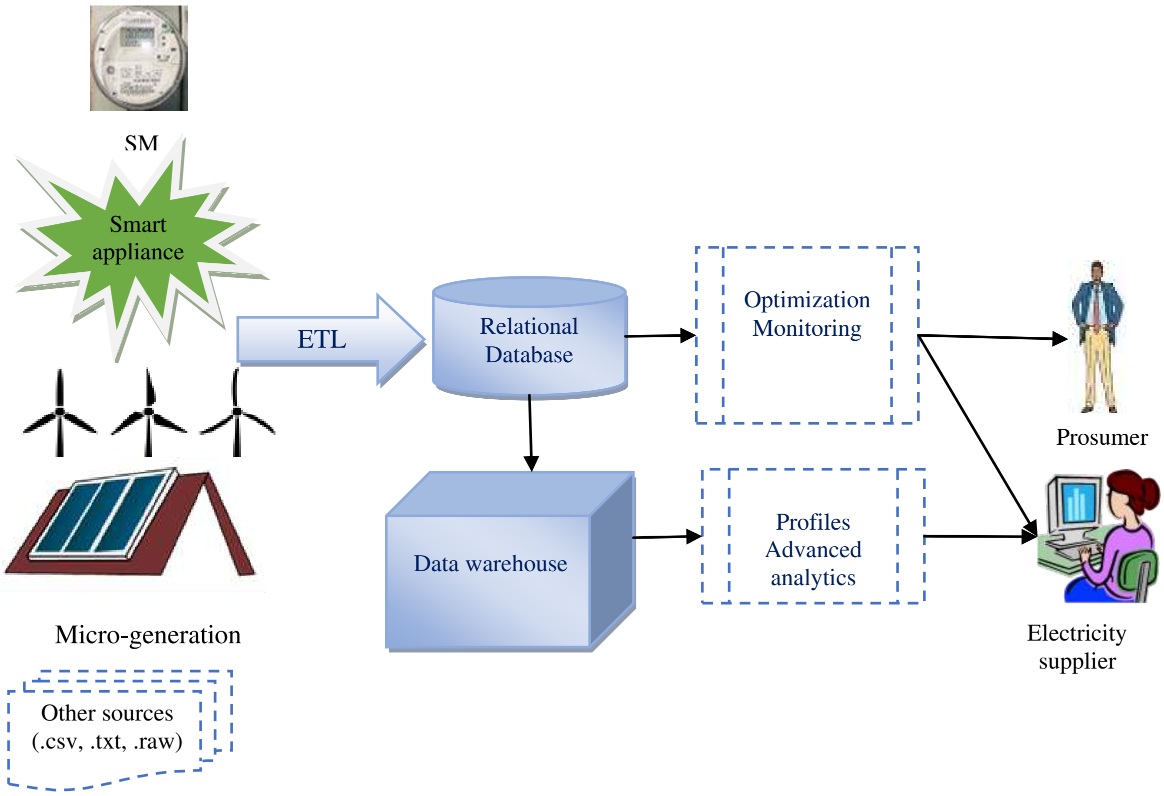
2. Consumption management informatics solutions

Smart grids and smart metering brigs new challenges regarding demand side management. Regarding ICT solutions, the following requirements must be fulfilled:

- scheduling and optimizing consumer's electrical appliances;
- real time monitoring of consumptions and micro-generation;
- historical analysis of consumption and generation;
- information and simulations regarding tariff prices;

Our proposed informatics solution (prototype) is addressed mainly to household consumers, but it contains also a management consumption module for electricity supplier. The informatics prototype implements the following functionalities: data acquisition from smart metering and smart appliances, consumption profiles estimation for setting up the tariff prices, consumption optimization and smart bills (Figure 1).

Figure no. 1 Architecture of the consumption management informatics solution



From SM or sensors data is collected in *.csv* or *.raw* format and loaded into a central relational database. The following devices are considered as data sources: SM, micro-generation equipment (small photovoltaic panels, wind turbines, electrical vehicles), manual reading done by electricity supplier' employees or via web interfaces. An extract, transform and load (ETL) process is designed with patterns for different types of SM and also procedures for extracting data from heterogeneous appliances. After ETL process completes, data is loaded into a central relational database for operational management and then into a data warehouse for advanced analytics.

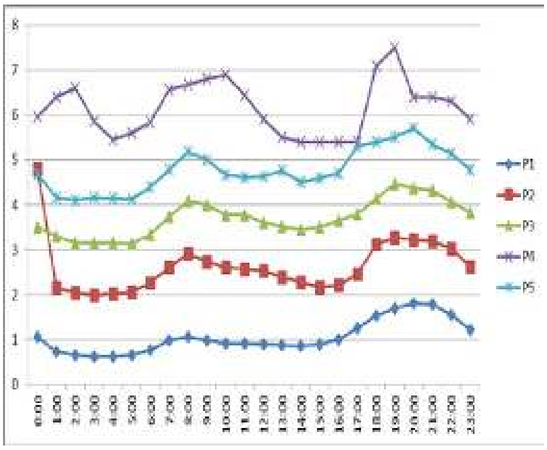
In order to fulfill the above requirements, the informatics prototype implements several models such as: load profiles, consumption optimization and advanced analytics.

2.1. Load profiles

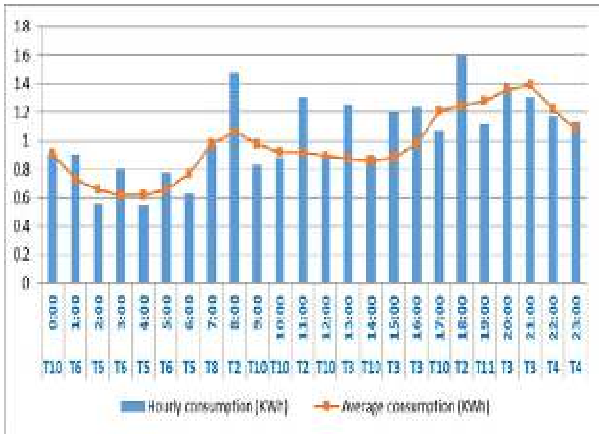
In (Oprea et al, 2016, p1) we analyzed several methods for profile calculation including fuzzy C-means clustering, auto-regression with exogenous variables and multi-linear regression. We also proposed a new method based on Self – Organizing Maps (SOM) that allows us to determine 6 profiles clearly delimited for consumers having the following types of consumption: heating, cooling, ventilation, interior lighting, exterior lighting, water heating, usual devices (washing machine, refrigerator) and other smaller devices (TV, audio, computer). These profiles were compared with other methods such as clustering and classification and the results shown that at some time intervals the profiles were not so much delimited in shape, but only in amplitude (consumption level). We performed clustering based on K-means method and for each cluster we again applied O-cluster (Orthogonal partitioning clustering) method. This method described in (Campos et al, 2002, p1) uses a recursive data grouping algorithm by orthogonal partitioning. We build 10 clusters that represent hourly consumption patterns.

In Figure 2 (a) we represented 5 profiles (P1, …, P5) determined by K-means and in (b) it is shown profile P5 split into 10 patterns (T1, …, T10) for a detailed perspective on electricity consumption. The patterns refine the clusters and gives a better understanding about consumption behavior regarding smaller groups of consumers and thus adjust the tariffs prices for these groups.

Figure no. 2 Profiles determination with K-means and O-cluster



a. Load profiles with K-means



b. Profile P5 patterns with O-cluster

2.2. Consumption optimization

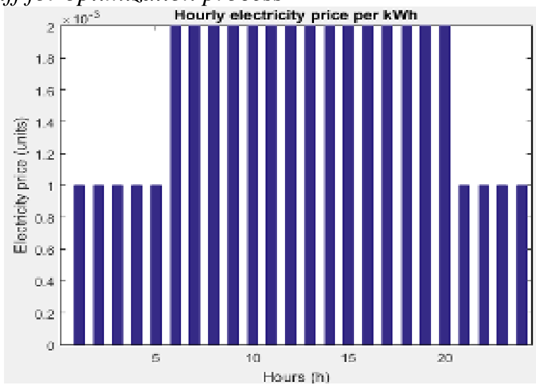
In the context of smart metering and controllable appliances, the electricity consumption becomes facile and rewarding for electricity consumers, grid operators and suppliers.

Different approaches are well known in terms of the electricity consumption optimization. On one hand, the grid operators and electricity suppliers would like to optimize consumption by minimizing the peak. This approach decrease the stress on the grid by shifting consumption to other time intervals when the total demand is lower. Otherwise only for short time intervals onerous investment in new grid capacity is needed. Also at peak consumption, the generators are stressed in order to produce more and the electricity is expensive therefore the suppliers have to buy it at higher prices.

On the other hand, the electricity consumer is stimulated to optimize the consumption in case the electricity payment is minimized. This incentive is usually strong enough to motivate consumers to change their behavior and become more active.

Therefore in order to increase the awareness of consumers, we propose the second approach in terms of objective function combined with storage devices and micro-generation sources such as wind turbines and solar or photovoltaic panels. This way all interested parties: consumers, grid operators and suppliers are satisfied since the storage device will shave the peak. In case storage devices are not used in the optimization process, then new consumption peaks might appear due to the fact that consumers would tend to follow the time-of-use (ToU) tariff scheme (Figure 3) that encourage consumption during the off-peak time intervals.

Figure no. 3 Time of use tariff for optimization process



Although, on long term the minimization of peak brings benefits also for consumers due to avoidance of investment in new grid capacities (such as overhead lines, cables, transformers), the second approach has more chance to improve awareness of consumers.

In this paper, considering the consumption of several appliances from a typical household, different simulations are performed in order to compare the impact of the objective function as shown in Figure 4 and 5. The constraints of the optimization problem are mainly related to the intrinsic characteristics, hourly and daily consumption of the appliances. Both types of appliances are taking into account into the optimization process due to the fact that they contribute to the peak consumption. For solving the optimization problem, the Matlab *intlinprog* function is applied.

Figure no. 4 Daily load curve with objective function: minimization of peak

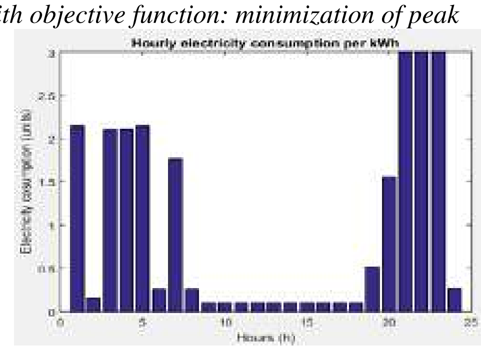
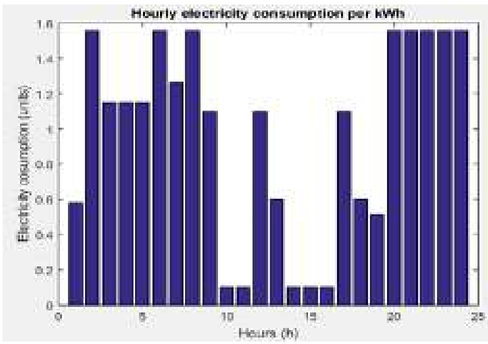


Figure no. 5 Daily load curve with objective function: minimization of payment



In case of payment minimization, the consumption is closing following the time of use tariff, therefore during the high tariff hours only the non-controllable appliances are in operation while the rest of them are off or at minimum. However, the peak consumption that stresses the grid and is recorded only 3 out of 24 hours is almost double comparing with the other objective function.

In terms of payment, when payment minimization is applied, the payment decreased by more than 20% compared with the reference case and when peak minimization is applied, it decreased only by almost 1%. Therefore, it is obvious that consumers' awareness would be increased when payment minimization is applied.

2.3. Advanced analytics

The informatics prototype is developed into a cloud computing platform and offers access for both consumers and electricity suppliers to friendly user interfaces to the following facilities:

- real–time monitoring consumption and micro-generation;
- optimizing and scheduling home appliances based on ToU;
- real-time information about prices and electricity bills;
- analyzing consumers' profiles and aggregate consumption;

The informatics prototype is developed in Java with Application Development Framework (ADF) and Oracle Database 12c for cloud access and data management. Offering cloud-based web-services, the electricity suppliers may benefit from this prototype without investing in costly infrastructure.

3. Conclusion

In this paper we presented an informatics prototype for increasing the prosumers awareness towards energy efficiency through ICT solutions. For prosumers it is important to schedule and optimize their electric appliances in order to reduce electricity costs and for electricity suppliers an important issue is peak shaving through the optimization model and also consumers' segmentation through load profiles. The proposed optimization method provide cost minimization for prosumers and also peak shaving for electricity supplier. The optimization uses ToU for electricity prices and we also proposed a solution for consumers segmentation in order to set up a more adjustable ToU. The profiling method uses K-means for clustering the consumers into 5 profiles and O-cluster for splitting clusters into more detailed consumption patterns. The informatics solutions are integrated through web-services developed in a cloud computing platform.

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