Informatics Solutions for Prosumers connected to Smart Grids

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This paper gives a brief overview about electricity consumption optimization based on consumption profiles of electricity prosumers that are connected to smart grids. The main object of this approach is identification of informatics solutions for electricity consumption optimization in order to decrease electricity bill. In this way, larger scale integration of renewable energy sources is allowed therefore entire society will gain benefits. This paper describes the main objectives of such informatics system and stages for its implementation. The system will analyze the specific profile and behavior of each electricity consumer or prosumer, automatically assist him to make right decisions and offer optimal advice for usage of controllable and non-controllable appliances. It will serve, based on big data transfer from electricity consumers or prosumers, as a powerful tool for grid operators that will be able to better plan their resources.

Keywords: *smart metering, advanced tariffs system, big data, electricity consumption optimization, prosumer, renewable energy sources*

1 Introduction

Our society is facing a significant change of paradigm and many challenges in energy fields. Large scale renewable sources integration has required innovative solution for the benefit of entire society. Nowadays traditional consumption prediction is almost of no use because the electricity modern consumers is beginning more and more active, acting in controlled mode based on clear and efficient incentives. They may have several options: consume energy from the grid when it is cheaper, act as prosumer and introduce power into the grid out of their own micro-generation, when it is more expensive, store energy for later usage, control their appliances and make better decisions for their budget. Smart metering, advanced tariff schema and informatics systems play an important role so that electricity consumer has more options. The price of electricity in each time period is given by availability of renewable sources. Whenever there is more wind then the price will drop and this will stimulate electricity consumption. In case of the rigid tariff schema there is no incentive to increase electricity consumption and therefore integrate less renewable sources. Flexible tariff schema should be well implemented so that consumers will not lose interest in optimization of their electricity consumption. By means of communication technology, smart metering systems involve big data transfer from electricity consumer or prosumer to grid and vice versa. This requires a scalable and powerful informatics system that integrates, analyzes, monitors and assists the behavior of electricity consumers or prosumers and grid performance.

For development of such system, specific objectives are taking into account:

- study of electricity consumption models in smart grid environment and model load profiles (households and non-households) based on type of appliances/specific activities, frequency and duration of their usage;
- identify informatics solutions to process data from smart metering devices taking into account the big data paradigm;

- design the data mining solutions for optimization of consumption.

The paper presents some informatics solutions designed and implemented into a prototype that will assist decisional process and propose optimal solutions for energy supply at minimal prices. It will assist decisional process at the operator grid level by integrating and analyzing consumption data in order to use their resource in an efficient manner. The solutions are design based on some specific conditions of electricity sector in Romania (load profiles, generation mix, volume and type of RES), but they can be extended for wide scale application.

2 Challenges related to new trends of electricity sector

2.1 Smart grid concepts

The concept of smart grid had been defined since October 1997 in the paper Grids get smart protection and control, by authors Khoi Vu, Miroslav M. Begovic, Damir Novosel, published in IEEE Journal Computer Applications in Power [1]. Power systems based on smart grid are characterized by a sum of equipment and modern systems, based on informatics and communications that collect and automatically make decisions in accordance with producers and consumers behavior in order to improve efficiency, reliability, economic aspects and sustainability of generation, transmission, distribution and electricity supply.

The most known components of smart grid are: automation and relay protection, acquiring, monitor and control data systems (SCADA), intelligent metering devices or smart metering, integrated communication systems, decision support systems and advanced interfaces, etc.

2.2 Renewable sources integration

Smart metering systems (SM), along with electricity generation based on renewable sources (RES) are advanced technologies recently introduced as a future solution that solves issues regarding conventional energy sources insufficiency, greenhouse gas emissions and dependency of primary energy sources located outside European Community, etc. European strategies have been taken over as national targets in the Romanian legislation.

Directive no. 28/2009 of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC establishes a common framework for promoting renewable energy sources. It sets mandatory national targets consistent with a 20 % share of energy from renewable sources and a 10 % share of energy from renewable sources in transport in Community energy consumption by 2020 [2]. The Romania's objective is 24%, as a consequence of its RES potential.

RES integration raises a couple of major problems as a matter of electricity production volatility, less predictable character and higher generation volume at night when electricity consumption is low. Integration of more renewable sources will be possible by means of SM along advanced tariff schema (ATS) and informatics systems that analyses the electricity consumption profile and decide based on electricity price and internal factors such as frequency and duration of appliances usage on the appropriate level of consumption.

2.3 Smart metering

In order to implement SM, National Regulatory Authority for Energy (ANRE) has been approved national targets for grid distribution operators that should be reached until 2020, implementing SM gradually up to about 80% of final customers. SM includes metering subsystems that contain measuring equipment (metering device, transformer and access security equipment), information transfer subsystems and information management subsystem.

SM are electronic systems that measures electricity consumption, ensure bidirectional secured transmission of information in both ways from/to electricity consumer and supply much more information than a regular meter, using electronic communication ways [3].

The role of SM, ATS and informatics systems for consumption decisional assistance is to flat as much as possible daily load curve and in this way to allow integration of larger volume of renewable sources into the power system.

The main objective of SM consists in measuring electricity adding more functions to the conventional measuring systems. These functions are useful for electricity consumers or prosumers and for strategic management of grid operators.

At the electricity consumption level, comparing with previous period before SM implementation, the consumers can play an active role, having the administration opportunity of automatic controllable consumption (washing machine, batteries, electric oven, heating/cooling systems, etc.). Also they can choose when to use non-controllable appliances, storage equipment (such as electric cars batteries) that can be unloaded back into the grid and/or supply energy produced by micro-generation (photovoltaic panels installed on the roofs or buildings' facades, small wind turbines) according to the electricity price. Electricity consumers that periodically supply energy to the grid are known as prosumers.

Informatics system interacts with smart metering system, controllable and non-controllable appliances, storage equipment, grid, micro-generation, etc.

3. Intelligent solutions for electricity consumption optimization

As a consequence of innovative character of SM, at the electricity consumer level in Romania does not exist such systems that optimize consumption according to their profile, hourly (or even quarterly) electricity prices and availability of micro-generation sources, but there are research activities at national level [5], [6]. At international level there are dedicated studies and also research activities regarding implementation of such solutions [7], [8], [9].

Load to prosumer profiles

Based on activities that are carried out by consuming electricity, final consumers are categorized into two: household and non-household consumers.

Final non-household consumers are characterized by specific consumption, defined by profile curve or profile that is built based on a certain procedure [4] according to the activities that are carried out, such as: electric transportation, gas stations, civil works, hospitals, public utilities, services, schools, agricultural activities, etc. These categories can be again split into two or more category (for instance services may have different profile curves) base on the volume of such activities and detailed profile that is required for specific purposes.

Final household usually have certain types of appliances: refrigerator, washing machine, dish machine, electric oven, electrical grill, water heater, iron, electric centralized heating system, electrical pot, vacuum, air-conditioning, car batteries, etc. Out of these appliances only some of them can be automatically controlled and used at certain time intervals when electricity price is lower (e.g. washing machine, dish machine, electric oven, car batteries can be charged at night).

Existing load profiles are obtained based on historical behavior of each typical consumer, but nowadays more and more non-household and household consumers become prosumers by installing photovoltaic (PV) panels, wind generating turbines or other types of RES.

Therefore load profile has to be transformed into prosumer profile that is automatically accomplished by prototype, through consumption optimization component (figure 1) that is capable of tuning prosumer profile.

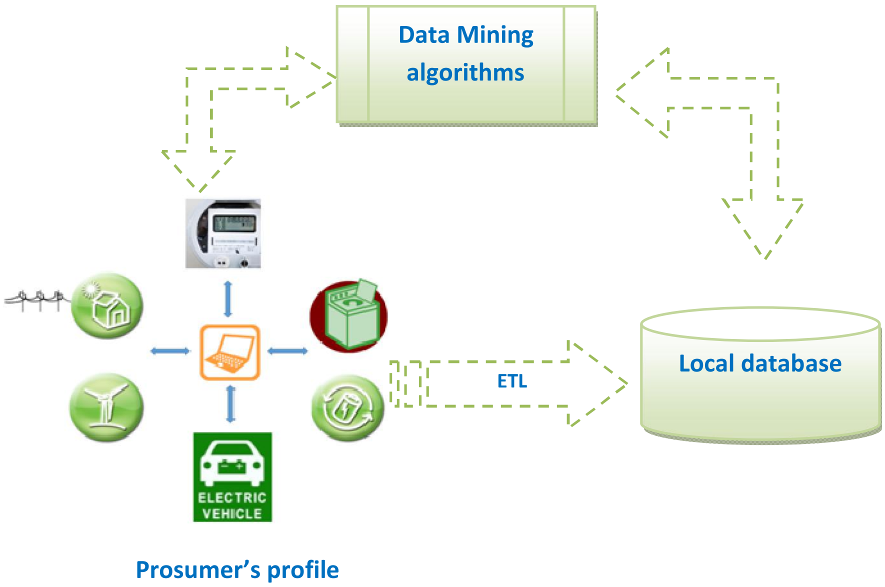

Fig. 1. – Consumption optimization component for prosumers

This component is based on data mining algorithms that take into account: type of working machines for non-household prosumers, type appliances for household prosumer, diurnal or nocturnal hourly consumption, seasonal changes (heating or cooling requirement) including efficiency of buildings, local self-generation volume, electricity price, etc.
Classification and clustering algorithms are adapted in order to optimize electricity consumption. Due to the fact that these algorithms are applied on very large volume of data that are generated mainly by consumption, they require an extract, transform and load processes that prepare data for the learning phase.

4. Decision support for strategic management

At strategic management of grid operators level, data integration received from SM permit a better planning of resources, reducing loses and integrating a larger volume of RES. By taking into advantages of Business Intelligence tools for aggregated data reporting through dashboards and also forecasting components related to the consumption profiles opposite to RES generation, at this level of management the decision process can be improved to efficiently analyze consumers' behavior and optimally plan resources of grid operators. Thus, a possible solution implies incentives for prosumers to consume or generate electricity from/to the grid by means of advanced tariff system. Adequate hourly or quarterly electricity prices are capable to motivate consumption at night during off-peak time intervals so that it will allow higher generation from RES when meteorological condition are favorable and to discourage consumption at peak hours.
Operational experience of wind power plants in Romania shows that they have better condition at night when consumption is reduced. In other words, their operation is less reliable and not helping the operation of the power system [11], [12].

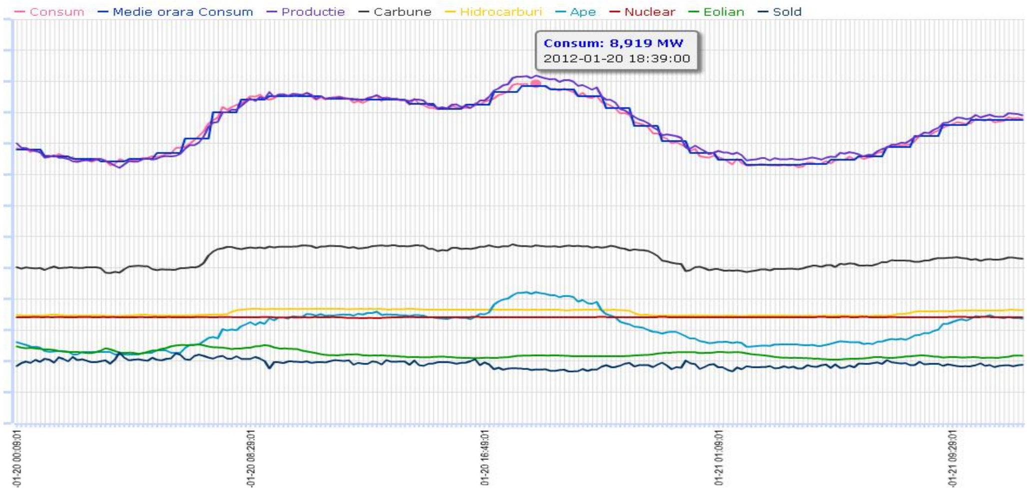

Fig. 2 - Power system load curve

Figures 2 and 3 depict typical power system load curve profile and 24-hour average generation of a large wind power plant in Romania named Tariverde.

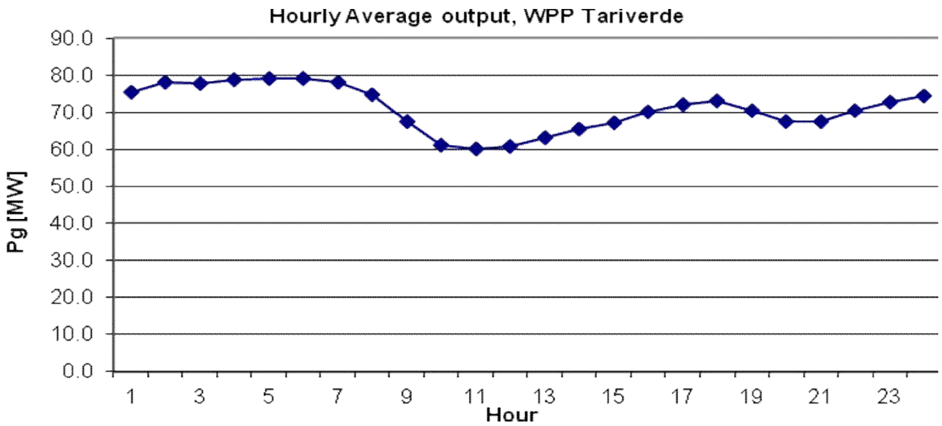

Fig. 3 - Hourly average of generation for a large wind power plant in Romania

It can be easily seen that the two curves are opposite, at night wind blows stronger than it blows during day time. Desirable case would be when second curve follows the first curve, by simultaneously increasing and decreasing. In Romania wind power plants operate at less than 20% of their total capacity and many times they were restricted especially at night, therefore more electricity consumption at night will let them operate with fewer restrictions.

At the national level, electricity consumers do not play an active role and there is no informatics system to assist decision makers. Thus, the prototype, through the prosumers' module can analyze electricity consumption based on their profile and to find optimal solutions for electricity supply that lead to actions meant to diminish electricity bill and also to avoid the limitation of wind power plants' generation. This system can change the consumer behavior as a result of ATS and SM that indirectly lead to large scale integration of RES (especially wind).

5. Research methodology

For analysis and design of informatics systems prototype, an object oriented methodology is used within an iterative development cycle. Iterative development cycle represent a succession of stages, one after the other, at each iteration a part of the entire system is achieved and validated and it is considered as starting point for the next iteration. In this cycle, each new iteration contains previous iterations with more details, modifications, by adding or eliminating some elements defined prior to it. Prototype's architecture is designed on three levels, accordingly to the decision support systems architecture described in [11], [13]: *data, models* and *interfaces* and each level contains specific methods and techniques (figure 4):

- *at data level*, data collecting and processing technologies are used. Data, provided by smart metering systems from all electricity consumers located in a certain control area, is integrated into several models of analysis and reporting at each grid operator responsible for its control area;
- *at models level*, in order to determine changes in electricity consumers' behavior and optimize consumption, algorithms and methods for extracting knowledge from data are used. Data mining techniques have an important impact because the process of automatic learning focuses on extracting regularities from the available set of samples;
- *at interface level*, for reports and dynamic analyses, business intelligence technologies are used.

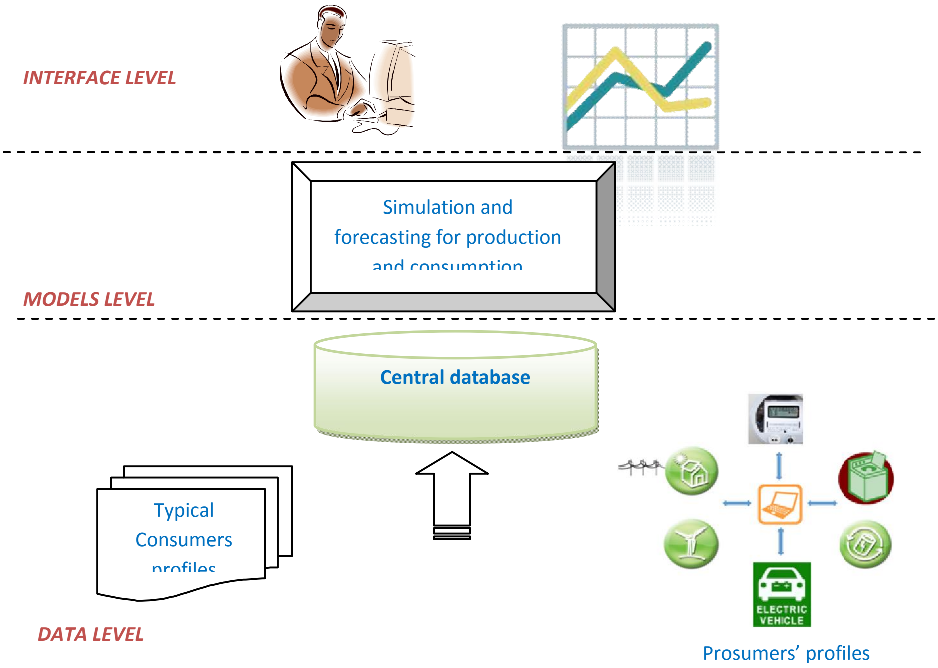

Fig.4 – Prototype's architecture

The following stages are followed in order to design and develop the prototype:

Stage 1 – Global analyses with following activities:

- planning activities for identifying the main and detailed requirements for designing informatics system;
- study of metering system functionalities emphasizing links and correlations with informatics system;
- SWOT analysis for advanced tariff systems;
- study of load profile for household and non-household consumers or prosumers based on activities and working regime;
- analyze the optimization solutions for electricity consumption supplied from smart grids that include SM, controllable and non-controllable appliances, micro-generation (prosumers), storage equipment, etc. Optimization module contains all possible options; each of them could be

activated by request (for instance micro-generation and storage should be flexible options depending on each type of consumer).

Stage 2 – Models designing with following activities:

- design the data model that collect and integrate data from SM. This activity consist in identification of data sources for desirable prototype and identification of methods for integration and processing of data into a central database;
- develop data mining algorithms for detailed analyses of electricity consumers or prosumers types in order to estimate their behaviour. Based on the data model, algorithms such as clustering, regression, classification and association are applied, comparing their performances;
- develop the electricity consumption optimization model at consumers or prosumers level that covers its needs with minimum costs for electricity and considering even revenues in case of prosumers;
- develop the analysis model at grid operators level that help them to know real time electricity consumers/prosumers' behaviour and better plan their resources for grid operation.

Stage 3 – Building of informatics system prototype. This stage consists in the following activities:

- achievement of prototype functionalities at electricity consumer or prosumer level. Online friendly interfaces are needed, available on mobile devices;
- achievement of data model at grid operators level. The central database allows the implementation of analysis models for obtaining reports for grid operation activities;
- achievement of prototype functionalities at grid operator level by business intelligence tools that deliver dynamic reports, dashboards for information related to real time electricity consumption;
- testing and evaluation of informatics prototype. Prototype functionalities are tested by using real time data and simulations. Future development directions and main risks about informatics system implementation are identified. In this sense, hedging measures are defined.

Informatics system prototype based on proposed solutions analyses types of electricity consumers or prosumers (householders, non-householders, controllable and non-controllable appliances) and evaluate supply of electricity consumption from own micro-generation, opportunity of generation/consumption to/from the grid, frequency and duration that characterize consumption, etc. The controllable appliances can be automatically shut down/started up based on optimization model via online interfaces and for the other appliances, based on data mining algorithms that extracted knowledge from previous behavior, it offers optimal variants of operation according to some factors such as frequency and duration of operation and electricity price.

In this way, electricity consumers or prosumers play an active role being capable to contribute to generation/consumption balance in the power system, flatting fluctuations that come from RES and helping to better integrate large size RES.

Conclusions

In this paper a brief overview about electricity consumption optimization based on consumption profiles of electricity consumers or prosumers that are connected to smart grids is given. The main object of this approach is identification of informatics solutions for electricity consumption optimization so that electricity bill to significantly decrease. In this way larger scale integration of renewable sources is allowed therefore entire society will gain benefits. This paper describes the main objectives of such informatics system and stages for its implementation. The prototype analyzes the specific profile and behavior of each electricity consumer, automatically assists him to make right decisions and offers optimal advice for usage of non-controllable appliances. It serves based on big data transfer from electricity consumers or prosumers as a powerful tool for grid operators that is able to better plan their resources.

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