Cloud Computing and Smart Grids

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Increasing concern about energy consumption is leading to infrastructure that supports real-time, two-way communication between utilities and consumers, and allows software systems at both ends to control and manage power use. To manage communications to millions of endpoints in a secure, scalable and highly-available environment and to achieve these twin goals of 'energy conservation' and 'demand response', utilities must extend the same communication network management processes and tools used in the data center to the field. This paper proposes that cloud computing technology, because of its low cost, flexible and redundant architecture and fast response time, has the functionality needed to provide the security, interoperability and performance required for large-scale smart grid applications.
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1 Introduction

Energy plays a fundamental role in shaping the human condition [1]. The main activities of social life are energy production and consumption. This is not surprising considering the fact that modern people's necessity for energy is important for existence. Also, it is said that the standard of living and quality of civilization are proportional to the quantity of energy a society uses [1].

The World Energy Council has presented several scenarios for meeting the future energy requirements with varying emphasis on economic growth, technological progress, environmental protection and international equity. During 1990-2050, the primary energy consumption is expected to increase by 50% according to the most environmentally conscious scenario and by 275% according to the highest growth rate scenario. [2]

In 2007, The European Council adopted ambitious energy and climate change objectives for 2020 – to reduce greenhouse gas emissions by 20%, rising to 30% if the conditions are right, to increase the share of renewable energy to 20% and to make a 20% improvement in energy efficiency [3]. The European Parliament has continuously supported these goals. The European Council has also given a long term commitment to the decarbonisation path with a target for the EU and other industrialised countries of 80 to 95% cuts in emissions by 2050 [3].

Energy efficiency is the most economical way to ensure safe, secure, sustainable and affordable energy for all, utilities and consumers, with greater environmental responsibility, by improving energy security and competitiveness, and reducing emissions. The research directions should be oriented on the whole energy chain, from energy production, thru transmission and distribution, to consumption.

An electrical network architecture is purposed for generating, distributing and administering efficiently the power consumption to end-users, known as Smart Grid.

1.1. Defining Smart Grid

The European Technology Platform Smart Grid (ETPSG) defines the smart grid as "an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies". [4]

According to the NIST [5], a Smart Grid is a complex infrastructure composed of seven main domains [6]:

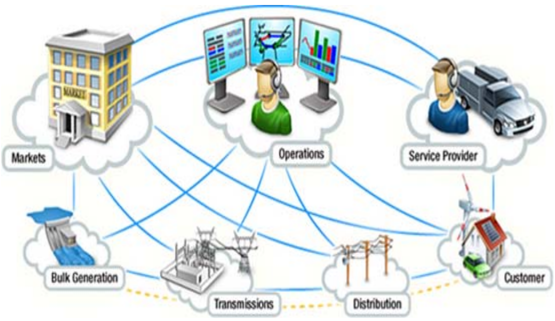


Figure1. General view of a Smart Grid [6]

- *Bulk generation* is the first process in the electricity supply to customers. The actors in this sub-domain are responsible for the bulk generation of electricity and the corresponding control, measurement, protection, and recording, procedures.
- *Markets.* The information management part of this sub-domain provides information support for the analysis and optimization of the pricing, for the balance of supply and demand, and for the energy trading between bulk generators, utilities, transmission operators, and customers.
- *Service providers.* The actors in this sub-domain typically perform a variety of functions that support the business processes of power system producers, distributors and customers [6]. The interfaces to the Operations domain are critical for controlling and warning the system but the interfaces to the Markets and Customer domains are influencing the economic advance through the improvement of the services.
- *Operations.* The typical applications performed within the Operations domain may include: network operation, network operation monitoring, network control, fault management, operation feedback analysis, operational statistics and reporting, real-time network calculation, dispatcher training [6].
- *Transmission* is the bulk transport of electricity from sources to distribution through multiple stations. The actors use monitoring information to manage the operations in this system, like optimizing power flows and asset utilization or improving reliability.
- *Distribution.* This domain is electrically linked with the transmission system and the customer sub-domain at the metering points for consumption. The actors in this sub-domain should manage in real-time a large amount of monitoring and control information.
- *Customers* are allowed to manage their energy usage, generation and storage. There are three types of customers within the customer sub-domain: industrial, commercial/ building and home. The limits of these domains are typically set at less than 20kW of demand for Home,20-200kWfor Commercial/ Building, and over 200kW for Industrial [6].

These smart grid systems offer substantial benefits for society: increased efficiencies and information availability can enable cheaper and greener energy generation, less loss in energy storage and transmission, better fault isolation and recovery, and support for widespread consumer use of alternative energy sources [7].

1.2. Defining cloud computing

The National Institute of Standards and Technology (NIST), defines cloud computing as "a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.” [8]

Figure 2. Cloud multi-access attribute [7]

Various definitions of cloud computing are circulating due to technology attributes and characteristics evolution but the common component of most definitions is that the cloud computing is an emerging computing model by which users can gain access to their applications anytime they want, from anywhere, through any connected device.
Cloud computing have four techniques Virtualization technologies, Security Management, Programming model and Data Management [9].

2. The cloud hits the smart grid

Even now the impact of the revolutionary cloud technology over smart grid is studied almost at theoretical level and also the advantages of this transformation of the power industry are not so well defined.
However this is starting to change since both the administration and the industry realize the interaction between these two models and the increasing interest for exploring and understanding of how the cloud hits the smart grid to the next frontier of heights.
The exponential development of the power industry requires progressively enormous and real-time computing and storage capacity. In smart grid concepts, the amount of these resources will grow in all levels of the grid in a uniform distributed manner. Here, the cloud model comes into the scene and becomes very significant.
Cloud computing is probably the simplest and best fitted way for these kind of application (smart grids) due to its scalable and flexible characteristics, and its capability to manage large amounts of data.
The construction of a smart grid necessitates large-scale real-time computing capabilities in order to handle the communication, the transport and the storage of big transferable data. But once the distributed entities are in place, cloud computing will unload the smart grid by offering automatic updates, remote data storage, reduced maintenance of IT systems – saving money, manpower and energy.
In recent times, researchers have studied how to use cloud computing to manage the smart grid.

- Yogesh Simmhan et al. [10] analyzed opportunities and challenges of using cloud platform for demand response optimization in the smart grid.
- Hongseok Kim et al. [11] proposed a cloud-based demand response architecture for fast reply time in large scale deployments, in contrast to master/slave based demand reply where the customers directly interact with the utility using host address- centric communication.
- Mohsenian-Rad et. al. [12] formulated the service request routing problem in cloud computing together with the power flow analysis in the smart grid and explained how this can lead to grid-aware cloud computing routing algorithms.
- Cristina Alcaraz et. al. [5] described some security mechanisms that will help in a better integration of smart grid and clouds.
- Sadia Fayyaz et. al. [9] focuses on security issues for smart grid

applications using cloud computing framework.

- S. Rusitschka et al. [13] presented a model for the smart grid data management based on specific characteristics of cloud computing, such as distributed data management for real-time data gathering, parallel processing for real-time information retrieval, and ubiquitous access.
- Nikolopoulos et al. [14] proposed a decision-support system and a cloud computing software methodology that bring together energy consultants, consumers, energy service procedures and modern web interoperable technologies.
- Xi Fang et. al. [15] analyzed the benefits and opportunities of using cloud computing to help information management in the smart grid.

Although smart grids seem fit for using in cloud computing, there are some views against. For example, Cornell University Computer Science Department identified breaches in the cloud computing technology, properties that power control and similar smart grid functionality will need [16]. These include security, consistency, fault tolerant services, real-time assurances and ways to protect the privacy of sensitive data. Their conclusion is that the cloud is not ready at this time to run the smart grid, but could be in the future if sufficient research is done.

3. Interactions between cloud computing and smart grids

Data centers, with massive computation and storage capacities, are key elements of the cloud computing.

K. Nagothu et al. [17] proposed to use cloud computing data centers as the central communication and optimization infrastructure, supporting a cognitive radio network of smart meters.

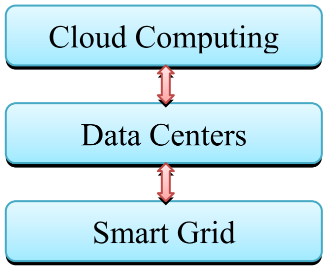


Figure 3 . The interactions between cloud computing systems, data centers and smart grid [12]

Data centers have a major impact on the electric grid by increasing the load at their locations. In order to reduce their high energy consumption and with the cooling problems that datacenters have, cloud providers decided to use some innovative methods of housing their centers operations. For example,

- Sun Microsystems has a data center located in an abandoned coal mine in Japan. Because of the constant, cool 59°F temperatures, no air conditioning is needed, so energy costs is cut down.
- In 2007, Google filed a patent for a first-of-its-kind “water-based data center”. The patent calls for electricity from tides and cooling from sea water. Building data centers offshore would allow Google to place its jurisdiction outside of the U.S. and in the same time by avoiding U.S. taxes.
- The latest idea about where to build and deploy data centers is “data centers in space”, powered by solar cells, propelled and steered by light pressure, networked and located by microwaves, and cooled by radiation into deep space [18].

Other weird data centre locations are: missile bunkers (Washington), old shopping malls (Eastgate Consumer Mall in Indianapolis), the 19th century chapel in Barcelona (The Barcelona Supercomputing Center), Siberia with its rough winters and the average temperature below 0^{o} C (Microsoft), servers in oil baths and fish tanks.

4. The twin goals of energy conservation and demand response

The critical service of an electric power grid is to balance the supply and demand of electricity at any occurrence of the situations: demand exceeding supply, or the supply exceeding demand. Both these situations threat the stability of the grid, and consequently power generation must track the load. These states are based on the time of the day and weather conditions.
The grid is designed to reduce demand during peak periods by making use of the metering technologies and communication protocols.
Smart meters, parts of the smart grid, provide an economical way of measuring "when" and "where" of energy consumption, allowing energy suppliers to introduce differential pricing based on the time of day and the season.

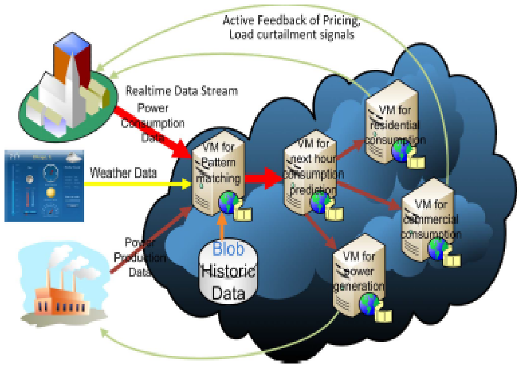


Figure 4. Smart Meters at consumers interacting with demand-response applications in the Cloud [10]

The utility agency and customers interact through the cloud, and the functions, to realize demand response. These requests are performed in a cloud rather than in the utility's energy management system.

5. Smart grid application in the cloud

The smart grid has a lot of applications but this paper focus on electricity management in smart homes.

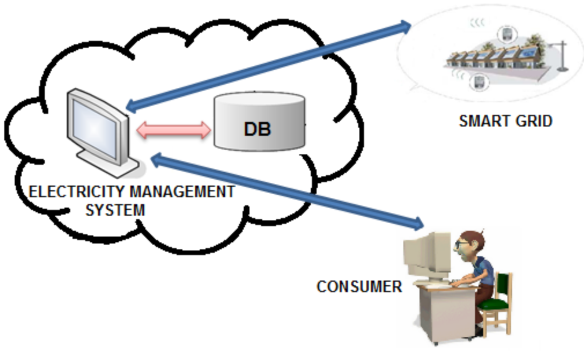


Figure 5. Our vision in the cloud

Figure 6. Electricity management system – main interface

The application brings a number of benefits to the electricity company, consumers and the environment, in terms of its functionality:

- Customers evidence (households, associations, buildings) (Fig.7)
- Follow electricity consumption indicators and temperature in real-time
- Reading at fixed intervals electricity consumption indicators
- Customer recommendations on the best tariff plans according to each user profile

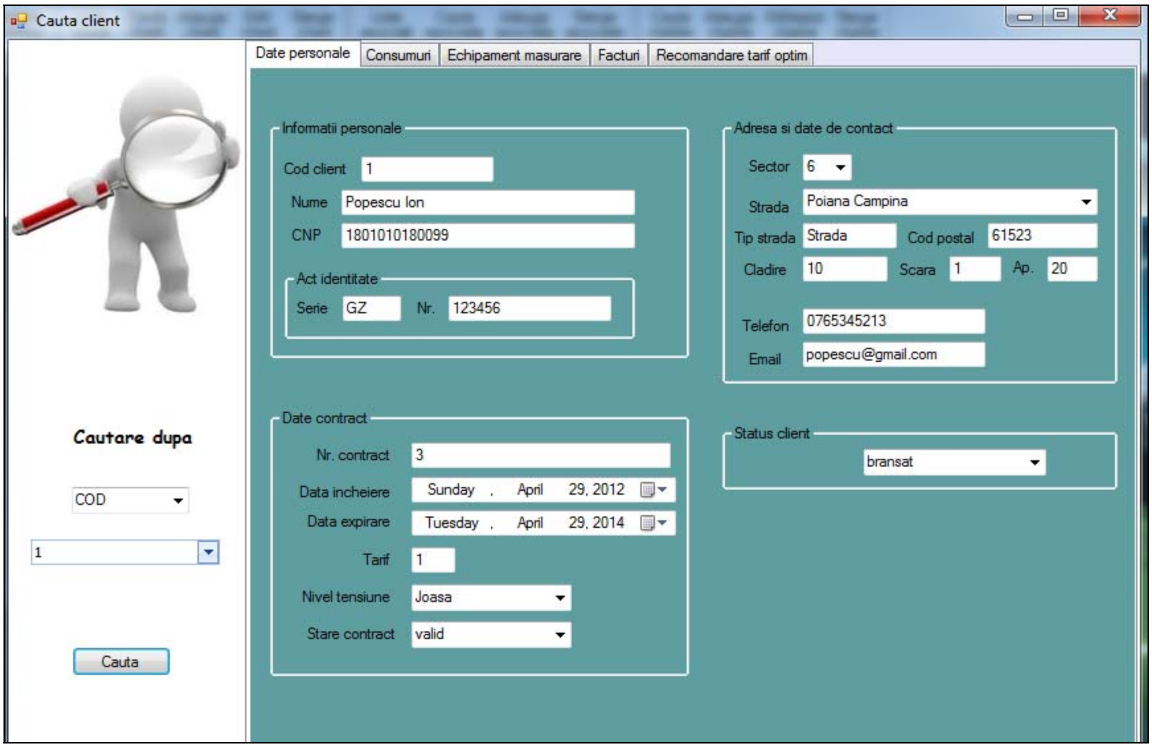


Figure 7. Customers evidence - interface

- Presentation of electricity consumption (through dynamic analysis, graphs and reports)

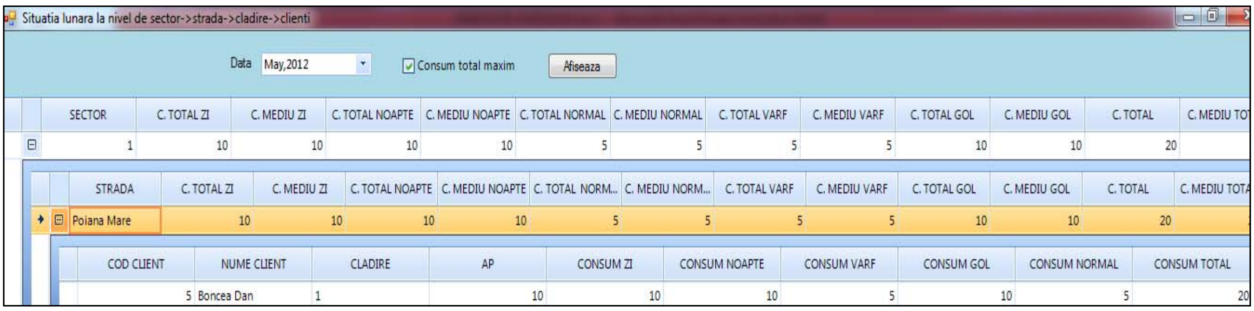


Figure 8. Monthly electricity consumption - interface

- Outbreak alerts based on measurable factors and notifying approved persons by desktop alerts and emails

- Calculation and application of penalties
- Automatically issue invoices each month
- Disconnecting bad-payers and notifying them by email
- Presentation of financial statements (issuing and paying invoices, billing, debt)

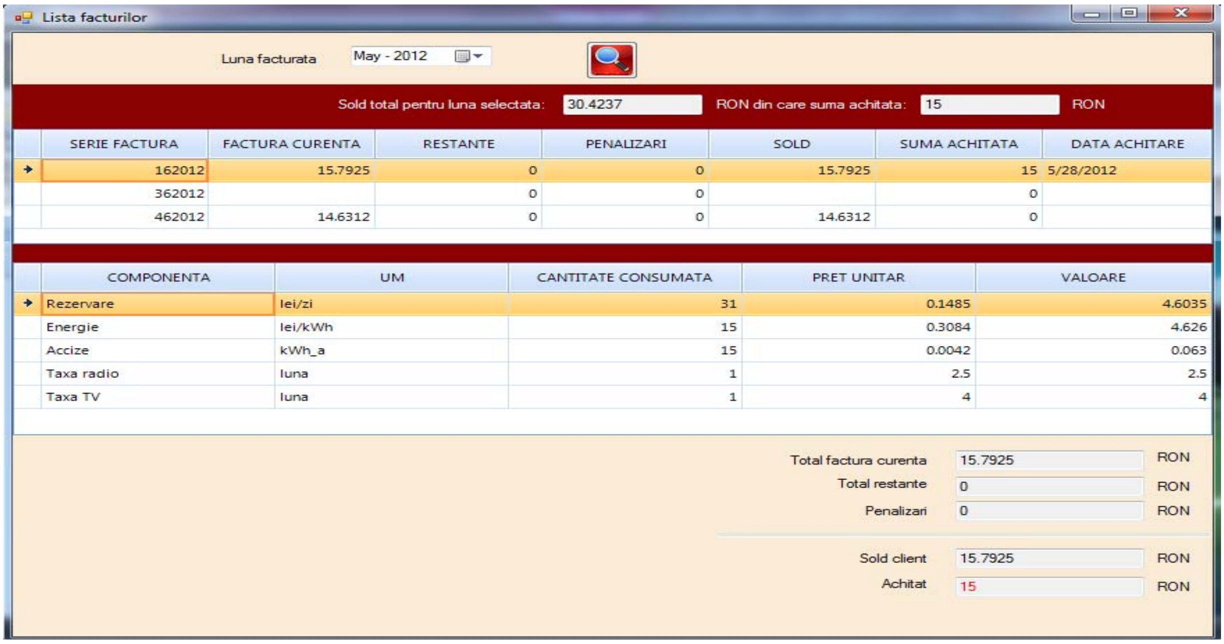


Figure 9. List of invoices - interface

- Identifying abnormal power consumption caused, for example, by the malfunctioning equipment and sensors distribution map with markers specific to each state.

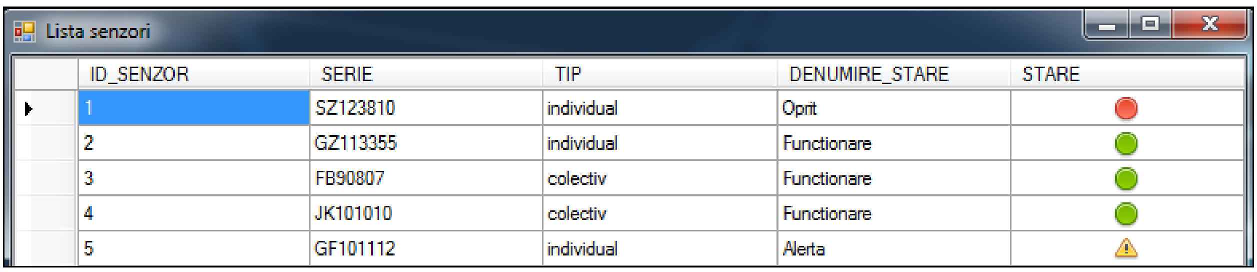
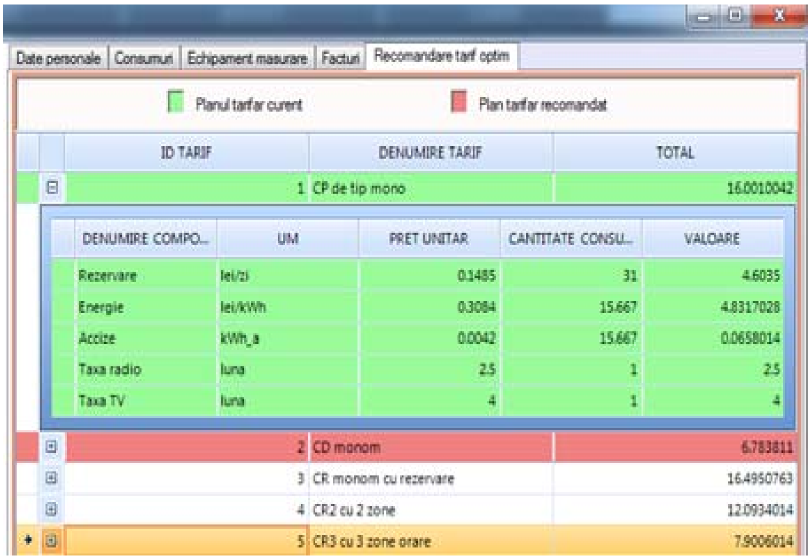


Figure 10. Sensors - interface

Figure 11. Sensors distribution map

Information on real-time energy usage and power pricing will need to be shared with consumers. The web presence of cloud platforms again is well suited for this.



ID TARIF	DENUMIRE TARIF	TOTAL
1	CP de tip mono	16.0010042

DENUMIRE COMPO...	UM	PRET UNITAR	CANTITATE CONSU...	VALOARE
Rezervare	lei/zi	0.1485	31	4.6035
Energie	lei/kWh	0.3084	15.667	4.8317028
Accize	kWh_a	0.0042	15.667	0.0658014
Taxa radio	luna	2.5	1	2.5
Taxa TV	luna	4	1	4

ID TARIF	DENUMIRE TARIF	TOTAL
2	CD monom	6.783811
3	CR monom cu rezervare	16.4950763
4	CR2 cu 2 zone	12.0934014
5	CR3 cu 3 zone orare	7.9006014

Figure 12. Optimal tariff plan

Knowing in real-time their energy consumption, homeowners can organize their energy consumption and reduce their utility bills. Also this application recommends optimal tariff plan according to customer profile.

6. Conclusions

Industry and economy depend on safe, sustainable and inexpensive energy. Lots of homes and businesses have been connected to regional and national networks that enable real time reporting and control of energy use.

Bringing cloud to smart grid will add optimal influence and substantial improvements in the performance of the whole grid for the current existing computing and storage capabilities.

The next steps in our research activities will transfer some of the decisional algorithms into the cloud for covering a larger area of inputs much easier. Also the cloud technology will help adopting a feasible solution for multi-sensorial consumer specific operations.

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