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Smart Electric Vehicle Charging System

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***Abstract*—In this work is proposed the design of a system to create and handle Electric Vehicles (EV) charging procedures, based on intelligent process. Due to the electrical power distribution network limitation and absence of smart meter devices, Electric Vehicles charging should be performed in a balanced way, taking into account past experience, weather information based on data mining, and simulation approaches.**

In order to allow information exchange and to help user mobility, it was also created a mobile application to assist the EV driver on these processes. This proposed Smart Electric Vehicle Charging System uses Vehicle-to-Grid (V2G) technology, in order to connect Electric Vehicles and also renewable energy sources to Smart Grids (SG). This system also explores the new paradigm of Electrical Markets (EM), with deregulation of electricity production and use, in order to obtain the best conditions for commercializing electrical energy.

I. Introduction

New paradigms are emerging, like the Electric Vehicle (EV), the Smart Grids (SG), the Vehicle-to-Grid (V2G), and the Electrical Markets (EM). EM is the consequence of the deregulation of electricity production and use, and in this reality, power suppliers and consumers are free to negotiate the terms of their contracts. Also EVs integration on current electrical distribution network, without violating the system's technical restrictions, requires electrical data consumption analysis and smart charging approaches, where EV batteries charging or discharging processes need to be coordinated among the several users. In this complex scenario, information knowledge related with charging periods, prices, decision of charging or discharging EV batteries, needs the assistance from data mining processes. Several issues have to be considered and analyzed before taking action. Although enormous data volumes related with this processes are stored day by day, and hour by hour, it is impossible (through human analysis or with traditional technology) to obtain knowledge from this data, in order to take wise decisions. This topic already catches a lot of attention of the scientific community under the topic of EM [1, 2, 3], and in this paper it is proposed a similar approach for the charging or discharging process of the batteries in an EV. This new reality brings additional problems, such as: (1) overload of electrical energy distribution network, if there is a considerable amount of EVs charging at the same time; (2) home consumption and contractual power limitation; (3) buying electricity at lower prices when renewable energy is produced in excess, and selling electricity at higher prices when the demand for energy is superior to the offer in the electrical network. Smart Grids with measuring devices and a communication infrastructure, among other devices, is part of a solution for this problem in a near future, and therefore, the proposal here presented could facilitate the creation of SG (because it is possible to perform some functions related with the control of power available in the electrical network based on historical data), and later, the proposed system, integrated on a SG, also could execute tasks related with EM (finding the hours with best prices for charging or discharging the EV batteries, and other home personalized functions).

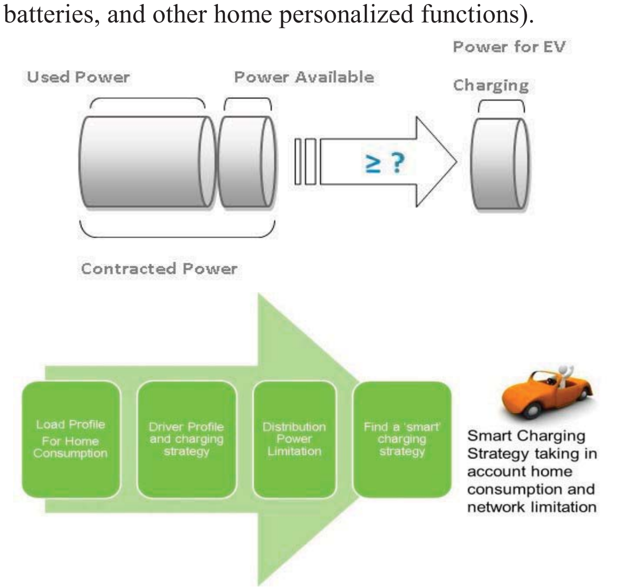

Fig. 1. Main system goals.

In this paper is proposed a smart charging system to achieve the goals identified in Fig 1, i.e. taking in account home consumption, distribution network limitations identify a smart charging strategy. This system is based on a central information repository can store and manage historical data on electricity consumption and production. From this central repository it is possible the development of tools to extract knowledge from past electricity exchange log files, EM

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prices, renewable energy availability, home energy consumption (if EV is connected at home) and electrical distribution network constraints. Also, the weather information can be used for the forecast of energy production from renewable energy sources, and the EV users arrival and departure times from home (obtained from a tracking device) can be used for consumption timing optimization (e.g., users can change their behavior, and thus historical data needs to be fitted). This central repository will be later, in a Smart Grid environment, a fundamental module to store all kind of SG data and to solve the problems of different data format diversity.

II. Smart EV Charging System

Our investigation proposal is to bring computer science work on software development, Web 2.0, geographic information systems, mobile computation and wireless communication, to a new growing area of Smart Grids (SG) and EV (Electric Vehicle). Due to the increasing complexity and diversity of options, users in Electrical Markets (EM), when performing an EV charging process, will need the help from software application, mainly to mobile devices. So our proposals, presented in this paper, are the conception and the creation of a mobile application and surrounding system, to help users on EV charging or discharging process, and also on EM participation.

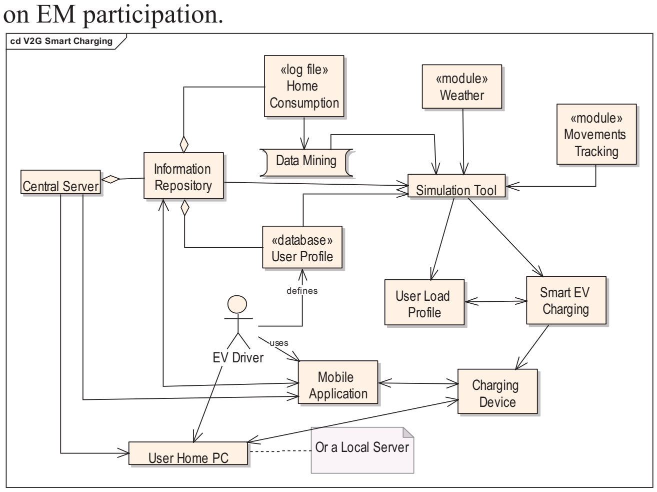

Fig. 2. Main modules of the Smart EV Charging System.

The main modules of the proposed system, called Smart EV Charging System, and which is illustrated on Figure 2, are: (1) Central Repository, with information about user energy consumption (amount and time), energy production with available information of power, energy supplier and source (e.g., hydropower, wind power, photovoltaic, etc), energy prices and weather information (temperature, wind direction and speed, rain amount, solar radiation, etc), user profile information; (2) Weather module, based on a web robot to pick weather information from pre-defined sites; (3) Movements Tracking application, developed for a mobile device with GPS functionality; (4) Simulation Tool, based on Netlog; (5) Charging Device; responsible for charging or discharging the EV batteries; and (6) Mobile Application, an application to run on a mobile device (like PDA or IPphone) to receive and send control information for charging the EV batteries. These modules are described in the next sections.

A. Weather Module

In the residential and commercial sectors, heating and cooling account for more than 40 percent of end-use energy demand. As a result, energy consumption in those sectors can vary significantly from year to year, depending on yearly average temperatures (http://www.energy.eu/). Several studies prove a relation between electricity consumption and temperature, especially for higher temperatures (most peak power consumption were reached on very hot days [4]). Cooling is related with air conditioners (electricity powered) and heating with central heating (gas powered), so peak electricity consumption occurs in hot summer days [4]. As indicated in Figure 3, there is a high correlation between the simple average daily temperature from the four sites selected and daily electricity demand in the CalISO region, which comprises most of the state of California, in the USA [5]. This relation has been observed by several authors [5, 6], and there is more or less 1% of electricity demand increase by 2ºC of temperature rising. Once this Weather Module application is running, it will be possible to estimate this relation.

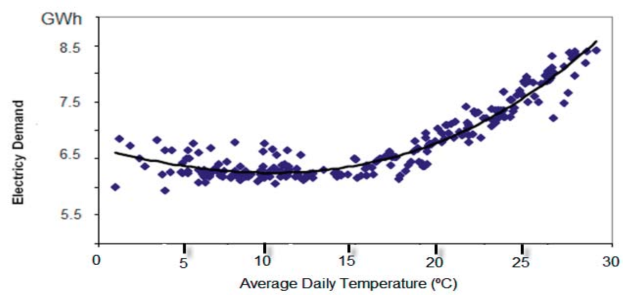

Fig. 3. Electricity demand in the CalISO area as function of average daily temperatures: 2004 [5].

A Web crawler (Web Content Extractor) was configured to take information from the main Portuguese weather site (www.meteo.pt). From the Web pages extracted with predefined forms we take information related with temperature, wind (direction and speed), rain and solar conditions (e.g, sunny, cloudy, etc). This crawler runs in a pre-defined periodicity and the information is stored on a database. In a near future we intend to add more information from different web sites and merge this information on the proposed database. When a failure occurs the previous available values are stored in the DataBase (DB). Temperature data is related with electricity consumption, and the other parameters are associated with renewable energy production: wind to Eolic, temperature and solar radiation to Photovoltaic, and rain to Hydropower production.

The weather data is geo-referenced (several locations were considered) and is stored in an information repository correlated with:

Temperature with average consumption. We apply

KMeans algorithm to identify main groups. The first groups are: (1) bellow 0ºC; (2) from 0ºCto 8ºC; (3) from 8ºC to 18ºC; (4) from 18ºC to 26ºC; (5) from 26ºC to 31ºC; (6) from 31ºC to 35ºC; and (7) above 35ºC. From this centroids data (average consumption) we calculate the percentage of consumption change due to group change;

Wind speed and direction with Eolic production;

Temperature and weather conditions with Solar Photovoltaic production;

Rain in month's periods with Hydropower production capacity. We propose in a near future to try to identify which is the best time period to collect rain data.

B. Tracking Drive Distances and Times

We have developed a tracking application to run in an offline mode (to avoid communication costs) in a mobile device with a GPS device. Our project is described at [7], and its high level vision is showed in Fig. 4. This tracking application mainly stores time, GPS coordinates and user identification. From the GPS coordinates it is easy to calculate travel distances. Using Google Maps API we can represent the drive route and obtain the travel distance.

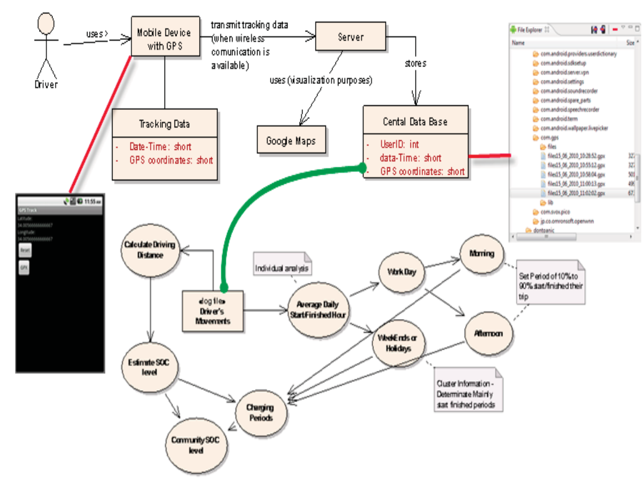

Fig. 4. Main module of driver's tracking system in a mobile device with GPS, and information created from Drivers Movements database.

From the travelled distance and EV efficiency we can estimate the remaining energy stored in the batteries of each EV (SOC – State of Charge level), as well as the community SOC level (sum of all individual community SOC levels). The studied population (from the city of Lisbon area), with 50 cases, contains a mixture of university students and their parents, and takes into account the first EV introduced in Portugal, the Nissan Leaf, with a battery pack of 24 kWh and autonomy of 160 km (obtained with a careful driving).

C. Home Consumption Simulation

An agent based simulation attempts to simulate an abstract model of a particular system. Computer simulations have become a useful part of mathematical modeling of many natural systems in physics, chemistry and biology, and of human systems in economics, psychology, social science, and engineering. Simulations can be used to explore and gain new insights into new technology, and to estimate the performance of systems too complex for analytical solutions. This approach already has been applied for EM [8, 9, 10], creating a simulation environment for market prices determination based on consumers demand, and for production capacity of producers. Our main idea is to simulate consumers consumption taking also into account unexpected user behavior, using past experience (consumption log files), and then, represent the information in an electrical network distribution graph (see Fig. 5).

There are several tools that can be used for this purpose, from which NetLogo tool has been chosen. NetLogo is a free agent-based simulation environment that uses a modified version of the Logo programming language, providing a graphical environment to create programs that control graphic "turtles" that reside in a world of "patches," which is monitored by an "observer". NetLogo also includes an innovative feature called HubNet, which allows groups of people to interactively engage in simulation runs alongside of computational agents.

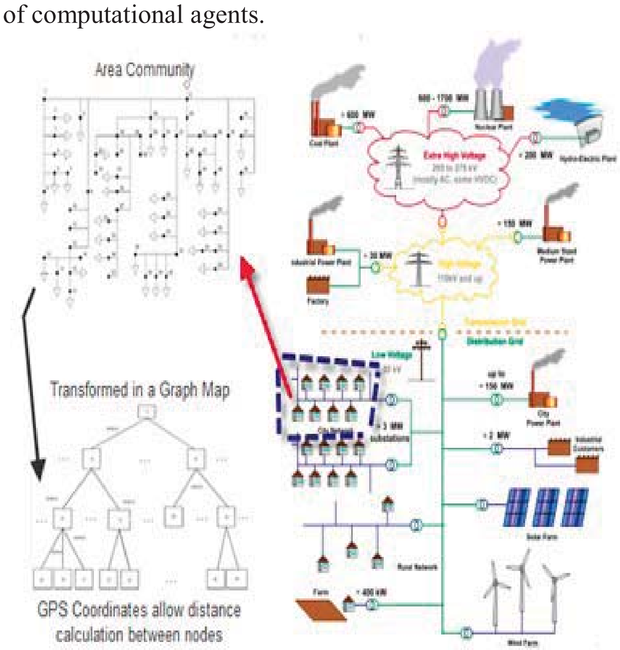

Fig. 5. Electrical network distribution, transformed in a graph.

The area with the distribution of the electrical network is manually transformed in a graph, where we add geographic information and power limitation between the nodes. This is a slow process where we expect in a near future to introduce some automation. Assumptions on consumer's behavior are considered: (1) Consumers define their house and family (number of house divisions, number of persons); (2) They define the number and type of electrical appliances from a pre-defined list; and (3) They define also their usual routine (arrival time, departure time). Tracking system data can tune arrival and departure times. Every consumer has its own behavior and changes or unexpected behavior are randomly generated at the beginning of the experiment, using an array of integers. Each consumer is represented by an agent who knows contractual power limitation and also the distribution.

On the simulation tool (Netlog) we follow a bottom-up approach where we estimate consumption based on consumer profile and historical consumption data. Weather information (temperature) is used as a percentage increase factor on usual consumption. Each consumer is represented by an agent that is based on historical data, profile and temperature information, based on a random function for energy consumption, which is estimated at every 15 minutes (this time interval is configurable). Each agent has a utility function, but the agent is not optimizing it because this process is too expensive under many aspects: in terms of information retrieval cost, in terms of information processing costs from a computational point of view, and in terms of cognitive effort in searching alternatives. We decide to model each consumer as a node on a network distribution graph. Simulation takes into account house power limitation contract and electrical energy distribution limitations.

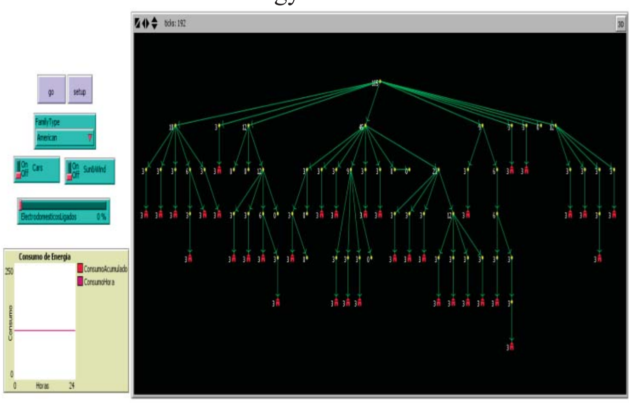

Fig. 6. Simulation application on Netlog. Red color shows that power limitation is reached with EV charging, so a smart charging approach is need.

Main Output information is the visualization of electrical distribution network on a graph with the indication of power limits. Red color means above power capacity, which indicates that EV charging should be processed in intelligent interactive process; green color means that we can charge EV batteries on full power. We can estimate consumption and use this information for a smart EV charging, without measuring devices and real time information. The main application screen of the consumption simulation is illustrated on Fig. 6. The first step was to estimate the energy consumed per household and given the power to contract determine the free energy for charging. The join this factor limiting the distribution system in which one branch of a transformer is dependent on average limited to 80% of this potential extension of established contracts. So depending on the percentage of existing VE, we may have additional limitations. Table 1 presents data used and taken from the simulation of families, as well as the type of VE that have (we assume one per family), and the average distance traveled daily. Main results in Fig. 7 and Fig. 8, for more details of results see [11]. These studies were oriented to simulate domestic consumption and distances traveled determine the most appropriate forms of loading. Regarding the time of day where there is a greater amount of energy to use, have compiled the values of consumption per hour and it was found that intervals during the week ideal for charging electric vehicle would be between one and six o'clock in the morning range (A) or between nine and the sixteen hours (range B), see Figure 7. Since the end-to-week, the ideal the electric vehicle would be loaded between one and eight hours (range A) or between fourteen and sixteen hours (range B), see Figure 8.

TABLE II
DATA USED AND PRODUCED IN NETLOG SIMULATION

	Family type		EV Type	EV Range(km)	Daily Km	Power Available (kW)	Power Needed for EV Charging (kW)
Building1	T2	Small Family	Nissan Leaf	160	10	56,67	120
	T2	Small Family	Volvo C30	150	30	56,67	120
	T2	Small Family	Nissan Leaf	160	40	56,67	120
	T2	Small Family	Toyota Prius	48	50	56,67	120
	T2	Small Family	Volvo C30	150	30	56,67	120
	T2	Small Family	Toyota Prius	48	20	169,11	120
Building2	T4	Big Family	Volvo C30	150	20	132,75	120
	T3	Medium Family	Nissan Leaf	160	40	169,11	150
House 1	T4	Big Family	Chevrolet Volt	64	50	169,11	120
House 2	T4	Big Family	Toyota Prius	48	40	169,11	120
House 3	T4	Big Family	Nissan Leaf	160	50	169,11	150
House 4	T4	Big Family	Chevrolet Volt	64	100	169,11	120
House 5	T4	Big Family	Volvo C30	150	20	169,11	120
House 6	T4	Big Family	Nissan Leaf	160	40	1656,54	1740,00

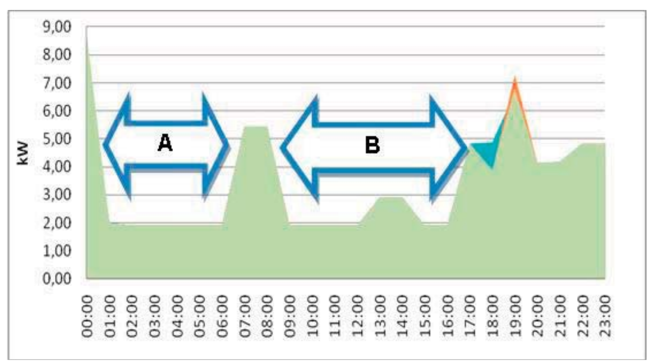

Fig. 7. Week days power distribution.

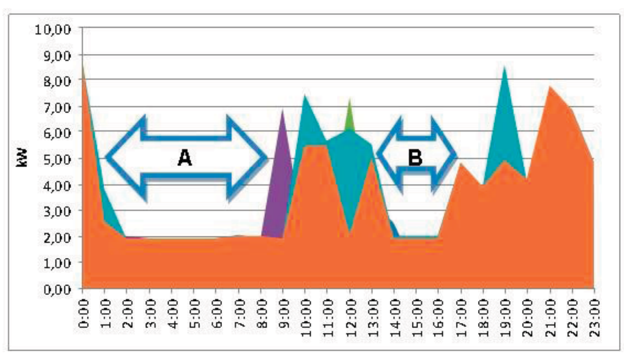

Fig. 8. Week-ends power distribution.

Relatively to Electrical Market (EM) functions, we can aggregate energy production and consumption data, and based on this simulation estimate prices and then determinate the best charging or discharging periods.

D. Mobile V2G Management System

Vehicle-to-Grid (V2G) technology utilizes the stored energy in Electric Vehicle (EV) batteries to deliver electricity back to the electrical network, when the network operators request it. Revenue from V2G will reduce the customer cost of EVs. Besides, V2G technology will also increase the efficiency and reliability of the existing electrical networks, decreasing fossil fuel use, and making possible a much larger share of intermittent renewable energy sources, like wind power and solar photovoltaic. EV charging will benefit from past data analysis and remote interaction. Mobile applications are a raising business area in Computer Science, with the widespread utilization of small mobile devices (e.g., PDA, IPhones), and the increase of bandwidth and availability of wireless communications. Our proposal is to implement communication devices to take data from charging devices and to send commands to them. This communication is performed from the Charging System to a user home PC or to a remote server. We shall differentiate communication devices and communication protocols to the following cases (see Table II): (1) Apartments, where distances to home computers or to the local server are considerable (in this case we will use Wimax); and (2) Individual houses, where distance to the home computer is small.

TABLE II
CHARACTERISTICS OF THE COMMUNICATION SYSTEM BETWEEN CHARGING SYSTEM AND PC OR SERVER

	Frequency	Transmission Rate	Distance
ZigBee	868 MHz (Europe)	20 kbps	10 – 100 m
	915 MHz (North America)	40 kbps	
Bluetooth	2.4 GHz	1 - 3 MHz	100 m (class 1)
IEEE 802.11p (G5)	5.85-5.925 GHz	10MHz	500m – 1000m
WiMAX	2 - 6 GHz	15 MHz	2 – 5 km

The main functionalities of the Mobile application are: (1) Registration: registration page for new users; (2) Password Recover: form for password recovery; (3) Login: home page of the application - the user is redirected to this page after login; (4) Profile Creation: page created for user profile by entering information on the EV; (5) Personalized Charge Profile: page load profiling, through the introduction of information regarding the date / time of travel, number of Km you intend to accomplish, and minimum SOC (State of Charge) allowed for the EV batteries; (6) Statistics: home energy consumptions, weekly, monthly and annual energy expenses, price variation of electricity, charging periods, among others.

The present application on the server is subdivided into five main modules: (1) Interpreter of Downloaded Files - this module will be responsible for reading and interpreting the files loading, giving the system a layer of abstraction over the file format of text issued by the loading system; (2) Smart Grid Interface - this module will be responsible for the interaction with the electrical network, i.e., it controls the flow of energy from or to the electrical network, with the objectives of helping network stability, and also, managing information on the variation of electricity prices, to optimize the profits obtained with the selling of energy to the electrical network; (3) User Manager - module responsible for registering the users and their EVs, allowing the recording and editing of users data, as well as the removal of users (if defined rules are not accomplished by specific users) - this module is also responsible for verification of user identity and ownership of registered vehicles (through the transmission of data received from the user to the authorities), and for performing regular cleaning from the database of users categorized as "spam"; (4) Manager Profiles - a user can set one or more load profiles for each of the vehicles registered by him. A common practice is, for example, the definition of profiles and needs of different charging to be carried out during the week (weekdays) over the weekend; and (5) Manager Central – consists in the main module of the V2G Smart System (see Fig 9), interacting with various modules mentioned above, and managing the distribution of system information (from other modules and database).

Fig. 9. V2G Smart System Mobile Application: (1) Main menu with information of user definition, statistics, and virtual account; (2) User profile; (3) EM prices - simulated with base on renewable energy production, based on installed capacity and weather information (wind direction and speed, rain percentage, temperature, solar radiation); (4) User account related with the EM; (5) Personalized menu links for user's fast access; (6) Application default menus; (7) EV and EM related news, created from personalized web search robot.

In relation to technologies to be used in the development of these applications, it was decided that, the management system database, using MySQL Server, will be weighting the choice that it is open source. The development of web application will be held in Java, and all graphical development will be carried out using the ZK Framework, which facilitates the development of Web applications with Ajax, and has the advantage of being open source. The development of the environment, using the Eclipse Project, will be integrated with the ZK plugin, with main modules: (1) ZK Loader - consists of a servlet (server side component that generates HTML and XML data to the presentation layer of a Web application) that processes the requests for resources zk; (2) ZK Client Engine - is processed on the client's browser and is responsible for monitoring the events page and realization of their requests to the server by Ajax technique. This engine is generated by ZK Loader when processing HTTP requests, and is sent in response to the client in the form of JavaScript code; (3) ZK Asynchronous Update - another servlet that serves asynchronously requests made by the ZK Client Engine. These requests are caused by interaction of the user with the various components of the page. The ZK Asynchronous processes the events triggered by the user, sending the response to the ZK Client Engine, encoded according to a protocol's own framework, which typically consists of changes to the page content; and (4) Index - home page of the application, from which the user can perform the login in the application or access the registration page if it is your first access. Fig. 10 shown the main application functionalities menu.

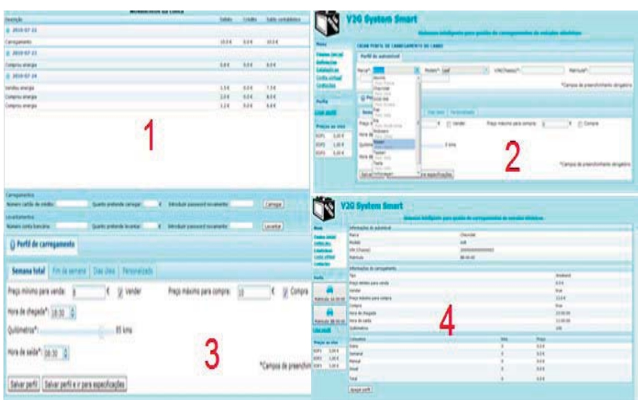

Fig. 10. Main application functionalities menu: (1) Tracking of electricity charging and discharging process; (2) Creation of a profile (pre-defined information, like EV type, helps the user on this process; (3) User profile with the identification of travel periods and electricity prices to sell and buy; (4) Report with all user profile information.

III. Conclusion

This paper describes work that has been developed in order to provide a conceptual system to assist and manage Electrical Vehicles (EV) charging process. This proposed Smart EV Charging System uses Vehicle-to-Grid (V2G) technology, in order to connect not only Electric Vehicles, but also renewable energy sources, to Smart Grids (SG). The new paradigm of Electrical Markets (EM), with deregulation of electricity production and use, is also explored in this developed system, in order to optimize the prices of selling or buying electrical energy, to or from the electrical network.

In the proposed Smart EV Charging System, the introduction of mobile applications will facilitate connectivity user's interaction. The Central Information Repository, with Data Mining approaches, can be used to program and assist smart EV charging, taking into account the electrical network distribution limitation. A simulation tool helps on this smart charging process, and can be used to identify overloaded electrical distribution lines, and also to simulate behavior and operating conditions under different assumptions. Electrical energy producers can also benefit from this data collection and manipulation, because they can tune their production according to users' consumption needs.

The application of Artificial Intelligent approaches has a great potential, once we are able to store consumption and production data and the knowledge information created, which can help both consumers and producers. Mobile devices and applications will help on the access to information. A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

Acknowledgment

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