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A Conceptual V2G Aggregation Platform

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Abstract— In this work is proposed the design of a system to create and handle an Electric Vehicle (EV) community, based on social networks collaborative approach and a credit mechanism to incentive participation and divide profits. This system is part of a V2G (Vehicle-to-Grid) module that allows EV owners to be aggregated in communities and participate in the electricity market. With this system it is possible for the EV owners to win money while the EVs are parked and plugged, delivering back to the electrical grid part of the energy stored in the batteries, increasing the attractiveness of EVs.

Keywords— Electrical Vehicle, Charging, Communities, Electrical Market, Aggregation

1. Introduction

The upcoming reality of smart grids, electrical vehicles, and electrical markets raise a diversity of problems, because an end-user is no longer a passive client. Also the charging and discharging process of an Electric Vehicle (EV) needs assistance of an intelligent process to find cheaper prices (mainly when energy from renewable sources is available), identify charging slots, and aggregate users in communities to participate in the electrical market (see section 2 for more details). The connection between power sources managed by a smart grid system and the EV is done by a Vehicle-to-Grid (V2G) system. That means that V2G enables EVs to both act as Distributed Energy Resources (DERs) and provide mobility services, bringing the transportation and the electricity systems together. Also EV charging process can be synchronized with the intermittency of renewable energy resources.

EVs and PHEVs (Plug-in Hybrid Electric Vehicles) are seen as one of the most promising means to improve the near-term sustainability of the transportation and stationary energy sectors [1].

Researchers have developed analyses and demonstrations of electric vehicles charging behaviour, but the long-term infrastructure and information architectures required for a massive market infiltration of EVs and PHEVs are not well defined yet. These studies have shown that the electrical grid could assimilate a significant fraction of a hypothetical national fleet of plug-in vehicles, performing V2G charging without significant infrastructure improvement, and without centralized charging control [2, 3, 4, 5]. Central utility control of EVs and PHEVs performing V2G has been shown to have significant benefits for the electrical grid system operator by enabling dynamic demand response, load profile flattening, and improved generation resource utilization [6, 7, 8]. However, fewer studies have considered the impacts of a fleet of EVs and PHEVs in the V2G system. Demonstrations have shown that single vehicles can interface to the electrical grid through V2G applications, and that given sufficient information infrastructure, the grid operator could control power flow from and to the vehicles [9] and [10].

Conceptual V2G studies have calculated that there exists a significant return on investment for the purchase of EVs and PHEVs, which can perform tasks to improve the electrical energy systems, mainly in the ancillary electrical grid services [9, 10, 11, 12, 13, 14, 15, 16, 17].

Also, these upcoming realities will benefit from a standardization process and from a high level of manipulation of information. In the present work it is proposed the conception of a system to create and handle an EV community, based on social networks collaborative approaches, in order to allow EV owners to win money, increasing the attractiveness of EVs.

2. Electric Vehicle and Electrical Market

On Figure 1 are identified the main vehicle types related with energy power supply. The main classes are the: (1) Conventional Vehicles, with ICE (Internal Combustion Engines), that present high CO_2 emission levels; (2) Hybrid Electric Vehicles (HEVs), commenced in 1997, in Japan, with the Toyota Prius, and which main specification is the utilization of one or more electric motors to allow the operation of the ICE on its more efficient interval, and also in order to permit regenerative braking; (3) PHEVs (Plug-in Hybrid Electric Vehicles), which are HEVs with additional capability to be charged from the electrical grid; (4) Electric Vehicles (EVs or EDVs - Electric Drive Vehicles), which are vehicles purely driven by electric motors; and (5) Fuel Cell Electric Vehicles (FCEVs), which are electric vehicles that use fuel cells as power supply.

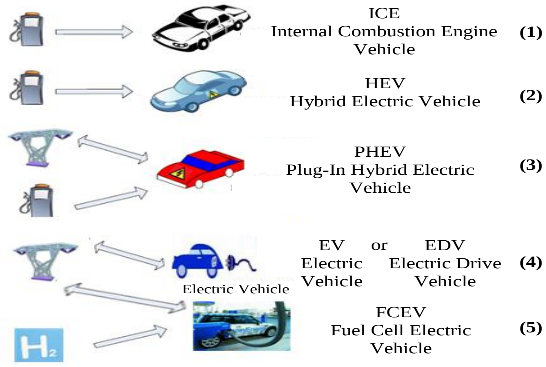

Figure 1: Main vehicle types.

The electricity industry throughout the world, which has long been dominated by vertically integrated utilities, is undergoing enormous changes. The electricity industry is evolving into a distributed and competitive industry in which market forces drive the price of electricity and reduce the net cost through increased competition.

A new concept appears: the electricity market. This market is a competitive trading of electricity, where a centralized mechanism facilitates electricity trading between buyers and sellers. The energy market's prices are reliable prices indicators, not only for market participants but for other financial markets and consumers of electricity as well. The main market stakeholders are: (1) ISO (Independent System Operator). The ISO is the leading entity in a electrical market and its functions determine market rules. A competitive electricity market would necessitate an independent operational control of the grid; (2) GENCOs (GENerating COmpanies). A GENCO operates and maintains existing generating plants. GENCOs are formed once the generation of electric power is segregated from the existing utilities. A GENCO may own generating plants or interact on behalf of plant owners with the short-term market (power exchange, power pool, or spot market); (3) TRANSCOs (TRANSmition COmpanies). The transmission system is the most crucial element in electricity markets. The secure and efficient operation of the transmission system is the key to the efficiency in these markets. A TRANSCO transmits electricity using a high-voltage bulk transport system from GENCOs to DISCOs for delivery to customers; (4) DISCOs (DIStribution COmpanies). A DISCO distributes the electricity, through its facilities, to customers in a certain geographical region. A DISCO is a regulated (by state regulatory agencies) electric utility that constructs and maintains distribution wires connecting the transmission grid to end-use customers; (5) RETAILCOs (RETAIL COmpanies). A RETAILCO is a newly created entity in this competitive industry. It obtains legal approval to sell retail electricity. A RETAILCO takes title to the available electric power and re-sells it in the retail customer market; (6) Aggregators. An Aggregator is an entity or a company that combines customers into a buying group. The group buys large blocks of electrical energy and other services at cheaper prices. The aggregator may act as an agent (broker) between customers and retailers. When an aggregator purchases energy and re-sells it to customers, it acts as a retailer and should initially qualify as a retailer; (7) Brokers. A Broker of electrical energy services is an entity or company that acts as a middleman in a marketplace in which those services are priced, purchased, and traded; (8) Marketers. A Marketer is an entity or a company that buys and re-sells electrical energy but does not own generating facilities; and (9) Customers. A Customer is the end-user of electricity, with certain facilities connected to the distribution system, in the case of small customers, and connected to the transmission system, in the case of bulk customers.

3. Driver Behavior

We have developed a tracking application to run in offline mode (to avoid communication costs) in a mobile device with GPS system. This project is described at [18], and a high-level vision is showed in Figure 2. The developed application stores time, GPS coordinates and user identification. From the GPS coordinates it is possible to calculate travelled distances, and using Google Maps API (Application Programming Interface), the drive route can be represented and the travelled distance can be obtained.

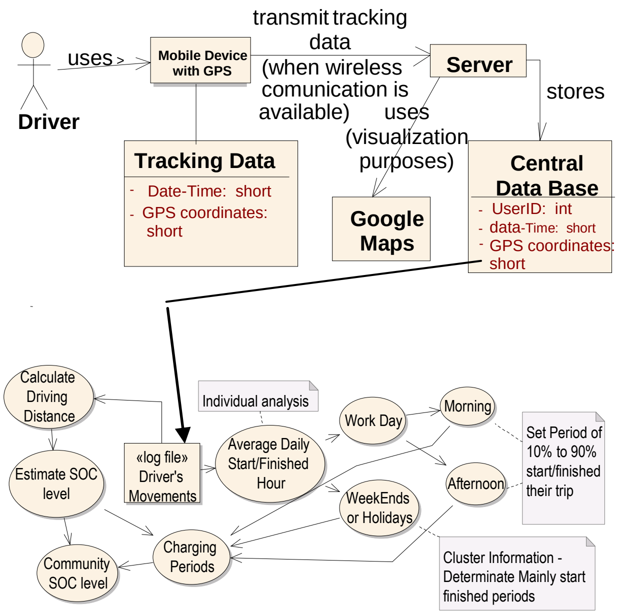

Figure 2: Main module of driver's tracking system in a mobile device with GPS, and information created from Drivers Movements data base.

From the travelled distance and vehicle efficiency it can be estimated the remaining battery energy of each EV (SOC – State of Charge level) and the community SOC level (sum of all individual community SOC levels). The studied population (from Lisbon area), with 50 cases, contains a mixture of ISEL (Lisbon Superior Institute of Engineering) students and their parents. Main assumptions made are: to reach a population of 500 a ten multiplication factor was introduced. In Portugal the first EV will be the Nissan Leaf with a 24 kWh battery pack and autonomy of 160 km (value considering a careful drive style). Volt's has a battery pack of 16 kWh. Once there is a diversity of EV with different battery power, we assume that in average we have 15kWh available for the energy market (each EV owner can choose battery type from a pre-defined list and define the energy for EM) and during working hours only 75% of EVs are plugged.

From tracking data we identify three main charging profiles: (1) from 19h to 23h (return home and home peak consumption hour), in this period test community have around 2 MWh. Minimum community available power is reached in this period. In this case we can assume 1.5 MWh as a safe value for energy market; (2) from 23h to 7h, charging period. Maximum community available power is reached in this period, after the charging process of EVs is finished; and (3) remain hours (7h to 19h - travel-work-travel period) assuming 75% of EV are plugged we have as community energy range from 3 to 4 MWh. These charging profiles were created through clustering data on a excel graph, presented in Figure 3. For more information see [18].

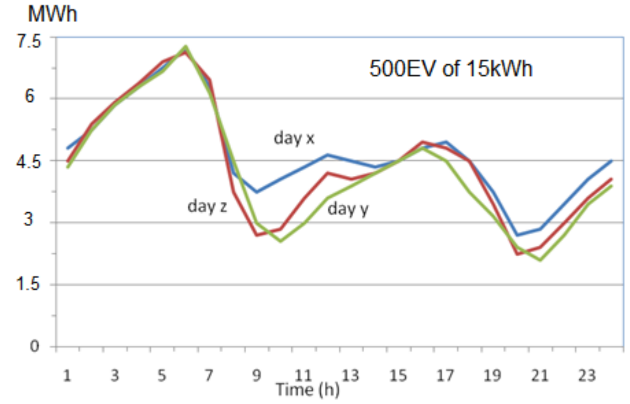

Figure 3: Electrical power available during day for 500 EVs of 15kWh of energy stored in batteries, taking into account the movements identified with the tracking system.

4. EV Aggregations

Because of their batteries, EVs present an interesting potential as energy storage facilities. However, the storage capability of the EV batteries is small on the grid scale, and consequently their individual power output cannot have any impact on the electrical power system. For the EVs to be able to play a role when interconnected to the electrical grid, they need to be grouped into communities. Once aggregated, they are able to provide different kinds of services, either as a controllable load or as a generation/storage device. However, the EVs may not always be plugged into the grid and their schedules are very uncertain. EV behavior can be quantified in a user profile, like time of trip, distance, daily hours connected to the grid and minimum energy stored. These profiles can be clustered in communities by a similarity measurement (taking into account the trips time) and also by the identification of the electrical distribution network mapped in a graph (see Figure 4). This graph geo-reference points correspond to end users locations and low voltage distribution points. The big problem of this approach is the work involved in the identification of geo-reference of each of these points. Having collected this information any geographic database can easily handle the problem.

The basic idea behind such community is the aggregation of the EVs taking into account the electrical distribution network (see Figure 4), so that together they represent a load or a resource of a size appropriate to exploit economic opportunities in the electricity markets. The created community is a new player whose role is to collect the EVs (profiles) by attracting and retaining them so as to result in a Megawatt capacity that can beneficially impact the grid. This impact is even bigger, because we take into account that the electrical distribution network minimizes loses of energy transfer. The size of the community is indeed a key to ensuring its effective role (100 EV of 24 kWh can store 2.4 MWh, and around 300 EV of 10 kWh can reach 7.2 MWh. In terms of load, a community of EVs represents the total consumption of all vehicles an amount in Megawatts that constitutes a significant size and allows each EV to benefit from the buying power of a large industrial/commercial customer. There are additional economic benefits that grow as a result of the economies of scale. The aggregated collection behaves as a single player that can undertake transactions with considerably lower transaction costs than would be incurred by the individual EV owners.

It is the role of the Aggregator to create and manage the community behavior by determining which EDVs to select to join the community, and by establishing the optimal deployment of the community. A single community may function either as a controllable load or as a resource, as depicted in Figure 3. We first discuss the EV community utilization as a controllable load and then as a generation/storage device.

First, the larger scale of the aggregated V2G power resources commanded by the Aggregator, and the improved reliability of aggregated V2G resources connected in parallel, allows the electrical grid system operator to treat the Aggregator like a conventional ancillary services provider. This allows the Aggregator to utilize the same communication infrastructure for contracting and command signals that conventional ancillary services providers use, thus eliminating the concern of additional communications workload placed on the grid system operator.

In the longer term, the aggregation of V2G resources will allow them to be integrated more readily into the existing ancillary services command and contracting framework, since the grid system operator need only to communicate directly with the Aggregators. The communications infrastructure of the Aggregator (central server) and the vehicles is a standard communication system, using available technology (Wireless, GPRS, Wimax, among others). Since there are no standards defined among EV infrastructure, the data exchange will be performed on the Internet standard XML. This approach will allow picking and giving information from different proprietary systems, since they provide and interface with XML data exchange. This Internet standard facilitates the application of data mining approaches to extract relevant information from the past experience (previous transactions performed).

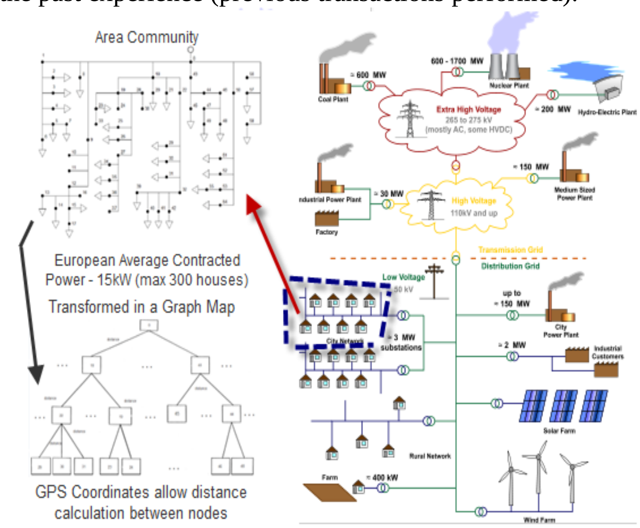

Figure 4: Electrical network distribution with low voltage distribution area community converted into a geo-reference graph used to create the driver community.

User Profile is defined by: type of EV (this feature characterizes the battery size), minimum SOC allowed, time and date of travel trips (working days and weekends), geographic data, personal data and log files of energy received or dispatched, and time intervals of the grid connection. Most of this information can be acquired (without costs) if the drivers run a tracking application in an offline mode (only transmitting the information when a wireless communication is available) in a mobile device.
Aggregation will be based on geographic distribution, taking into account the distribution of transportation lines and power stations, in a semi-automatic process. The system will calculate the power available in a circular distance of a pre-defined point.

4.1 System Main Modules

The System main modules are identified in Figure 5:

- V2G System – Is the system that controls the EVs and PHEVs connections to the power grid.
- Users' Profile – Is the module that interacts with the user, and is divided in the following modules: user registration module, user communication interface, and user profile. The user registration module is the responsible for detecting if the user is a registered user or not. If so, it shows its information, the number of credits that he has, allows him to change its personal data and driver profile, making suggestions, and also allows buying more credits. If it detects that it is not a registered user, it asks for the registration. The user communication interface formats the information for the end-user device (e.g PDA, Mobile Phone). The size of the information to be transmitted depends on the communication bandwidth and on the visualization capacities of the end-user device.
- Aggregation – Is the process of community creation by the selection of users. For the aggregative architecture, the Aggregator's ability to enter into contracts with the electrical grid system operator is independent of any individual vehicle's presence at the charging station. Because the Aggregator can vary the size of its power contract when fewer vehicles are present at charging stations, it is available to bid for ancillary services contracts at any time of day or night. This function identifies EVs in predefined areas (community areas, see Figure 4) and identifies available distribution power in a week. Historical data is analyzed (basic statistics functions are applied to time values) to determine safety values for electrical markets contracts.
- User Credits – This module try to measure the users' participation towards the common goal of the community.
- Agent System – The Aggregator system receives ancillary service requests from the grid system operator and issues power commands to contracted vehicles that are both available and willing to perform the required services. Under the data mining of available past data as community capacity aggregative architecture, the aggregator can bid to perform ancillary services at any time. From the available power in community (based on EVs plugged) the Aggregator bids into the hourly ancillary services market, and compensate the vehicles under its control for each minute that they are available to perform V2G. As such, this aggregative architecture attempts to address the two primary problems with the direct, deterministic architecture. We need to determine a good distribution algorithm to extract electricity smoothly from all available EVs.
- Transitions Record – All transactions between EVs and the Power Grid are stored in a database. This information would give a better insight into limits to charge/discharge which, in turn, would allow understanding the users' behavior. To keep user data privacy, the data is stored without a direct relation to the user.

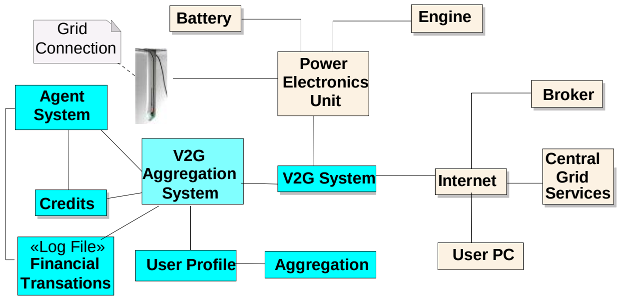

Figure 5: Main modules and Interfaces of V2G Aggregation System.

4.2 EV Community

A community of EVs can act as an effective distributed energy resource once it is interconnected with the distribution grid. However, we must keep in mind that the principal utility of EVs is to provide clean and economic transportation to their owners, rather than to generate electricity for grid operations. As a result, the aggregated EV may not always be plugged into the grid. Since EVs may travel different distances every day, they may have different levels of energy stored in their batteries at any time they become interconnected to the electrical grid. A community of many EVs serves to smooth out such heterogeneity and to make the aggregated entity behave in a more homogeneous manner. The time dependence of EVs travel may impact the level of participation of an individual EV to the load and the generation/storage device roles of the community. The variability in the contribution of each EV to the community creates considerable uncertainty in the capability of the community to act as a resource at any point in time.
Due to the personal preferences of each EV owner, the Aggregator cannot know with certainty the individual EV owner schedules and the amount of energy stored in each vehicle's battery when the EV gets plugged-in. We analyze the nature of this uncertainty, and construct an appropriate model under a set of reasonable assumptions. We deploy this model to simulate the impacts of a EV community as a load and as a generation/storage device.

The principal sources of uncertainty for an Aggregator are: (1) the duration of the periods during which each EV in the community is connected to the grid; (2) the distances travelled by each EV; and (3) the SOC of each EV at any point in time.
As said before, we propose an intelligent system based on agents' approach and a credit mechanism to support community and achieve a predefined performance. To analyze the nature of the resulting uncertainty, we need to introduce assumptions to allow quantification of the resulting randomness. Specifically, we limit our analysis to the following set of assumptions: (1) Losses in the EV batteries are neglected, because the losses due to conversion efficiency in the charging stations, or in the EV batteries, or due to transmissions losses are small – less than 10%; (2) The storage capability of each EV battery remains unchanged during the study period, and it is a known quantity based on the car model; (3) Parking lots have big capacities; (4) EVs are plugged-in when they are parked; and (5) Charging stations and outlets at a particular location do not have any power limitation and are adequate for the EV which gets plugged-in at this location.
Different communities should be established (when the number of EVs increases), mainly in function of their geographic location, and created based on the electrical distribution networks, in order to avoid investments or charging overloads. This community aggregation, illustrated on Figure 4 and Figure 6, should follow then pre-defined rules implemented by the Central Grid Operator.

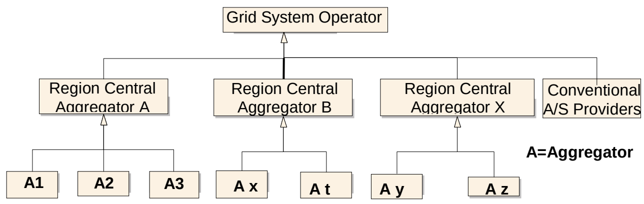

Figure 6: Aggregation hierarchy - a geo-reference system will match aggregation with physical electrical distribution network.

4.3 Managing user Behavior

Drivers express their behavior in a profile. Based on user's profile, the system calculates community aggregation efficiently based on individual data aggregation. However this pre-defined data will have changes due to unexpected situations, like failures, among others. Community goals are defined with a good failover gap, but system should manage the user behavior towards a common goal. For that, it is proposed in this work a novel approach based on the stock exchange metaphor, illustrated on Figure 7. This idea has been used in a collaborative system [19, 20]. The main idea is to promote a heath environment, where users' look for a common goal and this effort is converted in credits mechanism that can be converted in money. The System looks for users' data and transactions performed to identify critical hours (when less EVs are connected). This analysis divides time in several periods. In our work we propose 5 periods: (1) night period when more than 99% of EVs are plugged; (2) from 99% to 90% of EVs are plugged; (3) from 75% to 90% of EVs are plugged; (4) from 75% to 50% of EVs are plugged; (5) critical period, when less than 50% of EVs are plugged. From the tracking system, we can associate time to these periods.
Credits are based on the time intervals in which the EVs are connected, on the power available for market, on the energy delivered back to the electrical grid, and on time criticality (in our case, based on the criteria described above) for community goals.
Users' failures (change on plugged time profile) are penalized with lose of credits. If the user replaces automatically his failure by other user, no penalty is applied. If the failure isn't reported previously, the system penalizes heavily this behavior and forwards the failure report in order that the system finds a solution. An important research issue is how we can determine the right credits mechanism.
This collaborative environment can be applied for charging process of the EVs, where users will help each other to find the cheaper price.

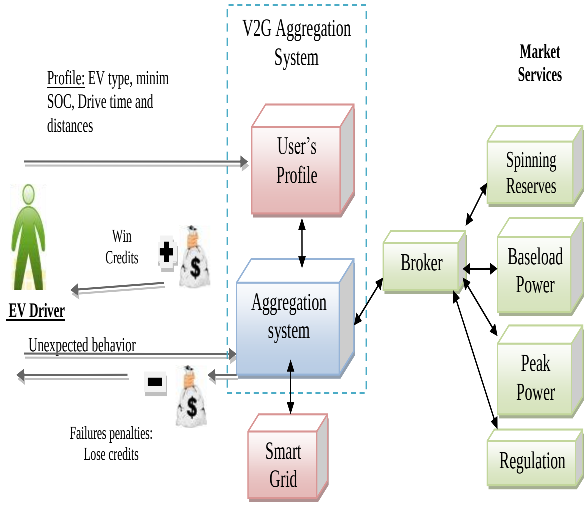

Figure 7: Credits mechanisms proposed.

4.4 Collaboration Features

Users can also interact and collaborate among themselves to improve their knowledge, or by allowing them to express their needs and preferences. The features presented below are created to keep users informed, motivated and with intention to collaborate more frequently:

- Punctual Changes on User's Plugging Time: users that identify in advance changes to their committed plug-in time, can among community members, find a replacement avoiding system penalties.
- Cooperation Area: An area where users can ask or provide different kinds of knowledge to cooperate in EVs related area. For example, one user that is good in dealing with information resource tools could provide prices and other helpful information to others, but if he knows nothing about the batteries or EVs working processes, he can ask any user if they want to cooperate with him.
- Helping Area: An area where users can post questions and answers and some sort of help of

any topic. This space could be accessed and viewed by any registered user. System gives credits to users that provide good helping answers to posted questions.

- Abuses or Faults Reporting Area: An area provided to report abuses of different kinds, like comments or bad use of the System. System manager can penalize users for it. The reason for providing this area is essentially for discouraging users to commit abuses or faults.
- Request: An area where users can ask for specific questions. System manager can use those requests to tune the community.
- Awards: Created in order to promote and recognize outstanding behavior (for example, no changes in the profile). The awarded users will receive extra credits.
- Community Newsletter: System Manager publishes a digital newsletter with Community information and EV related information.
- Users Rankings: User rankings will be created to represent the most valuable collaborators, calculated by adding all credits earned by each user.
- Alerts Subscription: Users can subscribe different kinds of alerts: notifications, comments or other EVs interactions.

5. Power Market Community Revenues

Main power markets for EV and PHEV are Regulation and Spinning Reserve (SR). Regulation is contracted and paid for the available power capacity at any one hour, with a separate and typically much smaller payment for the amount of energy provided. This means a generator sitting idle with the ability to provide regulation is paid the same capacity payment as the generator that was called upon to provide regulation. SR is the generation capability that can provide power to the grid immediately, and reach full capacity within 10 minutes when called upon by the ISO/RTO (Independent System Operator / Regional Transmission Organization). This power must be provided by equipment electrically synchronized with the electrical grid. Typically, requests for this generation to provide power are made around 20-50 times a year.

Major economic advantages for EVs and PHEVs comes from Regulation, because prices in average are three times higher than those obtained with SR, and in addition, the cycling of the storage device is much more frequent for Regulation than for Spinning Reserve.

Regulation is controlled automatically, by a direct connection from the grid operator (thus the synonym "automatic generation control"). Compared to Spinning Reserves, it is called far more often (for instance, about 400 times per day), and requires a faster response (less than a minute), and is required to continue running for shorter durations (typically a few minutes at a time). The actual energy dispatched for Regulation is some fraction of the total power available and contracted for. We shall show that this ratio is important to the economics of V2G, so we define the "dispatch to contract" ratio as:

$$R_{d-c} = E_{disp} / (P_{contr} \cdot t_{contr}) \quad (1)$$

Where R_{d-c} is the dispatch to contract ratio (dimensionless), E_{disp} is the total energy dispatched over the contract period (MWh), P_{contr} is the contracted capacity (MW), and t_{contr} is the duration of the contract (hours). R_{d-c} is calculated separately for regulation up or down. Kempton in [21] uses a value of 0.1 for R_{d-c}.

Based on previous studies of Kempton and Tomic [16], and taking into account \$30 MWh for Regulation services and \$10 MWh for Spinning Services, we have the following revenues, presented in Table 1, for European power markets. These values are calculated in an individual basis, but in a collective approach they should increase, mainly the SP values.

Table 1: Annual Revenue of EV and PHEV in the Power Market (values are given in US\$, assuming that vehicles are plugged-in 85% of the time).

	Regulation	SP	Total
2 kW	400	100	500
6 kW	1200	300	1500
10 kW	2000	500	2500
15 kW	3000	700	3700

6. Conclusion

Providing a conceptual system to create and manage the EV community, with a credit-based approach is the innovative proposal of this paper. We think that using this credit-base system, together with rankings, users would enjoy it as an open and healthy competitive environment. Also, in the future, to increase the market share of EVs and PHEVs, there is a need of these types of systems to explore the energy market potential of these types of vehicles. Also, renewable energy source integration can benefit from a community coordination action, where users' will capture renewable energy produced in excess at lower prices. This System could also be extended for Charging Station (CS) management, since the charging process is slow and for sure in the future we will not have a relation of one EV for one CS. This System could find available CS.

6.1 Methodology and Future Work

We have followed a scientific methodology to support our research, typically the kind of methodology followed in the area of IT engineering, based on the following activities: state of art analysis; problem statement; solution statement; design and implementation of a preliminary version of the system (e.g., a functional prototype); evaluation; refinement; and conclusion.

We started by analyzing the state of art on collaboration and community creation on Computer Science. Based on the analysis made we found out the most common and popular features, as well as the respective strengths and weaknesses. We realized that creation of communities and end-users' involvement is of crucial importance for the EV success and implementation, due to the amount of money involved. This business potential could be an enabler for EV start-up and future success. Since we are talking about money, the proposed model follows the stock exchange

market metaphor, and proposes the design and implementation of the system to fulfill user's interaction, motivation and interest, by changing credit values dynamically.
Since there is not yet a considerable number of EVs, we only can test and evaluate our system in similar cases, and with the submission of user's questionnaires. Tracking users movements are also a good information source. During this period, the system strengths and weakness will be evaluated. Feedback about the usefulness, available features and usability of the proposed System will be reached by doing different types of questionnaires to the users, together with usability tests. Finally, statistical analysis should be done to evaluate user's cooperation and the success of this credit-based approach.

7. Acknowledgement

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