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Vehicle-to-Anything Application (*V2Anything App*) for Electric Vehicles

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***Abstract*—This paper presents a mobile information system denominated as Vehicle-to-Anything Application (*V2Anything App*), and explains its conceptual aspects. This application is aimed at giving relevant information to Full Electric Vehicle (FEV) drivers, by supporting the integration of several sources of data in a mobile application, thus contributing to the deployment of the electric mobility process. The *V2Anything App* provides recommendations to the drivers about the FEV range autonomy, location of battery charging stations, information of the electricity market, and also a route planner taking into account public transportations and car or bike sharing systems. The main contributions of this application are related with the creation of an Information and Communication Technology (ICT) platform, recommender systems, data integration systems, driver profile, and personalized range prediction. Thus, it is possible to deliver relevant information to the FEV drivers related with the electric mobility process, electricity market, public transportation, and the FEV performance.**

***Index Terms*—Full Electric Vehicle, Information and Communication Technology, Mobile Information System, Public Transportation, Range Autonomy, Range Anxiety.**

I. INTRODUCTION

WITH the electric mobility paradigm in smart grids environment [1], mainly through the Full Electric Vehicles (FEVs) and Plug-in Hybrid Electric Vehicles integration around the world [2]-[5], the open electricity market, the advances in the production and integration of renewable energy [6][7], new research challenges are being opened. In this scenario, FEVs and renewable energy contribute to reduce the emission of greenhouse gases [8]. In [9] is presented an energy management system for smart grids including the FEVs integration, and in [10] are presented solutions to integrate distributed generation in smart grids. However, it is necessary to establish a set of technologies to allow the integration of these areas [11][12]. In [13] and in [14] are presented some opportunities and challenges to the wireless sensor area in smart grids, and in [15] is presented a survey of this communication technologies in smart grids. Therefore, communications and Information and Communication Technology (ICT) represents a fundamental area in the growth and performance of smart grids [16]. ICT can also play an important role from the point of view of integration system information [17][18], as well as from the point of view of the FEV drivers, as shown in Fig. 1. This upcoming reality will force to provide relevant information to the drivers, e.g., information related with electricity market and public charging stations, towards driver guidance [18]. In this context, the main goal of the presented research is to describe a mobile information system to provide relevant data to FEVs drivers. Thus, taking into account the information from the electricity market, considering different costs to different periods of the day, it is possible to promote the reduction of the costs to charge FEV batteries. Moreover, considering the integration of FEVs with bidirectional operation capabilities (Grid-to-Vehicle – G2V and Vehicle-to-Grid – V2G) [19][20], will strengthen the electricity market participation. These concepts are further discussed in the next section.

Nowadays, several projects related with smart grids are under development around the world [21]. In this context, smart homes with energy management and efficient solutions, smart appliances, and smart meters [22][23], will be the first steps to the smart grids evolution [24]. However, the main principles of micro grids [25], the guidelines of smart cities initiatives, the upcoming reality of energy markets, the electric mobility integration, and the power load profile are also key areas of smart grids [26]. Nevertheless, it is important to highlight that the combination of the information available in these systems represents a very complex scenario of data, which must be wisely coordinated.

In this context, the research presented in this paper intends to contribute with a prototype to deal with data integration

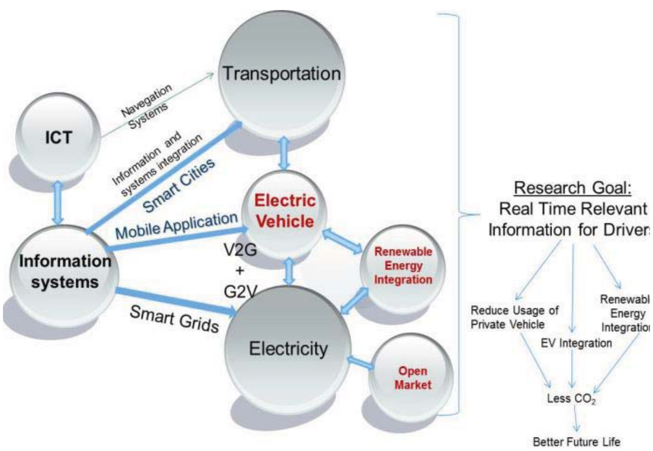

Fig. 1. Future tendencies for ICT in integration system information.

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from different sources, also considering FEV drivers profiles, and the cooperation with existing public transportation infrastructures. This cooperation can be achieved providing information regarding routes, schedules and pricing of public transportation, about availability of parking places, and even relatively to bike and car sharing systems. In this sequence of ideas, also the minimization of the driver range anxiety problem is a topic presented in this research work, in subsection II. E and section IV.

Taking into account the proliferation of mobile devices associated with the increasing communication connectivity in mobile systems (with higher speed rates and coverage areas), this paper presents the conceptual aspects of a mobile information system prototype denominated as Vehicle-to-Anything Application (*V2Anything App or V2**), designed to run in mobile devices. For this application we assume that each FEV driver has a personal mobile device, and that each vehicle can be used by several different drivers. Each driver profile is stored in the *V2Anything App* server module. Also, if a driver uses more than one FEV, then he should create different profiles, each one associated with each FEV. The driver uses the application on his mobile device, and the server is responsible for manipulating information, creating and storing the driver profile. Fig. 2 illustrates the usage of the *V2Anything App* in mobile devices. This application is mainly used by the FEV driver to trip planning (before the trip), to assist the charging process, to get a personalized range prediction, and to interact with the electricity market, transportation system (public and sharing systems) and road infrastructure, such as parking and charging stations. The application can use the MirrorLink technology [27] with FEV head unit, which allows displaying the *V2Anything App* on the head unit of the vehicle, where the user can interact with the application in a safety form. This mirror approach has already been tested in laboratorial environment in the head unit of the FEV VEECO [www.veeco.pt] (see Fig. 3). The head unit is a central controller and user interface that provides the control of several equipment (e.g., GPS navigation systems and bluetooth cellphone integration).

It is important to make clear that, in order to keep safety, avoiding that the use of the *V2Anything App* can interfere with a safe driving procedure, it is advised its use, as much as possible, when the car is stopped.

II. PROPOSED SYSTEM ARCHITECTURE

The proposed *V2Anything App* integrates a diversity of functionalities, taking into account the new realities of smart grids technologies, open energy market, and the increasing mobility sustainability in the cities. *V2Anything App* uses ICT supported functionalities, such as GPS, wireless communication and sensors, to perform a diversity of functions. The main modules and functionalities are illustrated in Fig. 4 and are described in the next subsections.

A. Charging Module

This module interacts with the charging process of the FEV and can be divided in two main charging processes interactions:

1) Home Charging – It is possible to control the battery charging process, in which the charging system permits the interaction through remote control communication. This allows establishing a smart battery charging strategy, taking into account the power limitations of the electrical power grids, in order to support FEVs integration in large scale. In [28] is studied a smart battery charging process that takes into account the power limitations at the distribution network and driver's home. It also allows choosing the best price periods to perform the battery charging. In section III is described the developed home charging system.

2) Public Charging Station (CS) – It is provided guidance to the nearest CS with the possibility of reserving a charging slot using the range charging assistant function. Based on the battery State-of-Charge (SoC), driver profile, and remaining distance, the system can calculate the minimum energy required in the batteries in order to make possible to reach the desired destination.

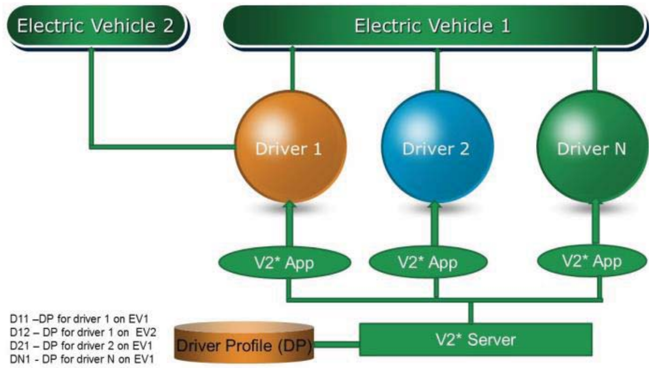


Fig. 2. System architecture to integrate the *V2Anything App* (*V2**) with the FEV and the driver profile.

Fig. 3. Head unit prototype with mirror approach of the *V2Anything App*: (a) VEECO cockpit; (b) Application with route guidance to near charging points.

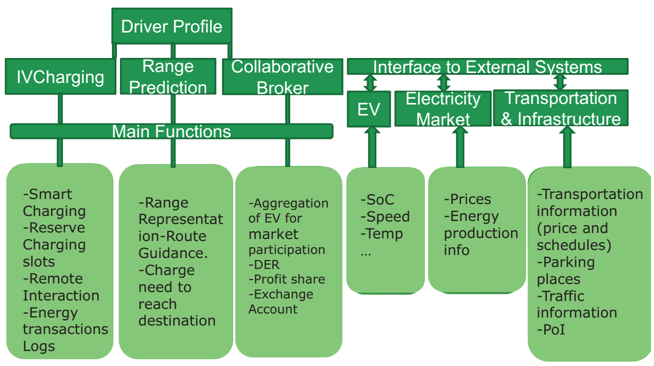


Fig. 4. *V2Anything App* main modules and functionalities.

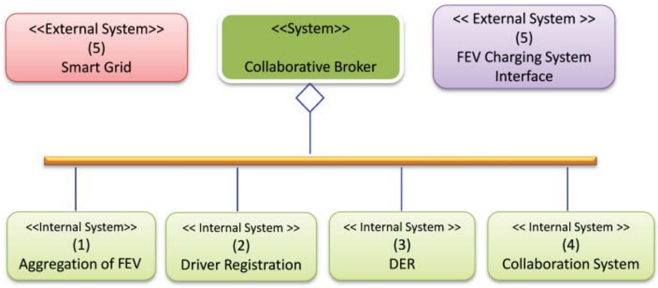


Fig. 5. Main modules of the Collaborative Broker application.

B. *Collaborative Broker*

This module is responsible to handle the FEV interaction with the electricity market, and has the following system modules, divided as internal and external according to Fig. 5 (for more details see [29]):

1) Aggregation of FEVs – It is made by an institution or company, called aggregator, which combines customers into a buying group. The group buys large blocks of electrical energy and other services at cheaper prices. The aggregator acts as an agent (broker) between customers and electrical energy retailers. For details see [30][31].

2) Driver Registration – It is a user interface for FEV driver registration at the system, with the definition of a login, password and e-mail, and with the choice of an associated FEV from a local database.

3) Distributed Energy Resources (DER) – It consists in small-scale energy generation technologies close to the power loads. It is expected to become an important part of the future smart grids, aiming to improve the overall efficiency, performance and stability of the electrical power grids. However, DER has the problems of variability (changes in load), uncertainty (supply contingencies) and unpredictability (associated to renewable energy generation intermittence, which depends on climate conditions). When a large number of vehicles (parked and plugged) is considered, in an aggregated way, this community of FEVs has the capability to store a significant amount of energy. On the other hand, FEVs can store the excess of production from local micro generation and, in a coordinate way, the users can tune their behavior to perform the FEVs battery charging process based on the micro generation production. Moreover, if a large number of FEVs operate using bidirectional battery chargers, they can be used to balance the production and consumption of energy of the power grid. This future collaboration between FEVs and power grids is extremely relevant taking into account that private vehicles are parked on average 93-96% of their lifetime [32]. Also in this scenario, it can be established a cooperative process based on the electricity production information and the electricity consumption of the FEV driver's home, involving those domestic appliances that do not have an obligatory usage time constraint.

4) Collaboration Module – It is based on a credit system for user collaboration, in division of profits, and in an aggregation module to join FEVs. The profits of spinning reserve participation are divided based on users participation. Users receive credits based on the time intervals in which the FEVs are connected to the power grid, on the power limit made available for market, on the energy delivered back to the power grid, and on time criticality for community goals. Time is divided in three periods: critical period (when users are usually driving), day period and night period. These periods are configurable because they change from country to country. Users' failures, caused by changes on the plugged time profile, are penalized with lose of credits. If a user compensates his failure by other user that is plugged in replacement, then no penalty is applied. Otherwise, if the failure is not previously reported, then the system heavily penalizes this behavior, and sends a failure report in order to be found a solution. Fig. 6 shows the information about the credit system. An important research issue consists on how to determine the right credits mechanism (for details see [28]).

5) External Interface System – Two main interfaces are available, for the smart grid and FEV charging system. The smart grid interface is based on a web service that gives a value in euro per electric energy available in the electricity market. Since this functionality is not yet available in the electricity market, it is simulated by the creation of a web service in a cloud platform (see [29]). This value is used to manage the FEV battery charging process, which is controlled by the charging module. Through the FEV charging system interface the driver can define a configuration, in which if the price of energy rises above a configurable threshold, then the system sends a command to the FEV battery charging system to stop the charging process, or the opposite if the price falls back. Since this reality is not currently available this process was only simulated, according to [29].

Fig. 7 shows some screens of the developed Collaborative Broker application, with the web screens of electricity price information (A) and operation mode information (B). Fig. 8 shows the information flow for the process of FEV connection (A) and disconnection (B) of broker.

C. *Transportation and Infrastructure Interface*

The adopted approach consists in the data integration of different information sources, such as:

1) Car and Bike Sharing Systems [33][18] – These systems are important to the growing interest of the sustainable transport systems, and to reduce the growth of energy use, noise, air pollution and traffic jam, due to a decrease in the number of cars moving and to an increase in the shared use of electric or low pollutant vehicles. Also, bike sharing systems permit door to door ride features and allow to access areas of the city that are forbidden for other kind of vehicles. The sharing system can be applied to FEVs, and bikes (including electric bikes) sharing can be a complementary offer in cities.

2) Public Transportation Data [34] – Providing information about the schedule and the price of public transport to the FEV driver, it allows planning a journey using FEV and public transportation in a complementary way. It can use functions as car parking booking (and charging) and ticket buying, when interface to transportation operator is available. The integration of FEVs with public transport systems allows the

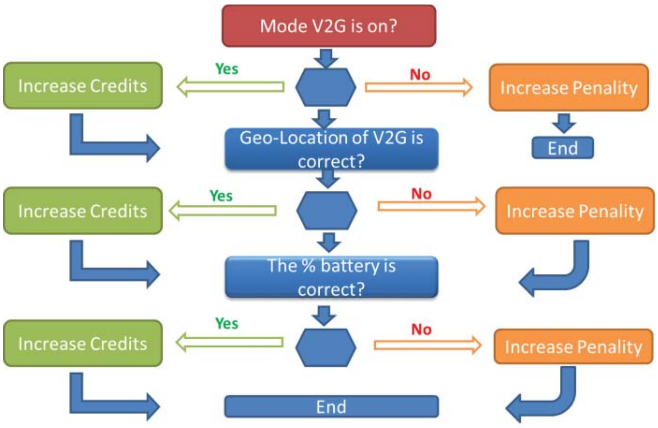


Fig. 6. Information about the implemented credit mechanism.

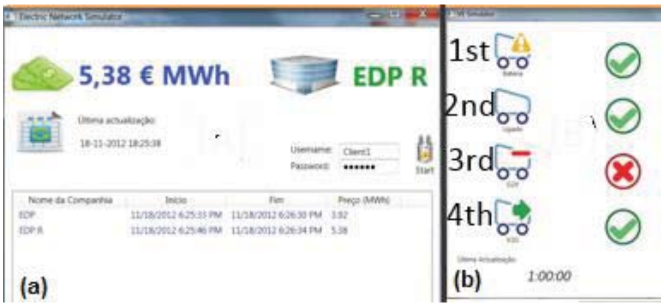


Fig. 7. Screens of the developed Collaborative Broker application: (a) Client interface with electricity price; (b) Client application mode of operation - 1st shows that the notification mode is on, 2nd shows that the FEV is in V2G mode, 3rd shows that the FEV is not disconnected from the broker, and 4th shows that the FEV changed from V2G to G2V mode.

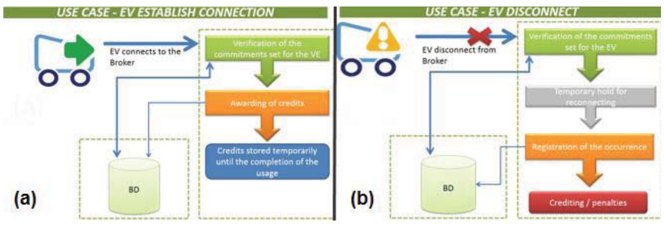


Fig. 8. Use case for FEV connection (a) and disconnection (b) of broker.

extension of autonomy beyond the batteries energy storage capacity. This approach explores the results of the START project [http://www.start-project.eu], where integrated information available in mobile devices increases the usage of public transportation among different experiences in European project partners (England, France, Spain and Portugal).

3) Points of Interest (POI) – Information related with POI is preloaded on the system, such that the driver can perform a quick search for any desired POI near the present location. This information is also used for guidance to FEV battery charging points that remain at a predefined distance [18].

4) Parking Places – Information associated to available parking places and remote reservation of FEVs battery charging slots (for more details see [18], [34]).

5) Green Route Planer (GRP) – It is based on the integration of different information sources, such as the four aforementioned. This GRP, which is detailed described in [35], allows users to have several modes and forms to travel from an origin to a destination. To extend the traditional shortest path problem an innovative framework is presented, which integrates a multi-decision criteria related with the integration of different transportation sources (own car, car and bike sharing, and public transportation). These functionalities allow the usage of FEVs as a public transportation complementary option, or even to cover a limited FEV range with public transportation or sharing systems (car and bike).

D. Electric Vehicle Interface

One of the major issues to implement the *V2Anything App* is the vehicle external information access and sharing among the different stakeholders. Through the usage of a CAN-Bus interface, it is possible to extract real time information from a FEV. The CAN-Bus is a standard designed to allow bidirectional communication between devices, as a vehicle and/or a host computer.

An implementation of a CAN-Bus interface is described at [36], and employed in a FEV developed at ISEL, the VEECO [www.veeco.pt]. From this previous work, and since there are standards, the idea is to create an open tool that can work in all vehicles with CAN-Bus. The user information access is mainly performed through a mobile application or a desktop computer, using the *V2G Smart System* application that was developed in a previous work [28].

E. Range Prediction

This work proposes a personalized range autonomy calculation using: (1) An accurate FEV range prediction, based on the past driver behavior and on external parameters like road traffic and weather; (2) Representation on a map of the distance that is possible to be reached by the FEV, combined with an uncertainty associated with driver behavior; and (3) Guidance and reservation of FEV battery charging points on public Charging Stations (CS).

Due to the limited range autonomy of FEVs, a personalized and more accurate indication of range autonomy will decrease the range anxiety problem, because this accuracy will allow the driver to better explore the energy capacity storage of the FEV without the fear of being without energy resources. We have used our previous experience on combustion engines with the study of a bus energy efficiency [37], in order to conduct a similar study using the VEECO FEV. Obtained driving data, combined with FEV characteristics and environmental information (weather and traffic) in a Data Mining approach [38], permitted to extract a personal range prediction estimation. Details of range prediction are presented in section IV, where are also showed some of the achieved results.

Fig. 9 illustrates the range prediction results developed for mobile applications in this work. Fig. 9 (a) shows the starting of a range prediction, where the application presents the location of the FEV. The option of specifying layers is shown in Fig. 9 (b). In this case, the user chooses the range prediction process, and the results are illustrated in Fig. 9 (c). A safe range is shown in green (without energy saving actions), in orange a range that the driver is able to reach with driving

Fig. 9. Range prediction process: (a) FEV position; (b) Available functions; (c) Range prediction representation: green, orange and red.

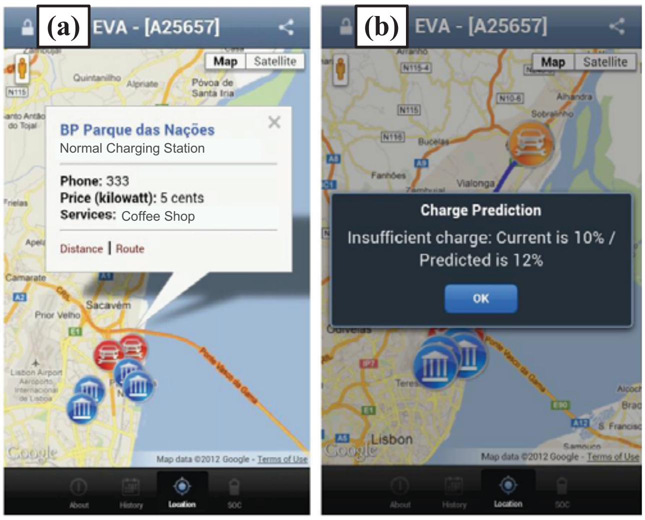


Fig. 10. (a) Guidance to Charging Stations (CS) and Points of Interest (POI); (b) Alert of insufficient charge to reach a desired destination.

optimization, and in red a range that is not guaranteed to be achieved unless full energy saving procedures are performed. This range information can be complemented with the location of POI and CS, illustrated in Fig. 10 (a). In Fig. 10 (b) is shown an example of alert of insufficient battery SoC for the FEV to reach a desired destination. In this case the proposed route is showed, the information about insufficient battery SoC is highlighted, and recommendations about actions to reduce energy consumption can be suggested, or the application can show options of the nearest CS in the proposed route.

F. Driver Profile

Driving range autonomy is intensively related with the driving style or mode. This happens in all types of vehicles, but on FEVs, due to the battery energy capacity limitation this relation is much clearer. Thus, changing driving style and driving habits may represent a considerable factor on energy saving and on extending vehicle range autonomy. Considering the actions or driving habits that can bring significant energy saving to the vehicle operation, it is important to evaluate how receptive FEV drivers will be in changing their driving style and habits towards the achievement of the intended energy saving.

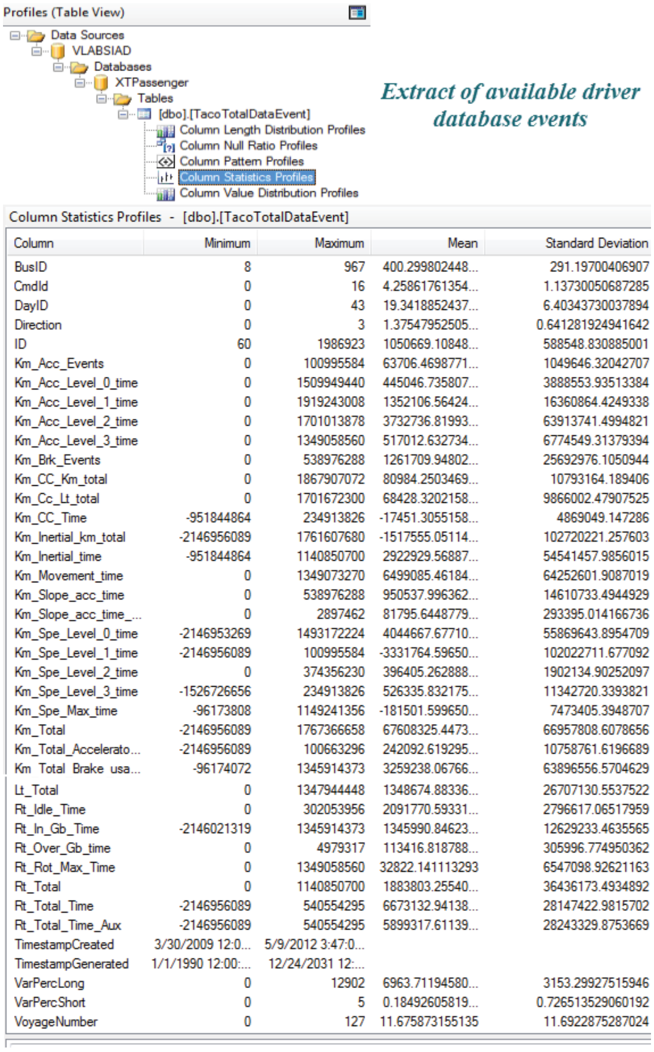
Some of the actions that the FEV drivers can take are related with their driving style, as travel speed and accelerations, or also related with other factors, like choosing the most convenient roads according to the FEV characteristics. Actions like cutting-off the air-conditioner or reducing the usage of other electric equipment can also be useful to energy saving. These actions are presented by the application in form of alerts or suggestions to the FEV driver, however the driver can simply ignore them.

Fig. 9 (c) shows the effect of driver behavior on the range autonomy of a FEV. The green curve shows the distance that the FEV is able to reach without any caution of the driver, the orange presents the distance that the FEV is able to reach with usual driver behavior, and the red shows the maximum reachable distance if the driver takes all precautions to save energy. For this case the difference of maximum achievable distances between the red and the green curves is around 20% of FEV range, which is significant (in a 160 km range autonomy this means around 30 km).

A set of tools were established to allow measuring key performance indicators from the FEV. It was used a CAN Bus on-board data collection system, and those variables were crossed with publicly available historical meteorological data, in order to build a driver profile and to find the most important parameters related with driver efficiency. All data was stored in a SQL Server database of collected event driven variables. Any time a driver starts and stops a voyage, an on-board recording system records several parameters, as the accumulated distances traveled, the energy consumption, and the time traveled per motor rotation band. The rotation band, also identified as power band, is related with the range of operating speeds and the motor efficiency. In our case the rotation band is classified in three bands: green; yellow; and red. From these variables the following ratios were defined:

- Energy spent per 100 km;
- Time traveled per motor rotation band;
- Excessive acceleration events per 100 km;
- Excessive braking events per 100 km;
- Inertial distance traveled percentage;
- Time percentage of inertial movement;
- Brake usage per 100 km;
- Accelerator usage per 100 km.

Additionally, historical meteorological data was obtained from Weather Underground, assuming a unique point as representative of all regions of the city. Collected variables examples are: temperature, visibility, wind speed, rainfall, and weather events (storm, heavy rain, etc). Fig. 11 shows a screen of the driver profile data base.



Column	Minimum	Maximum	Mean	Standard Deviation
BusID	8	967	400.299802448...	291.19700406907
CmdId	0	16	4.25861761354...	1.13730050687285
DayID	0	43	19.3418852437...	6.40343730037894
Direction	0	3	1.37547952505...	0.641281924941642
ID	60	1986923	1050669.10848...	588548.830885001
Km_Acc_Events	0	100995584	63706.4698771...	1049646.32042707
Km_Acc_Level_0_time	0	1509949440	445046.735807...	3888553.93513384
Km_Acc_Level_1_time	0	1919243008	1352106.56424...	16360864.4249338
Km_Acc_Level_2_time	0	1701013878	3732736.81993...	63913741.4994821
Km_Acc_Level_3_time	0	1349058560	517012.632734...	6774549.31379394
Km_Brk_Events	0	538976288	1261709.94802...	25692976.1050944
Km_CC_Km_total	0	1867907072	80984.2503469...	10793164.189406
Km_Cc_Lt_total	0	1701672300	68428.3202158...	9866002.47907525
Km_CC_Time	-951844864	234913826	-17451.3055158...	4869049.147286
Km_Inertial_km_total	-2146956089	1761607680	-1517555.05114...	102720221.257603
Km_Inertial_time	-951844864	1140850700	2922929.56887...	54541457.9856015
Km_Movement_time	0	1349073270	6499085.46184...	64252601.9087019
Km_Slope_acc_time	0	538976288	950537.996362...	14610733.4944929
Km_Slope_acc_time_...	0	2897462	81795.6448779...	293395.014166736
Km_Spe_Level_0_time	-2146953269	1493172224	4044667.67710...	55869643.8954709
Km_Spe_Level_1_time	-2146956089	100995584	-3331764.59650...	102022711.677092
Km_Spe_Level_2_time	0	374356230	396405.262888...	1902134.90252097
Km_Spe_Level_3_time	-1526726656	234913826	526335.832175...	11342720.3393821
Km_Spe_Max_time	-96173808	1149241356	-181501.599650...	7473405.3948707
Km_Total	-2146956089	1767366658	67608325.4473...	66957808.6078656
Km_Total_Accelerato...	-2146956089	100663296	242092.619295...	10758761.6196689
Km_Total_Brake_usa...	-96174072	1345914373	3259238.06766...	63896556.5704629
Lt_Total	0	1347944448	1348674.88336...	26707130.5537522
Rt_Idle_Time	0	302053956	2091770.59331...	2796617.06517959
Rt_In_Gb_Time	-2146021319	1345914373	1345990.84623...	12629233.4635565
Rt_Over_Gb_time	0	4979317	113416.818788...	305996.774950362
Rt_Rot_Max_Time	0	1349058560	32822.141113293	6547098.92621163
Rt_Total	0	1140850700	1883803.25540...	36436173.4934892
Rt_Total_Time	-2146956089	540554295	6673132.94138...	28147422.9815702
Rt_Total_Time_Aux	-2146956089	540554295	5899317.61139...	28243329.8753669
TimestampCreated	3/30/2009 12:0...	5/9/2012 3:47:0...		
TimestampGenerated	1/1/1990 12:00:...	12/24/2031 12:...		
VarPercLong	0	12902	6963.71194580...	3153.29927515946
VarPercShort	0	5	0.18492605819...	0.72651352906192
VoyageNumber	0	127	11.675873155135	11.6922875287024

Fig. 11. Screen shot view of the driving profile parameters available in the SQL data base.

From this data, and using data mining approach, it is possible to identify key energy consumption actions for each driver, and a set of conclusions can be taken [36]. From this type of analysis, the system identifies actions to reduce energy consumption, and automatically alerts the driver. However, no automatic actions are performed, because the ultimate decision of reducing or not energy expenses is made only by the FEV driver. Thus, the driver may accept or not the advising to turn off the air-conditioner or to reduce his driving speed. All data regarding alerts and driver's response is stored in a driver profile.

III. Developed Charging System

In the context of this work, it was developed a bidirectional battery charging platform denominated as *iV2G Charging System* [39]. This battery charger has as main advantage the bidirectional operation mode, and it was specially developed to allow full control taking into account a smart charging strategy, as presented in subsection III. C. The main functional requisites of the *V2Anything App* related with the battery charging process are described below:

1. Definition of smart battery charging strategies through remote commands, in order to manage the charging process. Considering that the battery charging system allows bidirectional operation (in Grid-to-Vehicle – G2V and Vehicle-to-Grid – V2G modes), it also can receive a command to operate in V2G mode, returning to the power grid part of the energy that was previously stored in the FEV batteries (it will be an important operating mode for the future smart grids). Also, the developed application takes into account the power limitations of the electrical power grid and of the driver's home.
2. Guidance for FEV battery CS, presenting the location of the nearest charging stations and making their reservation.
3. Utilization of electricity market functions to obtain information of prices that optimize the buying or selling of electrical energy, in accordance with the G2V or V2G modes, respectively.

A. Developed FEV Battery Charger

Nowadays, in typical FEVs, when it is necessary to charge the batteries, the energy comes from the power grid to the batteries without any control protocol given by the system that manages the power grid. Taking into account that it is foreseen that FEVs will become an important part of the power grids, their integration cannot be neglected [40]. Consequently, their integration must be controlled and regulated in order to avoid problems associated with power grids overload. Besides these problems, which will be managed by the future smart grids, the FEV battery chargers should avoid power quality problems [41]. The main power quality problem associated with the FEV proliferation is the consumption of distorted current, which influences other power quality problems (e.g., distorted voltages due to line impedance). In addition to other control architectures that can be used to regulate and compensate the voltage in smart grids [42]-[44], through collaborative operation a large number of FEVs can also contribute to regulate and stabilize power grid voltage.

The prototype of the FEV battery charger was developed to operate according to the Mode 2 of the IEC 62196 standard. It is composed by two bidirectional power converters: an AC-DC power converter and a DC-DC power converter. The AC-DC power converter allows controlling the power grid active and reactive powers, and the waveform of the consumed current. The control of the reactive power is a feature that will be managed by the future smart grids in order to mitigate some power quality problems (e.g., to regulate and stabilize the voltage). Fig. 12 illustrates the active power flow between the power grid and the FEV during the G2V and V2G operation modes. The DC-DC power converter presents a topology such that it operates as buck converter during the batteries charging process (G2V mode). On the other side, through proper control, this topology also allows the operation as boost converter when it is necessary, in order to make possible to deliver back to the power grid part of the energy stored in the batteries (V2G mode) [45].

Besides the bidirectional operation mode, the main advantage of this topology is related with the sinusoidal current waveform in the AC side of the battery charger for

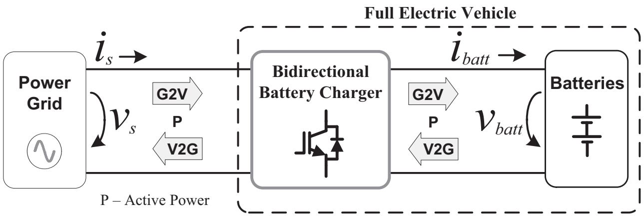


Fig. 12. Power flow between the power grid and the FEV during G2V and V2G operation modes.

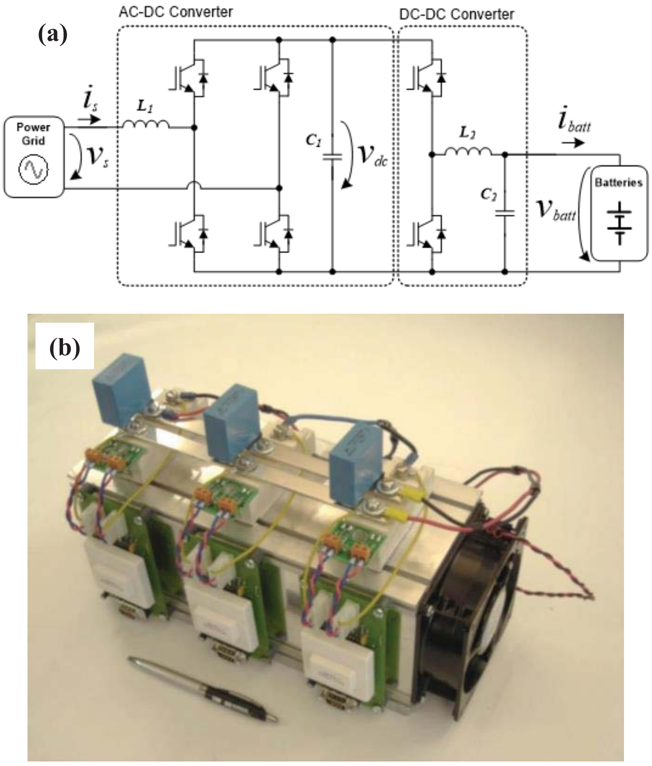


Fig. 13. FEV battery charger for smart grids: (a) Schematic; (b) Developed prototype of the bidirectional power converters.

both G2V and V2G operating modes, contributing to the power quality in smart grids.

Fig. 13 shows the developed FEV battery charger. More specifically, in Fig. 13(a) is presented the bidirectional power converters schematic, and in Fig. 13(b) the final aspect of the developed prototype of the power converters.

B. *Power Consumption Profile*

In most cases, FEVs battery charging processes will be performed at homes, and they should be made in function of the profile of power demand of each home. In order to analyze the best schedules to perform the FEV battery charging process, in accordance with the power limitations of the home and power grid, an agent-based electricity consumption simulator was developed in a previous project [46]. In this context, with the goal of analyzing the introduction of FEVs in electrical power grids, it was made a study for different types of residential consumptions. For such purpose were considered different home consumption profiles (with different power consumptions and daily traveled distances), assuming one vehicle per family. Then, compiling the obtained values of power consumption and the travelled distances, were determined the most favorable schedules along the days to perform the FEV battery charging process, without exceeding the contracted power for the home, which consists in a smart FEV battery charging process.

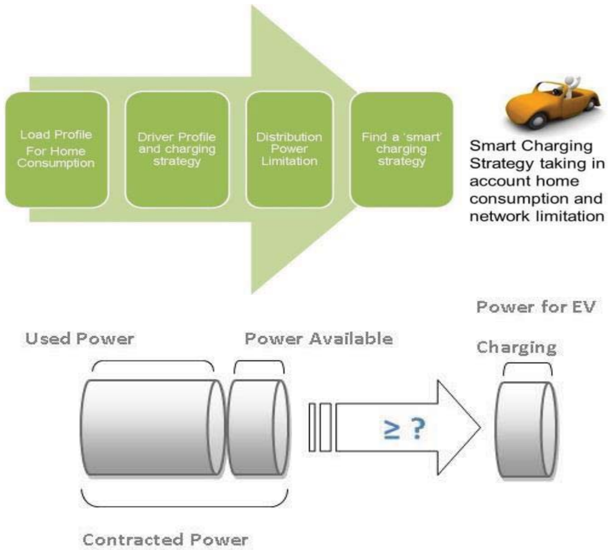


Fig. 14. Smart Charging approach and goals.

C. *Smart Charging Strategy*

Taking into account home consumption and power grid distribution limitations, it is identified a smart charging strategy, as depicted in Fig. 14. Real time information about power limitation and home consumption is usually not available in most of consumption places. To overtake this problem it was created a simulation tool based on a central information repository that can store and manage historical data on electricity consumption and production [28][46]. From this central repository it is possible the development of tools to extract knowledge from past electricity exchange log files, electricity market prices, renewable energy availability, home energy consumption (considering that the FEV is charged at home), and power grid distribution constraints. Main output information is the visualization of the power grid distribution on a graph, with the indication of power limits (for details see [28]). For that, the first step is to estimate the electrical power consumed per household, and given the contracted power, to determine the available electrical power for charging FEVs. It was considered a power limit for the electrical distribution system of 80% of the nominal power of the transformer that feeds a set of consumers of each particular zone of the low voltage system. However, depending on the percentage of existing FEVs, additional limitations can be imposed.

IV. Range Prediction

Due to the fact the FEV batteries cannot be very quickly recharged during a journey, it is essential that a precise range prediction is available to the driver of the FEV in order to check if the desired destination is achievable without a stop to charge the batteries, or even for him to know if to reach the destination it is necessary to perform an optimized driving, and to consider, for instance, to cut the air-conditioner, among others FEV functionalities. The FEV range autonomy prediction is based on three main dependency types:

1. FEV model and its main characteristics, like the chemical technology of the batteries (as lithium-iron-phosphate, lithium-titanate, or nickel-metal-hydride), the batteries characteristics (mainly variation of SoC, lifespan, performance, specific power, specific energy, and safety), and the FEV powertrain (electric motor and their power converter, as well as the other electric parts, as battery charger, controllers, and power cables). All these variables of the FEV will influence the battery SoC and consequently the range autonomy prediction. The batteries SoC and other relevant parameters are provided to the main control system through CAN-Bus communication, and then this information is stored in a data base, in order to predict the available range with the information of current speed and acceleration.
2. The driver behavior, in which it is mainly used the information of the battery SoC level versus achieved distance (which is stored in a data base), the FEV weight (that is a manual input), and driving directions (acquired based on the GPS information);
3. Environment information: current location, traffic conditions (taken from a web service), road information (obtained through a distances graph), weather information (wind and temperature - taken from a web service or from an FEV sensor), and altitude.

A. Range Autonomy Prediction Procedure

The range autonomy prediction procedure is, in a first step, based on the FEV previous known performance, on the battery SoC level, and on past driving behavior (taking the relation of battery SoC level versus travelled distance achieved, from experience, stored in a driver profile data base). On a second step, this distance is recalculated with base on weather information: (1) Temperature above or below a pre-defined threshold (since a percentage of the energy stored in the batteries can be taken for air-conditioning); (2) If it is raining, then a percentage of energy is taken for the window cleaning process, and for night driving a percentage of energy is taken for light services. A web service brings traffic information, and based on experience (e.g., information about driving times and traffic information), a new driving range is calculated and showed to the driver as a prediction. Current driving behavior (e.g., driving speed and accelerations) are also taken into account in this process. Once it is achieved an estimation of the FEV range autonomy, it is started the calculation of possible reachable points based on the current position. Most of these estimation processes are performed with resource to simple heuristics, based on deep studies that were previously developed [18], [38]. For example, if the weight is above a configurable threshold, a percentage of reduction is applied on the range autonomy (this value should be tuned from experience data and with dependence on FEV parameters). Also, altitude is taken into consideration, using Google Maps to obtain the altimetry of the desirable path. Again, several levels are configured, and it is also applied a percentage of reduction in the range in function of the altitudes to overcome in the path. Temperature is an important parameter, because of its relation with the use of the air-conditioner. Thus, temperature is divided into five classes range (classes are used to discretize the variable) applying the Naïve Bayes algorithm: (1) Less than 5ºC; (2) From 5ºC to 15ºC; (3) From 15ºC to 25ºC; (4) From 25ºC to 30ºC; and (5) Above 30ºC. For classes 1 and 5 it was assumed that all drivers use air-conditioner, for class 3 no usage is considered, and for classes 2 and 4 it is assumed that a percentage of drivers use air-conditioner (this is the initial profile parameter, but acquired past data can tune this behavior). Traffic information is used again as a parameter that can reduce the range autonomy, because possible starts/stops on traffic jams increase consumption.

B. Implementation

Fig. 16 shows the prediction web service, developed in Java, and Fig. 17 shows the mining models used for the prediction, which employs available data of the driver profile and weather information. Range prediction is based on data mining, Microsoft Decision Trees for step1 and Naïve Bayes algorithm for step2. In step 1 are correlated several input variables (battery SoC in percentage, the vehicle speed, the vehicle temperature, past driver behavior, battery type and the distance traveled) to reach a prediction. On step 2 are used environment class variables (as discrete variables) like traffic, altitude, and the weather conditions to refine the prediction based also on past data using Naïve Bayes approach (for details see [38]). Two main variables are predicted: DISTANCE_PREDICTION related with the range prediction distance, and CHARGE_PREDICTION related with the charge needed to reach the desired destination. The charge prediction process is similar to the range autonomy prediction.

C. Representation of Range Prediction

A simple circular distance can be represented for the range autonomy prediction, like is shown in Fig. 9 (c), or a detailed representation can be made, as depicted in Fig. 15 (a). In this figure is represented the distance that can be travelled taking into account normal driving (without energy saving actions): (1) The travel starts from Lisbon with the 100% of SoC; (2) Vila Franca city after 25 km; (3) Santarém city after 80 km with less than 50% of SoC; and (4) Leiria city after 150 km with 5% of SoC. Taking into account that the battery charging process occurs in Leiria, in Fig. 15 (b) are represented the distances that can be travelled from Leira city at the starting of the charging process (1), when 40% of SoC is reached (2), and when 75% of SoC is reached (3).

All representations are based on Google Maps API [https://developers.google.com/maps] and use as starting point the current FEV position. The detailed maps use in the first step the graph information of main roads and a range prediction value is used to mark a distance for each road. The result is a polygon line to represent the range. The uncertainty about the range due to driver behavior is represented in the same manner. If the SoC level is below 25% of full charge the representation procedure starts to use secondary roads.

Fig. 16. Prediction Model Web Service developed in Java.

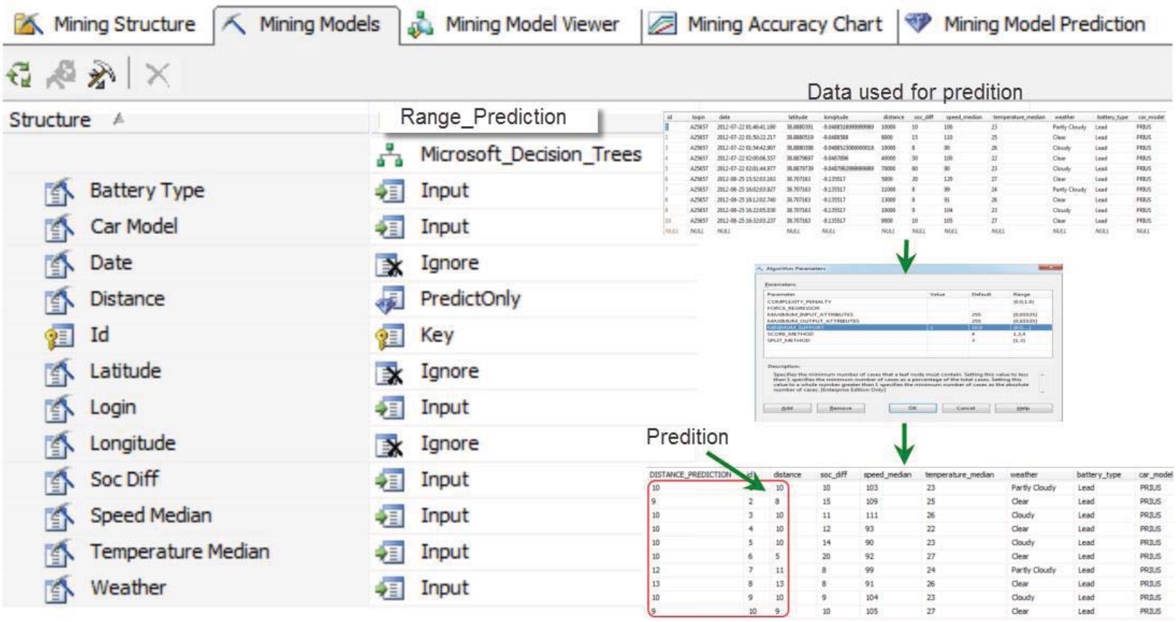


Fig. 17. Implemented range autonomy prediction process, from raw data using mining models to prediction range.

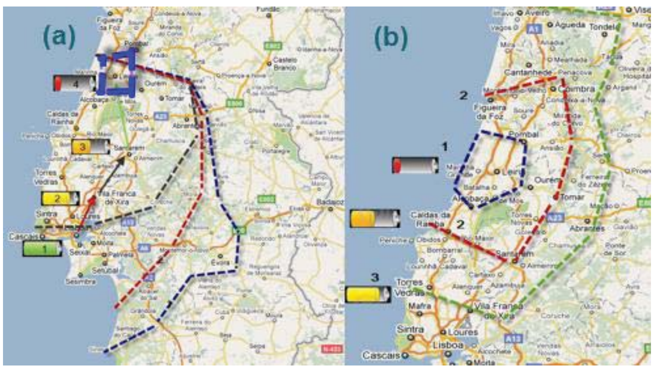


Fig. 15. Detailed representation for the range autonomy prediction: (a) Range estimation of a Lisbon trip to north where four different cases are showed. (b) Representation of the distances that can be travelled after the charging process for different SOC levels considering Leiria city as starting point.

V. Conclusion

This paper presents a developed mobile application named *V2Anything App*. It allows providing relevant information to Full Electric Vehicle (FEV) drivers from several sources of data. Using this application the FEV drivers can interact with battery charging systems by using information of public charging stations places, their availability and energy price, to make the reservation of a charging point with the associated parking place. Simultaneously, the integration with public transportation infrastructures ensures that the driver is capable of planning the use of public transport means on his journey, linking the FEV with parking places availability, transports schedule and ticket reservation. This information integration with driver's interaction devices and applications contribute for a better trip planning and energy usage, and also reduces the range anxiety of the FEV driver.

This paper also introduces a developed bidirectional battery charger, designed for the future smart grids, which allows performing FEV battery charging (G2V – Grid-to-Vehicle mode) and discharging (V2G – Vehicle-to-Grid mode) processes. It is commanded by the *V2Anything App*, and works with a management system created with a smart charging strategy that takes into account the power grid and the consumer power constraints. This developed battery charger also takes into consideration power quality aspects.

The main contribution of this work consists in the public transportation data integration and in the diversity of options for transport systems (public buses, trains and metros, and car and bike sharing), which can be made available to FEV drivers through a single interface: the Vehicle-to-Anything application (*V2anything app*). Prototypes of the *V2Anything App* were developed for Android [47] and Windows [48] systems. The inclusive view that is carried out by this developed application is significant for the FEV industry in general, but it is also important for governments, public operators and end-users, because it brings a unified overview, that makes easier the identification of the challenges and opportunities of this new paradigm of electric mobility.

In future works it is intended to analyze the influence of the operation in V2G mode in the State-of-Health of the batteries.

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