# V2G-based Smart Autonomous Vehicle for Urban Mobility using Renewable Energy

Redouane Khemmar
ESIGELEC – Institut de Recherche en Systèmes Electroniques Embarqués (IRSEEM)
Saint Etienne du Rouvray, Rouen, France.
redouane.khemmar@esigelec.fr

Jean-Yves Ertaud
ESIGELEC – Institut de Recherche en Systèmes Electroniques Embarqués (IRSEEM)
Saint Etienne du Rouvray, Rouen, France.
jean-yves.ertaud@esigelec.fr

Kostas Sirlantzis
Image and Information Engineering Research Group School of Engineering and Digital Arts,
University of Kent Canterbury, UK.
k.sirlantzis@kent.ac.uk

Xavier Savatier
ESIGELEC – Institut de Recherche en Systèmes Electroniques Embarqués (IRSEEM)
Saint Etienne du Rouvray, Rouen, France.
xavier.savatier@esigelec.fr

**Abstract— IRSEEM is coordinator of a research program Savemore [19] aiming to develop and demonstrate the viability and effectiveness of systems for electrical transport and urban logistics based on autonomous robotic electric vehicles operating within a smart grid electrical power distribution framework. As a part of this project, our work focuses on the study of the coupling of electric vehicles with renewable energy. At the scale of a city, electric vehicles can be considered as a means of intermittent storage of electric power which can be distributed to the network when it is required (e.g., at times of the date when demand spikes). When these vehicles belong to a controlled and intelligent fleet, network organization is dynamic and leads to a smart grid. The widespread use of electric vehicles in cities coupled with renewable energy appears as a powerful tool to help local and regional authorities in the implementation of the European Agenda for low-carbon, reduced air pollution and encourage energy savings. In this paper, we present a Vehicle to Grid model which implements the interaction between an electric vehicle and a smart grid. The model takes into account several kinds of parameters related to the battery, the charging station, the size of the fleet and the power grid as the expansion coefficient. A statistical approach is adopted for the setting of these parameters to determine the significant parameters. Several simulations are performed to validate the model. In first step, we have studied the behavior of the model on a typical day of a person who has traveled from his home to work (in France). As a second step, and in order to study the power consumption behavior of the model, we have tested it during several seasons. The results show the effectiveness of the model developed.**

**Keywords; V2G; smart grid, bidirectional charging station, design of experiment.**

## I. Introduction

In a context of the economics and development of renewable energy, the “Grenelle Environment” enables research and development of electric vehicles and infrastructure. The Electric Vehicle (EV) market although launched many years earlier does not have great success so far, mainly due to lack of sufficient infrastructure to reassure consumers about autonomy. The development of new batteries has given a new boost to the field of electric mobility. However, a problem has been identified: while for example, the French State has planned to put into circulation a number of electric vehicles in the year 2020, recharging all these batteries is a real problem since it will create additional demand in periods already known for very high energy demand. However, recent proposals for the creation of Smart Grids of Electricity Distribution are suggest the peak demand can be managed effectively by introducing intelligent management of power consumption and storage. Until now, we have always used electric vehicle batteries in unidirectional mode. That is to say that the use of the battery can be summarized in a load area and a discharge operation of the vehicle. The innovative idea in smart grids is to use the batteries in bidirectional mode this time, and to inject electricity back to the grid when needed. However, a question arises: will this bidirectional battery usage counter peak daily consumption?

At present, the countries of the world are confronted with serious issues and problems related to energy; whether for its production, operation, management or even transportation. It should be noted that the energy produced in the world comes, about 80% of fossil fuels [16][17]. The consumption of fossil fuels today poses a major environmental problem. Indeed, the production of energy from fossil fuels causes the release of greenhouse gases to the atmosphere, which results in global warming.

Today, and for the sake of sustainable development, some sectors such as the automotive and logistics industries have to address the problems and offer alternatives to the use of combustion engines (which consume major part of fossil fuels). One such alternative is the expansion of the use of electric motors. The introduction of electric vehicles fleets by 2020 is of increasing importance. This will lead to a significant change in the behavior of the electricity distribution grids. To


ISBN: 978-1-61208-414-5

anticipate this future behavior, the network must evolve to become "smart".

This paper is organized as follows: Section 1 introduces the motivation of the paper. Section 2 presents the state of the art on Vehicle to Grid (V2G) projects. Section 3 presents the V2G model we developed. Section 4 illustrates the impact of the V2G model parameters in the interaction between the EV and smart grid. An adjustment of the model parameters is presented in this section. Results are presented in Section 5. Section 6 concludes this paper.

## II. V2G STATE OF THE ART

There are different ways to integrate a vehicle in the network: V0G: direct load on standard household outlet, V1G: the vehicle communicates in real time with the network and the network load when needed (outside peak), V2G: as V1G but bidirectionally, discharge to the networks when it is needed, V2H: as V2G but only with a specific building or building complex, and V2G NGU: a V2G project related to renewable energy production.

The University of Delaware has launched the V2G project in 2004. This project is led by Dr. Willett Kempton [1][5][6]. Electric-drive vehicles, whether powered by batteries, fuel cells, or gasoline hybrids, have energy and power electronics capable of producing the 60 Hz AC electricity that powers homes and offices. They call it V2G. As an example of power production, the project has experimented for one vehicle that it can put out over 10kW, which is the energy consumption of 10 houses [2][3].

The company AC Propulsion Inc. has developed the concept of Vehicle to Grid by designing the eBox car [7], with a V2G system for the transfer of electricity in both directions between the battery and the electric grid. This car is derived from the Toyota Scion Xb equipped with an electric motor and a V2G interface for the transfer of electricity.

Danish Edison project stands for "Electric vehicles in a Distributed and Integrated market using Sustainable energy and Open Networks" [8]. The Danish electricity production environment is conducive to the development of this project as 20% of its energy is wind. This represents a large share of intermittent and difficult to control energy. They use them for the eBox project developed by AC Propulsion Inc.

As part of a project on a larger scale in the city of Toyota, the manufacturer available to Toyota Prius Plug conducted 10 tests at houses. They were equipped with a V2H (Vehicle to Home) interface for storing in the car battery intermittent production from photovoltaic panels. The injection of energy to the battery or to the network is managed by a specific charging station equipped with an inverter to convert the current system and Home Energy Management System (HEMS) [9].

V2G technology developed by the U.S. Company Nuvve is based on the possibility of using electric vehicles as energy buffer reserves [10]. On the one hand, electric vehicles, used on average 5% of the time, representing energy capacity "dormant", i.e., not used for 95% of the day [4]. On the other hand, energy production is not constant, particularly in cases such as Denmark, where the random nature of renewable energy needs to be considered.

Unveiled in August 2011, the Leaf-to-Home is a V2G device that reverses the energy flow of the Nissan Leaf to allow the vehicle to provide electric power to a private network [11]. Indeed, thanks to an integrated model that is 100% electric, Nissan offers the possibility to transform the electric charge stored in the battery into alternating current for the energy needs of a home. According to Nissan, this system would power a Japanese home for 48 hours and a more energy-consuming house, such as an American home, for a day. This is useful when system power fails (for the basic operation of lights, freezer, etc.), or to reduce demand on the national system during peak times.

The German E-Energy program aims to enable intelligent integration of electro-mobility in a global energy supply system. Electricity consumption is guided by the production and the vehicle battery is charged only before its next use, no matter what time of the day it will be connected to the mains for charging [12].

The GRIDbot Canadian Company is specializing in the design and installation of charging infrastructure for municipal, commercial and multi-residential electric vehicles. It offers a global solution for the EVs’ networking. It is one of the largest manufacturers across public, commercial and residential sectors in Canada for recharging devices. The project aims to make possible bidirectional electricity flows for the introduction of V2G in Quebec [13].

French Police Power Regulation assumptions are based on V2G, for a fleet of one million electric vehicles connected (the French government will provide a total of 2 million EVs by 2020). Their storage capacity could reach 10 GWh [14]. This storage capacity could be valuable during peak periods.

In [18], the author proposes a photovoltaic synthetic generator. The system developed show a stochastic model for solar energy based on Markov chain approach and uses real data to generate the solar states for different times of the day. The system can be applied to design the appropriate size of energy storage devices or to determine the charging rate of photovoltaic powered EV charging station [18].

## III. V2G MODEL: EV & SMART GRID INTERACTION

### A. V2G Model Parameters

In order to study the V2G model, it is necessary to identify the parameters constituting the model. In TABLE I, we summarize the whole of these parameters:

TABLE I. V2G MODEL PARAMTERS.

| N° | Description |
|---|---|
| 1 | Battery Capacity |
| 2 | Real Battery Capacity |
| 3 | Battery Voltage |
| 4 | Battery Intensity |
| 5 | Max Battery Power |
| 6 | Minimum Time of Charge/Discharge |
| 7 | Recharge Power Terminal |
| 8 | Transformation Efficiency DC/AC |
| 9 | Vehicles Number |
| 10 | Behavior Losses Coefficient |
| 11 | Theoretical Vehicle Autonomy |
| 12 | Real Autonomy Estimation |
| 13 | Conducted Middle Journey |
| 14 | Expansion Coefficient |

### B. V2G Model Calculation

In order to give a clear description for the model to be used, we consider the following parameters:

- Real Energy Injectable from the battery to the grid : $REIBG$
- Real Battery Capacity: $RBC$
- Transformation Efficiency: $\frac{DC}{AC}$ : $R$
- Number of Vehicles: $N$
- Average Journey carried out: $P$
- Manufacture Battery Capacity: $MBC$
- Real Autonomy Estimate: $RAE$
- Maximum Energy Injectable from the Grid to the Battery during Time $Tmin$: $MEIGB$
- Charging Station Power: $CSP$
- Charging Time in Hours: $T$
- Real Energy Injectable on the Batteries: $REIB$

The Eq. (6) shows the resulting model. For obtaining $REIBG$, we have to do the following calculations:

Firstly, we calculate the energy consumption for 1 km as shown in Eq. 1:

$$EG1 = \frac{MBC}{RAE} \tag{1}$$

Secondly, we calculate the energy consumption per day for one EV as shown in Eq. 2:

$$ECD1 = EG1 * P \tag{2}$$

Thirdly, we calculate the total energy (Eq. 3) expended per day:

$$TEED = ECD1 * N \tag{3}$$

Fourthly, we calculate the remaining energy in the batteries which corresponds to the real available energy (Eq. 4):

$$RAE = RBC * N - TEED \tag{4}$$

And finally, for obtaining the real energy injectable from the battery to the grid, Eq. 5 is presented as follows:

$$REIBG = RAE * R \tag{5}$$

And now in using the different parameters, we have (Eq. 6):

$$REIBG = R * \left( RBC * N - \left( N * P * \frac{MBC}{RAE} \right) \right) \tag{6}$$

The maximum energy injectable from the grid to the battery during time $T$ is presented in Eq. 7:

$$MEIGB = CSP * N * T \tag{7}$$

The Energy which really injectable on the battery is shown in Eq. 8:

$$REIB = RBC * N \tag{8}$$

### C. Significant Parameters

Significant parameters were selected initially based on an analysis of the impact of each parameter on the output of the system. In order to validate our choice, significant parameters determining strategy based on the Design of Experiments (DOE) [15] was adopted.

The resulting significant parameters which are taken into account in the simulation are: 1. Power charging station, 2. Time of charge/discharge, 3. Battery autonomy, 4. Reinjection capacity in the network, 5. Fleet size : vehicle number, 6. Fleet type and 7. Expansion coefficient.

## IV. V2G IMPACT SIMULATION

Several scenarios were simulated to validate the V2G approach presented in this paper. As an illustration, we present two of them:

### A. 1st Scenario

#### 1) Significant Parameters

The significant parameters which are taken into account in the simulation are: Battery Initial Level, Battery Target Level, Reinjection Capacity in the Network, Fleet Size: vehicle number, Expansion Coefficient.

#### 2) Selected Scenarios

The scenario chosen is based on a significant study of the RTE Company for the EV fleet at 2020: Lithium-ion battery

 ISBN: 978-1-61208-414-5 

capacity of 22 kWh, 2 Millions of vehicles (Special fleet: 1 200 000 vehicles, Captive fleet: 800 000 vehicles), Recharge exclusively off-peak: 00h00 - 5h00, summer and winter day consideration. The captive fleet behavior was simulated as follows (Figure 1):

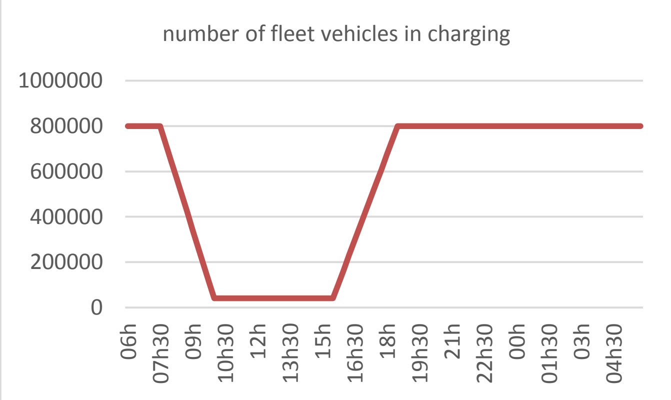


Figure 1. Captive Fleet Vehicle Behavior (X Axis in hours and Y Axis in number of vehicles).

The particular fleet behavior was simulated as follows (Figure 2):

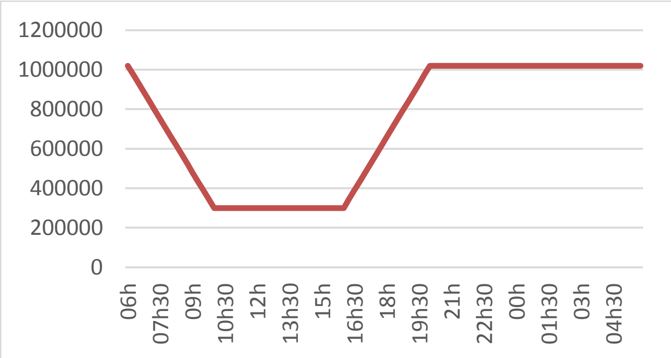


Figure 2. Particular Fleet Vehicle Behavior (X Axis in hours and Y Axis in number of vehicles).

3) Results Obtained

The simulation results were obtained following the choice of the following parameters: Initial Level of the Battery (Particular Fleet: between 70% and 80%, Professional Fleet: 25%), Battery Chargers Capacity (Particular Fleet: 3 kW, Professional Fleet: 43 kW), Security Level: threshold at 25% to avoid premature battery depletion, Users behavior, Charging has been restrained from 7h00 PM. The batteries must be recharged from 05h00 AM. We present in Figure 3 the case of a classic day in which we make comparison between classical consumption and V2G consumption:

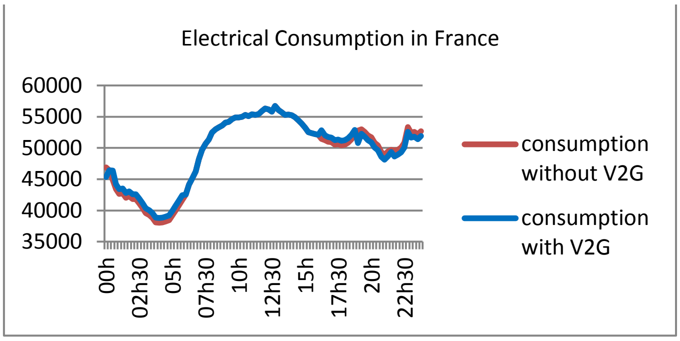


Figure 3. Case of Classic Day (X Axis in hours and Y Axis in MWh).

The case of a winter day is shown in Figure 4:

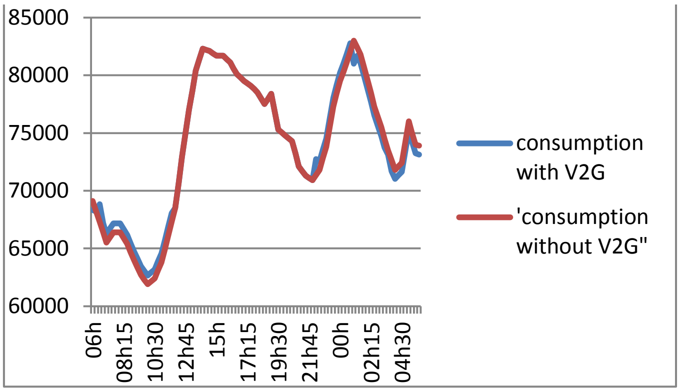


Figure 4. Case of Winter Day (X Axis in hours and Y Axis in number of vehicles).

The summer day is shown in the Figure 5:

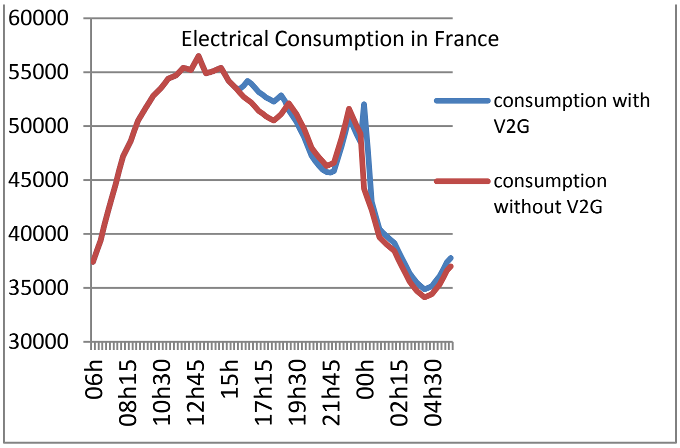


Figure 5. Case of Summer Day (X Axis in hours and Y Axis in MWh).

B. 2nd Scenario

1) Significant Parameters

The significant parameters were taken into account in this simulation are: Fleet Size, Fleet Type, Power Charging Terminal, Expansion Coefficient, Charge/discharge Times.

2) Selected Scenarios

For each simulation, we varied only one parameter of the model at a time. This amounts to 5 different simulations.

3) Results Obtained

The results obtained by varying the parameter "fleet type: particular/captive" are shown in Figure 6:

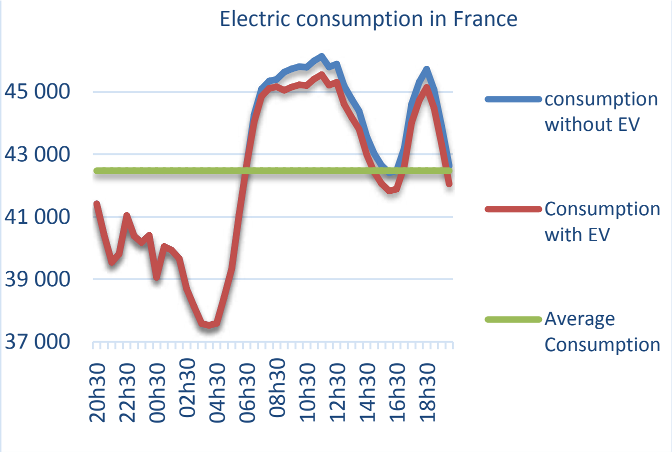


Figure 6. Power Consumption by Fleet Type (X Axis in hours and Y Axis in MWh).

The results obtained by varying the parameter fleet size are presented in Figure 7:

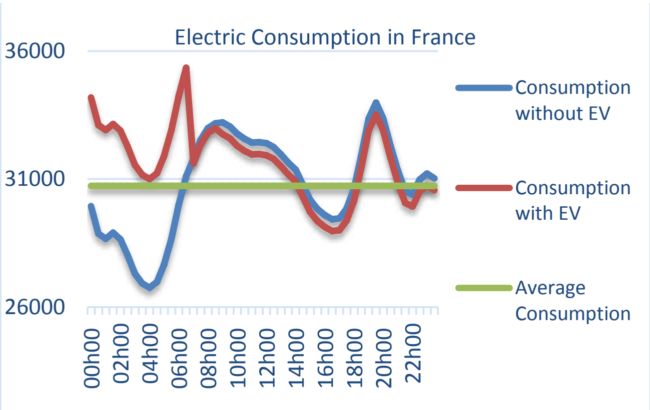


Figure 7. Power Consumption by Fleet Size (X Axis in hours and Y Axis in MWh).

The results obtained by varying the parameter expansion coefficient are shown in Figure 8:

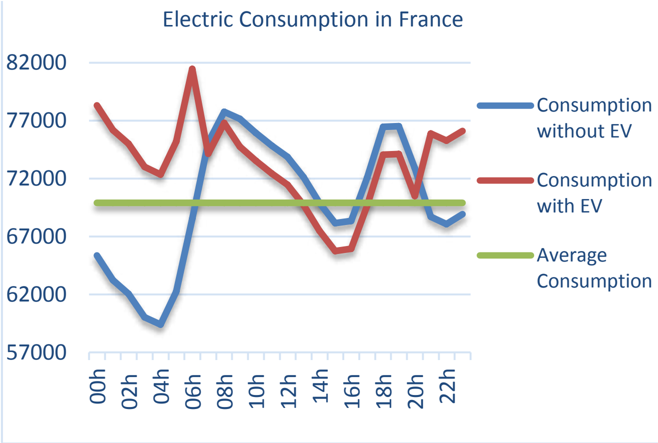


Figure 8. Power Consumption by Expansion Coefficient (X Axis in hours and Y Axis in MWh).

The results obtained by varying the parameter Times of Charge/Discharge are shown in Figure 9:

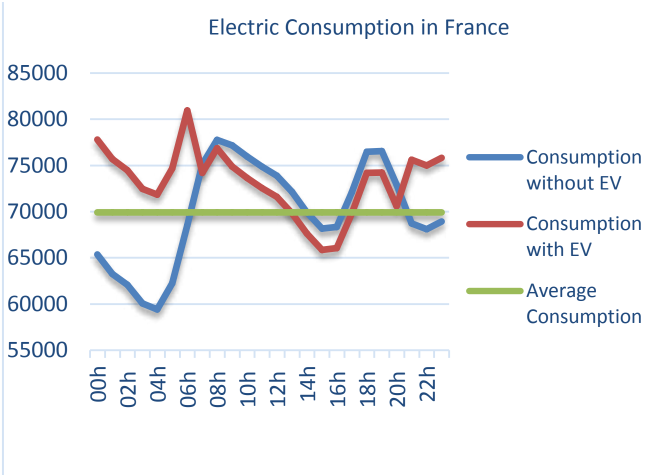


Figure 9. Power Consumption by Charge/Discharge Times Batteries (X Axis in hours and Y Axis in MWh).

C. V2G Model Significant Parameters

In order to refine the study on the significant parameters selection from the set of V2G model parameters, 4 scenario simulations were performed to test the V2G model for the following configurations, namely: summer, spring, autumn, and winter:

1) V2G 4 Seasons Simulations

The whole configurations for the simulations of the V2G for the 4 seasons are summarized in TABLE II:

 ISBN: 978-1-61208-414-5

TABLE II. V2G 4-SEASONS SIMULATIONS.

| | spring | summer | autumn | winter |
|---|---|---|---|---|
| Real Battery Capacity (kwh) | 15 | 15 | 15 | 15 |
| Battery Voltage (v) | 400 | 400 | 400 | 400 |
| Minimum Time of Charge/Discharge (h) | 5.5 | 5.5 | 1 | 5.5 |
| Recharge Power Terminal (kw) | 4 | 4 | 22 | 4 |
| Transformation Efficiency DC/AC (%) | 90 | 95 | 90 | 90 |
| Vehicles Number (million) | 1 | 0.5 | 1 | 1 |
| Behavior Losses Coefficient (%) | 85 | 85 | 85 | 85 |
| Theoretical Vehicle Autonomy (km) | 210 | 210 | 210 | 210 |
| Real Autonomy Estimation (km) | 179 | 179 | 179 | 179 |

The variation related to the expansion coefficient is shown in TABLE III.

TABLE III. EXPANSION COEFFICIENT VALUES.

| | 7h-12h | 12h-14h | 14h-18h | 18h-7h |
|---|---|---|---|---|
| Spring (%) | 70 | 60 | 40 | 100 |
| Summer (%) | 60 | 70 | 60 | 50 |
| Autumn (%) | 70 | 60 | 60 | 100 |
| Winter (%) | 50 | 60 | 40 | 80 |

2) Results Obtained

The results obtained for the energy interaction are shown in TABLE IV.

TABLE IV. ENERGY INTERACTION BETWEEN THE EV ANS THE SMART GRID.

| Maximum Energy | spring | summer | autumn | winter |
|---|---|---|---|---|
| Power back into the smart grid (MWh) | 6430 | 3218 | 6874 | 5321 |
| Injected from the network to the EV (MWh) | 2000 | 1000 | 11000 | 2000 |
| Injected from the EV to the network (MWh) | 9978 | 5265 | 9978 | 9978 |
| Consumption increase in EVs (%) | 0.66 | 0.26 | 1 | 0.64 |

3) Significant Parameter-based Design of Experiment

The setting of parameters based on methodology from the Design of Experiments (DOE) filed is used to identify the most significant parameters of our V2G model (by significant parameters we define those for which changes of values directly impacts the model output). The use of DOE has reduced the model parameters from 14 to 4 significant parameters. This significantly reduces the number of experimental simulations required and causes rapid converge towards an optimal parameter sets. The significant parameters obtained are shown in TABLE V.

TABLE V. V2G MODEL SIGNIFICANT PARAMETERS.

| | Description | Unit |
|---|---|---|
| 1 | Battery Capacity | kW.h or Ah |
| 2 | Recharge Power Terminal | kW |
| 3 | Vehicles Number | Vehicles |
| 4 | Expansion Coefficient | % |

## V. Results Analysis & Discussion

As a synthesis of the whole set of simulations, we present the following conclusions concerning the impact of EVs on the power grid: Despite 2 million vehicles added to the classic park, the consumption profile has not changed “very significantly”. In other words, the general behavior of the smart grid is the same but with a higher level of consumption. These two million EVs replace probably at least their thermal equivalent. This causes more power consumption, which requires more energy production. This in turn provides the benefit of reducing fossil fuel fleet and thus reduces the carbon footprint.

The energy feedback network does not affect the life of lithium-ion batteries; this is due to the fact that the discharge threshold setting of 25% was observed. Electric vehicles have an impact on electricity consumption although this impact remains "relatively modest" compared to the large size of the fleet of EV (2 million). Except for the private fleet (with 10000 VE), and during the charging period, we found an increase in electricity consumption. However, as the fleet in question is a V2G fleet, EVs outside charging periods inject energy into the network to reduce consumption during peak hours. The average consumption clearly shows a slight increase in the daily electricity consumption, which supports our first observation above about the non-significant impact of EVs on the overall energy consumption. In addition to the V2G, the introduction of future wind farms and hydro plants could reduce the load on the grid absorbed by the EVs during the daily power consumption. This is also aided by the contribution of Vehicle to Home (V2H), hence the strong interaction between the V2G and V2H.

## VI. Conclusion

We have presented in this paper an extensive experimental study on V2G and its impact in the production of renewable energy and its interaction with the conventional smart grid. This study included an overview of V2G projects. Subsequently, we presented our V2G model including several significant parameters. This model has been the subject of several simulations to demonstrate its feasibility.

Subsequently, a synthesis has been prepared to present the impact of EVs on the smart grid. We found during our various simulations that despite the 2 million EVs added to the fleet on the horizon of 2020, and despite additional consumption of energy caused by the large number of EVs, the general behavior of smart grid has not changed “very significantly”. The EV power returned to the network is important and could, eventually, relieve the smart grid. The regenerative feedback into the smart grid does not affect the life of lithium-ion batteries. The scenarios provide a minimum charge level for users. Designs of Experiments methodology have reduced the V2G model parameters from 14 to 4. As an example, our V2G model shows that for a fleet of 3 Million EVs, we can inject into the grid at about 31.6 GWh per day, representing energy production of two nuclear reactors (900 MW from each one and 32 GWh both of them) and a wind farm of 645 wind turbines (2 MW from each one and 31 GWh both of them). This illustrates the value of our V2G model and the benefits of using EVs within a Smart Grid environment.

## ACKNOWLEDGMENT

This research is supported by the Franco-British project Smart Autonomous Vehicle for Urban Mobility using Renewable energy (SAVEMORE with the website: http://savemore-project.eu/) that has been selected in the context of the INTERREG IVA France (Channel) England European cross-border co-operation program. The authors wish to thank the students of ESIGELEC Engineer Project for their contribution in the development of the results presented in this paper.

## REFERENCES

[1] W. Kempton, and J. Tomić, "Vehicle to Grid Power Implementation: from stabilizing the grid to supporting large-scale renewable energy". Journal of Power Sources, Vol. 144, Issue 1, p280-294, 1 June 2005.

[2] L. Steven, and W. Kempton, "The V2G Concept: A New Model for Power ?", Public Utilities Fortnightly, 140(4): 16-26, February 2002.

[3] J. Tomić, and W. Kempton, "Using fleets of electric-drive vehicles for grid support". Journal of Power Sources, 168 (20), p459-468. 2007.

[4] L. Steven, P. Denholm, and P. Lilienthal, "Electric and Hybrid Vehicles: New Load or New Resource ?", Public Utilities Fortnightly, p28-37, December 2006.

[5] W. Kempton, and J. Tomić, "Vehicle to Grid Fundamentals: Calculating Capacity and Net Revenue", Journal of Power Sources, Volume 144, Issue 1, Pages 268-279, 1 June 2005.

[6] W. Kempton, and T. Kubo, "Electric-drive Vehicles for Peak Power in Japan", Energy Policy 28(1): 9-18. 2000.

[7] eBox of AC Propulsion: http://www.acpropulsion.com/eBox%20specsheet.pdf. 2003.

[8] C. Binding, D.Gantenbein, B. Jansen, O. Sundstr ̈om, P. Bach Andersen, F. Marra, B. Poulsen, and C. Træholt, "Electric Vehicle Fleet Integration in the Danish EDISON Project - A Virtual Power Plant on The Island of Bornholm". Power and Enery Society General Meeting, 2010 IEEE, ISSN 1944-9925, P1-8, 25-29 July 2010.

[9] Toyota City Project. http://www.downtowntoyota.ca/about_us/news_and_events/toyota_develops_vehicletohome_v2h_power_system. 1982.

[10] NUVVE V2G http://www.greentechmedia.com/articles/read/can-nuvve-make-v2g-work-in-the-real-world. June 20, 2011.

[11] "Vehicule to Home" Electricity Supply Chain: http://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/vehicle_to_home.html. 2011.

[12] E-Energy : http://www.efficiency-from-germany.info/ENEFF/Redaktion/EN/Standardartikel/e-energy.html. 2007.

[13] GridBot Project – Intelligent Charging Solutions: http://www.gridbot.us/about.html. 2012.

[14] Smart Grids – CRE : http://www.smartgrids-cre.fr/index.php?rubrique=dossiers&srub=vehicules&action=imprimer. 2014.

[15] Design of Expriments. Release 6, SAS Institute Inc. Cary, NC, USA, ISBN 1-59047-816-9.

[16] Fossil Fuels http://instituteforenergyresearch.org/topics/encyclopedia/fossil-fuels/. 2014.

[17] http://www.ademe.fr/. 2015.

[18] W. Tushar, S. Huang, C. Yuen, J. Zhang, D. B. Smith, "Synthetic Generation of Solar States for Smart Grid: A Multiple Segment Markov Chain Approach", ISGT Europe 2014.

[19] The Smart Autonomous Vehicle for Urban Mobility using Renewable energy (SAVEMORE) project (URL: http://savemore-project.eu/) is supported by the European Regional Development Fund (ERDF) and has been selected in the context of the INTERREG IVA France (Channel) England European cross-border co-operation program.