EVS24
Stavanger, Norway, May 13-16, 2009

Some aspects of joining photovoltaic micro-generation systems with plug-in hybrid electric vehicles

Cláudio Casimiro[1], Duarte Sousa 2[2], Jorge Esteves[3]
[1]*CEEETA-ECO, Consultores em Energia, Lisboa, Portugal – claudio.casimiro@ceeeta.pt*
[2]*Instituto Superior Técnico, DEEC AC-Energia/CIEEE – Center for Innovation in Electric and Energy Engineering, TU Lisbon – Av. Rovisco Pais – 1049-001 Lisboa – Portugal, duarte.sousa@ist.utl.pt (corresponding author)*
[3] *ISEL – Instituto Superior de Engenharia de Lisboa – Rua Conselheiro Emídio Navarro, 1 1950-062 Lisboa – Portugal and CIEEE – Center for Innovation in Electric and Energy Engineering, Av. Rovisco Pais, 1049-001 Lisboa, Portugal, jesteves@deea.isel.ipl.pt*

Abstract

The models and number of Electric Vehicles (EVs) circulating in Portugal is not very significant; however, the number of electric vehicles has been slowly increasing and a boom is expected in the coming years. Under this scenario, increasing the number of EVs and fostering the introduction of Hybrid Electric Vehicles (HEVs) circulating (replacing the vehicles with internal combustion engines) will contribute to increase the electric power consumption. In addition, new technological challenges will be launched, not only related to the charging points but also related to the impact of such systems in the electrical grids. So, this subject can be discussed from different point of views and distinct perspectives being the following topics under analysis in this work: impact of the connection of the electrical vehicles to the low voltage AC grid; technical solutions allowing charging the EV using the domestic AC grid; technical solutions allowing to recover the energy stored on-board; interconnection with alternative energy solutions, mainly the domestic photovoltaic systems.

So, in this paper, a HEV with parallel configuration is used having on board the following chains: IC Engine + Generator + Electronic + Batteries; Ultra capacitors + Electronic converter + Batteries; Batteries + Electronic converter + Electric motor; Batteries + Electronic converter + AC grid.

In order to study the impact, the benefits and the constraints of such solutions, different scenarios to the number of vehicles with electrical propulsion were traced, based on the number of electrical vehicles sold in Portugal during the past years.

On the other hand, it is crucial to forecast the impact of such systems in the production of electric energy and in particular, to analyze the role of renewable energies. With particular interest nowadays, the micro-generation systems can play an important role in order to fulfill the power requirements of the HEVs and providing charging points independent of the AC grids.

Keywords: Vehicle to grid, Electric Vehicles, Energy, Photovoltaic

1 Introduction

Societies all over the world are facing a dilemma originated, mainly, by the increasing demand of oil in road vehicles and the environmental commitments for global climate change. Furthermore, in the last decade the oil consumption has been increasing and, simultaneously, is price in international markets.

In fact, the increasing demand of oil is strongly related to the increasing number of road vehicles circulating. As it is well known, most of the road vehicles are oil addict.

In addition to the economical aspects, also the environmental concerns, as for instance local pollutant emissions to the atmosphere, are influencing not only the our daily lives routines but also the technical decisions related with the road vehicles.

All of this is encouraging new solutions to phasing-out the conventional internal combustion engines, in order to attain less pollutant, more efficient and consequently more environmental friendly solutions. So, vehicles with electric propulsion have seemed an interesting challenge for achieving green mobility. Furthermore, the technical solutions on-board can include different features and equipments, as for instance:

- Energy buffers using ultracapacitors;
- Plug-in systems; and
- Inject the stored energy in the AC grid (Vehicle to Grid - V2G).

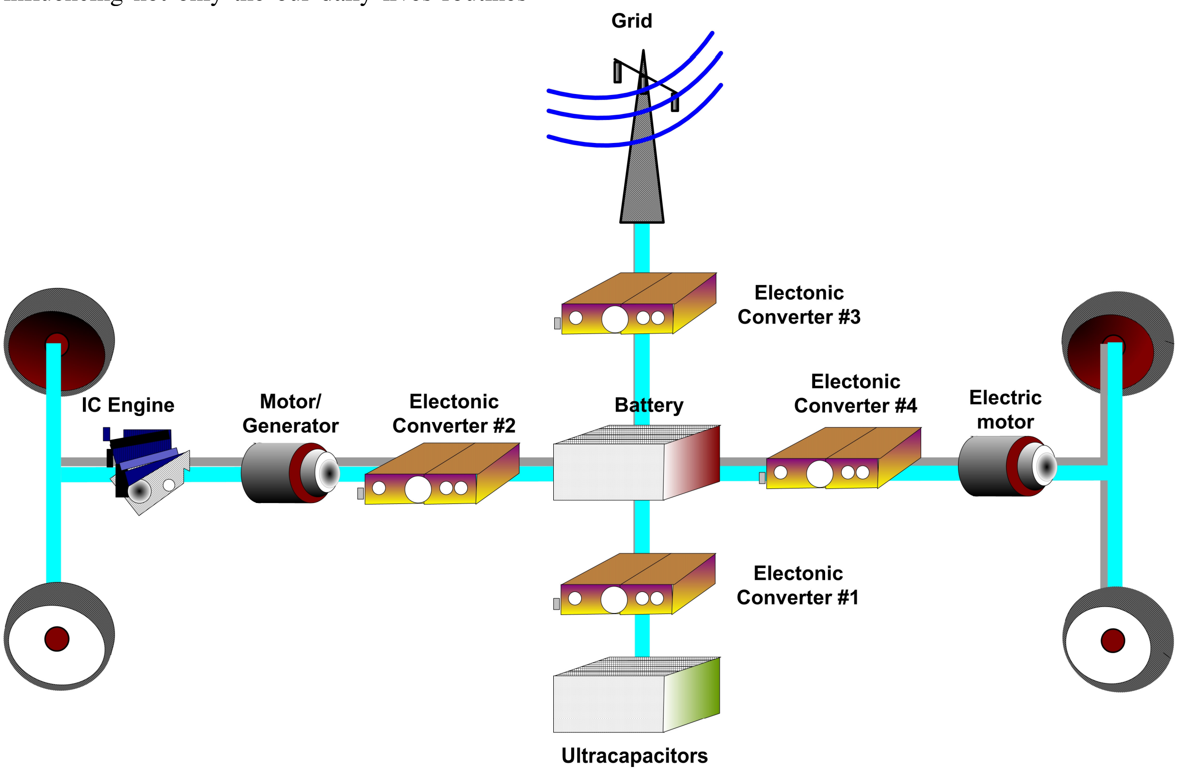

Figure1: Diagram of the ICE - Vehicle – AC Grid interactions

Considering the mentioned outlook, this work considers an analysis of the V2G in a point of view of a Portugal. In order to study the impact, the benefits and the constraints of such solutions, different scenarios related to the number of vehicles with electrical propulsion were traced, based on the number of electrical vehicles sold in Portugal during the past years. According to these scenarios, the aspects discussed in this work are mainly focused in the following topics:

i) impact of the connection of the electrical vehicles to the low voltage AC distribution grid;
ii) technical solutions allowing to charge the EV using the domestic AC distribution grid;
iii) technical solutions allowing to recover the energy stored on-board;

iv) interconnection with alternative energy solutions, mainly the domestic photovoltaic systems.

From a global point of view, figure 1 illustrates the system under study.

2 The Portuguese EV's Framework

According to the Portuguese Automobile Association (ACAP) statistics the Portuguese road vehicles fleet in 2006 had approximately 5,7 millions units, corresponding to 73,8 % of light passenger vehicles with an average of 8,4 years old.

In terms of EVs and HEVs, the number of vehicles circulating is reduced (Figure 2) when compared to the total number of vehicles circulating in Portugal.

However, the estimation of the number of vehicles (hybrid or purely electric) in circulation in the coming years depends on several factors. It is clear that the panorama is changing and a boost is expected for the near future.

Based on the data showed in figure 2, the following scenarios to the number of road electric vehicles for individual use circulating in Portugal in the coming years are the following:

- Scenario #1: $Vy = 180(Y - 2000)$
- Scenario #2: $Vy = 1{,}7(Y - 2000)^3$
- Scenario #3: $Vy = 180[e^{0{,}2(Y-2000)} - 1]$

Where Vy is the number of vehicles circulating in the year Y (Y ∈ [2000, 2020]).

3 Electric chains on-board

Starting from the vehicle basic topology shown in figure 1, it is possible to identify different electric chains, which depend of state of operation of the vehicle. From this point of view it is possible to analysis separately the dynamic behaviour of the following systems:

- IC Engine + Generator + Electronic converter #2 + Batteries;
- Ultra capacitors + Electronic converter #1 + Batteries;
- Batteries + Electronic converter #4 + Electric motor;
- Batteries + Electronic converter #3 + AC grid.

The system was studied testing different topologies for the electronic converters and type of motors. Among other solutions, figure 4 shows some of the solutions simulated.

About the proposed solutions, it is important to refer that the batteries are the focal point of the proposed car topology. As it is well-known, batteries strongly influence the car performance and mainly, define the car's autonomy. So, different types of batteries were tested (developing simulation models to the following types of batteries: Lead Acid, Nickel Metal Hydride and Lithium Ion) in order to improve the system efficiency and autonomy.

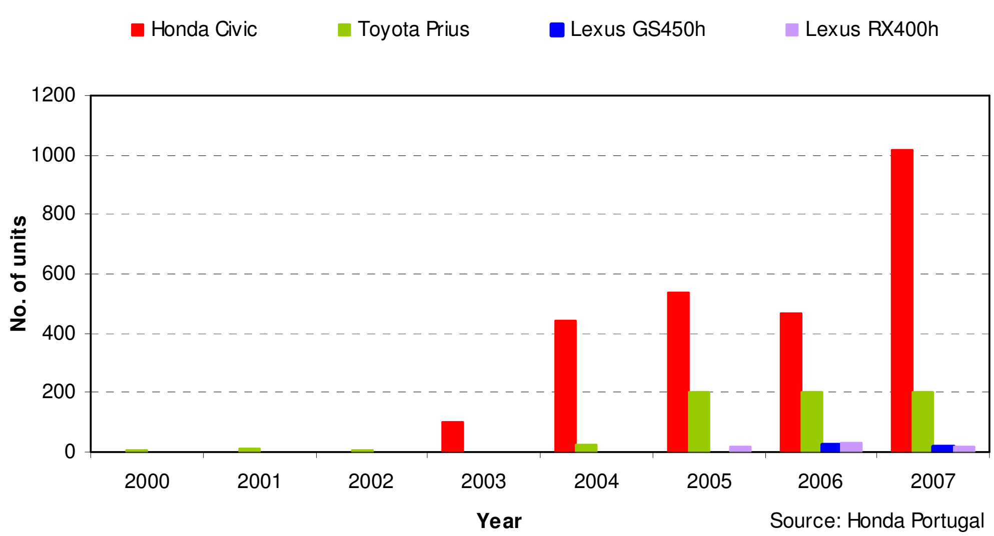

Figure2: Evolution of the HEVs in Portugal

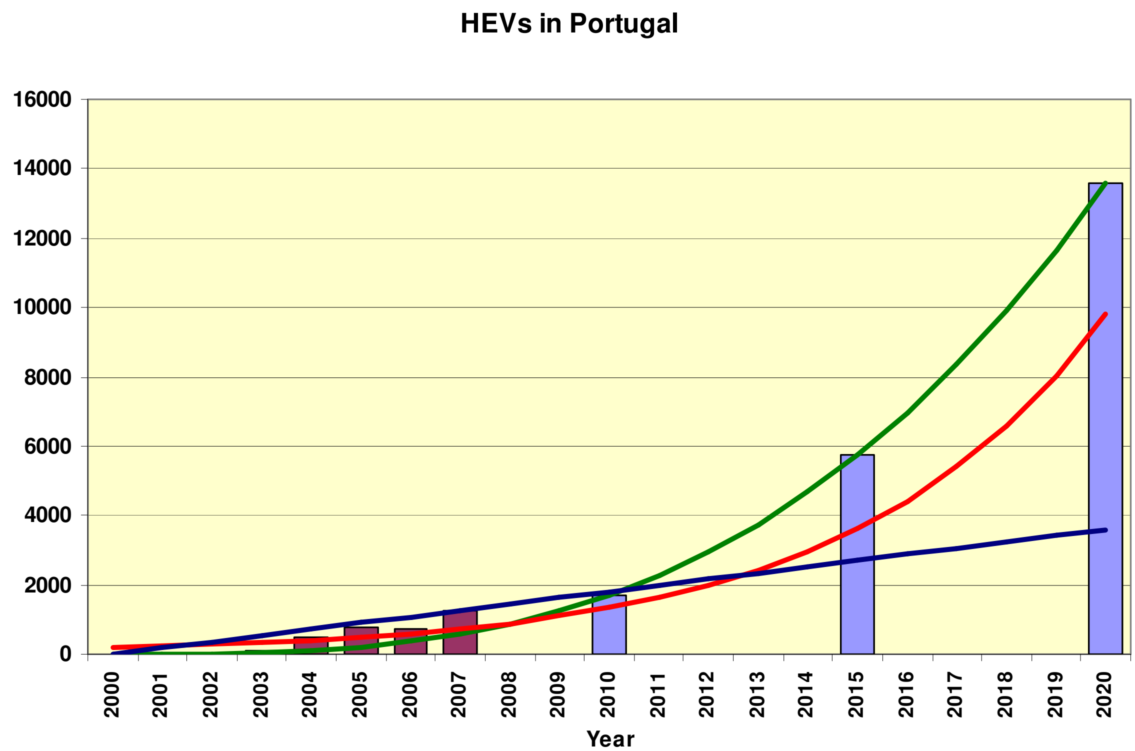

Figure3: Three scenarios for HEVs circulating in Portugal in the coming years

About the electric chains referred before, it is also important to point out the role of the ultra capacitors. In addition to the characteristic of storing energy, ultra capacitors can contribute significantly to improve the performance of the system since that they avoid high current peak and fast discharges of the batteries.
According to the state of operation of the vehicle, the systems shown in figure 4 were used in the power balance of the system.
Taking into account, the nowadays issues about the energy (price, consumption rate and environmental concerns, mainly) the proposed system can benefit by the use of renewable energy. Furthermore, renewables have been and will be important to sustain the power demands. Based on this premise, a proposal upgrading the proposed system is described and discussed in the coming points.

3.1 Vehicle topology upgraded

Taking into account the operation modes allowed by the solutions shown in figure 4, when ordinary AC grids are not available the electric system can be supplied by autonomous power sources. Particular case, domestic photovoltaic systems can be used with this purpose.
About these systems, it is important to refer that some countries, as for instance Portugal and Spain, have been defining the legal issues for domestic photovoltaic power production (PV micro-generation solutions). Using as reference the Portuguese legislation, the more appellative electrical energy feed-in tariff (650 €/MWh) with the solutions is limited in time and in power (3,68 kW), with the production constraint 2,4 MWh/year in the AC grid.
Following this concept, in figure 5, the car including this electric chain is schematically represented.
One of advantages of the proposed system is being able to use energy provided by the photovoltaic modules and therefore and also to inject the power in the low voltage AC grid. In this case, the batteries, the controlled inverter /Electronic converter #5) and the AC grid constitute the basic elements of the photovoltaic system – AC grid electric chain.

Incorporating in electric vehicles the possibly of recharging the system using photovoltaic modules increases, at least, the cost of the system. Furthermore the technical implications when projecting domestic electric networks, the potential of this solution should be evaluated in terms of the expected number of points or houses with micro-generation systems installed.

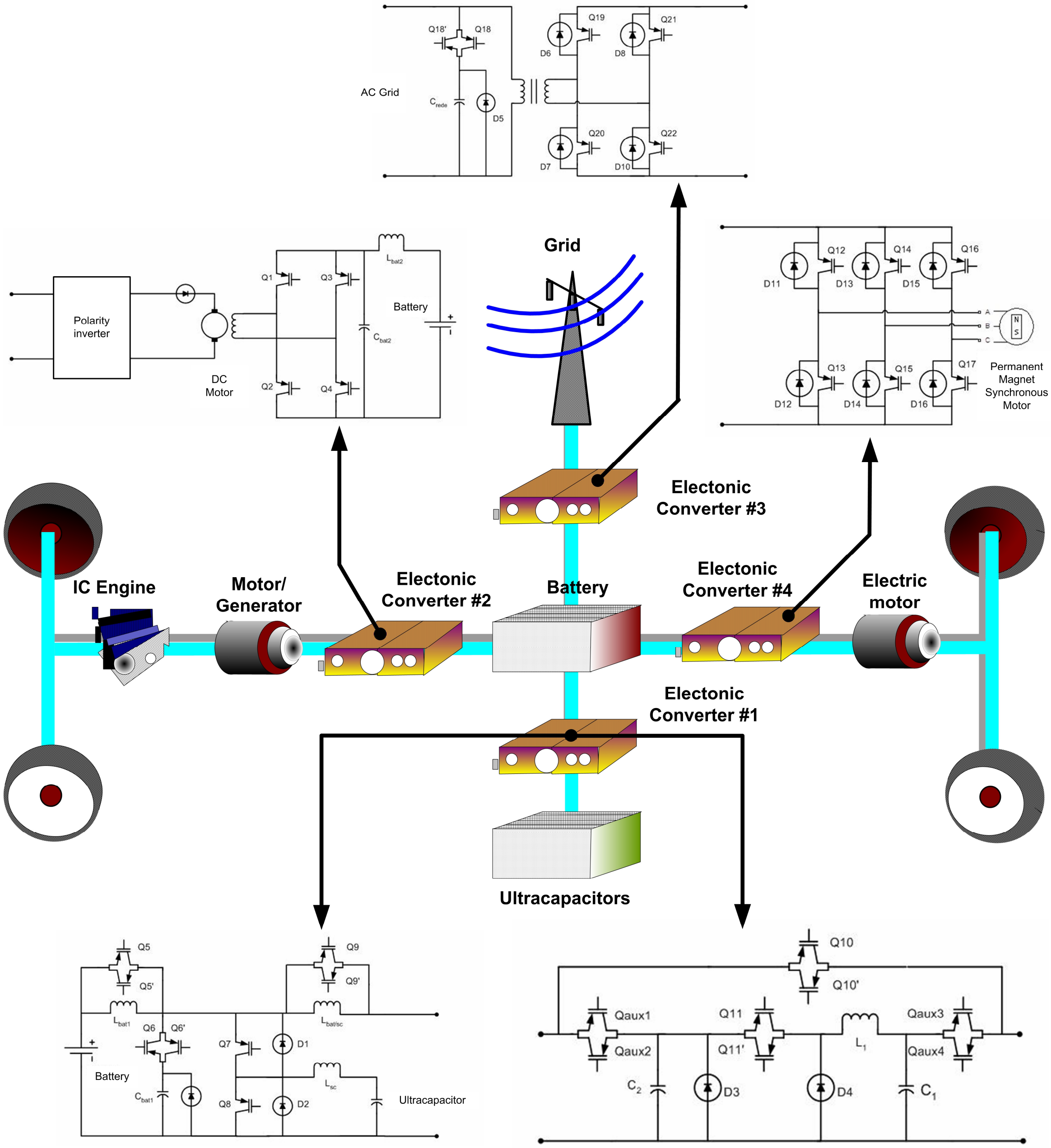

Figure4: Examples of possible solutions for each branch of the car topology

3.2 Expected evolution of the on-grid power systems

All over the world and in particular in Europe, the micro-generation systems have been increasing being expected that, in the coming years, these systems have a significant contribution to the installed power in Portugal. Anyway, according to the number of applies to install these systems and their rate of execution, it is expected that the real number of micro-generation systems will be situated in between the scenarios represented in figures 7 and 9. Assuming that the installed systems fulfil the maximum power requirements allowed by the legislation, to these two scenarios correspond the power installed shown in figures 6 and 8.

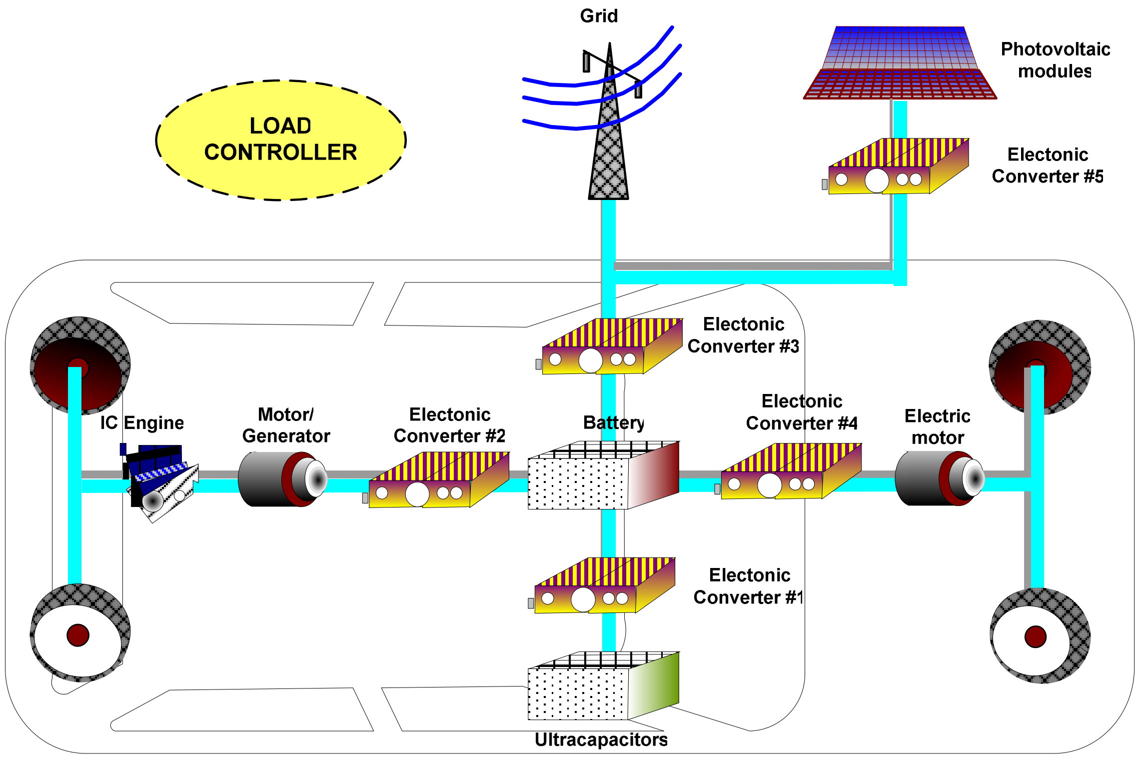

Figure5: Main car chains including the photovoltaic system

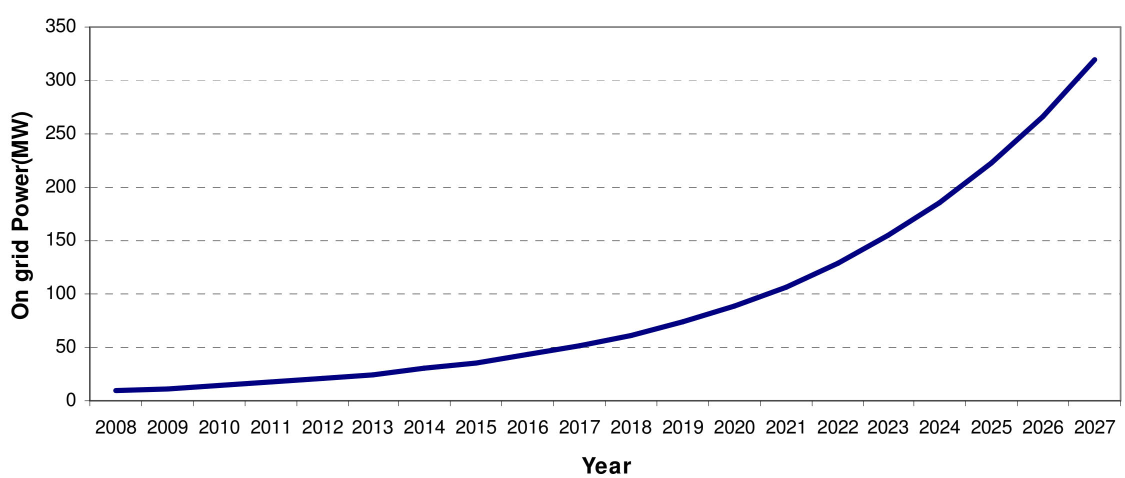

Figure6: Expected evolution of the on-grid power in Portugal [Source: Renovaveis na Hora - www.renovaneisnahora.pt]

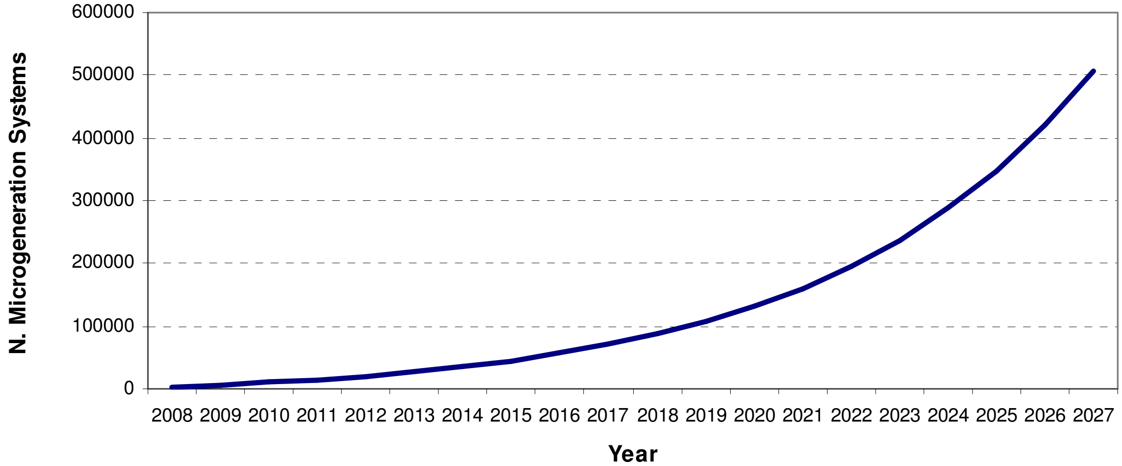

Figure7: Expected evolution of the number of micro-generation systems in Portugal [Source: Renovaveis na Hora - www.renovaneisnahora.pt]

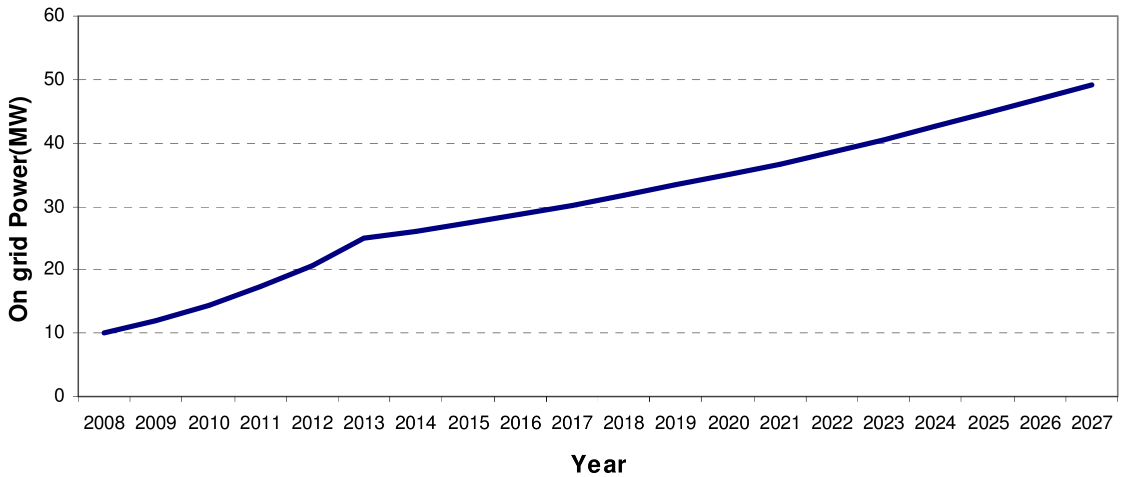

Figure8: Conservative evolution of on-grid Power systems in Portugal [Source: Renovaveis na Hora - www.renovaneisnahora.pt]

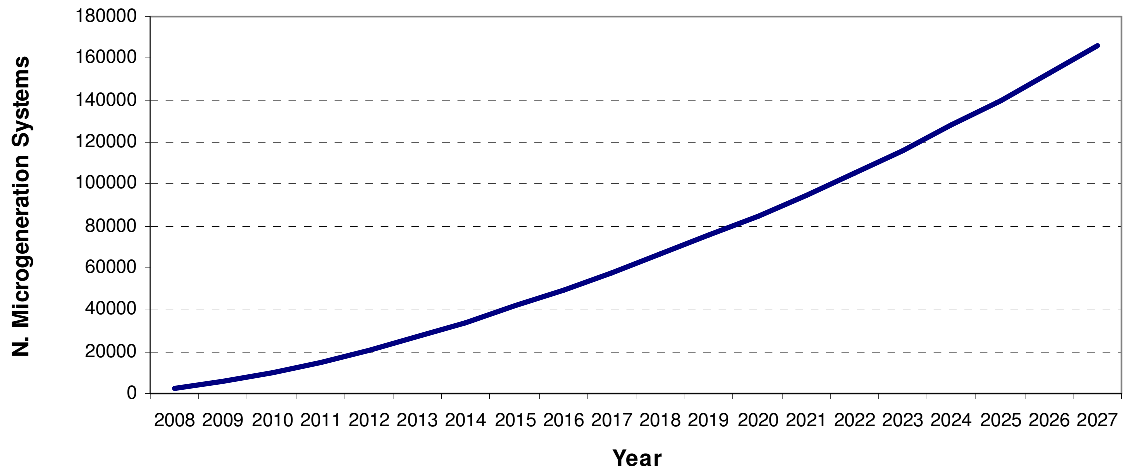

Figure9: Conservative evolution of the number of micro-generation systems in Portugal [Source: Renovaveis na Hora - www.renovaneisnahora.pt]

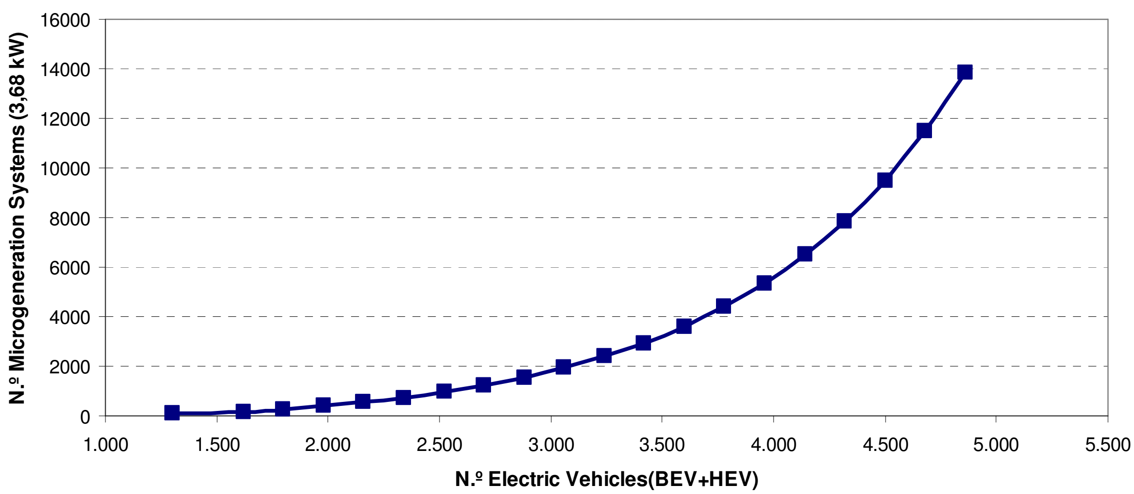

Figure10: Relationship between the number of micro generation systems and the number of BEV + HEV for the conservative evolution

3.3 Number of electric vehicles vs. number of micro-generation systems

One challenge of the usage of EVs is the available number of charging points. In addition, the power needs should be fulfilled by the available power sources (ac grid or not). To the proposed vehicle configuration and in order to maximize the efficiency of the micro-generation systems, it is possible to use, at least, the unused power of the micro-generation to charge EVs. Taking into account the results shown in figure 10, to charge the EVs using the micro-generation systems could not constitute a constraint if the micro-generation system has enough energy stored.

4 Power Balance

Joining the power needs of EVs and the scenarios about micro-generation systems and taking into account the versatility allowed by the chains on-board of the proposed system, a power balance should be performed in order to frame the importance and viability of using such systems.

4.1 Results

To study the proposed vehicle performance it was made a power balance from a test circuit with up hills and down hills but without curves, which characteristics are shown in table 1.

Table1: Characterization of the test circuit

Traject No.	Distance [m]	Inicial speed [km/h]	Final speed [km/h]	Average time [s]	Power delivered [W]
1	500	0	30	120,00	16879,35
2	500	30	25	65,45	1054,29
3	500	25	30	65,45	27720,11
4	1000	30	65	75,79	5385,12
5	1000	65	70	53,33	31226,43
6	1000	70	70	51,43	7290,10
7	1000	70	70	51,43	17482,12
8	1000	70	90	45,00	13581,88
9	1000	90	110	36,00	33759,98
10	1000	110	100	34,29	16887,35
11	1000	100	100	36,00	6953,94

The EV has, in this model, a permanent magnet synchronous motor operating in parallel with a IC engine and allowing regenerative breaking. The mechanical loses are neglected, the engine efficiency is expected to be 25%.
To each trajectory of the test circuit, the power balance is shown in table 2.

Table2: Power balance for the test circuit

Traject no.	E battery [Wh]	E PMSM [Wh]	E engine [Wh]	E break [Wh]
1	597,42	562,64	0,00	0,00
2	20,35	19,17	0,00	0,00
3	-362,51	-363,64	0,00	-140,37
4	60,19	56,69	56,69	0,00
5	245,60	231,31	231,31	0,00
6	55,29	52,07	52,07	0,00
7	-248,97	-249,74	0,00	0,00
8	0,00	0,00	169,77	0,00
9	0,00	0,00	337,60	0,00
10	0,00	0,00	160,83	0,00
11	0,00	0,00	69,54	0,00
total	367,38	308,50	1077,81	-140,37

To this circuit, globally, the engine supplies 1077,81 Wh, the PMSM supplies 921,88 Wh, 631,38 Wh are recovered and 140,37Wh are lost in breaking efforts. It is needed to supply 4 311,24 Wh to the engine, which equals to 0,45 litters of petrol.
According to the average fuel and electricity prices in Portugal in 2008, the cost associated to the test circuit (total distance of 9,5 km) is 0,63€. If this vehicle uses only its engine, 1 999,69 Wh are required to the test circuit meaning that the engine is supplied with 7 998,75 Wh of fuel, being the associated cost 1,1€.

4.1.1 Charging the batteries using the Portuguese distribution grid

Another important analysis is the batteries behaviour. To charge the batteries from a complete discharge state, it is needed 10,5 kWh. The charger has not a unitary efficiency so it is needed 10 741 Wh are demanded from the grid. If the battery returns this energy back, only 10 290 Wh reach the grid, being the rest losses.
If we charge the batteries completely from the Portuguese distribution grid, the energy mix comes from:

Table3: Origin of the Portuguese electrical energy

Energy production	Share	Power share [Wh]
Water	0,22	2 357,146
Wind	0,11	1 178,573
Biomass	0,03	321,429
Coal	0,28	3 000,004
Fuel+Diesel	0,03	321,429
Thermal emission	0,2	2142,86
Energy bought	0,11	1 178,573
Others	0,02	214,286

From the table above we can conclude that 36% of the recharge energy is renewable, 51% comes from thermal plants/ electric energy sources and 13% from an unknown source.
If the battery set is recharged from using the IC engine chain, to supply de alternator 12 206 Wh are demanded. Neglecting the mechanical losses in this chain, this power corresponds to 40 688,3 Wh supplied to the IC engine (oil consumption), which equals to 4,2 liters of petrol with a cost of 5,6€.

5 Conclusions

In this paper, some aspects of joining photovoltaic micro-generation systems with plug-in hybrid electric vehicles are described and discussed

mainly based on the following premises: the number of PHEVs and pure EVs will increase in the coming years; cars will be equipped with systems allowing energy exchange with conventional and unconventional AC grids; cars can have on board micro-generation systems (photovoltaic or other); and, the number of micro-generation systems (mainly photovoltaic based) will be installed and ready to be connected either to ordinary grids or to isolated loads.
Anyway, some technological aspects of the systems mentioned above have to be improved. Furthermore, the oil prices fluctuation will remain a decisive factor in decisions related with the automobile sector.
As final remark, according to the traced scenarios about the number of plug-in vehicles, it is important to point out that the electric energy consumption due to this type of vehicles will increase significantly and will produce an important impact in the AC grids. So, alternative energies and isolated micro-generation systems can play an important role in order to reduce the impact of such systems.

Acknowledgments

Authors thank the CIEEE – "Center for Innovation in Electrical and Energy Engineering" of IST/TU Lisbon and POSC – "Programa Operacional da Sociedade do Conhecimento" for financial support of this work.

References

[1] Saifur Rahman, B. H. Chowdhury, *Simulation of Photovoltaic Power System and their Pergormance Prediction*, IEEE Transactions on Energy Conversion, Vol. 3, No. 3, September 1988.

[2] Y. Nozaki, K. Akiyama, H. Kawaguchi, K. Kurokawa, *An improved method for controlling an EDLC-battery hybrid stand-alone photovoltaic power system*, APEC 2000. Fifteenth Annual IEEE Applied Power Electronics Conference and Exposition, Volume 2, pp. 781 – 786, 2000.

[3] Portuguese Legislation: Ministério da Economia e da Inovação, Decreto-Lei n.º 363/2007de 2 de Novembro de 2007.

[4] Pablo Sanchis, Jesús López, Alfredo Ursúa, and Luis Marroyo, *Electronic Controlled Device for the Analysis and Design of Photovoltaic Systems*, IEEE Power Electronics Letters, Vol. 3, No. 2, June 2005.

[5] Chang Ying-Pin; Shen Chung-Huang, *Effects of the Solar Module Installing Angles on the Output Power*, ICEMI '07. 8th International Conference on Electronic Measurement and Instruments, 2007.

[6] Yaow-Ming Chen; Chien-Hsing Lee; Hsu-Chin Wu, *Calculation of the optimum installation angle for fixed solar-cell panels based on the genetic algorithm and the Simulated-annealing method*, IEEE Transaction on Energy Conversion, Volume 20, Issue 2, June 2005, pp. 467 – 473.

[7] Y. Ueda, K. Kurokawa, T. Tanabe, K. Kitamura, H. Sugihara, *Analysis Results of Output Power Loss Due to the Grid Voltage Rise in Grid-Connected Photovoltaic Power Generation Systems*, IEEE Transactions on Industrial Electronics , Volume 55, Issue 7, July 2008, pp. 2744-2751.

[8] Tom Geist, Haresh Kamath, Suzanne Porter, and Peter May-Ostendorp, *Designing Battery Charger Systems for Improved Energy Efficiency*, Epri Solutions, Inc., 2006.

[9] H. Chan, *A New Battery Model for use with Battery Energy Storage Systems and Electric Vehicles Power Systems*, IEEE Power Engineering Society Winter Meeting, 2000.

[10] Zolot, Matthew and Kramer, Bill *Hybrid Energy Storage Studies Using Batteries and Ultracapacitors for Advanced Vehicles*, 12th International Seminar on Double Layer Capacitors and Similar Energy Storage Devices, 2002.

[11] *Selection of Electric motors for aerospace applications*, NASA – National Aeronautics and Space Administration, Practice No. PD-ED-1229.

[12] Stefano Barsali, Massimo Ceraolo, *Dynamical Models of Lead-Acid Batteries: Implementation Issues*, IEEE Transactions on energy conversion, Vol. 17, no. 1, 2002.

[13] Lijun Gao, Shengyi Liu, Roger Dougal, *Dynamic Lithium-Ion Battery Model for System Simulation*, IEEE Transactions on components and packaging technologies, Vol. 25, Nº3, 2002.

[14] Richard Perez, *Lead-Acid Battery State of Charge vs. Voltage*, Home Power, 1993.

[15] John Miller, Patrick McCleer, Mark Cohen, *Ultracapacitor as Energy Buffers in a Multiple Zone Electrical Distribution System*, Maxwell Technologies – White paper.

[16] D. M. Sousa, P. J. Costa Branco and J. A. Dente, *Electric Bicycle Using Batteries and Supercapacitors*, "EPE 2007 - 12th European

Conference on Power Electronics and Applications", Aalborg, Denmark, 2 - 5 September, 2007, Paper no. 346.

[17] D. M. Sousa, P. J: Costa Branco and J. A. Dente, *Electric Bicycle Supplied by an Electronic Converter Using Distinct Forms of Energy Storage*, "Powereng – 1st International Conference on Power Engineering, Energy and Electrical Drives", Setúbal - Portugal , 12-14 April, 2007, Paper no. 223.

[18] A. Roque, D. M. Sousa, C. Casimiro, *Camping Car with Self Power Generation*, "2nd International Conference on Power Engineering, Energy and Electrical Drives", Costa da Caparica - Portugal, March 2009.

[19] D.M. Sousa, C. Casimiro, I. Santos, J. Esteves, M. J. Resende, R. Stüssi, *Implications for EV in Portugal from the new European CO2 emissions limits*, 23 rd International Electric Vehicle Symposium (EVS 23), Anaheim, CA, USA, 2-5 December 2007.

Authors

Cláudio Casimiro (b. 1974) graduated as Process and Energy Engineering from Universidade de Évora. Post-graduated in Economical Sciences and is MBA from Technical University of Lisbon (ISEG). He has been active in the energy field for 10 years being project manager at the Portuguese National Energy Agency and at the Algarve Local Energy Agency, responsible for developing several energy audits to industrial sites. Since 2003 until 2007 he was Project Manager at APVE – Portuguese Electric Vehicle Association. There, his activity included the organization of conferences and events and the coordination of research and demonstration projects in the transportation sector. Actually he is Project Manager at CEEETA-ECO Energy Consultants.

Duarte M. Sousa was born in Viana do Castelo, Portugal, in 1970. He received the Dipl.Ing., M.S. and Ph.D. degrees from the Instituto Superior Técnico, Technical University of Lisbon, Portugal, in 1993, 1996 and 2003, respectively, all in Electrical and Computer Engineering. In 1993, he joined the, Technical University of Lisbon, where, since 2003 he has been an Assistant Professor.

Jorge Esteves, graduated and got his M.Sc. and Ph.D. degrees in Electrical Engineering from Instituto Superior Técnico, Lisboa, Portugal, in 1983, 1986, and 1992, respectively. Since 2004, he has been Coordinator Professor of the Department of Electrical and Automation Engineering at the Instituto Superior de Engenharia de Lisboa. He is also a researcher at the Centro de Automática da Universidade Técnica de Lisboa and Director of Dispatch and Networks at the Portuguese Energy Regulator Authority (ERSE). His main research interests are electrical machines modelling, variable speed electrical drive and generator systems and application of electric and electronic systems to the transport domain. He is President of the Consulting board of the Portuguese Electric Vehicle Association.