Analysis of the penetration and impacts of hybrid and electric vehicles in the electrical system of Uruguay

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***Abstract*—In this paper, a study of the evolution and the characterization of the Uruguayan vehicle fleet is presented. Then various scenarios are built, considering different levels of penetration of hybrid and electric cars in the Uruguayan vehicle fleet in the medium and long term. Using a demand model of the vehicle fleet, the electrical energy demand introduced by this new actor is obtained in each of the scenarios. Finally, a study of the impact of the incorporation of electric vehicles in the Uruguayan electrical sector is performed.**

***Key Words*–Electric cars, hybrid cars, energy demand, impact, modelling, simulation.**

I. Introduction

The advent of hybrid and electric vehicles produces transference within the transport sector, from petroleum fuel demand to electricity. This transference brings about different impacts, from the consumption of electrical energy and petroleum, to an energetic redistribution of the country.

Thinking of a Uruguay with different levels of insertion of electric and hybrid vehicles in the medium and long term, it is necessary to perform impact studies, as well as energy and regulatory planning associated with these scenarios.

In this paper, it is presented an analysis of the evolution of the Uruguayan vehicle fleet and its current characterization, based on data collected from different sources (Municipalities, Ministries, among others). Then, from this data and projections with other economic variables such as GDP, different scenarios with different levels of penetration of hybrid and electric cars in the Uruguayan vehicle fleet in the medium and long term are built.

Projected data is combined with a model of the vehicle fleet demand developed for this purpose, obtaining in this way the electrical energy demand associated with a projected vehicle fleet for Uruguay.

Finally, taking into account the expansion planning of the generator park for 2030, the increase in demand and other variables, and adding the demand associated to the vehicle fleet mentioned before, an impact study of this "new" variable in the electrical sector is performed.

To do this, Monte Carlo simulations were performed, using the simulation software SimSee[1] which allows incorporating the different generation alternatives.

II. Working Methodology

This work can be separated into two big blocks. In the first one, the study and characterization of the current vehicle fleet is done with views of future projection. In the second block, the vehicle fleet demand model developed in [1] is used, combined with the projected scenarios in such a way that the corresponding impact studies can be performed.

A. *Characterization and evolution of the vehicle fleet*

In order to study different future scenarios of the incorporation of electric vehicles to the Uruguayan vehicle fleet, the categories of vehicles which could be replaced by electric cars were defined. For these categories, a historical database for the period between 1993 and 2008 was compiled as a base for simulating the future evolution of the vehicle fleet and the incorporation of electric vehicles, until the year 2030.

The categories of interest comprised vehicles for private use and light transportation, with a capacity of up to 4 people, a weight of up to 2 tons and a maximum of 5 doors. For the elaboration of the database, vehicles were classified according to the type of fuel they consume (gasoline, diesel) and according to the area of the country where they are (Montevideo, Interior).

The database was compiled using data available from the Transport and Public Works Ministry (Transport Statistical Yearbook 2007), from the Industry, Energy and Mining Ministry – National Energy Directorate, which had the vehicle registry of most of the Municipalities, and from the National Institute of Statistics which had some records of the statistics of the evolution of the vehicle fleet.

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[1]SimSEE – Power Systems Simulator – http://iie.fing.edu.uy/simsee/

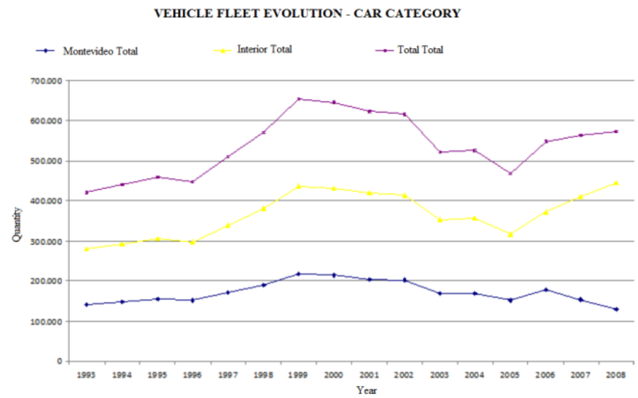

***Figure 1**. Vehicle fleet evolution period 1993 -2008.*

The future evolution of the vehicle fleet under study was performed based on the expected growth of the Gross Domestic Product (GDP), given the high correlation this variable has presented in the past with the development of the vehicle fleet in Uruguay. Fig. 2 shows the historical evolution of the vehicle fleet together with the GDP evolution in Uruguay.

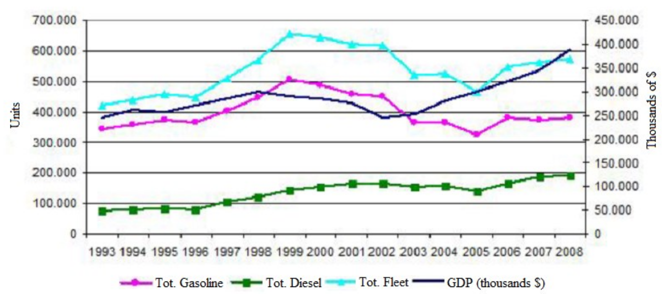

***Figure 2**. Historical evolution of the vehicle fleet and the GDP.*

Three scenarios for the evolution of the GDP were considered, which were obtained from a study conducted by the Planning and Budget Office (Spanish acronym: OPP): Uruguay Strategy III Century Productive Aspects, [2]. These scenarios are the Normative Strategic Scenario (Spanish acronym: ENE), the Intermediate Scenario and the Minimum Scenario. According to the GDP growth estimation for each of these scenarios, it can be appreciated that the number of vehicles triplicates by the year 2030 with respect to the number of vehicles in 2008 in the ENE scenario. In the Intermediate scenario the number of vehicles duplicates in the same period, while in the Minimum scenario the vehicle fleet grows a 50%. At the same time, from these base scenarios for the vehicle fleet development, scenarios for the introduction of electric vehicles were developed. According to a study carried out for the European Community [3], where the different aspects which can influence the development and incorporation of electric vehicles are taken under consideration, three scenarios where formulated to simulate the introduction of this type of vehicles in the vehicle fleet: Pessimistic, Realistic and Optimistic.

Within each introduction scenario, the amount of vehicles of the fleet is weighted depending on the type of vehicle: Fully Electric Vehicles (Spanish acronym: VCE), Plug-in Hybrid Vehicles (Spanish acronym: VHE), Extended range Electric Vehicles (Spanish acronym: VERE) or the Vehicles with Internal Combustion Engine (Spanish acronym: VMCI). Table 1 shows the quantities considered.

To be clear, the different types of electric vehicles are defined below:

VCE: VCE vehicles have only an electric engine, there is no combustion engine.

VHE: VHE vehicles have a combustion engine, an electric engine and batteries which can be charged from the electrical network.

VERE: VERE vehicles have an electric engine and also a combustion engine which can be used to charge the batteries and extend the vehicle reach. Batteries can be charged from the electrical network.

VMCI: VMCI vehicles are conventional vehicles which use oil derived fuels for operation.

***Table 1.** Percentage of penetration of the different technologies.*

Realistic Scenario	**2010**	**2015**	**2020**	**2025**	**2030**
VMCI	100%	100%	99%	94%	82%
VHE	0%	0%	1%	4%	11%
VERE	0%	0%	0%	1%	4%
VCE	0%	0%	0%	1%	3%
Pessimistic Scenario	**2010**	**2015**	**2020**	**2025**	**2030**
VMCI	100%	100%	99%	97%	93%
VHE	0%	0%	0%	2%	5%
VERE	0%	0%	0%	0%	1%
VCE	0%	0%	0%	0%	1%
Optimistic Scenario	**2010**	**2015**	**2020**	**2025**	**2030**
VMCI	100%	100%	98%	88%	67%
VHE	0%	0%	1%	7%	18%
VERE	0%	0%	0%	3%	8%
VCE	0%	0%	0%	2%	7%

B. Demand Modelling

In order to perform impact studies, it was necessary to develop a model for the electrical energy demand. This model is described in detail in the paper "Hybrid – electric vehicle fleet energy demand modelling", [1]. The main characteristics of the model are described below.

- A typical working day is modelled, taking into account travels performed and vehicles average departure and arrival hours.
- Five different periods of the day are modelled: Dawn, Morning, Day, Evening and Night.
- The simulation step is 10 minutes.
- Locations: House, Outside. Charging is only available at the house.
- The type of charging available is slow.
- In cases where a charging policy is imposed, it is assumed that intelligent chargers are available which can be programmed to optimize the charge/discharge from the network at different times.
- Both charge and discharge of the battery (in particular when it is delivering energy to the network), were taken as constants.

Modelling of the vehicle fleet consists of two big parts, in the first part the working scenario and the conditions are generated, and in the second part the simulation is performed. The scenario generation, in turn, consist of five differentiated parts: vehicle draw, travel distances (short and long), number

of travels per period of the day, travel allocation and departure hours. Even at this stage of scenario generation, the size of the fleet and the average speed of the vehicles are defined. For the latter one an average speed of 15 km/h, value obtained from a previous study performed for Montevideo [4].
The simulation can be described through the flowchart shown in Fig. 3.

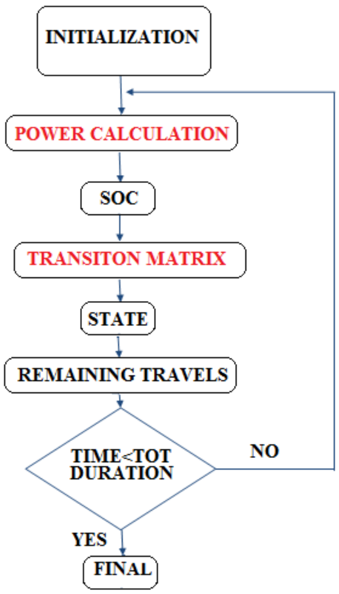

***Figure 3**. Simulation flowchart [1].*

The main points of the simulation process are on one hand the power calculation, which depends on the state of the vehicle (stopped, generating, charging or moving). On the other hand, the heart of the process is in the representation of the transition states matrix, which determines the probabilities combination that being the vehicle in state A, it moves to state B in the next simulation step. Fig. 4 shows all possible states and transitions which determine the transition states matrix.

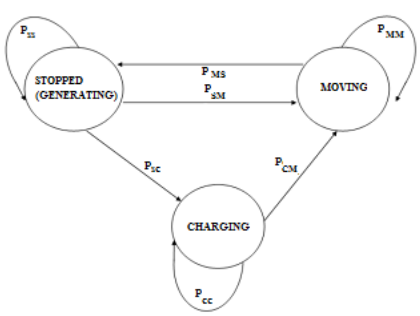

***Figure 4**. Possible states and transitions [1]*

Finally with the system operating, three typical demand curves are defined.

1. Non regulated charge

In this case it is shown the situation it would take place if no kind of incentive or penalty were applied regarding charging at certain hours. This is translated into allowing the user to charge their vehicle as long as there is a charger available. Fig. 5 shows the curve obtained.

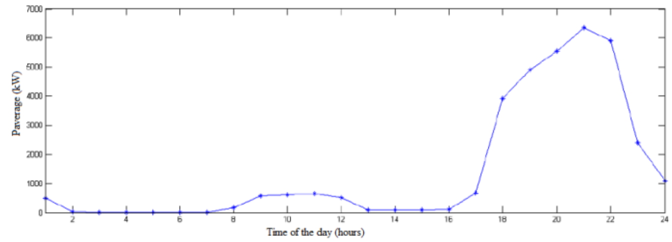

***Figure 5**. Non regulated charge [1]*

2. Regulated charge

This case is intended to show what would happen if users were not allowed to charge their vehicles at certain hours. The way in which this measures are implemented is not the matter of discussion of this paper, but for example certain hours could be assigned a price higher than the average price, or on the contrary, there could be certain hours with a price significantly lower than the average value, were it would be much more convenient in economic terms, for the user to charge their vehicle. Either way, the objective is to seek for alternatives that allow moving the peak of the vehicle fleet demand with respect to the peak of the conventional energy demand. Fig. 6 shows an example of this type of curve.

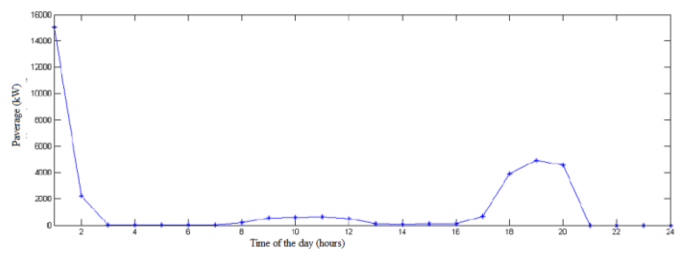

***Figure 6**. Regulated charge [1]*

3. Network charge and discharge (V2G)

Finally it is presented the possibility that users inject the remaining charge of their batteries after a working day into the network. This alternative is known as V2G and it is presented as an alternative to reduce the peak of energy consumption and smooth the demand curve. Fig. 7 shows an example of this curve.

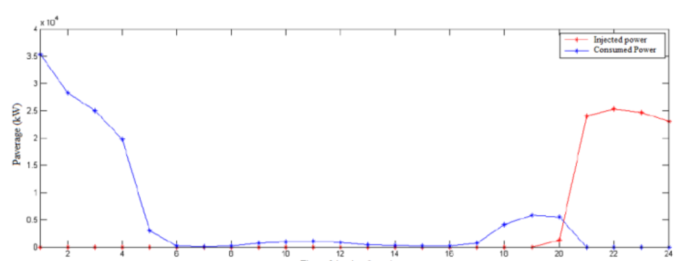

***Figure 7**. Charge and discharge (V2G between 20 and 24 hours) [1]*

C. Impact Studies

With the model described in the previous section, there are several impact studies that can be performed, among which the following stand out.

1) Impact on the electrical energy demand associated with the reconversion of the vehicle fleet

With the model described before, the impact on the electrical energy demand was evaluated. To this end, it was necessary to elaborate a set of hypothesis to model the expansion of the electrical energy generation park of for the year 2030. To this end, the expansion plan suggested by the National Energy Directorate was considered [19].

Different scenarios for the incorporation of vehicles were generated, in accordance with Table 2.

Table 2. *Vehicle incorporation scenarios.*

	2010	2015	2020	2025	2030
Pessimistric	0	0	6000	45000	150000
Realistic	0	0	8000	60000	220000
Optimistic	0	0	10000	78000	300000

Nine different cases were simulated, combining three hybrid and electric vehicles penetration scenarios (pessimistic, realistic and optimistic) and three charging scenarios: with regulation, without regulation and network charge and discharge (V2G). Simulations were performed using the simulation software SimSee.

2) Impact on the energy demand curve associated with the storage capacity of electric vehicles

To complete the analysis of the impact on the energy demand, the effects on the daily demand curve were analyzed, considering the storage capacity of electric vehicles. This study allowed considering this vehicles not only as mobile loads, but also as mobile generators.

These effects were analysed considering the three charging alternatives: without regulation, with regulation and network charge and discharge.

3) Impact on network expansion and efficiency associated with the use of storage capacity and distributed generation of electric vehicles

In this case, it is studied through simple examples the impact of distributed generation/load (DG) on losses and use of the distribution network. Hybrid and electric vehicles connected to the system present potential network infrastructure savings, when batteries charge and discharge cycles are coordinated with the system peak and off peak hours respectively. This situation can be achieved through tariffs which reflect the costs and benefits imposed in the network by the users, with charges that penalize the consumption for battery charge at peak hours and at the same time pay users for injecting power at the same hours.

III. Results

Some of the most relevant results obtained are summarized below. All results are described in the full paper [20].

Regarding the impact study on energy demand, Table 3 shows the electrical energy demand increase associated with each of the following scenarios.

Table 3. *Electrical energy demand increase in different scenarios.*

	Non regulated	Regulated	V2G
Pessimistric	5.25%	5.79%	8.34%
Realistic	7.70%	8.49%	12.24%
Optimistic	10.50%	11.57%	16.69%

It can be seen that for the pessimistic scenario, not allowing the network charge and discharge regime, an increase of the net energy demand of approximately 5.5% can be expected, with respect to the projection for the year 2030. On the other hand, for the optimistic scenario, considering a V2G regime, it can an increase of the energy demand of 16.69% can be expected with respect to the trend scenario, as it can be seen in Fig. 8.

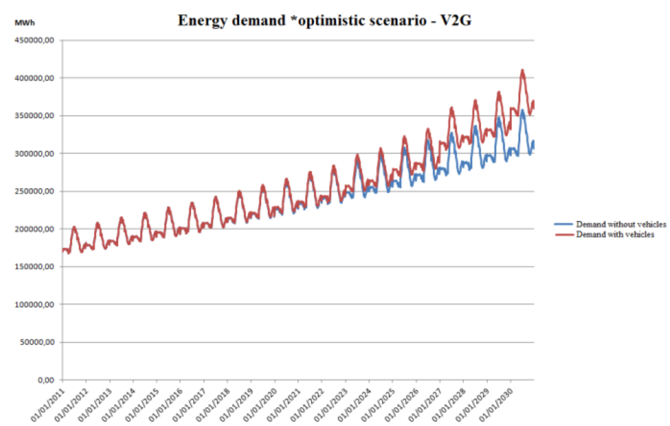

Figure 8*. Energy demand with and without electric vehicles (V2G)*

Regarding the impact on the demand curve, the effects of the three charging alternatives were considered: without regulation, with regulation and network charge and discharge. In the first case an over peak at the time of maximum demand can be appreciated, which could imply an increase of up to 22% of this peak.

In the second case the curve is smoothed reducing the distance between the peak and the valley of the curve. In the latter case a relief in the peak demand can be appreciated, when cars inject to the network the remaining battery charge. This phenomenon can be significant enough to reduce the night peak in a 35% moving the demand peak to the middle of the day. These effects can be seen in Fig. 9. It can be concluded regulation is necessary to avoid negative effects on the network, and that these phenomena must be taken into account for the network planning and development.

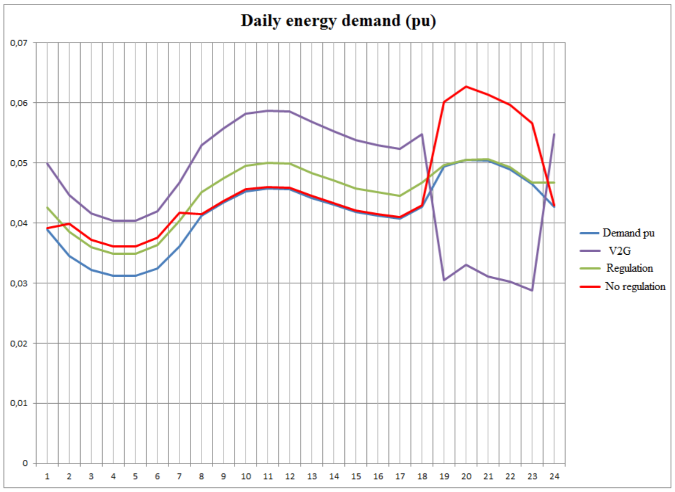

Figure 9. *Daily demand curve for different cases.*

Finally, regarding the impact on the network expansion and efficiency, the results obtained show that it is not advisable to consider the no regulation charge case, as it produces an increase in costs in the system due to the need to expand the network because of the power consumption. In the case of charge regulation, the additional consumption is distributed without changing the demand peak. From the point of view of the network the impact of this case can be catalogued as neutral. In the V2G case, the vehicle charge is done far from the peak hours not imposing additional costs in the network. Furthermore, considering these vehicles inject their batteries remaining charge during peak hours acting as a distributed capacity which reduces the need of extra capacity in the network, savings are generated which can be translated into investments postponement. In this case, for a medium scenario, long term network infrastructure savings could rise to 370 MMUSD a year. Table 4 summarizes these results.

Table 4. *Annual costs and savings in USD*

		2020		2025		2030	
Scenario	**Type**	**MW Dem**	**MW Injec.**	**MW Dem**	**MW Injec.**	**MW Dem**	**MW Injec.**
No regulation	**Optimistic**	13.647.096	0	100.276.488	0	356.011.200	0
	Realistic	10.086.984	0	73.575.648	0	261.074.880	0
	Pessimistic	7.120.224	0	50.434.920	0	178.005.600	0
V2G	**Optimistic**	0	-19.248.516	0	-141.434.748	0	-502.135.200
	Realistic	0	-14.227.164	0	-103.774.608	0	-368.232.480
	Pessimistic	0	-4.184.460	0	-71.135.820	0	-251.067.600

IV. CONCLUSIONS

This paper is framed in the first research project conducted by the University of the Republic about this technology. In this paper, different impacts from the electrical system point of view have been presented, which would result from the incorporation of electrical vehicles. The analysis of these impacts allows observing the opportunity it constitutes this kind of technology to the network, as it is a load curve modulator, and can contribute to improve the utilization factor and decrease expansion costs.

While electric vehicles are the subject of research even today in many parts of the world, the electrical sector development with the consolidation of renewable non conventional energies as an alternative for the energy supply and the need derived from upgrading demand management instruments with a strong emphasis on energetic efficiency, suggests that electric vehicles can become a reality for the system, for which it is necessary to be prepared.

It can be seen worldwide a great impulse to start migrating the vehicle fleet from combustion to electric. This impulse is based on better efficiency and environmental protection associated with the use of this technology, but economical and social barriers have to be overcome for it to be definitely installed within society. To achieve the advent of electric vehicles in the market, technological development, increase in efficiency and reduction of costs are not enough, it is also necessary for the government to impulse the technology and give regulatory signals.

It is necessary to reach the final user in order they chose the electric vehicles, as it cannot be ignored the fact that consumers are who will determine the electric vehicle penetration and change success. It has to be taken into account it is not only the vehicle, but also the infrastructure around it that is required; strategy and logistics must be defined for municipalities and utilities to address them. This means there is a set of changes and modifications which must happen simultaneously. Hybrid and electric vehicles will play a key role in the future, even if there is no certainty regarding how or when the transition will be done, it is clear it is the correct path.

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VI. Biographies

Virginia Echinope was born on June 28, 1972 in Montevideo, Uruguay. She obtained her Electrical Engineering degree, with a Power Systems profile, at the Faculty of Engineering of the University of the Republic in 1999. Since 2007 she works as the head of the Electrical Energy Department of the National Energy Directorate of the Industry, Energy and Mining Ministry of Uruguay, working on the electrical sector planning, the definition of regulatory and normative aspects and the development of instruments for the introduction of new renewable sources into the country. Since 2003 she is a member of the Electrical Engineering Institute of the Faculty of Engineering of the University of the Republic. She is a teacher of the Power Electronics course and the Power Electronics Workshop. Her current working areas include power electronics, electrical energy quality, and energetic planning. She worked in the company UTE, in the areas of Transmission Planning, Distribution Planning and Distribution Management. In the private sector she has worked in the design and manufacturing of power electronic equipment, low voltage electrical material manufacturing and in the AMR systems design and implementation.

Diego Oroño was born on October 9, 1985 in Montevideo, Uruguay. He obtained his Electrical Engineering Degree, with a Power Systems profile, at the Faculty of Engineering of the University of the Republic in 2010. Since 2014 he works as head of the engineering sector of the company NOVASOL Engineering – Tecnogroup, working in the design of a 100 MW photovoltaic solar farm to be installed in Uruguay. Since 2009 he is a member of the Electrical Engineering Institute of the Faculty of Engineering of the University of the Republic, where he teaches in the courses “Solar Photovoltaic Energy”, “Electrical Energy Markets Introduction” and “Electrical Energy Markets Seminar”, as a grade 2 teacher, as well as being co-responsible of the research group on Solar Photovoltaic Energy at this University. He has worked in the area of Distribution Normalization of the company UTE, and on the National Load Dispatch Centre of the company ADME. He is currently finishing his Master on Energy Engineering.

Mario Vignolo, Electrical Engineer graduated from the Faculty of Engineering of the University of the Republic. He made his Master on Power Systems at the University Of Manchester (UMIST) - Manchester, United Kingdom. He obtained his PhD in a mixed regime between the Faculty of Engineering of the University of the Republic and the Public Utility Research Centre of the University of Florida, EE.UU, specializing in Electricity Markets. He also earned a Postgraduate Diploma on Economics (Economic Sciences Faculty, University of the Republic) and he is a Technician in Quality Management Systems UNIT- ISO 9000. He worked as an engineering consultant for UREE/URSEA between 2001 and 2004, and since 2005 as an engineering independent consultant in the areas of energy and electrical engineering, advising several national and international companies. Since 1992 he is a teacher of the Faculty of Engineering of the University of the Republic, currently aggregated teacher (grade 4) and head of the Power Systems Department of the Institute of Electrical Engineering. As part of his teaching activity, he dictates various undergraduate and postgraduate courses, being responsible of the postgraduate course “Introduction to the Electrical Energy Markets” and the “Electrical Energy Markets Seminar”.