Project: Power demand estimation and power system impacts resulting of fleet penetration of electric/plug-in vehicles (MIT-Pt/SES-GI/0008/2008)

PI:Carla Silva
Participating Institutions:

Designação	Nº Pessoas Mês
Instituto Superior Técnico (IST/UTL)	126.4
Instituto de Engenharia de Sistemas e Computadores do Porto (INESC Porto/FE/UP)	64.8

Objectives
According to the original project proposal: The project's main objective was to develop a model to estimate the electric grid demand and power system impacts resulting from the market penetration of electric based vehicles, along a specified time frame (2010-2050) in Portugal and S.Miguel.
The developed model should account for:

- economic interaction between technology prices, energy prices, taxation policies and demand;
- end-user choice/preferences concerning energy/technology;
- end-user driving patterns;
- electric power generation and network systems evolution;
- vehicle and grid interaction;
- renewables potential do decrease electrical energy life cycle emissions.

The model would be able to analyze the influence of externalities on daily/monthly/yearly electric grid load profiles and smart grid interaction. Market opportunities resulting of these technologies penetration would also be considered.

Task description
The project was divided in 9 Tasks, respectively:

- Task1: Characterization of the electric power grid
- Task 2: Characterization of the existing light-duty fleet
- Task 3: Life cycle energy consumption and CO2 emissions
- Task 4: Fleet model development
- Task 5: Electric power systems model development
- Task 6: Impact on the electric power grid model development/smart-grid
- Task 7: Cost benefit analysis
- Task 8:Final model development and application
- Task 9: Dissemination

During the first year, special focus was given to Task1-4. Portugal mainland and Flores Island from the Archipelago of Azores were characterized in terms of generation system, distribution grids and energy demand. A detailed characterization of the existing Portuguese light-duty fleet was performed. The top sale light-duty vehicles (LDV) were identified having a typical power/weight ratio of 55W/kg. The fuel consumption and CO2 emissions of such vehicles and future powertrains of electric, hybrid and fuel cell vehicles were simulated and validated. A master thesis was developed regarding the study of driver behavior, charging frequency, road grade and cargo influence on vehicle/prototypes autonomy and electric and chemical fuel consumption. A complete life cycle analysis was assessed for the light-duty fleet representative actual and future technologies, regarding conventional diesel/gasoline fuel pathways, biofuels pathways for blending in diesel/gasoline fuels, electricity production (actual and future), hydrogen production via on-site electrolyses, centralized natural gas reforming, biomass fermentation. The Portuguese fleet model development, including light-duty and heavy duty vehicles, historic data on vehicle density per inhabitants, historic data of fleet turnover, historic data of sales, historic data on biofuels blending and historic data on fuels consumption was sketched and 7 scenarious were studies with inputs from GALP company: SCENARIO 1 - BASELINE TREND (8% of LDV fleet displaced); SCENARIO 2 – LIQUID FUELS BASED (70% of LDV fleet displaced); SCENARIO 3 – LIQUID FUELS BASED WITH LOWER DIESEL SHARE (70% of LDV fleet displaced); SCENARIO 4 – POLICY ORIENTED (44% of LDV fleet displaced); SCENARIO 5

– ELECTRICITY POWERED (90% of LDV fleet displaced); SCENARIO 6 – HYDROGEN POWERED (90% of LDV fleet displaced), for LDV; and SCENARIO 7 – HDV and BUSES (30% displacement in heavy duty vehciles) to add the contribution of HDV and buses to the total road transportation sector. A preliminary sensitive analysis of the developed model regarding electricity mix generation evolution effect on life cycle results was performed and also a preliminary application of the model to S. Miguel Island.
Task 5-7 were initiated and was assessed a power electronic converter model capable of managing efficiently the energy flow between the Low Voltage grid and the EV battery and was assessed the Flores Island power system dynamic behaviour when different quantities of EV adhere to a smart charging scheme that provides an ancillary service, namely the participation in primary frequency control. , a preliminary energy systems modeling was applied to the Island of São Miguel in Azores; was discussed the potential benefits of expanding responsive demand to help displace electric energy generated by fossil fuel power plants by adjusting the shape of the demand curve to increase use of electricity generated by renewable sources. Potential benefits of fast charging and strategic marketing plan for battery electric vehicles were analyzed.

During the second year, special focus was given to Task 6-8. Preliminary Computer applications for vehicle-grid interactions were sketched. A grid steady state analysis model with a Monte Carlo approach for simulating the transitions of EV loads within a distribution network buses along a given period. Inputs: EV penetration, types of EV, mobility patterns (daily commute profiles), EV owner charging behaviour, conventional load diagram. Outputs: Load diagram (EV+conventional load), voltage profiles, branches congestion profiles, losses. Application: Flores island, S. Miguel island and typical networks from Portugal mainland. A grid dynamic simulation platform using a primary frequency control model for EV in isolated grids, based on a droop control implementation, using numerical integration method with a variable time step to perform the necessary simulations. Inputs: EV penetration, types of EV, mobility patterns (daily commute profiles), EV owner charging behaviour, conventional load diagram, generation units representations for dynamic studies, disturbances on the network or on resource availability. Outputs: voltage and frequency fluctuations, machines power and torque, EV and conventional load active and reactive power. Application: Flores and S. Miguel islands. Electricity price evolutions, cost-benefit analysis from the user and society points of view, management and business insights were further explored.
Concerning Task 4 the PATTS was further developed and the biohydrogen energy vector was studied aiming it's incorporation in this plattform. A first attempt of integration of the fleet model with vehicle-grid model in Flores Island was completed.

During the third year, all models/computational applications regarding the fleet model (PATTS), the vehicle-grid interaction applications for voltage/frequency control analysis and the economic, energy and environmental impacts simulator (EEEIS), developed based on simulating the Iberian spot market using the hourly buying and selling bids available at the Iberian Electricity Market Operator, were finalized.

Final results

The models and respective computational applications involved to fulfill Task 4-7 were successfully developed.

For the fleet model evaluation in the period 2010-2050, in terms of discrete and combined scenarios of energy consumption, HC, CO, NOx, PM and CO2 emissions, was created the PATTS- Projections for Alternative Transportation Technologies Simulation software. It evaluates the road transport energy consumption and emissions evolution in the time-frame 2010-2050 based on historic fleet turnover behavior, diesel/gasoline share, policy targets, renewable increase in electricity mix, biofuels use and different technology penetration in the sales and in actual fleet. Possible results are discrete scenario analysis and combinatory analysis allowing observing the maximum and minimum energy/emissions deviations. Roughly 80% energy and CO2 reduction is only achieved by 60% renewables, high level of vehicle electrification and low levels of mobility. Additionally the scenarios included results of Total ownership costs (TOC) over time for Portugal as a function of fixed and operational costs (e.g. acquisition price, circulation tax, maintenance, fuel prices). It is concluded that the TOC for the several alternative vehicles (different powertrains) will converge over time.

For the vehicle-grid interaction, was created a Monte Carlo simulation method to generate different scenarios of EV load in a given distribution network and ability to estimate the EV impacts in a given distribution network in what regards branches' congestion levels, voltage profiles and changes in load diagrams and in networks' energy losses. This algorithm also allows evaluating the EV availability to participate in controlled charging schemes aiming reducing the differences between offer and demand; this implies a minimization of intermittent renewable energy waste. Was also developed .

For the cost analysis, an economic, energy and environmental impacts simulator (EEEIS) was developed based on simulating the Iberian spot market using the hourly buying and selling bids available at the OMEL (Iberian Electricity Market Operator). The electricity wholesale prices are more influenced by the technology mix, weather conditions (mainly because of the hydro production) and the fuel costs of the thermal power plants. The charging profile in a high EV penetration scenario has great impacts in the hourly market price. In a scenario of low hydro production, the price could reach 20 cents/kWh, for 2 Million EVs charging mainly at peak hours. In a high hydro production and low wholesale prices, an off peak recharge could reach the 5.6 cents/kWh. In these extreme conditions, EV energy prices were between 0.9-3.2€/100km.

Task 8 was not fully accomplished; however, a first attempt of Task 4-7 model integration in Flores Island was attempted. The costs from the users perspective was also integrated with the PATTS application.

The project physical research indicators were successfully accomplished and surpassed.

Indicadores	Quantidade realizada
A - Publicações	
Livros	0
Artigos em revistas internacionais	10
Artigos em revistas nacionais	0
B - Comunicações	
Comunicações em encontros científicos internacionais	34
Comunicações em encontros científicos nacionais	6
C - Relatórios	4
D - Organização de seminários e conferências	0
E - Formação avançada	
Teses de Doutoramento	4
Teses de Mestrado	0
Outras	0
F - Modelos	4
G - Aplicações computacionais	4
H - Instalações piloto	0
I - Protótipos laboratoriais	0
J - Patentes	0
L - Outros	5 book chapter

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