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Potential impacts assessment of plug-in electric vehicles on the Portuguese energy market

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ABSTRACT

Electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs), which obtain their fuel from the grid by charging a battery, are set to be introduced into the mass market and expected to contribute to oil consumption reduction. In this research, scenarios for 2020 EVs penetration and charging profiles are studied integrated with different hypotheses for electricity production mix. The impacts in load profiles, spot electricity prices and emissions are obtained for the Portuguese case study. Simulations for year 2020, in a scenario of low hydro production and high prices, resulted in energy costs for EVs recharge of 20 cents/kWh, with 2 million EVs charging mainly at evening peak hours. On the other hand, in an off-peak recharge, a high hydro production and low wholesale prices' scenario, recharge costs could be reduced to 5.6 cents/kWh. In these extreme cases, EV's energy prices were between 0.9€ to 3.2€ per 100 km. Reductions in primary energy consumption, fossil fuels use and CO_2 emissions of up to 3%, 14% and 10%, respectively, were verified (for a 2 million EVs' penetration and a dry year's off-peak recharge scenario) from the transportation and electricity sectors together when compared with a BAU scenario without EVs.

1. Introduction

In the last decades, the energy uses for electricity production and for the transportation sector have more than doubled (IEA, 2007a) and today face a number of challenges related to reliability, security and environmental sustainability. The scientific evidence on climate change (IPCC, 2007) has been calling for urgent cross-sector emission cutting and electrified transportation is in the portfolio of the technology options that may help to solve the problem (IEA, 2008). In Portugal, as in most of OCDE countries the transportation and electric power systems contribute to the majority of CO_2 emissions (IEA, 2007b). Portugal imports all the fossil fuels (coal, natural gas and oil), that uses to produce electricity and for transportation. Oil accounts to 70% of this primary energy imports and 40% of it is used for transportation (DGEG, 2007) and so is responsible for the majority of emissions associated to the transport sector. All these facts are pressing decision makers/manufacturers to act on the road transportation sector, introducing more efficient vehicles on the market and diversifying the energy sources.

Vehicles with electric propulsion are considered an attractive option on the pathway towards low emission vehicles. Electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs), which obtain their fuel from the grid by charging a battery, are set to be introduced into the mass market and expected to contribute to oil consumption reduction. PHEVs and EVs could provide a good opportunity to reduce CO_2 emissions from transport activities if the emissions that might be saved from reducing the consumption of oil would not be off-set by the additional CO_2 generated by the power sector in providing for the load the EVs represent. Therefore, EVs can only become a viable effective carbon mitigating option if the electricity they use to charge their batteries is generated through low carbon technologies. In addition to the environmental issue, EVs bring techno-economical challenges for electric utilities as well. This is because EVs will have great load flexibility as they are idle 95% of their lifetime, making it easy for them to charge either at home, at work, or at parking facilities, hence implying that the time of day in which they charge can easily vary. The addition of extra load for electric vehicles' recharge in the electricity system can be challenging, if its integration with the transportation system can improve energy efficiency and reduce overall emissions.

In this research, we try to quantify the contribution of the transportation and electricity production sectors together to energy consumption, fossil fuels use and emissions reductions

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through different scenarios of EVs penetration and recharging profiles and simulate the impacts, these different scenarios have, on daily electricity demand as well as electricity prices. Simulations of the impacts in load profiles, spot prices and EV's energy costs (€/100 km) are obtained for the Portuguese case study for year 2020.

2. Literature review

Electric drive technology exists for more than a century but it was not a viable transport option due to limited range and production costs when compared with the internal combustion engine technology. Only recently with battery technology development, electric cars came into scene again and many studies have been done to evaluate the benefits of transport electrification in terms of energy and emissions reductions. The potential social, environmental and economical impacts of electric vehicles (EV) and plug-in hybrid electric vehicles (PHEV) are being studied in many OCDE countries in particular in the US.

The capacity of the electric power infrastructure in different regions of the US was studied for the supply of the additional load due to PHEV penetration (Kintner-Meyer et al., 2007) and the economic assessment of the impacts of PHEV adoption on vehicles owners and on electric utilities was also studied (Scott et al., 2007).

Other studies (Hadley, 2006) considered the scenario of one million PHEVs added to an US sub-region and analyzed the potential changes in demand, impacts on generation adequacy, transmission and distribution and later the same analysis was extended to 13 US regions with the inclusion of GHG estimation for each of the seven scenarios performed for each region (Hadley, 2008).

The ability to schedule both charging and very limited discharging of PHEVs could significantly increase power system utilization. The evaluation of the effects of optimal PHEV charging, under the assumption that utilities will indirectly or directly control when charging takes place, providing consumers with the absolute lowest cost of driving energy using low-cost off-peak electricity, was also studied (Denholm and Short, 2006). This study was based on existing electricity demand and driving pattern; six geographic regions in the United States were evaluated and found that when PHEVs derive 40% of their miles from electricity, no new electric generation capacity was required under optimal dispatch rules for a 50% PHEV penetration.

A similar study was also made by National Renewable Energy Laboratory (NREL) but here the analysis focused only one specific region and four scenarios for charging were evaluated in terms of grid impact and also in terms of GHG emissions (Parks et al., 2007). The results showed that off-peak charging would be more efficient in terms of grid stress and energy costs and a significant reduction on CO_2 emissions was expected though an increase in SO_2 emissions was also expected due to the off-peak charging being composed of a large amount of coal generation. The potential impacts of PHEVs on the locational marginal prices (LMPs), when there is grid congestion, were also studied using a PJM five-bus example and empirical data (Wang, 2007) and concluded that a 10% load increase due to PHEVs recharge would lead to a 26% increase in locational marginal prices. The effects of battery stations that provide battery-swap services were also studied. If the load increases by 10%, by taking advantage of the spatial price differences and shipping batteries between different locations, the battery stations could recharge the batteries and the mean of LMPs would only increase by about 6%.

In recent years an interest in V2G technology has increased; several researchers have studied that by adding vehicle to grid capability (V2G) where the vehicle can discharge as well as charge, a potential storage capacity can be provided to the grid offering regulation, peak power and spinning reserve's services with possible high revenues to vehicle's owners. Vehicles are parked about 93%-96% of their lifetime constituting an idle asset with associated maintenance, insurance and parking costs. By itself, each vehicle is small in its impact on the power system, but a large number of vehicles could have a significant impact either as an additional charge or a source of distributed generating capacity (Kempton and Letendre, 1996). This first article presents an analysis based primarily on peak power, further work (Kempton and Letendre, 2002) show the value of ancillary services to be far higher than that of peak power. Follows a very complete exposition of the fundamentals of both the vehicle fleet and electric markets (Kempton and Tomic, 2005a), and a companion article evaluating the overall size of V2G in comparison to electric generation and load, control strategies and business models for implementation, analysis of V2G as storage for large-scale renewable electricity (Kempton and Tomic, 2005b), an examination of two actual electric vehicle fleets, their operating cycles and the value of revenue from these vehicles if they were equipped for and gives the revenue potential in the electric markets in which they operate (Tomic and Kempton, 2007).

Other studies regarding battery electric vehicles and Plug-in hybrids are being performed almost every month in different countries. In fact, the results obtained in one place in earth cannot be used in other regions, only the methodologies can be used. Apart from reasons that are related to car use habits and roads' topology, there is the electricity production source mix that is different from place to place, more expensive in some places and with more use of renewable sources in others.

3. Research scope and methodology

This research is concerned with studying the potential impacts of the EVs on the Portuguese electricity system, with a focus on the additional power demand, power generation's emissions associated with EVs and the role of demand side management (DSM) strategies in supporting their penetration/recharge profiles as well as the economic impacts of EVs on electric utilities. Tools that evaluate these impacts were developed to provide energy, economy and environment impacts assessment of the plug-in technology. Those include the impacts of the additional electric load EVs would impose in Portugal by analyzing several EVs penetration scenarios and recharging strategies. The tools, developed in MATLAB, were as follows:

(1) Economic energy and environment impacts simulator—EEEIS
(2) Electricity market simulator—EMS

The following scheme (Fig. 1) shows the main inputs and outputs and how the simulators are integrated to be used in the case studies.

For a studied region, the electrical system and the light duty fleet characteristics are inputs, and the EVs penetration and recharge profiles scenarios allow the construction of the load profiles for EVs recharge. The EMS simulates the Iberian spot market using the hourly buying and selling bids available at the OMEL (Iberian Electricity Market Operator) site. The bids are identified by the generating unit and owned company so it is possible to isolate the Portuguese supply curves per technology associated to the selected day and hour. This simulator helps to understand how the supply curves of each technology relate with the weather conditions, time of day, season and the power installed. Based on these observations, rules to generate supply curves can be settled for further simulations. Then, for each