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Electric Vehicles and the Electricity Sector Regulatory Framework: The Portuguese example.

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Abstract

This paper analyses the advantages of plug-in Electric Vehicles (battery or hybrid) to provide new ancillary services to the power system. The Portuguese case is studied as an example, where at the same time, there is an attempt to replace oil in the transportation sector and increase the penetration of renewable energy into the grid. Two different situations are analyzed: (1) the Portugal Mainland (big electric system synchronized with all the European Mainland), where a high growth in wind energy is happening, increasing the power output fluctuations with more wind power being produced during the lower consumption (valley) hours and (2) St Miguel Island in Azores (lower electric system isolated in "island"), where the power installed in geothermal energy could be increased if the valley consumption increases. With a relative high level of penetration of EVs and considering that the wholesale electricity prices can suffer variations between peak and valley hours of almost 50% and the 5.18 c€/kWh difference during valley and off-valley hours of the regulated energy tariffs final price in force for 2008, we can foresee a competitive opportunity for a new business related to the peak shaving of the power consumption diagram.

Keywords: Plug-in EV, G4V, V2G, off-peak charging

1 Introduction

The technological evolution of the electric drive vehicles (EDV) of different types: Hybrid vehicles (HEV), all electric-battery vehicles (BEV) and fuel cell vehicles (FCV), will probably lead to a progressive penetration of EDV´s in the transportation sector taking the place of vehicles with internal combustion engines (ICEV). The next step in EDV technological development, already announced by some of the main automakers, is the possibility of plugging into a standard electric power outlet so that they can charge batteries with electric energy from the grid. Furthermore, several researchers have studied that by adding vehicle to grid capability where the vehicle can discharge as well as charge, a potential storage capacity can be provided to the grid offering regulation and spinning reserves services with possible high revenues to vehicle´s owners. By itself, each vehicle is small in its impact on the power system, but a large number of vehicles can have a significant impact either as an additional charge or a source of distributed generating capacity.

The first description of the key concepts of V2G appeared in 1996, in an article [1] written by researchers at the University of Delaware. In this report the approach was to describe the advantages of peak power to be supplied by EDVs connected to the grid. Further work from the same researchers was continued [2] and the possible power services provided for the grid by vehicles were increased by the analysis of spinning reserve and regulation. The formulation of the business models for V2G and the advantages for a grid that supports a lot of intermittent renewable were described specially for the case of wind power [3-4]. The use of a fleet for providing regulation down and up was studied and how the V2G power could provide a significant revenue stream that would improve the economics of grid-connected electric-drive vehicles and further encourage their adoption were evaluated [5]. 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 [6-7]. 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 by using low-cost off-peak electricity, was also studied [8]. This study was based on existing electricity demand and driving patterns, 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.

All this research regarding PHEVs impacts on the electric grid were conducted using the technical specifications that emerged from two of the EPRI reports [9-10] that provided the best approximation in terms of what to expect regarding PHEV characteristics and performance for different all electric ranges (20, 40 and 60 miles) as well as its environmental impacts [11].

A recent study performed in the UK on behalf of the Department for Business Enterprise and Regulatory Reform (BERR) and the Department for Transport (DfT), has investigated the scope for the transport sector to switch to vehicles powered through electricity from the grid in the period until 2030[12].

An evaluation of V2G application to integrate large scale wind energy and combined heat and power CHP when there is excess of power supply with plug-in electric vehicles was developed for the Danish electric grid case [13].

In this paper a similar analysis is proposed in terms of how to integrate renewable energy resources in the supply side with plug in electric vehicles either as an extra demand charge or as a supply source of power to provide help in regulation and peak power support for the systems operation. This analysis is made for two different case studies: The first one studies the impact in terms of energy and prices that should happen in an isolated island with several scenarios of plug in vehicles penetration. The Island studied was St. Miguel in Azores. The second case study is the mainland Portugal, a much larger system connected to the Iberian and European grid.

2 Electric Vehicles leveling the power consumption diagram

One of the main features of power consumption is the difference in demand along the day hours.

Figure 1 presents the evolution of the hourly average power consumption in Portugal over the 24 hours of the day during the last year.

This evolution along the day with a valley during the night representing 55% of the peak consumption has great financial consequences with the need of having several power plants that are useless and an underutilized network during the night.

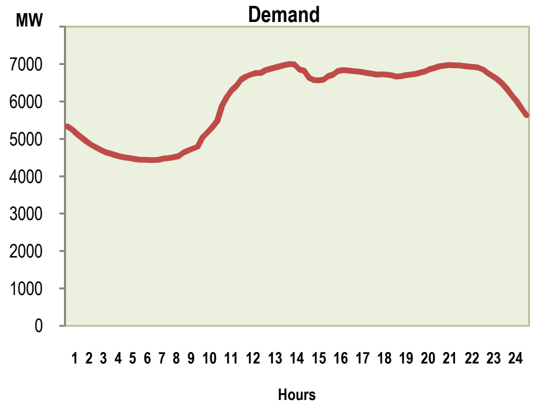

Figure1: Portuguese hourly average power consumption during the last year (weekdays 2008)

This situation gives the opportunity for electric vehicles contribution for levelling the power consumption diagram. As an example, Figure 2 shows the estimated contribution for the power consumption diagram levelling when considering different levels of the electric vehicles penetration in Portugal.

The extra demand for charging the vehicles at each hour of the day was computed using equation 1.

$$P_i = \frac{E_{Vavg}\left(1 + p_{loss}\right)p_{charge}}{h_{charge}} N \qquad (1)$$

Where E_{Vavg} is the daily average energy needed for charging a vehicle, p_{loss} is the percentage of energy lost in the transmission lines, p_{charge} and h_{charge} are respectively the percentage that is charged in each period (valley and off-valley) and the length of the considered period and N the number of vehicles.

It was considered that 85% of the electric vehicle charging happens uniformly during the valley hours with the rest happening uniformly during the others 16 hours of the day. The extra energy that each electric vehicle should charge from the grid in average was considered about 2.5MWh per year, more or less 7kWh per day, and a 10% in transmission losses.

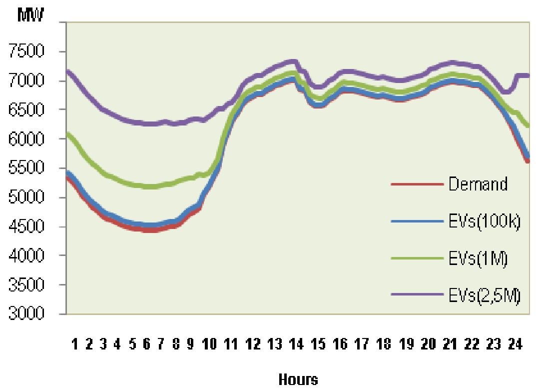

Figure2: Electric vehicles contribution to the consumption diagram leveling

As can be observed in fig.2 only with a high penetration of vehicles like ca. 1million units the impacts are visible in the consumption profile. The main question is how to incentivise off-peak charging?

There have already been made simulations concerning different times for EVs charging in Portugal in recent studies, either in a micro scale [23] where a distribution network was tested for different charging hours with a power systems simulator (PSS) to test the capacities of the wires, or in a more macro scale [24] where it was shown that, a large penetration of EVs could bring problems to the grid if uncontrollable charging is allowed. In these studies, a full life cycle analysis was studied in the computing of emissions associated with EVs [25-26].

The effort for differentiating the power consumption during the valley and the off-valley hours is already in force in Portugal when we see the price for peak and off-peak access to the networks and the regulated energy tariffs final price (low voltage customers), Table 1.

Table1: Tariffs paid in Portugal during 2008 for low voltage customers at valley and off-valley hours

	Period	Tariff
Network Access Tariff	Valley hours Off- Valley hours	0,0325 €/kWh 0,0748 €/kWh
Regulated energy tariffs final price	Valley hours Off- Valley hours	0,0614 €/kWh 0,1132 €/kWh

Would this differentiation in tariffs be sufficient to incentivise valley charging?

If these tariffs induce off-peak charging would the levelling of power profile lead to the levelling of prices?

In fact energy marginal prices depend on the power plant technologies available for dispatch at any time.

3 Electric Power consumption and power plants technologies

The hourly average power consumption during a day presented in Figure 1 has an equivalent diagram when analyzing the distribution during the 24 hours of the day of the annual energy consumed. Figure 3 presents this distribution and also the different power plants technologies that generated this energy demand.

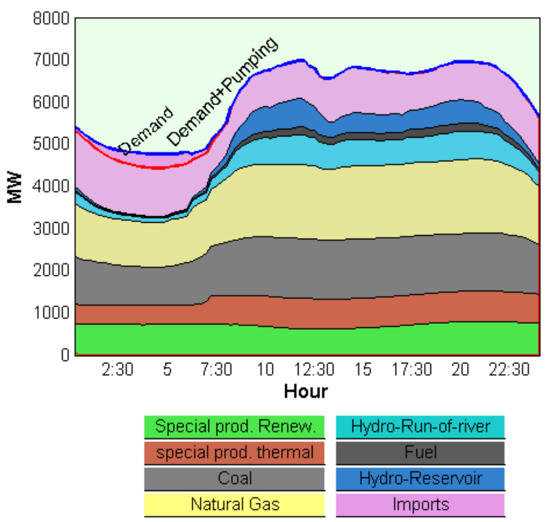

Figure3: Hourly energy consumption during the last year and used power plants technologies

The great difference between the consumption at valley and at off-valley hours represents a barrier to the penetration of generation technologies that need to work more hours per year in order to became economically viable (usually with low unit variable costs but with large fixed costs) or non dispatchable units (renewable energies).
This last situation is more visible for instance at St. Miguel Island in Azores, Figure 4, where the Geothermal energy production (renewable energy without CO_2 emissions that should be used as base load due to its impossibility of production variation) penetration is limited by the valley consumption. If base load electricity generation is much higher than actual demand, excess electricity will be wasted unless it is coupled to a storage system. This is an example, where the use of EVs, charged during off-peak hours, allow the development of a production technology from a renewable, endogenous source, with no CO_2 emissions, against the systematic fuel imports (for vehicles and for electricity production).
S. Miguel has 24MW of existing geothermal capacity and the government wants to expand this capacity to meet future demand [18]. Expanding existing capacity would mean that geothermal production will meet or exceed 37MW. Current base load electricity demand is nowadays less than 40MW (figure.4).

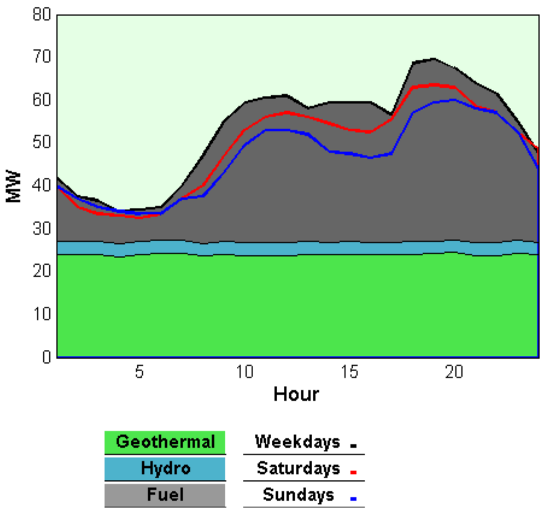

Figure4: Power consumption diagram at the S. Miguel island, Azores, Portugal (Winter load profile)

On the other side, due to technical and security issues, a load profile such as those occurred in Portugal limits the renewable energy penetration rate of technologies based on non dispatchable and intermittent power sources like the wind case, Figure 5. This situation is worst due to the fact that wind power is more available during the valley hours. This technological limitation creates unnecessary barriers to the renewable technologies penetration and all contribution for overcome these difficulties are crucial ones.
The Portuguese government imposed a 45% target to the national power generation based on renewable energies that will be reached without great difficulties but to overpass this number is almost impossible without changing the power consumption diagram.

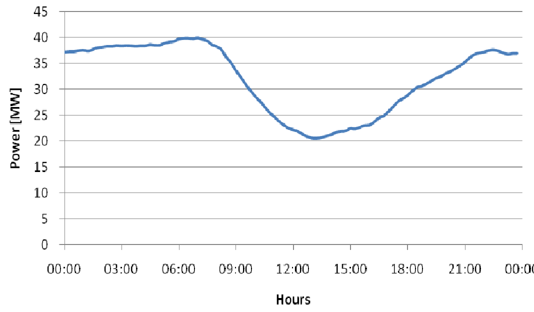

Figure5: Annual wind power variation at a wind power plant [18]

4 Electric vehicles giving new power system services

Returning to the diagram presented at Figure 3, it is possible to introduce the direct consequences of the EVs different penetration levels that were presented, as shown in Figure 6, for a 1M EV contribution.

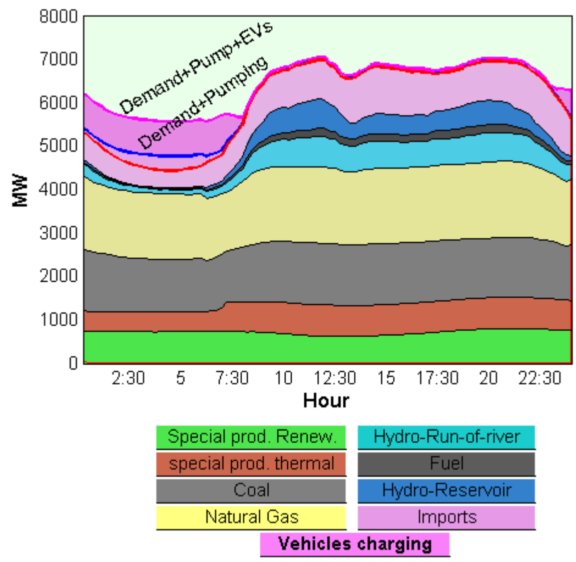

Figure6: Hourly energy consumption and used power plants technologies plus 1million EV contribution to load diagram leveling

In fig. 6 it is observed, that the extra demand for charging a huge amount of electric vehicles would be fulfilled mainly with extra coal and natural gas what would only transfer emissions from the streets to the thermal power plants. Although if we study the power systems not in terms of energy and average power and consider situations that already occurred in the Portuguese power system where the power installed in wind energy is increasing, the synergies between renewable energies and electric vehicles are increasingly important.

In fig 7 it can be analyzed a situation that occurred last year, were 73% of wind power installed was producing and where 30% of the daily consumption was satisfied by wind power [20].

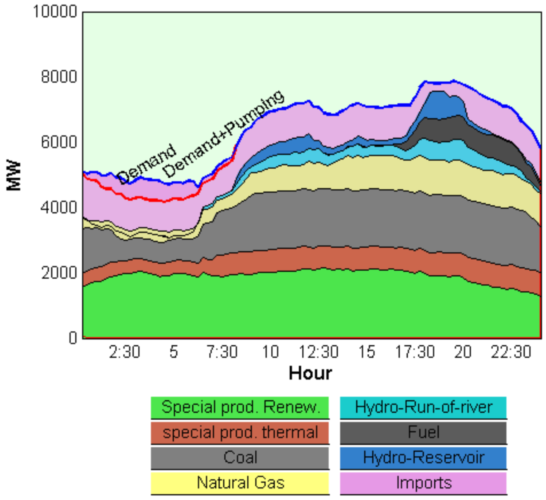

Figure7: Hourly energy consumption and used power plants technologies on the 24th Nov 2008 (30% of National consumption from wind power)

In fig 8 a similar situation occurred with the majority of wind production happening during the valley hours.

In this day more than 70% of the power installed in wind capacity was injected into the grid, the coal power plants were not producing during off--peak and the CCGT may not be producing at its optimal efficient point so that all the CO_2 free wind power could be used.

The Portuguese targets lead to keep on increasing renewable power generation capacity. Wind energy has an important role in these policies as it is expected that by the year 2015 the capacity installed in wind power almost reaches the 5000 MW. [21].

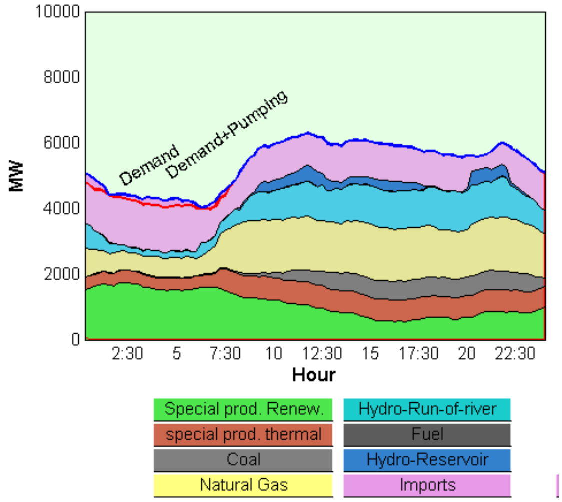

Figure8: Hourly energy consumption and used power plants technologies on the 9th Jun 2008

Based on the [21] report it is expected that the capacity installed in Portugal mainland for the coming years should be as depicted in fig.9.

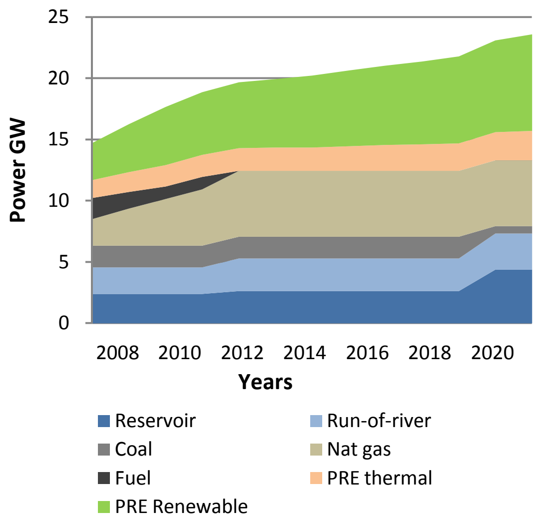

Figure9: Expected evolution of power capacity installed for the next years.

Considering that demand increase should not be higher than 2% a year, there could be situations where the wind power production is higher than the valley consumption. For example in fig.10 the situation described in fig.8 shows the result for a similar day considering the expected renewable capacity installed in 2015 and a demand increase of 2% uniformly distributed along the day.

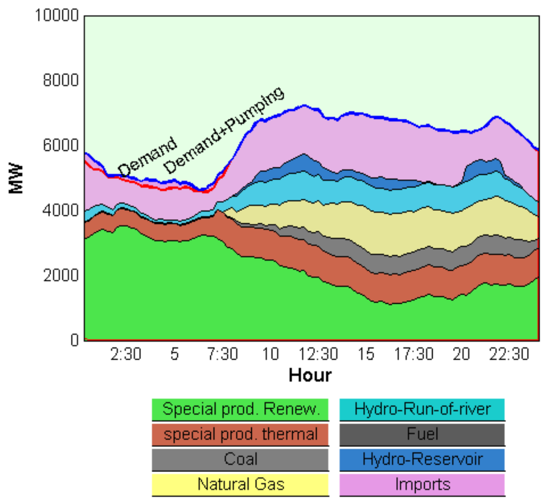

Figure10: Hourly energy consumption and used power plants technologies projection for 2015

In these situations there is of great convenience that a big amount of plug-in vehicles were connected to the grid so that they could be charged with this extra green energy that otherwise could have to be shut down for the grid's stabilization sake.

In fig. 11 it is a case where 1 million of EVs charged 85% during valley hours could be charged with a high percentage of renewable energy. The off peak mix with mainly renewable power sources and imports from Spain was projected considering that the Spanish off peak energy supply has to dispatch nuclear and also a lot of wind power.

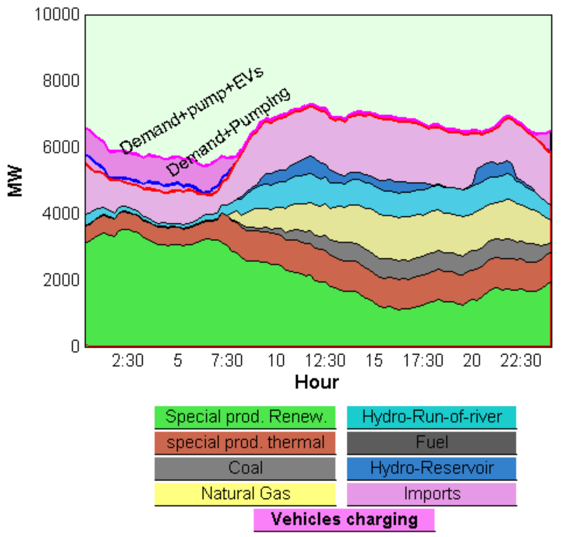

Figure11: Hourly energy consumption and used power plants technologies plus EV contribution to load diagram leveling with proposed increase in Wind power for Portugal mainland

Following the idea of overcoming the barriers to a deeper penetration level of renewable energy sources, an example for S. Miguel Island, Azores, with 5000 vehicles will allow a leveling of the power diagram allowing a bigger penetration of the geothermic power generation technology at the power generation mix of the island.

A total of 37MW of geothermal capacity was considered by the year 2013 [18]. Future electricity demand is uncertain, historically, demand has increased 4% annually [17]. However, scientists estimate that this annual demand increase will be approximately 2% annually if the island becomes more efficient. It is quite difficult to change geothermal production in short periods of time; this may also increase the cost of operation. Thus, geothermal production is considered to be constant during operation. It is assumed in this analysis that, on any given hour of a day, geothermal production is equal to the product of geothermal production capacity and the capacity factor.

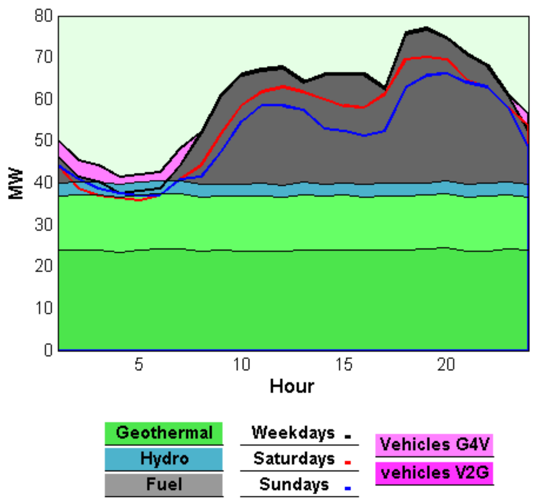

Figure12: Hourly energy consumption and used power plants technologies plus EV contribution to load diagram leveling with proposed increase in Geothermal for St. Miguel (Azores) projections for 2013

With some technological advances and a relative high level of penetration of EVs we can foresee the possibility of EVs provide ancillary services to the power system. For instance, a certain number of EVs can be grouped in order to be charged during the valley hours with energy lower prices and selling energy during the peak hours.

The 5,18 c€/kWh difference during valley and off-valley hours of the regulated energy tariffs final price in force for 2008, presented at Table 1, should be enough for remunerating this new ancillary service.

With a broader perspective and in line with the liberalization perspective in place during the last years for the energy sector, the implementation of wholesale power markets happens all over Europe. Since the 1st July 2007, the MIBEL spot market is in place at the Iberian Peninsula ruling the wholesale energy exchanges and giving reference price for energy. Figure 13 shows the average hourly values of the power price at the MIBEL spot market during the last year.

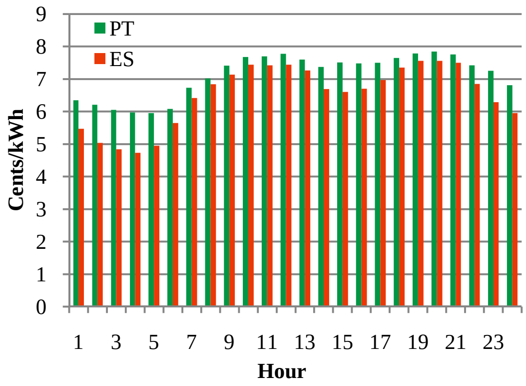

Figure13: Average hourly MIBEL prices for Portugal (PT) and Spain (ES)

With a yearly average price of 72 €/MWh but with prices variation from 42€/MWh till 103€/MWh, (in average from 60€/MWh to 79 €/MWh) it is possible to foresee a competitive opportunity for a new business related to the peak shaving of the power consumption diagram. Considering the direct addition of the network access tariffs showed in table 1, the difference between valley and off-valley end final prices should become even higher.

Having as basis the scenario of 25% of EVs penetration (about 1M vehicles), Fig. 14 shows the peak shaving effect that it will be possible when considering a more 25% of charging during the valley hours, when comparing with Fig. 11, and the selling at the peak hours.

Considering that this peak power supplied by V2G could reach almost 1000MW, a number of 285000 vehicles (30% of the whole expected EV fleet) should be plugged in simultaneously to provide this power for at least two hours. In reality a higher number of vehicles should be connected (at least 50% of the whole fleet) as the energy dispatchable in each vehicle could not be enough to provide for the total peak duration.

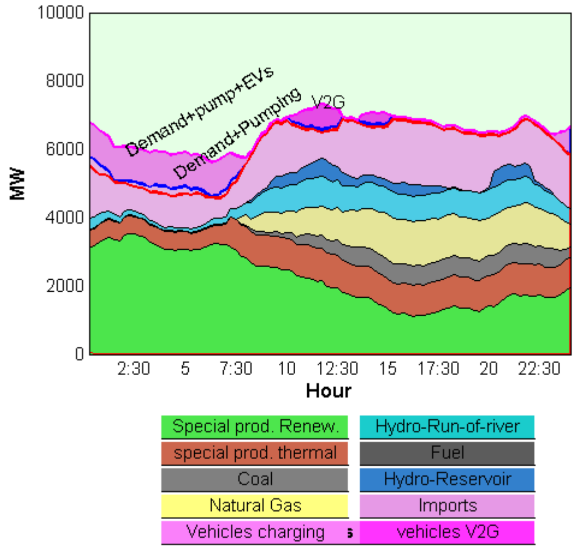

Figure14: Peak shaving effect with 1M EVs for Portugal mainland

Fig 15 represents the Azores case study. Here, as it is an Island, we considered that the km the vehicles need to drive daily are less in average so we count a 40% of energy for V2G, thus an extra demand during off-peak was added to fulfill this extra service.

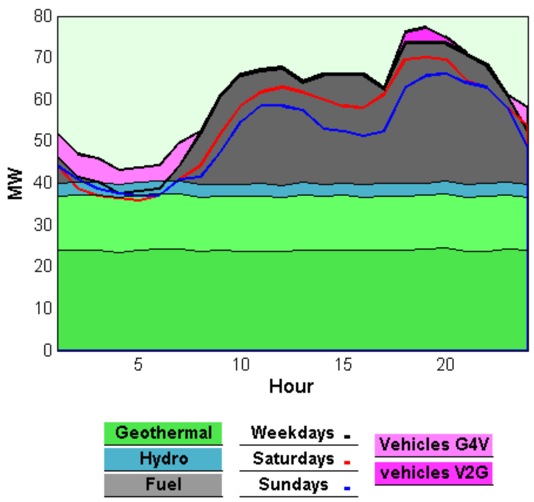

Figure15: Peak shaving effect with 5000 EVs in St Miguel including V2G

With the correct level of penetration of EVs offering this ancillary service to the power system, this new business opportunity will allow to reach a more constant power consumption diagram during the day and gives new opportunities for new power generation based in technologies conceived for working more constantly during more hours of the year and usually presenting lower marginal costs.

Also intermittent technologies like wind will take advantage from this new solution offered by EVs. It should not be forgotten that due to the intermittent and unpredictable characteristics of most renewable energy, the installed capacity in renewable power generation cannot be relied on to meet peak load. Even though with the expected over capacity, when demand is less than production, electricity is wasted unless stored. Thus it is imperative to consider investing in storage when considering the expansion of geothermal capacity in Azores and wind capacity in the mainland. The two case studies are different: In St Miguel the renewable source of electricity production is constant predictable and cannot be adjusted to meet varying demand needs during the day; Wind power is more complex because adds the unpredictability to the impossibility of regulation.

For the Azores case, it is imperative that the plug-in EVs exist ready to be charged during off-peak hours in order to invest in new geothermal capacity. There are periods that could be critical in terms of excess of renewable power supply like Saturdays or Sundays mornings as it can be viewed in figures 16 and 17.

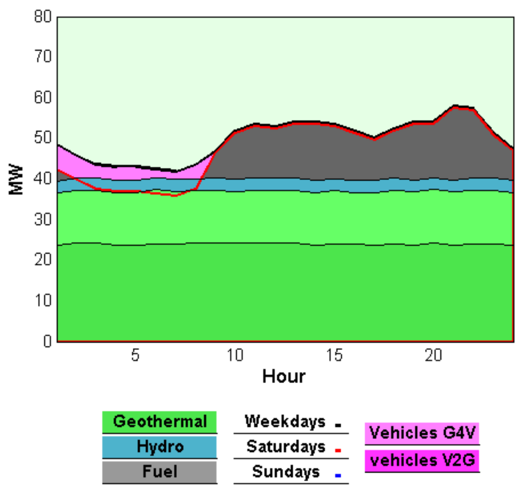

Figure16: Hourly energy consumption and used power plants technologies plus EV contribution to load diagram leveling with proposed increase in Geothermal for St. Miguel (Azores) projections for 2013 in a Saturday at Spring season.

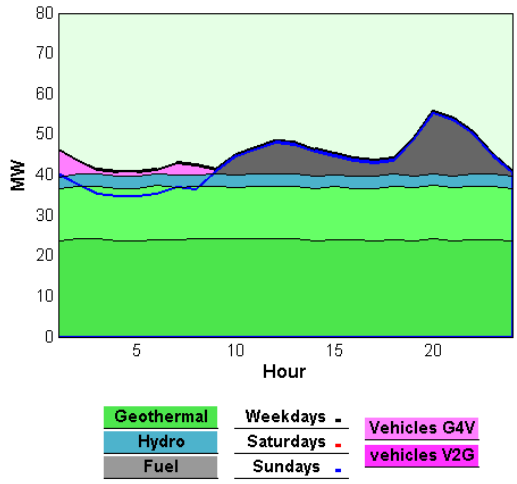

Figure17: Hourly energy consumption and used power plants technologies plus EV contribution to load diagram leveling with proposed increase in Geothermal for St. Miguel (Azores) projections for 2013 in a Sunday.

The EVs' penetration tents to be continuous while the geothermal facilities begin production abruptly when they are ready so it is expected that in the meanwhile the first EVs should be charged with extra fuel.

5 The electric sector regulation framework and business models

In Azores, the electric power sectors follows the traditional model, characterized by the existence of one single company vertically integrating all the activities of generation, transmission, distribution and retailing of electricity, the price of electricity paid by consumers in Azores is an exogenous variable determined by the Portuguese government. In the mainland, however with the European Union legislation imposing the unbundling of these activities so that generation and retailing should be deregulated and subjected to market competition rules whereas the transmission and distribution activities, as natural monopolies, should remain regulated.

Apart from these two different electric power systems models EVs can improve the power systems by offering ancillary services. On the other hand this type of new business must be attractive to EVs owners.

5.1 Estimation of revenues for vehicles owners

Calculating revenue for vehicle owners depend on the market that V2G power is sold into. The following equation can be used for markets that pay for available capacity and for energy [3] (regulation and spinning reserve, whose equivalent in the Portuguese Electric sector are secondary and tertiary regulation [16]):

$$r = p_{cap} P t_{plug} + p_{el} R_{d-c} P t_{plug} \qquad (2)$$

Where r is the total revenue [€], p_{cap} is the market price for capacity [€/kW-h], P is the contracted capacity available less or equal to P_{V2G} [kW], t_{plug} is the time the EV is plugged in and available [h], p_{el} is the price of electricity for the plugged in hours [cents/kWh], R_{d-c} is the dispatch to contract ratio given by $E_{disp}/(P.t_{plug})$.

Capacity payments are an important part of revenue and compensation for energy delivered generally nets out taking into account the energy that must be purchased to charge the vehicle and the cost of batteries depreciation. Furthermore, to compute energy payments, a profile of grid services provided by the vehicle must be defined.

In Portugal, the average capacity prices for regulation for the first months of 2009, were shown in table 2.

Table2: Average prices and capacity for regulation services in Portugal [16]

Capacity Price	Power range	Regulation Valley [€/MW]		off-valley	
[€/MW-h]	[MW]	up	down	up	down
21	127	46.2	29.7	55.2	35.5

The average power range for regulation was 127 MW for the same period as it represents more or less 2% of expected power demand in each hour.

For markets that pay only for energy (peak power and base load), revenue is computed [3]:

$$r = p_{el} P_{disp} t_{plug} \qquad (3)$$

r is the total revenue [€], p_{el} is the market price of electricity [€/kWh], P_{disp} is the power dispatched, less or equal to P_{V2G} [kW], t_{disp} is the total time the power is dispatched [h].

5.2 Estimation of costs for vehicles owners

The cost of V2G is calculated from purchased energy, wear and capital cost. The energy and wear for V2G are those incurred above energy and wear for the primary function of the vehicle, transportation. Similarly, the capital cost is that of additional equipment needed for V2G, but not for driving. The general formula for annual cost is:

$$c = c_{en} E_{need} + c_{ac} \qquad (4)$$

c is the total cost per year [€], c_{en} the cost per energy unit produced for V2G [€/kWh], E_{need} is the electric energy needed to be dispatched in the year [kWh] considering the conversion's efficiencies.

$$E_{need} = E_{disp} / \eta_{conv} \qquad (5)$$

c_{ac} is the annualized capital cost for additional equipment needed for V2G including also the cost of equipment degradation (wear) due to extra use for V2G. [€].

$$c_{ca} = c_d + c_c \frac{d}{1-(1+d)^{-n}} \qquad (6)$$

c_d represents the annual costs of battery degradation, c_c, the capital cost of extra equipment, d the discount rate and n the investment's life time.

The extra equipment should be: A power electronics system that allows charging and discharging to the grid, on board metering of electrical flows for billing purposes and a wireless communication system to allow communication with systems operator or aggregator.

The costs for battery degradation depend on the cycling regimes. As V2G extra cycling would increase battery replacement and additional cost for that should be taken into account.

For example considering that a lithium-ion battery could have a 3000 cycle life time [5] at a 100% of discharge and could last almost 10 years with less than a daily charge, an extra shallow, 4% cycling for regulation services occurring in average 10 times in a day it would shorten batteries life in 40% so that after 8 years they should have to be replaced. To compare investments with different life times we use the annuity method.

$$c_d = c_{bat} \left(\frac{d}{1-(1+d)^{-n1}} - \frac{d}{1-(1+d)^{-n2}} \right) \qquad (7)$$

c_{bat} is the cost of battery and $n_1=8$ and $n_2=10$ are the expected life times with and without V2G.

5.3 Estimation of financial results for vehicles owners

In this way, estimates for annual profits for BEV and PHEV owners, as a result of capacity payments providing regulation capacity could be computed considering the following:

Table3: Estimation of costs and revenues for V2G providing regulation services in Portugal

	Revenue	Costs
p_{cap} [cents/kW-h]	2.1	
P [kW]	3.5	
t_{plug} [h]	10	
P_{el} [cents/kWh]	11.32	
R_{c-d}	0.1	
P_{disp} [kW]	3.5	
E_{need} [kWh]		4.4
η_{conv}		.8
c_{en} [cents/kWh]		6.14
c_{bat} [€/kWh]		1000
c_d [€/yr]		225
c_c [€]		500
d [%]		8%
n [yr]		10
c_{ca} [€/yr]		300

As V2G is connected at low voltage this regulation service should be purchased by a distribution company that should act as an aggregator to provide enough regulation power to sell in the power markets subjected to the prices shown in table 2.

We consider that the EDVs provide regulation during off-valley hours. During valley hours they are charging for further use (for driving and for grid support) so at least they could provide regulation down during this time. For providing regulation up and down we considered the vehicles are plugged-in daily during at least 10 off-valley hours. If the vehicles offer this service for 300 days per year a total of 215€ could be earned only for providing capacity (considering a 2% earnings for the aggregator). If an average energy of 3.5kWh is supplied daily to the grid, an annual revenue of 116€ could be expected. If this energy was charged at valley hours the costs would be 80.6€.

This is a result of 250€ when ignoring the annualized capital costs for extra equipment for V2G and the extra wear of batteries.

The annualized capital costs for additional equipment and early substitution of batteries due to extra use should could reach the 300€ a year so other policy measurements should be taken in order to incentivise the V2G business.

It should not be forgotten that the aggregator that trades directly to the grid for offering regulation services with V2G works with the market prices showed in table 2 and has to include the network access tariffs described in table 1. If EVs have to support the net access tariffs the price they should be paid for a kWh of power supplied, should be, during off-valley hours of 13 cents instead of 11.32 cents.

6 Conclusions

A scenario like this offers good opportunities of production for technologies designed to work with higher load factors that usually have lower marginal costs. It also contributes to a higher use of the final wires of the low voltage distribution network, and would allow a reduction in the value of the low voltage network use tariffs.

These two aspects are very important for the system's design and justify the encouragement of the EV solution in Portugal.

With mass production, and public acceptance of EVs, the critical components' prices may decrease and an optimized combination to an electric system with high percentage of renewable energy source, may bring advantages in terms of emissions reductions and, at the same time, the flourishing of new profitable business.

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