Integration of Renewable Energy Generation with EV Charging Strategies to Optimize Grid Load Balancing

Rui. Freire, Joaquim Delgado, and Aníbal T. de Almeida, *Senior Member, IEEE*

***Abstract* - In this paper we will discuss three different Electric Vehicle Charging Strategies known as Dumb Charge, Smart Charge and Vehicle To Grid (V2G); as well as their impacts on the Portuguese Electric Transmission Grid for a 100% Electric Vehicle Fleet scenario. The future interaction between V2G and the large-scale penetration Renewable Resources will also be analyzed.**

I. INTRODUCTION

A large portion of the electric energy produced today is based on non-renewable resources like Coal, Natural Gas, Oil and Uranium. The fossil resources, as we know, contribute to the amount of carbon dioxide in the atmosphere. Adding to this, we have the transportation sector supported 98% by Internal Combustion Engines (ICE) [1], mostly using oil derived fuels and so responsible for more carbon dioxide emissions. Fortunately renewable sources like hydroelectric, wind, solar, geothermal, biomass and wave power are playing an increasing role in both electric energy production and transportation sectors. After nearly a century of hibernation, the automobile industry is returning to the process of electrification. Motivated by the increasing awareness of oil depletion and climate change, the electric vehicle (EV) sector is currently developing rapidly with new players entering the scene and with the traditional industry actively developing new models.

The use of Plug-In charging without any constraint (Dumb Charge) leads to a large number of electric vehicles connected the grid nearly at the same time. This will may cause a peak demand that the grid cannot support. A controlled strategy of charging, the so called smart charge, is therefore needed to permanently adjust the demand to the available power. This procedure will be discussed in the next section. However, with the proliferation of electric vehicles (EV´s) in the market another charging strategy might be considered. Because the most significant renewable sources, like wind and solar, are intermittent, V2G might contribute as a powerful mechanism to integrate this type of production, see Section 3.

II. EV´s PENETRATION AND CONSUME

Taking account the number of light vehicles of the last years [2], we develop , with Matlab´s Toolbox curve fitting, equation (1) which gives the estimated number of light vehicles for next years.

$$N=1.72\times10^{5}\times(x\text{-}2000)^{0,795}+3,58\times10^{6} \quad (1)$$

Whereas:
N - estimated number of light vehicles
x - year (> 2000)

From (1) we obtain a the portuguese fleet that consists of 4.700.000 light vehicles by the end of 2010.

Assuming a 10% EV´s penetration in the Portuguese market, which corresponds to 470.000 EV´s, and also assuming an average daily distance traveled of 50 km per vehicle as well as an average consume of 200 Wh/km per vehicle, then we have 200x50x365x470.000 = 1,72 TWh consumed per year. This corresponds to 3,43% of the Portuguese total actual consume per year (aprox. 50 TWh).

For other EV´s penetration scenarios you might see the following table.

TABLE I
EVs PENETRATION AND CONSUMES

EVs Penetration	Number of EVs	Increased Energy	EVs Consume per year
10%	470.000	3,43%	1,72 TWh
25%	1.175.000	8,6%	4,29 TWh
50%	2.350.000	17,2%	8,6 TWh
75%	3.525.000	25,7%	13 TWh
100%	4.700.000	34.3%	17,2 TWh

Considering that the Portuguese fleet light vehicles will not increase more than 5.000.000 vehicles in the next decades, and considering the improvement in the efficiency of the Electric Power Drive Systems, the maximum increased consume will not be greater than **36,5%**. This increase will be gradual and it will expand simultaneously with the future renewable sources. In fact, for a 25% EV´s penetration, the extra energy needed is lesser than 2009 wind production of 7.44 TWh [3].

Anyway there are concerns, that should be taking into account, when we plug an entire fleet of electric vehicles to the grid. As will see on the fourth chapter, plug in an 100% EV´s fleet (worst case scenario), could lead to high peaks of demand that can be perfectly avoided.

Preprint submitted to 13th International IEEE Annual Conference on Intelligent Transportation Systems. Received March 15, 2010.

III. Charging Profile

In order to depict the charging profile or consume, during a week for an 100% EV´s scenario, we start by considering an average medium consume of 200Wh/Km per vehicle and an average daily distance traveled of 50Km per vehicle.

With this two parameters we could expect a total daily consume of 47 GWh per day, for the actual Portuguese fleet of 4700000 vehicles (this number corresponds to an 100% EV´s Scenario). The daily schedule consume was then modulated considering [4]-(Fig 5).

The charging profile was finally extended during one week (Fig. 1), regarding that we could expect an slight decrease at weekends [5].

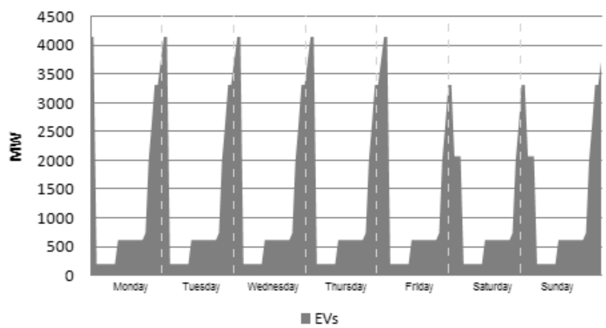

Fig. 1. Estimated EV charge profile for one week.

IV. Smart Charge Vs Dumb Charge

Dumb charge is the basic common charge procedure. Drivers park their cars in a suitable site and connect them to the grid so they have a fully charged battery for the next journey.

Fig. 1 shows the charging profile with dumb charging created by this 100% EV for one week.

The total demand for one day, taking this scenario into account, including the extra energy needed for charging this 100% electric fleet, corresponds to the dotted black line in Fig. 2. The normal load of the transmission grid, corresponds to the real load of the Portuguese transmission grid on 16 March 2009. The data was obtained from [6].

The projection was then extended to an entire week (16 March 2009 to 22 March 2009) and is shown in Fig. 3. As it can be seen, Dumb Charge might create very high peak demand on the grid (about 8 GW). This happened because the peak load of the transmission grid is nearly coincident with the peak charge of EV´s.

With Smart Charge the charging process is controlled by a charge-controller embedded in the vehicle or in the charging station. The system operator provides the charger with real-time information about the price of energy (real-time tariff). The strategy is to offer lower energy prices at periods which are more favorable to the grid for charging EV´s, and so attract customers during these periods. The result will be a more stable total demand (Fig. 4 dotted black line).

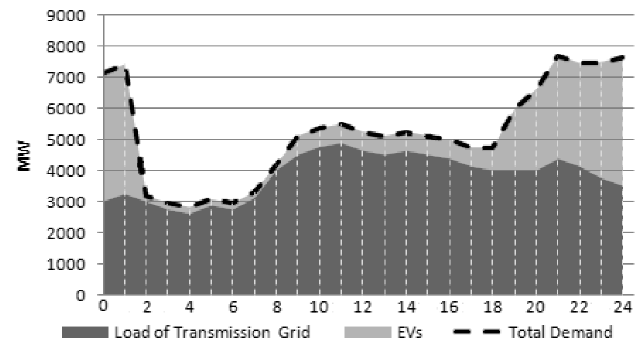

Fig. 2. Total demand for one day

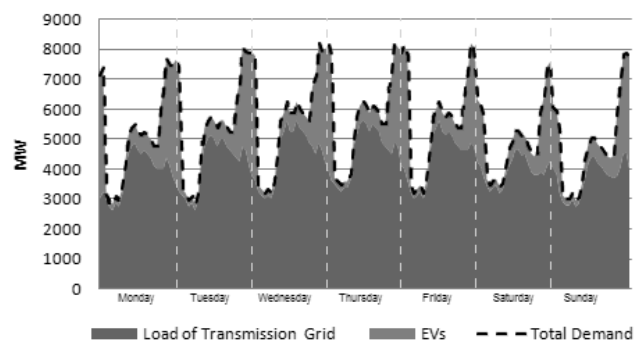

Fig. 3 Total demand with Dumb Charge for one week

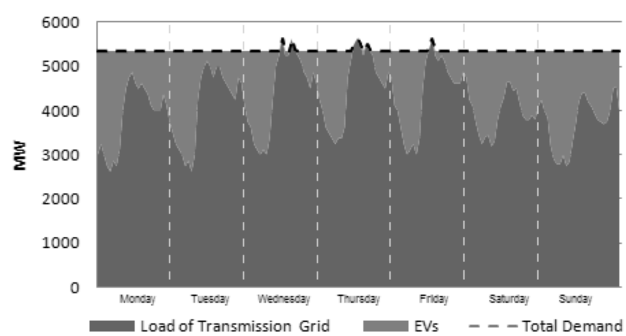

Fig. 4 Total demand with Smart Charge for one week

The real-time tariff must be provided by the system operator and could be easily broadcast by radio frequency, GSM, UMTS, GPRS, etc.

V. Vehicle To Grid And Renewable Energies

Compared with the current ICEs, EV´s do not have local CO_2 emissions at local level, but that does not mean that EV´s do not generate emissions. Actually, CO_2 EV´s emissions depend on the type of primary energy source used for producing the electricity that they consume. If we look at Fig. 5, a large part of the Portuguese electric energy today comes from burning fossil fuels such as Natural Gas and Coal (68%) [7] which generates large quantities of CO_2.

Preprint submitted to 13th International IEEE Annual Conference on Intelligent Transportation Systems. Received March 15, 2010.

In Portugal the production of electric energy generates about 510 grams of CO_2/kWh in a dry year, and 410 grams of CO_2/kWh in an ordinary year [8]. So, an EV that consumes 200 Wh/km will produce nearly 82 grams of CO_2/km in an ordinary year and 102 grams of CO_2/km in a dry year.

Knowing that the European goal is to reduce the average emissions of CO of conventional vehicles, to 120g CO_2/km [3] by the year of 2012, then 82 grams of CO_2/km is not an over ambitious value. What becomes clear is that we need a change not only in the transportation sector but also in the power generation sector, more specifically by using renewable energy sources as a primary energy source, instead of fossil fuels.

In Fig. 6 we can see the Portuguese energy mix predicted for 2020 [9]. With this gradual transition to renewable sources a reduction of 60% in CO_2 emissions [9] will be achieved, compared to the actual energy mix. So an EV that consumes 200 Wh/km will only emit about 41 grams of CO_2/km then. This value may be considered a very good target.

But some renewable energy sources such as wind or solar do have a strong handicap: they are intermittent. There is not always enough sunshine, rain or wind. Since an Electric Vehicle has an energy storage system (like electrochemical battery or a supercapacitor), an entire fleet of EV´s, could act as an enormous distributed energy storage system to integrate generation from renewable sources. If connected to the grid, the EV could absorb excess production when the wind blows strongly or the Sun shines, and put it back on the grid when there is no wind and during periods of no Sun radiation. This is a bi-directional concept called the Vehicle to Grid or V2G [10]. V2G basically consists of putting EV´s to work, not only as consumers (when they charge their batteries), but also as producers (like emergency generators) supplying energy back to the grid.

V2G was originally imagined by Willet Kempton, about thirteen years ago [10]. The original concept was basically to make the future electric vehicles absorb energy from the grid at night, when it is abundant, and put it back on the grid during peak periods of consumption, when it is scarce and expensive. For various reasons like very cheap oil prices, energy density of traditional batteries, limited life cycles, and the small number of EV´s, this basic concept seems hard to achieve, at least at present. There is a grid service that a V2G can easily provide even today, and which seems to have a large potential. This one is called regulation service and is an ancillary grid service characterised by short dispatch times in order to regulate the frequency and voltage. But discussing this matter is not the aim of this article.

There are various projects around the world researching the use of V2G with Electric Vehicles, namely the project led by Kempton himself, that actually feeds power back into the grid, providing regulation services. This happened in January 2009 in Newark, New Jersey.

Unidirectional systems that take advantage of renewable energy sources like wind or the Sun are all ready on field.

For example, in Denmark DONG Energy recently signed a letter of intent with Better Place to introduce electric cars to the Scandinavian country, where the batteries will be charged using wind power. In Israel, the 250 MW Negev Desert Solar Project, might be used to power their future

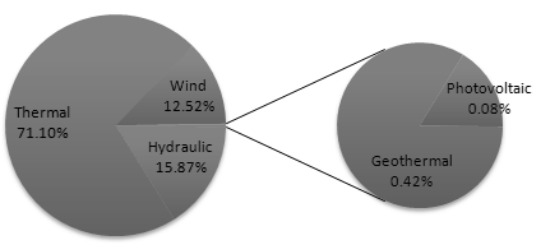

Fig. 5. Portuguese Energy Mix 2008.

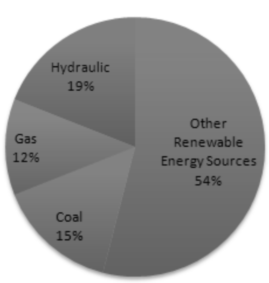

Fig. 6. Portuguese Energy Mix expectd for 2020.

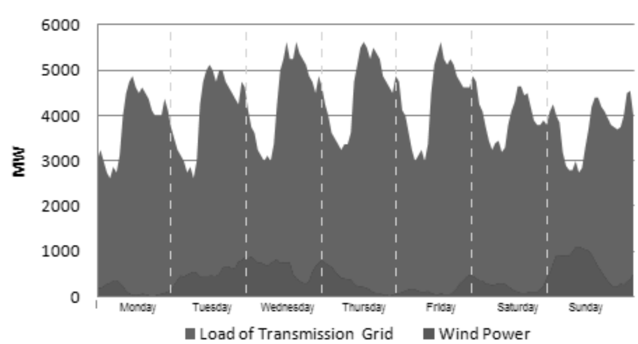

Fig. 7. Portuguese Power Wind production in one week

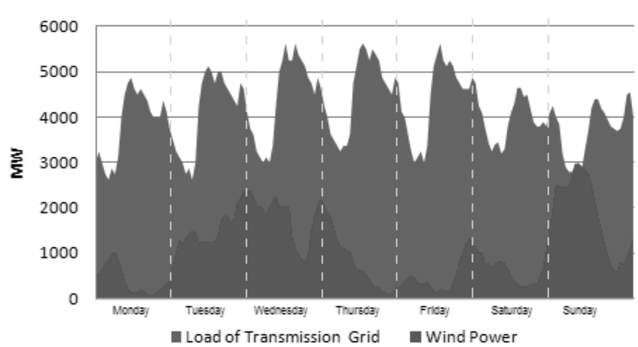

Fig. 8. Portuguese Power Wind production of Fig. 7 multiplied by 2.7

EV´s Li-Ion batteries. But these are unidirectional systems. A bidirectional system like V2G, is far more complex but far more advantageous since it can be more helpful to the grid.

Portuguese wind power produced between 16 and 22 March 2009 is shown in Fig. 7. It is predicted that by the year 2020, Portuguese wind power will be 2.7 times as large as today. That predicted scenario is shown in Fig. 8. As expected, wind power is not proportional to the load supplied by the transmission grid.

For example, on Monday there is hardly any wind power, but on the following Sunday wind power exceeds the load transmission grid.

V2G can be widely spread throughout the country, like renewable resources and can absorb wind power peaks and supply the grid when it is needed most, allowing a constant Base Generation Supply (P_b). This constant Base generation Supply should be calculated, with the condition that its sum with wind power can supply the load on the transmission grid and the EV´s. If in any energy system $P_{IN}=P_{OUT}$, (plus losses that are included in P_{OUT}, for simplicity) so does $W_{IN}=W_{OUT}$.

Then:

$$W_B + W_W = W_L + W_{EVs} \Leftrightarrow W_B = W_L + W_{EVs} - W_W \quad (2)$$

Whereas:

W_B - Total Constant Energy Base Supply during a week (Wh)

W_W - Total Wind Energy Produced during a week (Wh)

W_L- Total Energy consumed by Load during a week (Wh)

W_{EVs} - Total Energy consumed EVs during a week (Wh)

In this case we consider the energies consumed and supplied during a week.

Knowing W_L, W_{EVs} and W_W for the specific week, we can now calculate P_B.

$$P_B = W_B/(7\times 24) \qquad (3)$$

If $P_{IN}=P_{OUT}$, then:

$$P_B + P_W = P_L + P_{V2G} \Leftrightarrow P_{V2G} = P_B - (P_L - P_W) \qquad (4)$$

Whereas:

P_B - Constant Power Base Supply (W)

P_W - Wind Power (W)

P_L- Load Transmission Grid (W)

P_{V2G} - Vehicle To Grid Power (W)

W_L has been calculated measuring the load of transmission grid power, hour by hour, for one week (16 to 22 March 2009) and all of the 7x24 values added. W_W has been calculated the same way as W_L and $W_{EV´s}$ is the result of the charging profile depicted in Fig. 1 (the values are also defined on an hourly basis). All the data was introduced in a Matlab script that calculates all of the needed values using equations (2), (3) and (4), generating then figures 9, 10 and 11. In Fig. 9 we can see the power profile of charging and discharging of V2G´s. The constant power supply can be provided, for example, by modern combined cycle power plants.

Both Smart Charge and V2G are based on the fact that light vehicles are used for traveling, typically around 1 hour per day, being idle 23 hours or 96% of the time [9].

That means that an electric vehicle is available 23 hours for charging/discharging, so the charging profile does not have to look like the one in Fig 1. The charging profile can

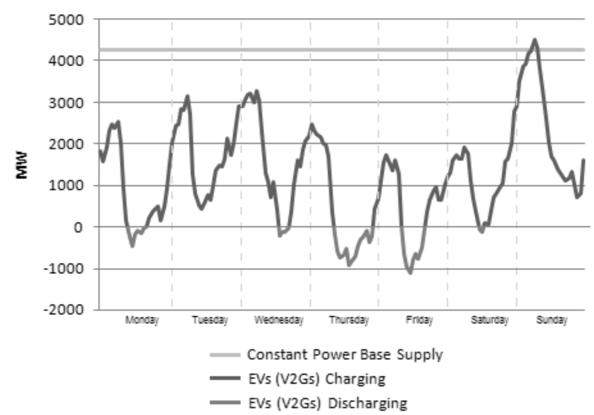

Fig. 9. V2G Charge Profile for a week

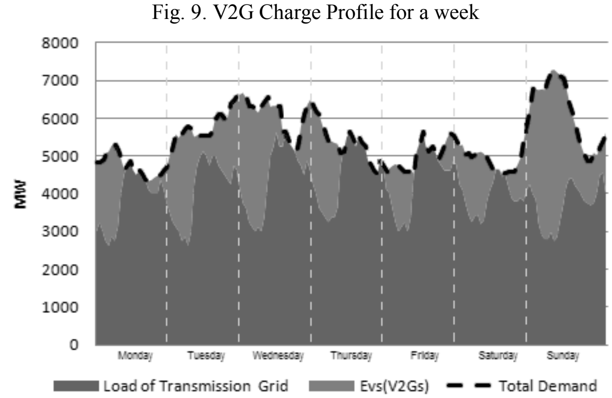

Fig. 10. Total Demand with V2G for one week

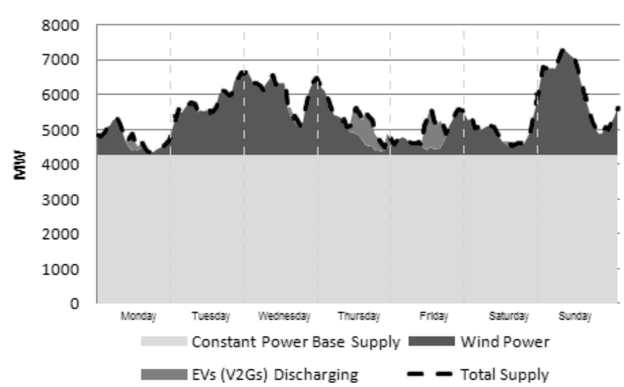

Fig. 11. Total Supply with V2G for one week

be modulated in order to permit Smart Charge or a V2G system. As can be seen, the maximum power that all the V2G´s had to absorb was about 4.5 GW on Sunday morning. This value is equal to 26% of the actual Portuguese vehicle fleet working as V2G, and plugged into a lower power 3.5 kW outlet. Another important aspect that we can conclude from Fig. 9, is that V2Gs will be almost of the time charging from the grid, and not supplying it.

Note that in this study wind power was used as the renewable energy source, but in fact we could use any other renewable mix source, including solar and geothermal sources, for example.

Nowadays, the ancillary grid services adapt the power supply to demand. V2G will do the opposite. It will adapt demand to supply.

If you look at the total demand depicted in figure 10, you can see that it matches the total supply of figure 11.

Similarly to Smart Charge, V2G also depends on an automatic charge/discharge controller system. An onboard "metering and control device" is an optional solution to manage charging and discharging. This device communicates with the onboard management and the smart meter of the grid. It considers the needs of the vehicle user (distance, time of next trip), battery (status, possible load), grid (need for storage/load), infrastructure (cable, possible power) and the local grid situation. Next the estimated amount of CO_2 produced to charge EV´s today and in the year 2020 will be shown. Based on the expectation that a 60% reduction of CO_2 emissions in the Portuguese production of electricity will be achieved, the values are listed in table 2.

TABLE II
TOTAL CO_2 PRODUCED IN A WEEK

Type Of Charge	CO2 Produced
Dumb Charge (At Present)	374×10^3 Ton.
Smart Charge (At Present)	374×10^3 Ton.
Smart Charge/V2G (2020)	150×10^3 Ton.

VI. IMPROVING SAFETY AND EFFICIENCY

Energy and power management are key functionalities to consider when developing both regulation and standards in the area of charging infrastructure. This needs to be discussed with the electrical utilities industry. Given the stress under which energy grids are in many countries due to insufficient investment in transmission infrastructures, a proper load management like smart charge will help to ease stress on the grids, thereby helping to reduce the risk of blackouts [11].

V2G acts like a energy storage that could absorb the excess of produced energy, or alternatively supplying it to the grid when there´s lack of it, improving efficiency of future renewable energy sources.

VII. CONCLUSIONS

As it can be seen from the Portuguese example, in the medium term, Smart Charge will be necessary in order to prevent large peak demand on the grid. The strategy will basically be to move EV charging to more favorable hours of energy availability and transmission grid availability. That can be achieved by real-time pricing, using lower energy prices to attract consumers during these hours.

In the long term, V2G technology could work as a complementary energy storage system for future renewable energy sources, creating a symbiosis between the electric energy production sector and the transportation sector. All of this supported only by the energy storage system provided by future EV´s.

VIII. REFERENCES

[1] Nick Zielinski; "Chevy Volt and E-Flex Enabling Energy Diversity"; Cascadia TransTechEnergy Series, p.4, May 2007.

[2] Parque Automovel Português 2007, Available: http://www.autoinforma.pt/

[3] Direcção Geral de Energia e Geologia "Renováveis - Estatísticas Rápidas - Novembro/Dezembro 09", p.6, Available: http://www.dgge.pt.

[4] A. Peças Lopes, F. J. Soares, P. M. Almeida, M. Moreira da Silva; "Smart Charging Strategies for Electric Vehicles: Enhancing Grid Performance and Maximizing the Use of Variable Renewable Energy Resources", p.1, Stavanger, Norway, May 13-16 2009.

[5] Frauke Heider, Markus Büttner, Jochen Link, Christof Wittwer; "Vehicle to Grid: Realization of power management for the optimal integration of plug-in electric vehicles into the grid", pp 1-6, Norway - May 13-16, 2009

[6] Rede Electrica Nacional (2009), Available: http://www.centrodeinformação.ren.pt/PT/Paginas/CIHomePage.asxp

[7] Direcção Geral de Energia e Geologia; "Produção/Consumos (1994 a 2007)", Available: http://www.dgeg.pt

[8] "Carvão: um combustível fóssil na via da sustentabilidade?", Instituto de Estudos para o Desenvolvimento, November 2007.

[9] REN; "Relatório sobre Segurança de Abastecimento ao nível da Produção de Electricidade - Análise intercalar Período 2009-2020", April 2008.

[10] Willett Kempton, Steven E. Letendre; "Electric Vehicles As New Power Source For Electric Utilities",pp 1-19, August 1996.

[11] Orgalime. "Electric Vehicles: Issues for the European Engineering Industries", pp 3-8, Brussels, 1 February 2010