DEMAND SIDE MANAGEMENT AND ELECTRIC VEHICLE INTEGRATION (VERDE)

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ABSTRACT

Due to the 2020 Strategy in the European Electrical Sector, there are different initiatives to lead the CO2 reduction, the renewables increment in the generation mix and the efficient energy management. A new component of this scenario will be the plug-in electric vehicles (PEVs), able to support not only better ratios of efficiency or maintenance, but also a key role in massive deployments as load-in-movement for the new Smart Grids. This will lead to a new Energy Management concept, in which these PEVs will play a new role to support and enhance the current electrical generation vs demand curve, able to flat it due to load movement from peak to valley.

INTRODUCTION

In this paper, the issue of coordinating the power network congestion with electric PEV load management on real time basis is addressed. Random effects of clime (temperature, pressure, wind conditions) and user behaviour will both affect to network status, and to the PEV consumption (daily business and human behaviour due to stationary conditions or clime).

This paper emphasizes the effect of load management in a distributed regional environment. Different proposed scenarios will be presented, including the casuistic effect of running PEVs with different battery size, needs and priorities, and balancing this effect with power grid available power. Technical and price criteria are considered, and their effect evaluated from economical point of view as well as quality of service.

Due to governmental Spanish initiatives (CDTI), there are some local and national pilot and R&D projects to study the massive introduction of electric car in the electrical scenario. The VERDE Project[1] is a CENIT project from the Ministry of Science in Spain leaded by SEAT, the Consortium integrates sixteen companies and their Research Institutes, with a 34 MEUR budget. Almost every agent of the national arena is represented, to ensure the technical success and the correct business model approach. VERDE consortium will issue a new concept for both, the EV itself and the EV management, so that at the end of the R&D project, new standards, devices and systems, will be ready for industrialization processes and pilot deployments.

The arrival of plug-in electric vehicles to the worldwide light vehicle market marks an important change in the energy supply chain of the transport. Recent market penetration forecasts [1] show the expected growth of the PEVs market share in Europe, representing a range of 15% to 62% of new car sales shares in 2030 depending on the battery progress and infrastructure deployment.

The introduction of PEVs also marks a major point of departure for the management of the European electricity grid with the introduction of a significant new charging load. Existing and potentially new grid management strategies will be needed to manage PEVs integration into power networks in order to ensure quality, security and profitability of the system.

Hence, in this paper a technical-economic model of the system has been used to carry out a set of simulations for the assessment of different demand side management (DSM) tools for electric vehicles. Decentralized Energy Management System (DEMS) from SIEMENS has been used to develop a model where a bottom up approach has been implemented, taking into account the individual mobility needs of EV users as well as their optimal choice to minimize the electricity cost for electric vehicle supply. The chosen scenario is a part of a Spanish city in the 2030 scenario, where residential, commercial and industry consumers are connected.

Since currently the most common tools for DSM are based on price signals and they also provide greater acceptance among consumers, price signals have been the selected tools to be analyzed in this first study.

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[1] For more information: www.cenitverde.es.

METHODOLOGY

General approach

Most of the state of the art analyses regarding demand side management are based on elasticity estimation through pilot projects and econometric tools [2-3]. However, since the elasticity is sensible to technological changes as well as temporary social evolution, the results obtained from this ‘top-down’ approach are difficult to be extrapolated to the PEVs case.

Hence, an alternative methodology is proposed using a ‘bottom-up’ approach simulation model based on optimal behavior of PEV users, subject to a set of restrictions related with their mobility needs. For doing that, topology data regarding power network has been introduced into the simulation platform. Then, mobility patterns have been estimated by using MOVILIA project’s results [4] regarding household mobility for the analysis region. As a result, combined power consumption from conventional loads and PEVs is obtained through a single-day planning horizon unit commitment model, providing 15 min resolution data results.

PEV demand model

For each set of simulations, the PEV fleet has been assumed to consist on a fixed number of vehicles. The first step for the PEV demand model was the estimation of the number of trips by car or motorcycle in the simulation area: 41,153. Then, modal distribution was used to estimate the number of PEVs, taking into account the penetration scenario for 2030 of VERDE project:

- Plug in electric vehicles (PHEV) 30.82% of cars.
- Battery electric vehicles (BEV) 37.67% of cars.
- Electric motorcycles 68.49% of the total amount of motorcycles.

Trip motivation-time matrix from MOVILIA project was used to develop a sort of 16 ‘user profiles’ with different driving patterns. The total contribution to the objective function and technical constraints from each user profile is determined by multiplying the variables associated with each user profile by the number of PEVs of that type. Depending on the trip motivation, different distances were fixed. By considering modal dependant energy consumption figures (0.173 kWh/km for BEVs and PHEVs and 0.084 kWh/km for electric motorcycles), minimum battery state of charge (SOC) values were introduced in the optimization restrictions.

Regarding on vehicle technical restrictions, it was assumed that hours in which a PEV is not driven it has access to a charging station, where it can be charged. Energy storage limit of the battery was considered to be of 25 kWh for BEV, 10 kWh for PHEV and 5 kWh for motorcycles. For the power capacity of the on-board electronics and of the plug used in the charging station, 3.7 kW were considered taking into account the Spanish regulations regarding on low voltage facilities.

Conventional demand model

Conventional demand was modelled using standardized parameters for hourly variation form REE (Spanish TSO) [5]. It was divided in four usage-groups including residential, commercial, industry and others. Conventional demand growth until 2030 was estimated to be 45.7 % [6]. Moreover, it was modelled as a scheduled load.

Power network model

The electricity grid considered in the simulation is composed by two 13.2 kV distribution feeders. They are connected to one of the main substations of the city, with more than 30,000 clients. In order to link PEV and conventional demand model with power network model, distribution transformers were classified in residential, commercial, industry and others.

For dealing with electricity growth related with demand increase between 2011 and 2030, an 80% peak load factor was considered to determine the electric grid capacity

Price schemes

Different price schemes are simulated in order to assess the system congestion in the different day time periods. Real Time Pricing (RTP) tariffs, Critical Peak Pricing (CPP), Time of Use tariffs (TOU) and flat rates, were calculated using real prices of the Spanish pool market (Figure 2).

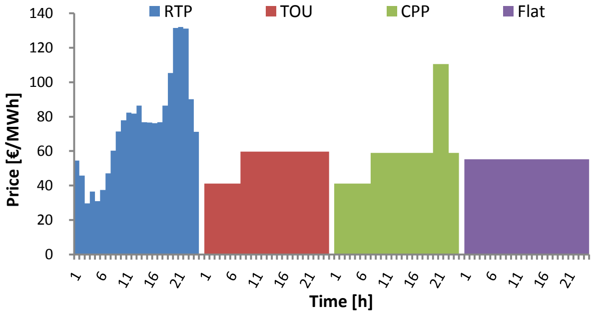

Figure 2. Price schemes

All of these programs attempt to give end-use customers economic incentives to reduce their demand at times when the supply/demand balance in the system is tight. In addition, a flat rate has been introduced in the simulation model in order to compare its effects with the other efficient pricing schemes.

The calculation of the efficient price for energy considered for each time period *T* is shown in Equation 1. For each pricing period, the efficient price is a load-weighted average of the hourly wholesale competitive prices for that time period, where the weights are the hourly loads.

$$P_T^* = \frac{\sum_{h\in T} Q_h \cdot FMP_h}{\sum_{h\in T} Q_h} \qquad \text{(Equation 1)}$$

where the variables are as follows:

P_T^*	efficient price in period T (€/MWh)
Q_h	load in hour h (MWh)
FMP_h	final market price in hour h (€/MWh)

Final market price includes wholesale prices of energy as well as ancillary services for the system.

RESULTS

Once the model was defined including conventional demand, PEV demand and power network parameters, a set of 4 simulations was carried out — one for each of the different price schemes defined in the previous section.

Regarding on RTP (Figure 3) surprising results were obtained. Loads were shifted to off-peak hours as expected, but demand profile was the worst in terms of peak power consumption, achieving 46,529 kW. Most of the charging is made during nigh time, when energy prices are the lowest — between 2 a.m and 6 a.m. This effect can be found because PEVs range for all user profiles is enough for daily mobility needs. Then, cost minimization drives users to charge their PEV during the cheapest time periods.

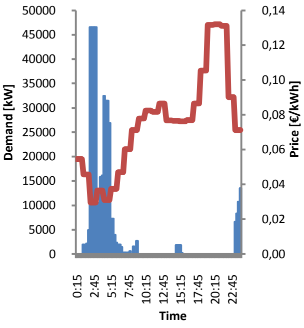

Figure 3. PEVs' Demand response to RTP

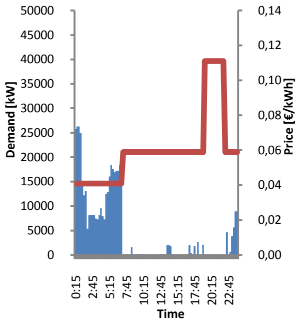

Figure 4. PEVs'Demand response to CPP

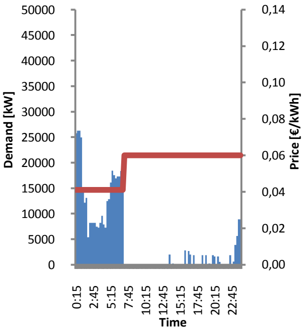

Figure 5. PEVs'Demand response to TOU

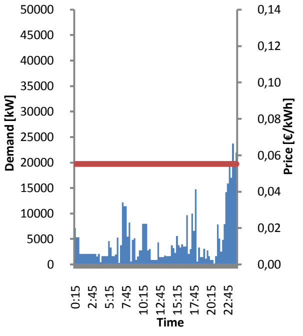

Figure 6. PEVs'Demand response to flat rates

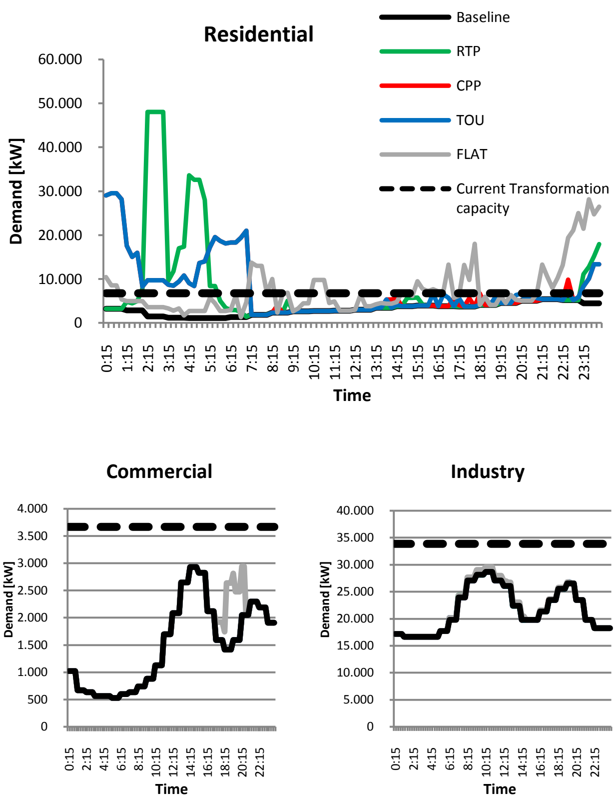

Figure 7. PEV and conventional demand per zone

For CPP and TOU tariffs, results obtained were mostly the same for the first part of the day (Figures 4-5). The reason of this effect can be explained through energy rates which are roughly the same — for CPP off peak prices are lower but the difference is not significant. Main differences can be found during the second part of the day, where TOU consumption during critical periods is shifted to early time periods. Peak consumption is lower than the obtained for RTP, being 26,271 kW.

For the flat rate (Figure 6), the best results surprisingly were obtained from the system congestion point of view, providing a grid peak load comparable with the one obtained with TOU and CPP — 23,729 kW. Constant prices without off-peak blocks avoid charging inrushes during particular moments. As expected, no load shifting to traditionally low price periods was found, being the charge behavior mainly driven by the user mobility needs.

Regarding on the spatial effects, residential zones are identified as the most affected by the introduction of electromobility (Figure 7). For all dynamic pricing schemes, charging during nigh period was enhanced. As a consequence, PEV charges were concentrated in residential areas, were most of the vehicles are located during night hours.

From user’s costs point of view, results obtained are in accordance with the expected figures (Table 2). RTP provides the most cost-effective option for PEV users, allowing them to take advantage of the lower system prices. Regarding on CPP schemes, a slight increase in the cost is found in comparison to TOU tariffs. This is due to the simulation period chosen, which includes a critical period — critical periods are only declared occasionally. For flat rates, higher costs are founded as expected, producing a 51% increase in the daily energy budget of PEV users in comparison to RTP schemes.

However, user’s costs are not the only ones to be taken into account. Electricity grid expansion costs have to be also considered when a particular measure is promoted to enhance demand response of PEVs. For this reason, two columns indicating the peak load corresponding to each of the price schemes — which can be considered as a first proxy to approximate network costs — has been introduced.

Scheme	Cost	Extra cost	Peak load	Peak load increasing
RTP	4,076€	-	68,424kW	33%
CPP	4,840€	19%	51,510kW	-
TOU	4,830€	18%	51,510kW	-
Flat	6,156€	51%	52,402kW	2%

Table 2. Cost comparison between price schemes

CONCLUSIONS

In this paper a bottom up model of 16 PEV household user profiles has been simulated with the software Siemens DEMS. The simulation has been carried out using the data of a Spanish city, where residential, commercial and industry demand is supplied. In order to assess different alternatives for demand response of PEV users, a sort of price schemes have been introduced in the model. Price schemes were calculated using real prices of the Spanish wholesale market

Results obtained in simulations show how dynamic pricing might be a double-edged sword, shifting PEV consumption to off-peak periods — as expected —but enhancing charging inrushes in low pricing periods. In conclusion, in order to avoid system overloads caused by PEV charging during low pricing periods more advanced tools to demand side management must be considered apart from price signals.

Results obtained also highlight how the most affected network zones by PEV household mobility are the residential ones. This effect can be explained because the most of the PEVs are in residential areas during night period, when prices are the lowest and daily charge is done. For commercial and industry areas, PEV impact is negligible. Only for flat rates charging processes are found in commercial and industry areas. As a consequence, new criteria might be developed to network planning in residential areas taking into account the number of PEVs to be supplied.

SMART GRIDS INTEGRATION

Due to the open architecture defined in the Smart Grid concept, the PEV will be a new component of the already defined loads in the last mile (domestic / Commercial / industry). Please refer to studies about Smart Grids or Demand Management (references [7] to [10]).

ACKNOWLEDGMENTS

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