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Simulation of consumers and markets towards real time demand response
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Current status and new business models for electric vehicles demand response design in smart grids

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Abstract

Global electric vehicles sales increased about 10 times from 2011, reaching more than 1 million vehicles in roads by 2015. This number is very likely to increase at a steady pace as more models are made available and battery technology improves and costs decrease. It is recognized that the electric vehicles mass integration will imply more complexity to the operation and planning tasks of power systems, but also allow additional opportunities. Indeed, demand response can play a major role to integrate electric vehicles in the future smart grid. This paper discusses the current initiatives from the retailing business in Portugal, Spain and Germany to deal with electric vehicles integration and discusses some new demand response models shaped for the smart grid that can be the new business model of tomorrow energy providers. Currently, the electric vehicles demand response measures adopted by the industry are very limited, mostly offering time of use tariffs with a discount rate.

Keywords: demand response, electric vehicle, smart grid, tariffs

1. Introduction

During the last years, a growing number of Smart Grid (SG) initiatives has been rolled out. In fact, 459 SG projects have been funded in Europe from 2002 to 2014, with a total investment of €3.15 billion investments, both public and private [*1*]. Several demonstration and deployment projects have started in this field and rollout of smart metering is increasing over time. Research and development activities in some related topics, such as aggregation models and vehicle-to-grid concepts are also going on [*2*,*3*]. In the meantime, Electric Vehicles (EVs) sales have been steadily increasing since 2011, with the pure electrics capturing 62% of sales by mid-September 2015 [*4*]. In Norway the market share astoundingly surpassed 22% by the end of 2015, increasing from 6% in 2013 [*5*]. In Germany the acceptance is being much slower with only 0.73% market share by 2015. In the United States, EVs stock reached 410,000 by December of 2015, but still half behind the 2015 target of one million EVs announced some years ago [*6*]. Portugal is ahead of Spain regarding EV transition, but these two countries currently do not have significant market share and EVs stock. Nevertheless, the charging infrastructure to support EVs adoption has been growing dramatically with projections suggesting more than 12 million public charging points in the year of 2020 [*7*]. The mass integration of EVs has been planned and their integration implies more complexity to the operation and planning tasks of power systems, but also enables significant benefits [*8–10*].

In this context Demand Response (DR) shaped for EVs is a big opportunity that the power industry cannot miss. The DR programs can be classified in price-based DR, incentive-based DR, and emergency DR, among others [*9*]. DR refers to *"changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized"* [*11*]. According to [*12*] vehicles are parked more than 90% of the time during a day, thus they can be available to serve as a storing device to the grid. Indeed, EVs are represent additional loads which are well suited for DR participation as their demand can be shifted or reduced through incentive or price-based schemes. In addition, EVs charge and discharge can be controlled using optimization algorithms and control means, though these imply higher complexity and increased infrastructure costs.

Currently, some initiatives to avoid high peak demand have been started in the retailing sector. These initiatives mainly consist in introducing some special tariffs targeting EV customers. In this paper, some of them devised by companies in Portugal, Spain and Germany are briefly described. These business models seem functional and rapidly available in the short-term horizon but are very limited to attain the full potential of SG deployment. Therefore, immediate rethinking is urged and new business models must be developed to ensure the successful EVs' integration in the SG.

DREAM-GO is a European Union (EU) funded project (H2020-MSCA-RISE-2014) that aims to leverage the state of the art regarding DR implementation. The project consists in a transcontinental cooperation and knowledge sharing between EU partners and the United States. Regarding the work developed so far, it is believed that DR response can play a significant role to integrate EVs in the existent grid without deep modifications. This paper discusses some possible ways to implement DR for EVs in the context of SGs.

After this introductory section, the paper is structured as follows: section 2 presents a brief overview of the current status regarding EVs DR implementation, section 3 presents the DR business models envisaged for the future SG, and, finally, section 4 draws up the main conclusions of the work.

2. Current Status

EVs will be responsible for a significant part of the energy bill in the near future. This section discusses the EV household impact and briefly describes the initiatives of the retailing sectors in 3 countries: Portugal Spain and Germany.

2.1. EVs household impact

The shift from petrol-fueled transportation to electric means will carry significant shifting of money transactions from petrol stations directly to the electricity supplier. It is important to understand how EVs charging will impact the energy bill and how this energy will be consumed. Fig. 1 shows a daily curve demand for a Portuguese household with 4 occupants in the winter[1]. We are considering that the family living in this house owns one EV (Renault Zoe), which travels 80 km per day in average. The EV plugs and starts charging immediately after arriving home by 7 p.m. to fulfill the needs for its daily journey at 3 kW/h charge rate.

It can be seen in the load curve that the EV arrives around 19h and starts charging immediately without any control. The total amount of charging is 11 kWh for a daily commute of 80 km. The battery is fully charged around midnight. The EV contributes to increase the winter household consumption by 64%. By contrast, in the summer the EV contributes to increase the same household consumption by 220%.

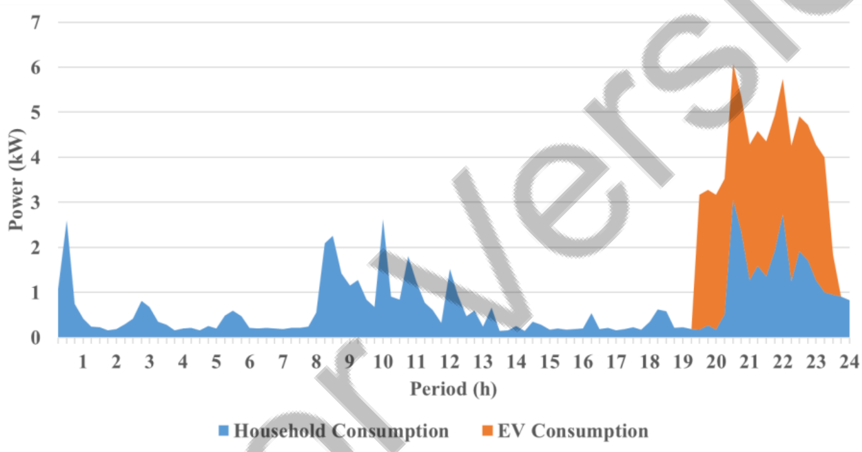

Fig. 1: Household winter consumption with uncontrolled EV charging.

By the above example, it is easy to understand that the EV adds a significant portion of the household load demand. The peak load reaches 2 times the original value. In fact, with the EV the peak power reaches 6 kW instead of 3 kW without the EV. The situation would be worse if the household had 2 EVs.

2.2. Retailing activity initiatives

Currently, few initiatives are offered by the retailers to motivate the EV adoption and differentiate the EVs demand. EDP Comercial is the only retailer in Portugal to offer a differentiated tariff. EDP Comercial is offering a 400 EUR discount to those who buy an EV from their partners [13]. The discount is done on a monthly basis, i.e. 40 EUR/month during 10 months. EDP claims that the discount is equivalent to 15.000 km.

[1] The household dataset, in what regards the load demand, excluding the EV charging, can be obtained in http://sites.ieee.org/psace-idma/data-sets/

In addition to that discount, EDP Comercial launched a special time-of-use based tariff, named energy2move, for those who own an EV. The energy2move is a bi-tariff with 10% discount during the night (10 p.m. to 8a.m.) for the daily option and 1% discount in the remaining periods. A weekly option[2] is also available. The discount rate is also applied to the basic monthly fee. In the case of the tri-tariff option the discount rate is 7% in the remaining periods. However, the tri-tariff is only available for contracts between 27.6 kVA and 41.4 kVA. The energy2move has not a single-tariff option. Instead, this retailer is motivating his customers to shift EV load to economic periods using bi-tariff (or tri-tariff) with some discount. The economic periods are mostly during the night.

In Spain an hourly pricing scheme is in place, which applies for all the Spanish territory regardless of the time-zone, known as voluntary price small consumer (PVPC). There are three types of tariffs: default, 2 periods and electric vehicle. Active energy invoicing term in €/kWh of PVPC for tariffs 2.0 A (default tariff), 2.0 DHA (2 periods tariff) and 2.0 DHS (EV), are established in section 2 a) of the Article 8 of the Royal Decree 216/2014. The royal decree states the calculation methodology of PVPC of electrical power and its legal and contracting system [*14*]. PVPC includes several terms, namely day-ahead market price, ancillary services, distribution and transmission tariff, capacity payment, interruptible service and operation, and maintenance fees.

Fig. 2 shows the PVPC prices along an entire day (26th April 2016) for the three mentioned tariffs. Those prices do not include taxes. The prices range for each period can be seen in the *xx* axis; in green color the hours with prices lower or equal than 0.10 €/kWh, in yellow color for prices between 0.10 €/kWh and 0.15 €/kWh and in orange color for prices higher than 0.15 €/kWh (which did not happen in the considered day). For the 26th April 2016 most of the periods are in the green price range. The EV tariff is cheaper at night, namely between 0 a.m. and 12p.m. The customers can freely choose PVPC. Retailers are not allowed to charge the customer higher prices than the PVPC in this mode [*15*].

Fig. 2: Active energy invoicing price in Spain using PVPC (26-04-2016) [*15*].

In Germany, despite high electricity prices (>0.25 €/kWh) for the typical household, some utilities are introducing benefits for EV owners by proposing different tariffs. The e-mobility night tariff proposed by Litchblick, a German utility, allows customers to charge their cars at lower rates during the night [*16*]. Other retailers such as Polarstern energie are offering night tariff reductions for EV charging as well [*17*]. Moreover, Litchblick is studying an aggregator

[2] Bi-tariff low price periods:
Summer week cycle: Monday-Friday: 0h-7h; Saturday: 14h-20h and 22h-9h; Sunday: 24h.
Winter week cycle: Monday-Friday: 0h-7h; Saturday: 13h-18h30 and 22h-9h3; Sunday: 24h.

model for small generation and controllable loads. EVs, heat pumps, and overnight electric heating systems can all function as controllable consumption equipment [*16*]. This German utility believes that a household's power rate could be 30 percent lower when controllable consumption is correctly scheduled, and the cost of charging EV could drop by up to 200 EUR annually.

A few players in the retailing activity are introducing a variety of appealing schemes for the EVs end-users. However, it is fair to recognize that these schemes are based on discount rates and still very limited, not adequately adapted for the future smart grid. Nevertheless, the paradigm shift is occurring and eventually more advanced models have to be developed and implemented in practice. In the following section some innovative models are discussed, which could be increasingly viable with proper charging, communication and IT infrastructure.

3. Demand response business models for the SG

This section discusses some DR models shaped for EVs. These business models envisage a SG context, and therefore, smart metering and other important infrastructure is assumed to be in place. The presented programs include incentive-based programs – smart charging, V2G, trip shifting, trip reduced – and one optimal pricing DR model (price-based). Fig. 3 represents the mentioned DR programs and the necessary information flow.

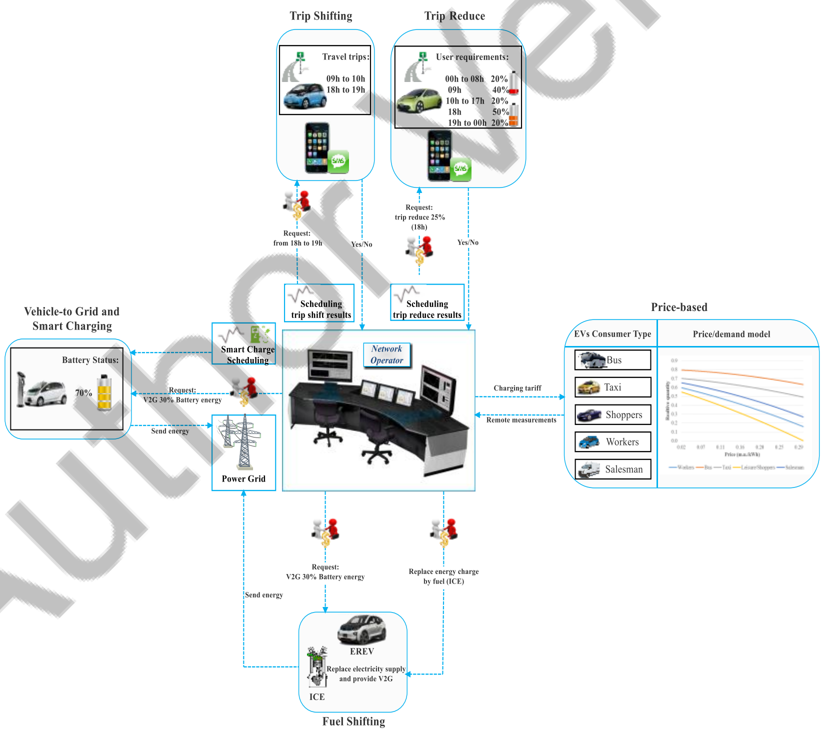

Fig. 3: Representation of the DR programs for EVs

3.1. Smart charging and vehicle-to-grid

EVs can provide power to the grid while they are connected to it, which is usually referred as Vehicle-to-Grid (V2G) [*18*]. The control approach requires a control connection for communication with the grid operator and a meter sensor to indicate the battery state in each moment [*19*]. The Society of Automotive Engineers, known as SAE, establishes a series of requirements and specifications for communication between plug-in vehicles and the electric power grid, for energy transfer to and from the grid in the standard SAE J2847/1 "Communication between Plug-in Vehicles and the Utility Grid" [*20*]. The International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) are also developing a similar series of standards known as ISO/IEC 15118 "Road vehicles -- Vehicle to grid communication interface" [*21*].

The smart charging and V2G approaches are effective types of DR resources use in the context of EV management. The EV charging can be effectively controlled while reducing operation costs and network problems, while still maintaining the comfort of the users. The drawback of V2G and smart charging is the high complexity and high capital costs of the infrastructure. Nevertheless, aggregators may convince users to shift from uncontrolled charging to smart charging by financial incentives and convenience of charging, e.g. with smart charging, the user could benefit from discounted flat tariffs

3.2. Fuel shifting

Fuel shifting is a special DR program, specifically proposed to target a particular kind of EVs, the Extended Range Electric Vehicles (EREV). These vehicles have an Internal Combustion Engine (ICE) that can charge the battery when a threshold limit is reached. This greatly increases the travelling range, while mitigating the user’s range anxiety. Examples of EREVs are the Chevrolet Volt, Opel Ampera and BMW i3. The fuel shifting has 2 variants. One is to incentivize customers to leave the charging point (home/workplace) even if the minimum amount of state of charge was not satisfied (soft constraint). The customer in turn receives an incentive to cover the fuel costs that may be needed to cover the trips not satisfied by the electric energy supply. The grid in turn can mitigate and/or avoid network problems and costs and reduce the peak demand. The other variant of fuel shifting DR is that these cars can participate in V2G services, namely in extreme situations, and use the ICE more than intended.

3.3. Trip reduce

The trip reduce is an incentive-based DR program to provide the aggregator with a flexible resource, in which users can participate by agreeing to reduce the EVs’ charge requirements. This program enables EVs’ owners to get a financial incentive by agreeing to reduce their trip energy requirements and consequently the minimum battery level requirements. The participation of users in this DR program can be performed as follows: users should sign up to the DR trip reduce program and notify the aggregator about the maximum amount they are willing to reduce. With this information the aggregator runs a daily routine optimization. In the day-ahead, an initial optimization is made assuming that EVs with contracted DR program will participate. With the first-round optimization results, it is possible to identify the EVs that are scheduled to participate in the event and notify the respective users. Then, the notified users should confirm their participation within a defined time period. With the confirmation responses, the optimization program can perform a rescheduling with the updated information, fixing the users with confirmed participation and making the required adjustments. Users that do not confirm their participation within the requested time period are excluded from the DR event. A penalty scheme can be implemented for the EV users who confirmed the participation and withdraw it later.

3.4. Trip shifting

The trip shifting program is an incentive DR program similar to the trip reduce. However, this DR program enables EVs' users to provide a list of flexible departure periods. This could be implemented in a similar way to the DR trip reduce program, i.e. the users sign up and setup their profiles and definitions by using an internet-based app. The DR program specifically enables the aggregator to shift EVs charging, which may help to reduce operational costs and alleviate network contingencies. The shifting is limited to the alternatives that users introduce, thus limiting the computational complexity of the optimization process. The users' participation in the DR shifting program would be similar to the process described for the trip reduce program. In face of the users positive replies to participate in the DR shifting event after being notified, the optimization program should perform a rescheduling with the updated information.

3.5. Price-based optimal pricing

The price-based DR strategy consists in defining the price that the EV owner pays to the aggregator, while ultimately changing his charging behavior. In this case it is assumed that the EV charging process cannot be controlled and consequently smart charging and V2G algorithms are not possible.

The advantage of this approach is that it does not require an advanced and complex infrastructure, such as the previous DR programs. Therefore, the price is the relationship for indirectly controlling the timing and amount of charging. The proposed price-based DR assumes that there is a correlation between the quantity of charging and the price to be paid for it. Also, the decision-maker can describe the behavior of its customers and the correlation between the quantity that the owners of EVs usually charge and the price they pay. The EVs can be classified according to several groups of consumers as suggested in Fig. 4, which shows an example of price elasticity curves for five groups of EVs' consumers.

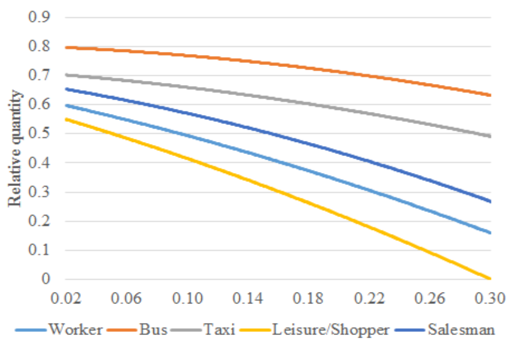

Fig. 4: Elasticity curves for distinct groups of EVs consumers.

A relative quantity of 1 means that the EV would charge whenever it would be possible, while a relative quantity of 0 means that the customer is not willing to charge at all. The represented data can be obtained using historical data or surveying consumers.

The price is directly correlated with the quantity that the user is willing to charge. Looking at Fig. 4 we can conclude that the workers group is willing to charge more than the leisure group even if the price is higher, whereas the bus fleet group is willing to pay and charge more than the other two groups due to its higher responsibilities towards third parties.

4. Conclusions

This paper briefly presents the current status of the retailing sector in some countries of Europe, namely Portugal, Spain and Germany, in what regards electric vehicles charging tariffs. Time of use tariffs are being offered by a few energy provider utilities for this purpose. In some cases, tariffs intended for general use have some discount when the customer owns an EV. Flat rates with discount or without discount are not proposed by any of the analyzed energy providers. Instead, tariffs propose a range of economic periods for EV charging.

EVs will account for a significant part of the consumers' energy bill in the future, both in costs and energy terms. With the mass integration of EVs, sophisticated demand response models are urged. This paper discussed incentive-based models and a price-based model to deal with a large number of EVs in the grid. Those DR programs are shaped for EVs and can be offered in the future, independently or combined with the already established agreement/contract between the EV user and the energy provider.

Energy aggregators are well suited entities to take full advantage of the opportunities offered by these DR programs in combination with other tasks they already perform. Therefore, implementing those measures may allow to postpone network investments, reduce operation costs, increase competition in the retailing activity, provide some benefits to customers, while successfully tackling the advent of EVs.

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