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Matias, Samuel; Mateus, João; Pereira, Manuel; Silva, Tarcísio; Furtado, António; Ziras, Charalampos; Marinelli, Mattia; Dias, Luiz; Rodrigues, Rafael; Morais, Hugo

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V2X INTEGRATION IN SELF-CONSUMPTION ENERGY MANAGEMENT SYSTEM

Samuel MATIAS
EDP NEW R&D – Portugal
samuel.matias@edp.pt

João MATEUS
EDP NEW R&D – Portugal
joaofilipe.mateus@edp.pt

Manuel PEREIRA
INESC-ID/IST - Portugal
manuel.afonso.pereira@tecnico.ulisboa.pt

Tarcísio SILVA
EDA – Portugal
tarcisio.t.silva@eda.pt

António FURTADO
EDA – Portugal
ajaguiar@eda.pt

Haris ZIRAS
DTU – Denmark
chazi@dtu.dk

Mattia MARINELLI
DTU – Denmark
matm@dtu.dk

Luiz DIAS
EDP NEW R&D – Portugal
luiz.dias@edp.pt

Rafael RODRIGUES
EDA – Portugal
rafael.oliveirarodrigues@edp.com

Hugo MORAIS
INESC-ID – Portugal
hugo.morais@tecnico.ulisboa.pt

ABSTRACT

Europe aims to be the first climate-neutral continent by 2050. One of the most important key factors for success is shifting to electromobility leading to the mass deployment of electric vehicles (EV).

Mass deployment of EVs embraces several challenges that will be addressed by EV4EU - Electric Vehicles Management for carbon neutrality in Europe project.

This paper aims to discuss the vehicle-to-home (V2H) control strategies to be implemented in a demonstrator in the Azores, Portugal. Some of the houses that will be used for demonstration also have photovoltaic (PV) systems.

At the house level, the study will focus on several controllers that will be developed and deployed based on different objectives, such as minimising electricity bills, maximising self-consumption and maximizing participation in grid support services. The algorithm is validated and calibrated by simulating multiple scenarios with different combinations of user driving patterns, tariffs, load demands and renewable energy sources (RES) curtailment management.

INTRODUCTION

RES are proliferating in the electrical distribution network at the same time the EVs are growing, which poses challenges to the power systems. The use of V2X technologies can delay or even mitigate grid reinforcements and provide a prompt response to balance the increasing energy demand [1]. EV batteries can facilitate the integration of intermittent RES by providing power on demand [2]. The implementation of this concept to reduce local energy demand can be performed by using control strategies for self-consumption energy management. A common example is the use of the EV battery as a means of flexibility tool to shift the load from periods of low consumption (during the night) to peak hours in residential areas.

Numerous algorithms for smart charging and discharging schemes have been developed that focus on distributed generation [3], [4] aiming to minimize costs [5], [6]. Moreover, bidirectional power between EVs and the grid could further boost the network support services (e.g. frequency and voltage control, congestion management, peak shaving, etc.) [3], [7].

Despite the obvious benefits of these control strategies, this potential is highly reliant on local conditions. V2X use depends on several variables (driving behaviour, self-consumption installations, tariffs, ancillary services, etc.) that can influence the control algorithms. The herein proposed algorithm is set to be implemented in a demonstrator on the island of S. Miguel in the Azores (Portugal), which is tailored to meet societal, technical, and regulatory aspects of the region.

ALGORITHM DESIGN

The rule-based approach proposed in this paper is presented in Figure 1. The algorithm prioritizes the use of energy produced by PV (maximize the self-consumption), and at the same time reduces the cost by avoiding the use of energy at high tariff periods. To ensure low prices, a threshold ($Price_{\mathrm{thr}}$) is used. When the grid price ($Price_{\mathrm{G}}$) is lower than the threshold, the vehicle is charged until the minimum battery level before a trip ($\underline{E}_{EV}$). When $Price_{\mathrm{G}}$ is higher, the flex discharge mechanism is activated. This mechanism allows the vehicle to discharge beyond than the $\underline{E}_{EV}$ and until minimum battery level ($\underline{\underline{E}}_{EV}$), only if it is possible to charge back to $\underline{E}_{EV}$ before the next trip and at a low tariff. If the EV can not be charged by PV or at trices lower than the threshold, the EV should be charged in the "Last chance charge" process. For, it is defined a minimum state-of-charge in each period (I_{SOC}).

RESULTS

Case study

S. Miguel Island, in the Azores archipelago, Portugal, is being used to test and evaluate self-consumption control strategies in the context of V2X integration. S. Miguel is particularly interesting because the Azorean government has been developing a green policy, focusing in the decarbonization of the economy, with a high impact in the electrical system. Plus, it's an isolated system that makes the analysis richer compared with mainland Portugal.

The case study is influenced by 5 variables: (1) Demand

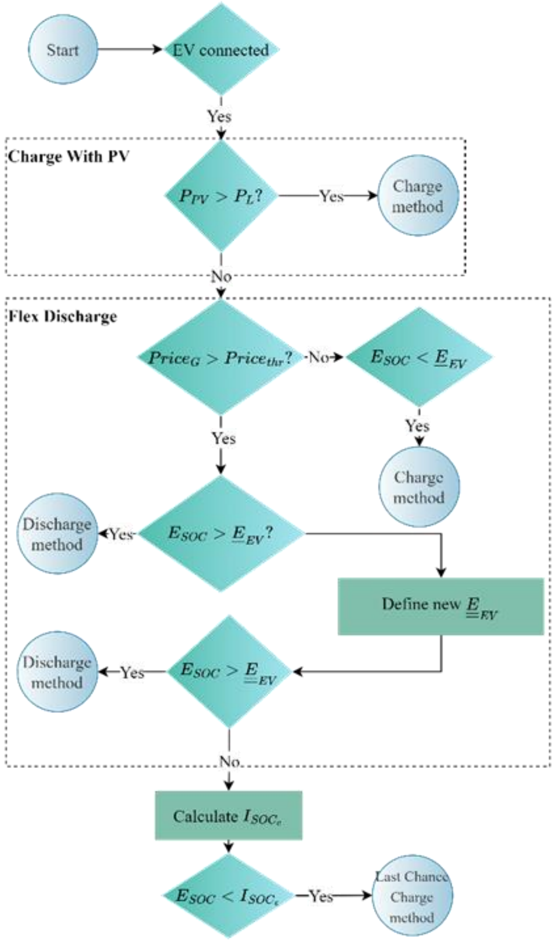

Figure 1. Diagram for the stepwise approach explained

profile; (2) PV Generation; (3) Time-of-Use Tariffs; (4) EV's and chargers characteristics; (5) Grid Services.

All of variables are modelled based on real data. The demand profiles comprehend two user behaviour profiles: Scenario 1 where the EV remains most of the time at home; and Scenario 2 with a common commute to work. Individual driving patterns are difficult to predict, yet these user profiles are based on previous historical data [8], [9]. The studied scenarios consider that the EV will charge only at home, something common in Azorean reality.

In Scenario 1, the EV owner makes two trips at the beginning and end of the day (e.g., shopping, gym, dropping-off kids at school). The travel hours are defined based on a probability distribution function with a probability of 95%. On weekends, the trip probability drops to 80% and the patterns are more irregular. A uniform probability distribution is assumed from 8 AM to 3 PM to start a trip, and a uniform distribution from 3 to 8 hours to represent trip duration.

In Scenario 2, the owner of the EV commutes daily on weekdays and leaves the car at the office. A 95% trip chance during weekdays is also assumed, as well as the departure of these two trips which are synced with the departure and arrival distributions of Scenario 1. The duration of these trips follows a uniform probability distribution between 30 minutes and 1 hour. The weekend profile is equal to Scenario 1.

These scenarios describe the plug-in intervals in which the EVs can be charged or discharged. However, it is necessary to model the amount of energy needed for daily mobility, which could be indirectly applied to the distance covered by the EVs with an average consumption of 15 kWh/100 km. According to the driving habits in the Azores, the average driver covers 30 km per day, around 2/3 compared to mainland Portugal [10]. Considering the probability dispersion according to international surveys [11], the following probability distribution function is proposed in Figure 2.

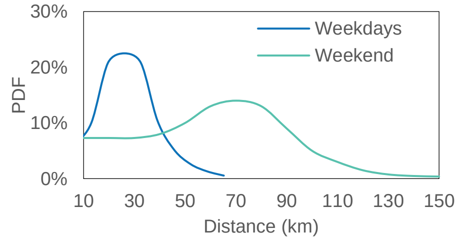

Figure 2. Average mobility needs for Scenarios 1 and 2

It's worth mentioning that the described user behaviour profiles try to replicate real driving patterns, nonetheless, they are fictitious scenarios that seek to test the sensitivity of the algorithm.

The house consumption standard scenario (Figure 3) considers a 4 MWh single-family house consumption from real data collected on Madeira Island [12], reflecting the average electricity consumption patterns in the Azores.

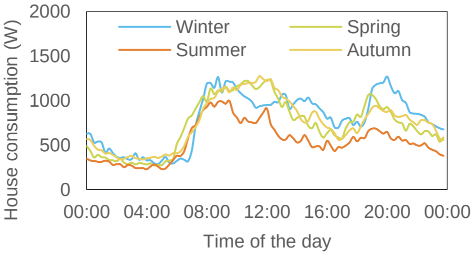

Figure 3. Average house consumption per season (without EV)

In terms of PV generation (Figure 4), the default scenario reflects a 2.2 kWp PV system in the S. Miguel Island (~2000 sunshine hours per year).

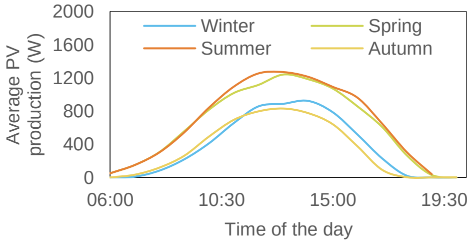

Figure 4. Average PV production per season

Regarding the tariff, electricity prices in Azores market are regulated and fixed throughout the year. The tariff hours are divided into super off-peak, off-peak, and peak times, whose prices vary according to simple, bi-hourly, and tri-hourly tariffs. The tariff structure is explained in further detail in [13].

The reference simulation uses Scenario 1 (car at home), an EV with a 40 kWh battery size and a 3.6 kW V2H charger with 95% efficiency for bidirectional charging. The SoC ranges from 20% to 80% for charge/discharge cycles, which can reach 90% when charging with self-generation (PV). To minimize small discharges to supply the house load, a threshold of 0.4 kW is considered if the required load demand is below this limit. Figure 5 shows the charge/discharge cycles during the summer months.

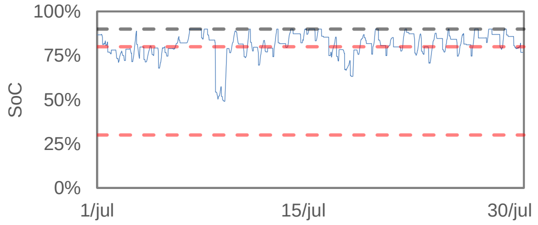

Figure 5. Charging/ discharging curve example

All simulations focus on smart V2H control strategies, but to evaluate the potential of this technology for self-consumption, the different costs for a whole year in the reference scenario can be observed in Figure 6.

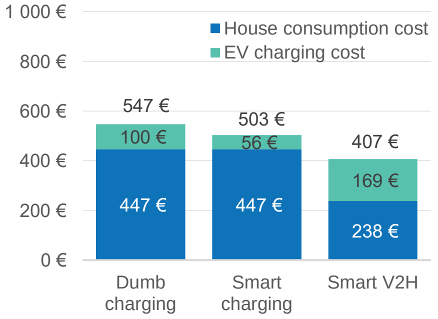

Figure 6. Yearly costs with different control strategies

It can be observed that by implementing smart charging technology, the savings in charging costs can reach almost 50%. Using a smart V2H strategy, the operational savings increase by 25%. In this case, the cost of charging the car increases by over 100€, but the cost due to the house can be reduced by 200€ by shifting the load to high-demand periods. This smart V2H strategy focuses on the flexibility of the system without compromising mobility needs. Notwithstanding, it is important to mention that the total cost increases by 15% under these assumptions when mobility needs are prioritized.

Demand profile

The drive behaviour of individual EV users is highly unpredictable and has a significant impact on V2H energy flow. In all simulations, Scenario 1 (car at home) is used as a driving pattern that maximizes the potential of V2H capabilities and further reduces electricity house costs. For Scenario 2 (car at work) the EV is not connected to the house charging point during long periods of the day. In this case, the annual energy cost increases by 34% due to this unavailability, mainly due to PV generation not being used (an increase from 10% to 47%) and a reduction in the usage of EV battery to supply the house (30%).

Pricing

Since the drive pattern in Scenario 1 promotes high charging flexibility, tri-hourly contracts are interesting, but with a low margin. The standard bi-hourly scenario costs 407€ per year, which reduces to 400€ for the tri-hourly tariff. The simple tariff results in a 526€ total invoice. These results depend strongly on the tariff system, but the high flexibility of the user behaviour favours the tariff mode with the lowest price possible.

PV generation

Recently, PV self-consumption has boomed due to government incentives, technological improvements, and a drop in the components' price.

To test the sensitivity of V2H control strategies to different PV generation capacities, 2600 kWh/year is used as the standard scenario and three alternative scenarios of 500 kWh/year, 1500 kWh/year and one with no PV system.

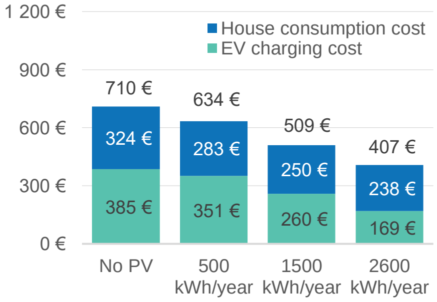

Figure 7. Yearly costs with different PV systems

Figure 7 shows the total operational cost of using different PV systems, highlighting the impact of self-consumption on V2H operations. In the scenario without a PV system, the V2H system alone still manages to reduce the total cost by 17% in a year, nevertheless, as the PV installation capacity increases, the price drops even further. With smaller systems, there is less PV curtailment, so the savings percentage is almost equal to the ratio between PV generation and house consumption. Because PV generation prioritizes house consumption needs, smaller systems favour faster cost reductions in the house invoice.

EV and charger characteristics

How much and how fast an EV can charge/ discharge plays an important role in V2H control strategies. Battery capacity has a large impact on electricity costs, as the charging flexibility increases with the battery capacity, as shown in the Figure 8. Below a certain capacity, operating costs increase dramatically due to a saturation of battery usage. Conversely, the increased battery capacity above this value is not relevant to the overall cost. For the hypotheses, battery capacity above 50 kWh does not lead to significant improvements.

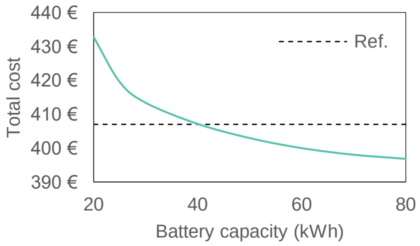

Figure 8. Effect of battery capacity on the overall operational cost

Concerning the charging/ discharging power, it is immediately noticeable that lower discharging power leads to marginal higher house consumption costs, as the EV is not available to meet house demand.

Another issue is the increasing EV charging costs with higher installed capacity, which can be improved through the usage of PV generation forecasting. Moreover, the larger the V2H charger power, the higher the cost of the required installed capacity. According to the simulated scenarios and due to the low mobility demand in the Azores, it may be beneficial to contract a lower installed capacity contract to reduce the total electricity costs, see Figure 10.

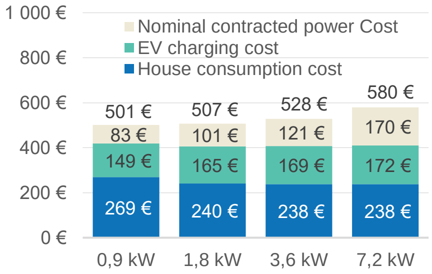

Figure 9. Effect of charging power on the overall cost

Grid services

An isolated electrical system such as the S. Miguel grid, is more complex to manage and more vulnerable to grid instability, compared with the mainland. To ensure the safety and security of the network, during off-peak periods, often the grid operator must curtail wind generation. To mitigate that, the V2H control strategies include the possibility to participate in grid services by starting a charging session, if possible, to increase the load demand on the system (and reduce the curtailment). In other words, the house management system in combination with the system is forcing green charging.

The communication between the system operator and the house is not direct and is not in the scope of this paper. The purpose here is to test the control strategies considering this hypothesis.

Real data from a wind farm on S. Miguel Island is used as a reference. This data was post-processed to create a probability density function to assess the chance of curtailed energy. Using this data, and assuming 1500 EVs available to participate in grid services (approximately 20% of the estimated number of EVs in S. Miguel Island by 2030 [14]), Figure 10 shows the likelihood of a request for grid service being made depending on the time of day.

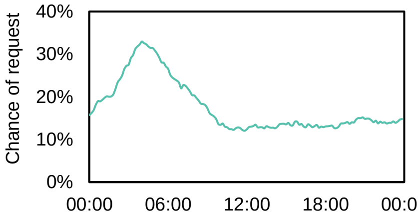

Figure 10. Chance of an EV being requested to participate in grid services

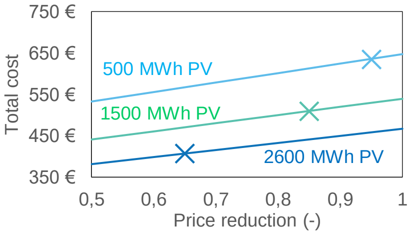

Figure 11. Price sensitivity from green charging

Participation in grid services can provide benefits to users willing to participate, including cost reduction. Given these assumptions, prosumers with a given installed PV system may need an additional incentive to participate. As expected, higher PV generation requires a strong incentive to participate because the contribution in grid services uses a portion of the battery capacity that could otherwise be charged with solar energy. Based on the generation-consumption curve, a break-even value motivates prosumers to participate in grid services. In that case, if the price of electricity when partaking in grid services is less than 65% of the lowest tariff, these individuals are likely to participate (Figure 11).

CONCLUSIONS AND FURTHER WORK

The uptake of electromobility brings new challenges, but also new opportunities to improve grid flexibility. The main objective of this work was to design, develop and validate versatile self-consumption control strategies using a rule-based algorithm to coordinate generation and consumption. In developing this algorithm, a stepwise approach was taken to build confidence in a reliable tool for simulating V2H energy flow.

The next contribution of this work is related to the validation of the algorithm as a proof of concept to be implemented in a real demonstrator. This demonstrator will be located on S. Miguel Island in the Azores, so several realistic scenarios have been modelled to simulate island operation. The main findings are:

- Due to the shorter distances travelled by Azorean drivers and the high car usage on the island, V2H proves to be an important tool to make the grid more resilient.
- More flexible charging by users favours equally flexible tariffs, which may mean that these users are more price sensitive

- The PV system promotes and enhances the potential of V2H control strategies, especially in low mobility demand scenarios.
- Participation in grid services such as RES may require financial incentives for users, depending on the trade-off between generation and consumption.

With respect to future improvements in control techniques, there are several issues that require further attention and are proposed here:

- Further simulations with dynamic tariffs, different user behaviour, alternative storage systems, grid congestion management, green charging, and dynamic power contracts.
- Integration of the obtained results and recommendations into the evaluation of life cycle costs, considering investment and payback costs, such as grid investments and battery wear.
- Evaluation of load demand and grid participation forecasts based on stochastic modelling.
- Incorporation of an advanced self-learning module to predict user behaviour.

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