Economic Assessment of V2B and V2G for an Office Building

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Abstract—**The development of smart grids, bidirectional chargers and the increase of the number of electric vehicles (EV) have made possible the implementation of technologies such as vehicle-to-grid (V2G) and vehicle-to-building (V2B). Under optimized operation, these methods can lead to savings in the energy bill and benefits to the electricity grid. This paper aims to assess the usage of V2G and V2B concepts in a business setting. For this purpose, we simulate an EV parking lot in the Southern California Edison (SCE) territory, connected to an office. A mathematical programming optimization determines when the charging and discharging of the stored energy should take place in order to minimize electricity bill given specific customer electricity rate regimes. The expected cost savings are analyzed according to SCE's real-time pricing tariffs for medium-size businesses.**

Index Terms—**Vehicle-to-Grid (V2G), Vehicle-to-Building (V2B), Real-Time Pricing (RTP).**

I. Introduction

THE NUMBER of electric vehicles (EV) on the road has increased rapidly in the last few years. According to Global EV Outlook, in 2018 the global electric fleet exceeded 5.1 million [1]. The projections for 2030 predict between 125 and 230 million electric vehicles on the road. The increased penetration of EVs poses numerous challenges to grid management. The contribution of the daily charging patterns of EV will modify the customer demand profile with the corresponding changes in equipment loading and the need for charging coordination to avoid exceeding operations limits. This requires changes both to the operational method as well as to the planning processes of electric distribution systems.

The total amount of energy stored in the EV batteries will also continue to grow. Assuming 25 million of EVs in the US and an average battery capacity of 40 kWh, the total amount of energy storage will be around 1 TWh. As a comparison, let us consider that the electricity consumption in the U.S. in 2018 was 4,177 TWh [2], with an average daily consumption of 11,44 TWh. That means that a significant portion of today´s U.S. consumption could be stored in EV batteries. If this stored energy is fully utilized, it can provide significant benefits for system operation.

The emergence of bidirectional EV chargers, which allow power to flow in both directions, has made possible the implementation of vehicle-to-grid (V2G) and vehicle-to-building (V2B) technologies. These concepts add more flexibility to the system operation and enable operational regimes that were not possible before. One of the main benefits is the usage of the stored energy to smooth the demand during peak hours. When aggregated, this approach can decrease the amount of power needed from conventional power plants, the amount of required system reserve, and the needs for capacity expansion on the power delivery system. On the other hand, the batteries could provide economic savings by charging during valley hours, when both the demand and the prices are lower, or when renewable energy resources are providing an excess of energy. Another application of smart vehicle charging is firming variable renewable generation.

Overall, flattened load profiles can reduce both cost and uncertainty, and make system planning easier as net power demands and injections can be anticipated. Furthermore, any required re-schedule would be easier to accomplish as storage systems can rapidly modify their injections if needed. This is especially important in systems with high penetration of renewable resources, where the power injected by renewable generators can vary largely during a period of time. It also gives the customers the ability to adapt their energy consumption according to the electricity price. In this scenario, stored energy can be sold or used to supply buildings when the prices are higher and purchased during valley hours when the price is lower, leading to significant cost savings for residential and commercial electricity customers.

The significant potential benefits of V2G and V2B technologies have started a shift in the approaches adopted by EV manufactures. Tesla and Nissan already have models with V2G capabilities, while other brands such Mitsubishi and Honda have also announced plans to include this capability. It is expected that in a near future, a large portion of the EV fleet will serve as a large conglomerate of small energy storages on wheels with a large aggregated storage capacity.

From the point of view of the electric company, the main objective is to deliver reliable electricity to customers, including to electric vehicle charging stations, at reasonable cost. In order to accomplish this, the utility must select a suitable generation portfolio and also ensure that various electrical quantities such as voltages at the point of delivery and distribution transformer flows are within operational limits. For instance, simultaneous changing of various vehicles in a distribution circuit may create an electric overload in the transformer, or an under-voltage condition. These conditions are both dangerous and costly. The charging of various electric vehicles must therefore be coordinated and scheduled dynamically. This requires real-time exchange of information between the vehicles, the charging station node, and the utility.

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In this paper we develop an economic assessment of a business EV parking lot equipped with V2B and V2G capabilities. The system aims to provide the optimal charging and discharging patterns that minimizes the business utility bill. The simulation results show that cost savings provided by V2B and V2G technologies to residential customers can be expanded to medium-size businesses.

II. Background

There are several research studies that have identified and described the opportunities of Plug-In (or gridable) EV batteries to minimize charging costs. All of these studies have in common the basic strategy of providing energy from the battery during peak hours and charging during the valley hours. Although most of the approaches consider a "single cycle" pattern, where the battery is discharged only once during peak hours and charged only once during the next valley period, the algorithm proposed in [3] also considers several charging and discharging cycles during peak hours. It is claimed that this strategy is more profitable if there is a high fluctuation in the prices. A comparison between V2G and V2H approaches is also presented in [3], showing that V2G may achieve a larger cost reduction as the energy that it is sold to the grid is the maximum that the battery can provide in that period of time, and it is not coupled to the building consumption.

Other works, such as [4], add further contributions to a base algorithm. In this paper, the state-of-charge (SOC) of the battery is considered during the whole day and it takes into account the amount of energy that each vehicle spends during the daily routine and the energy that is restored through regenerative braking. This data is gathered by equipping each vehicle with a GPS.

Figure 1 illustrates the evolution of the SOC of a vehicle with V2G capabilities. The battery is used during the evening to supply the grid and this power is restored back during the night. However, this approach leaves some gaps (which sums up to one half of the day) where the level of the battery is constant. During these periods of time, the aforementioned advantages of V2G are not exploited.

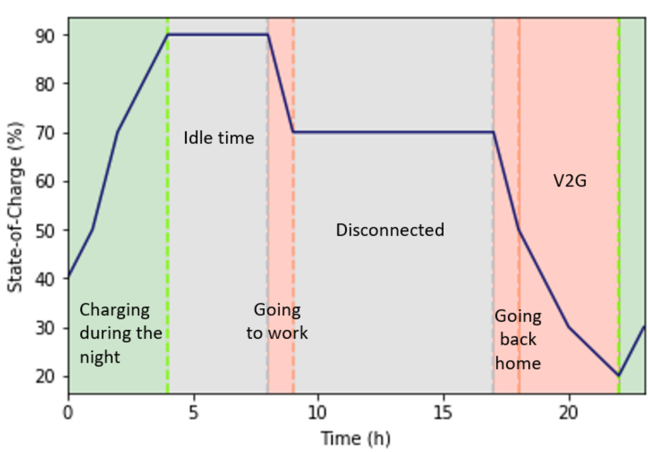

Figure 1: Battery State-of-Charge along a full day

The analysis performed in [5] includes the average mobility patterns to estimate how much energy each car would be able to provide to the building. It is stated that the chosen vehicle, a Nissan Leaf with 40 kWh storage, employs only 14% of the battery in the daily routines. Therefore, there is plenty of battery capacity that can be used for V2G or V2H purposes.

The reported reduction in the charging costs can vary significantly. In [3], it is stated that a reduction of around 50% can be achieved in conventional conditions. However, in a highly fluctuating price scenario, it is even possible to make profit. The analyses in [4] and [5] are more conservative and claim a reduction of approximately 15 or 20%.

Finally, in [6], the power system regulation that can be achieved with gridable EVs (GEVs) could be very useful, as bidirectional chargers incorporate a DC link capacitor and therefore are able to provide reactive power when needed. The enormous potential of V2G and V2B technologies regarding smoothing daily load profiles, providing active and reactive power support and the high efficiency of a local power source makes these technologies very promising for the future development of the smart grid.

III. Proposed Method

We propose a temporal optimization problem where the decision variables are charging and discharging of the EV with V2B and V2G technologies. The core method uses linear programming optimization with upper and lower bounds:

$$\min f(x) \tag{1}$$

$$subject\ to:$$

$$A_{eq}x = b_{eq} \tag{2}$$

$$Ax < b \tag{3}$$

$$lb \leq x \leq ub \tag{4}$$

where $f(x)$ is the objective function, x is the vector of decision variables, matrix A_{eq} contains the coefficients of the equality constraints, while A contains the coefficients for the inequality constraints. b_{eq} is the constraint vector for the equality constraints and b is the corresponding vector for the inequality constraints. In (4), the lower and upper limits of the decision variables are specified.

A. Objective Function

The goal is to reduce the total cost of purchasing energy, using the EV batteries as independent energy storage systems. The algorithm is applied to each vehicle and the total savings are equal to the sum of the individual savings by each vehicle:

$$f(x) = \sum_{n=1}^{N}\left(\sum_{t=1}^{T} \pi_t P_{x,n,t}\right) \tag{5}$$

where N is the number of vehicles, π_t is the hourly price and $P_{x,n,t}$ is the hourly energy purchase considering the effect of one energy storage.

B. Constraints

Equations (6) and (7) model equality constraints corresponding to power balance and energy balance for each hour and for each vehicle. The initial energy for each individual battery is modeled by a normal distribution using equations (8). In this way, the variability of the battery level of each incoming EV is addressed. At the end of the working hours, the energy stored in each battery is set to be the same as the initial (9). Otherwise, users wouldn't find attractive to leave their car in the parking lot.

$$P_{Purchased,n,t} = P_{Demand,t} + P_{Charge,n,t} - P_{Discharge,n,t} \quad (6)$$
$$E_{n,t} = E_{n,t-1} + \eta * P_{Charge,n,t} + {}^{1}/_{\eta} * P_{Discharge,n,t} \quad (7)$$
$$E_{n,0} = E_0 \in N(\mu, \sigma^2) \qquad 0 < \mu < 1, \sigma^2 = 0.1 \quad (8)$$
$$E_{n,T} = E_0 \quad (9)$$

Here, P is power, E is stored energy, t is the present hour and η is the power charge and discharge efficiency. The limits of the optimization variables are as follows:

$$- P_{Disch,max} \leq P_{Pur,n,t} \leq P_{Dem,max} + P_{Char,max} \; \forall n, \forall t \quad (10)$$
$$0 \leq P_{Discharge,n,t} \leq P_{Dicharge,max} \; \forall n, \forall t \quad (11)$$
$$0 \leq P_{Charge,n,t} \leq P_{Charge,max} \; \forall n, \forall t \quad (12)$$
$$E_{n,min} \leq E_{n,t} \leq E_{n,max} \; \forall n, \forall t \quad (13)$$

As specified in equation (10), the minimum power that can be bought is actually negative (a saving). This would be the discharged power of the battery assuming that the demand of the building is zero. On the other hand, the maximum purchased power is achieved when both the building demand and the battery charging process have to be satisfied. $P_{Dem,max}$ is the maximum reachable demand by the office during operation. We assume a medium business with a maximum capacity of 100 kW. Equations (11), (12) and (13), the maximum power transfer through the charger and the maximum energy storage in the batteries are specified. These quantities depend primarily on the car model. For simplicity, all cars are assumed to have same rating.

C. *Savings*

The hourly savings for each individual battery is computed as the difference between the power discharge and the power charge times the price, as in equation (14).

$$\pi_t \left(P_{Discharge,n,t} - P_{Charge,n,t}\right) = \pi_t \; \Delta P_{Purchased,n,t} \quad (14)$$

Therefore, it is more profitable to charge the batteries when electricity is cheap and sell this energy when electricity is more expensive. If the power discharge is greater than the actual load of the building, the outcome would be a sale of energy back to the grid. The profit associated with the sale is assumed to be the full retail value of every kWh sold. This approach considers V2B as the main procedure, and V2G is only reached when the discharged power exceeds the building consumption.

D. *Demand*

For the hourly demand, normalized profiles for summer and winter were used as it can be observed in Figure 2. The data used is based on the study carried out on [7]. The study considers that EV will be available from 8 am to 6 pm. This approach addresses the fact that the time cars are parked exceeds the working day. As it can be noticed, the demand during wintertime is slightly higher during the first hours on the morning due to the usage of the heating system, while during the summer the high temperatures make essential to use the air conditioning in the afternoon. The normalized profiles are then multiplied by a base of 100 kW, corresponding to a medium-sized office building.

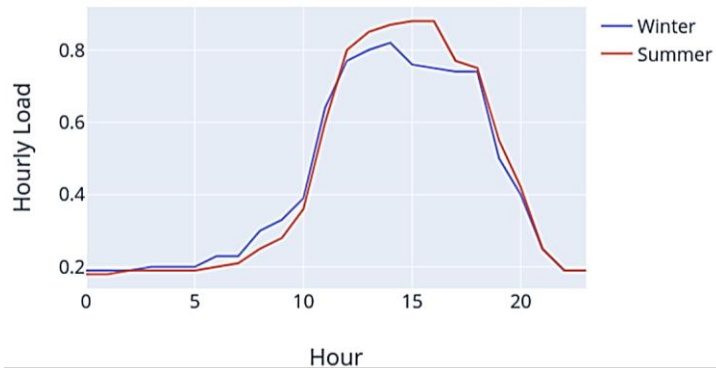

Figure 2: Normalized load profiles for summer and winter periods

E. *Price*

In this study, seven Real-Time Pricing (RTP) tariffs provided by Southern California Edison [8] were considered. As an example, two of the RTP tariffs is illustrated in Figure 3. Note that for the extremely hot summer days, the prices can be up to 50 times the low-cost tariffs during the winter. The type of day depends on the maximum temperature of the previous day in downtown Los Angeles. The corresponding weather data can be accessed at the webpage of the National Oceanic and Atmospheric Administration [9].

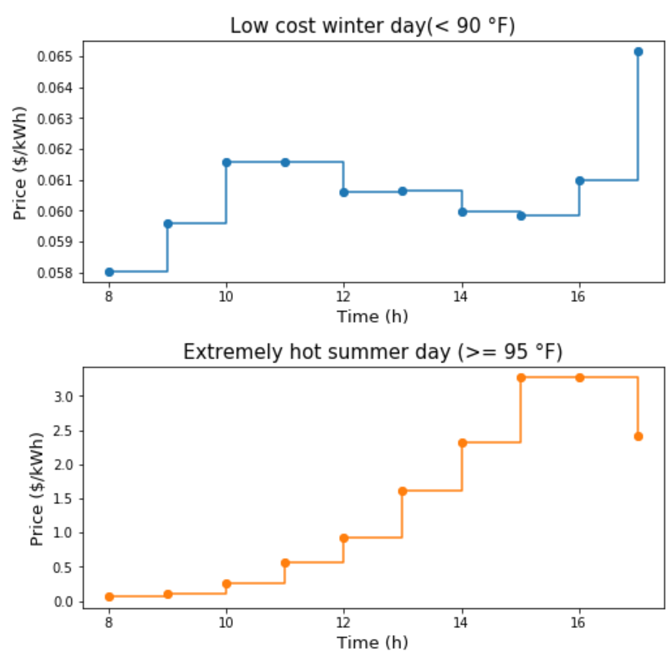

Figure 3: Real-Time Pricing tariffs for a low-cost and a high-cost day

IV. SYSTEM STUDY

This paper considers two study cases: a sensitivity analysis for a typical winter week marked by low and average prices, and a study for 180 days across winter and summer periods where seasonal changes in the savings can be studied.

A. Sensitivity Analysis

The purpose of the sensitivity analysis is to show the interaction between different parameters of the model and the total savings. During the winter period, prices remain stable. which provides an excellent benchmark that can be used as a default case. This analysis was developed for 7 winter days using weather data from February 10, 2020 to February 16, 2020. The load corresponds to the winter normalized profile with an injected random noise, so each day is slightly different.

For this sensitivity analysis the assumed parameters were as follows: the number of cars considers was in the range from 20 to 200, the considered charger power rates were 6, 7.2 and 8 kW; the capacity of the battery were 40, 64 and 80 kWh; the efficiencies were 0.9, 0.95 and 0.97; and the means for the normal distribution of the average initial battery level were 0.6, 0.7 and 0.8.

The matrix in Figure 4 presents the correlation among all the simulation input features and output variables (in particular, total savings). The matrix suggests a strong correlation of the savings with the battery efficiency.

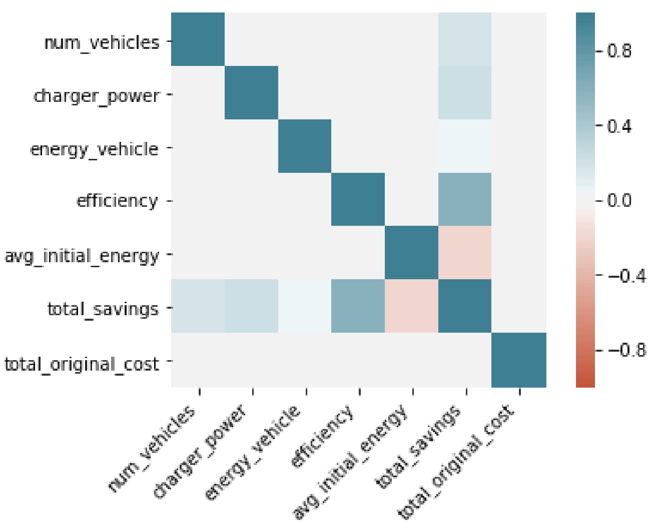

Figure 4: Correlation matrix between input and output variables

Further analysis of Figure 5, considering the role of the battery efficiency as the main feature, reveals that only significant savings can be achieved with a high level of efficiency (97%) in the charging and discharging processes. For lower efficiencies such as 90% and 95% no matter which parameters are considered, savings are almost zero or negative for the cases studied.

The maximum percentage of savings is 12.57% and is achieved with 200 vehicles, an efficiency of 0.97 a combination of medium settings (7.2 kW charger, 80 kWh battery) and with the lowest mean for initial battery level: 0.6. This is explained taking in account that a lower battery level allows a larger charging and a larger discharging before returning the EV.

B. Seasonal Analysis

This analysis was developed for 180 days starting from February 2nd, 2019 to August 1st, 2019, considering the switch to winter to summer on June 21. The load profile is considered as changing linearly from the winter profile to the summer profile. In this case, the settings are fixed: 100 vehicles, an efficiency of 0.97, a 7.2 kW charger, 64 kWh battery and 0.7 for mean of the initial battery level. Therefore, the variations are just the daily load profile and the daily prices (due to the changes in temperatures throughout the period).

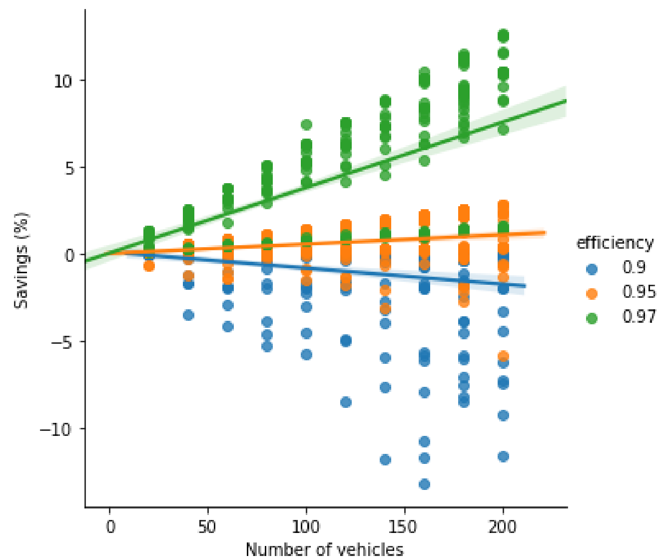

Figure 5: Savings for different ranges of efficiency and number of vehicles

The results indicate that during wintertime, both the daily cost and the achieved savings tend to be fairly constant: the average cost without considering V2G or V2B is $39.8 and most of the days remains close to it. The achieved average daily savings using the proposed method sums up to around $5.84, which gives an average of 14.66% daily savings. However, most of the days the savings are lower: on average $2.39 (about 6 %, which is in accordance with the results of the sensitivity analysis for 100 vehicles). There are some warmer days, some outliers, that raise up both the cost and amount of savings giving a higher average of savings for the period.

During the summer period the scenario is quite different. The larger number of tariffs leads to a higher variability of prices and eventually, to a higher variability in the savings. This summer variability can be appreciated in Figure 6.

In the summertime, prices are higher and savings tend to exceed the original cost without considering any V2G or V2B. The algorithm identifies the large inner price variabilities during the same day where profit can be made, and sells the stored energy during the afternoon, where prices are more expensive than earlier in the morning.

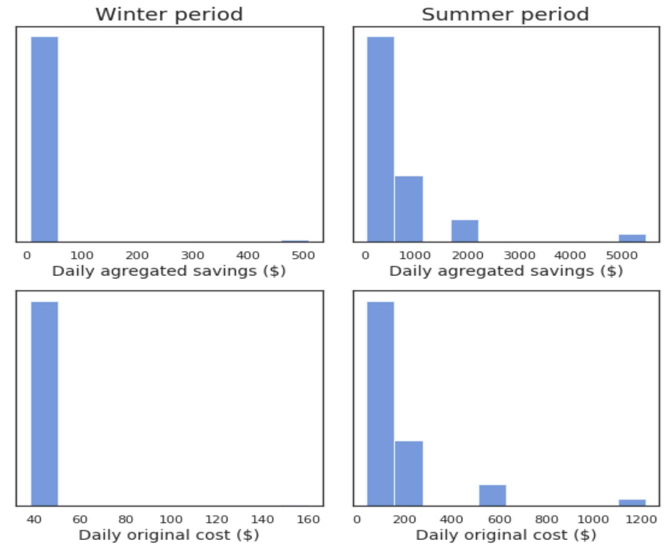

Figure 6: Original cost and savings for winter and summer period

We note that daily savings usually exceed the cost without V2G and V2G, as it can be appreciated in Figure 7. The two peaks in the distribution function are around 120% and 450% (daily savings tend to be 1.2 and 4.5 times greater than the cost), which correspond to different types of days in terms of tariffs, achieving a larger profit during the warmest days. It is noticeable that, with these RTP tariffs, the total savings will depend on the yearly temperature distribution. In the 41 days of summer period considered, the cost without V2G or V2B is $5865, while the profit for the sale of energy are $20528, which is more than 3 times the original cost.

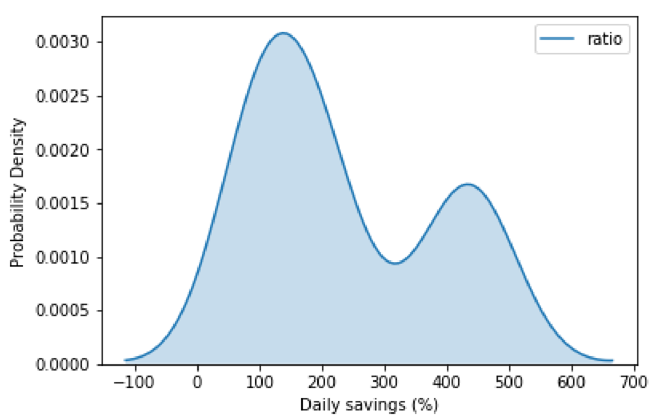

Figure 7: Distribution of daily savings during summer days

In order to obtain a more complete understanding of the process, it is necessary to study the behavior of the system. In Figure 8, for a low-cost day, the hourly cost, savings, amount of discharged power and charged power are displayed. It can be noticed that the consumption of the building is larger than at the beginning of the day due to the charging of the batteries (this extra purchase leads to negative savings in the early morning). Later on, when the cost ($/kWh) is higher around 5 pm, that energy is used, giving net savings of around 6 %. The fact that the amount of power drawn from the grid (power charge) is slightly larger than the amount of power given back to the grid or the building (power discharge) can be explained because of the efficiency of 0.97. Some of the purchased energy that is stored is actually wasted due to these losses.

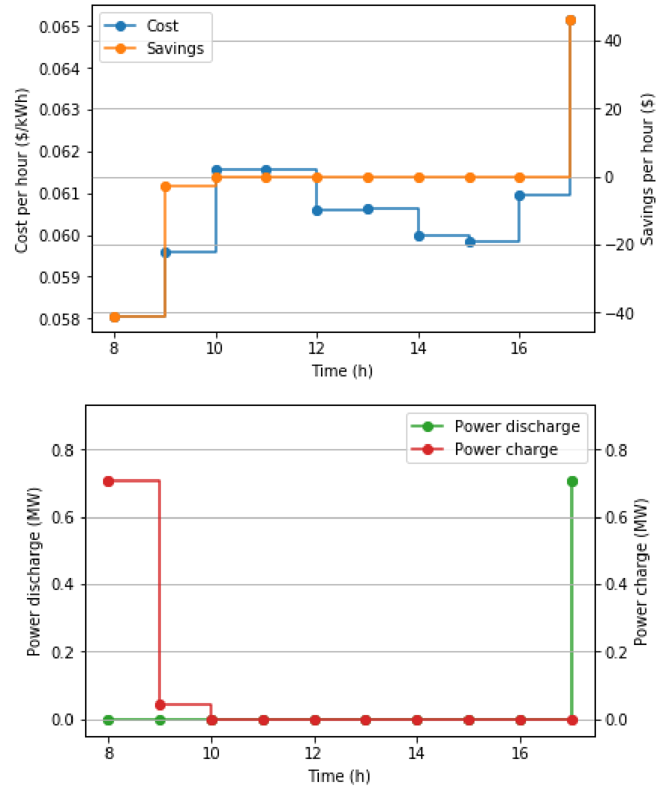

Figure 8: Cost, savings, power charge and discharge for a low-cost day

However, during the summer, the price variations are much larger even within the same day, allowing the optimization to obtain much more profit out of the energy stored in the batteries. This is illustrated in Figure 9. If all the energy is reserved for the afternoon, the profit that comes from the sale of this energy at the peak hours is about 8 times the corresponding cost ($) of the business demand for energy. The amount of energy injected into the grid is very large in comparison with the consumption of the building, which explains why the savings exceed the cost several times. The balance of this specific day is that the savings are around 4 times the cost without V2G and V2B technologies.

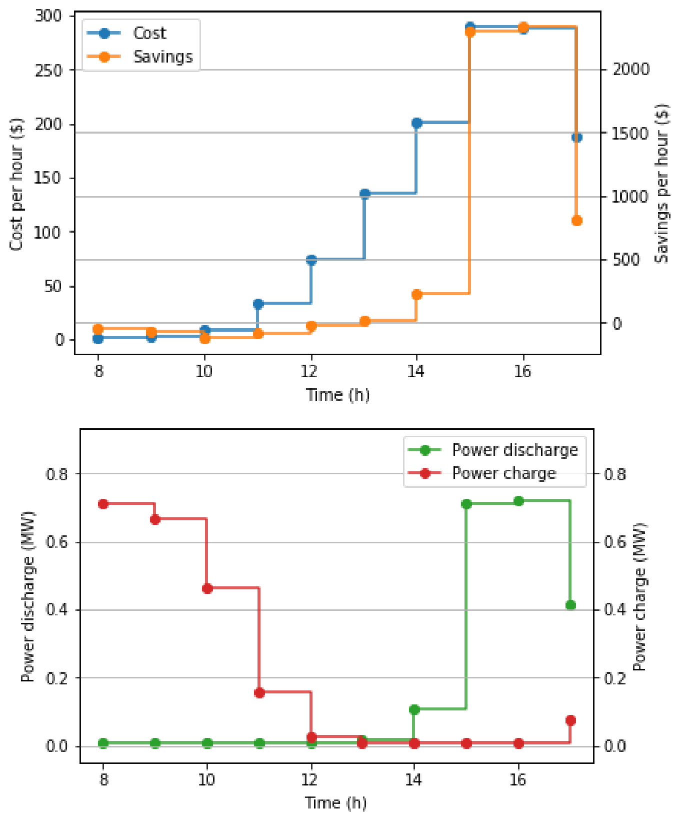

Figure 9. Cost, savings, power charge and discharge for a high-cost day

V. Discussion

The results from this assessment validates some of the claims in the literature regarding the potential of V2G and V2B, and that the savings can be obtained by commercial customers.

In [4] and [5], it is stated that the expected savings would be around the 15 or 20 %, which is in line with the 14.66% of savings achieved for wintertime for reasonable assumptions regarding the number of cars, efficiency, capacity of the batteries and power of the charger for this particular case.

In [3], it is stated that multiple cycles patterns and high volatility of prices result on larger savings and even profit. Our results indicated that during the summer, the high variability of prices inside the same day lead to the fact that the profit from sale of energy in the afternoon exceed the cost for the demand.

Both the results during winter and summer suggest that V2G and V2B technologies can be profitable for a business setting. However, it is important to notice that the achieved earnings are highly dependent on some factors, such as the number of vehicles, the RTP tariffs and the efficiency. Therefore, the amount of earned savings will vary according to the scenario.

VI. Future Work

This paper can be considered as the starting point for an economic assessment of a real V2B and V2G projects. A more detailed study should consider additional factors, such as the degradation of the battery and user's remuneration for their participation. Existing batteries tend to lose their storing capabilities. This effect would lead to a loss of effectivity in the process, negatively affecting savings. There are also considerations regarding batteries owned by a third-party (the EV owner), which could be damaged.

As the operation of the EV parking lot is actually a business, a fair remuneration should be provided to the user to make this parking option appealing, which represents a cost to the parking lot operator.

In order to help with the integration of renewable resources and smoothing the demand, a regulation about the limits of power injection and demand should be endorsed. These limits would appear as corresponding constraints in the optimization algorithm. The technical characteristics of the parking lot should be included as constraint as well.

VII. Conclusions

This paper assesses the expected cost savings that a medium-sized company exposed to real-time pricing would realize by using the stored energy available in the EV of their employees to partially satisfy the building demand in an optimal manner.

Using a linear programming algorithm, it has been determined that during the wintertime, when prices are stable and low, the expected savings could be around the 15%. However, in the summer, the high prices during the afternoon can make the sale of energy very profitable for the company and the savings amply exceed the costs, being as large as 4.5 times the original cost without any V2G or V2B technology for the warmest days.

The paper provides a specific analysis for a particular case, but the advantages of the algorithm are demonstrated. An optimal charging and discharging pattern for the EV parked on the office lot can be developed such that the promising advantages of using a V2G and V2B technology (cost savings in this case) are attainable in a commercial customer setting.

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