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Optimal energy management system for V2G chargers combined with PV and ESS in a real environment

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Summary

The integration of Electric Vehicles in electricity grids is very likely to pose several challenges to the electrical grid operation and expansion. The potential flexibility of the load associated to the EV charging and the possibility of discharging the EV using vehicle to grid (V2G) chargers offers the opportunity to provide new services to the end users. One real installation in Nissan headquarters in Barcelona has been selected to perform and present a comparative analysis of the differences in EV charge performance and electricity purchase between the use of dummy chargers, smart chargers and V2G chargers managed by an EMS based.

Keywords: V2G, V2H, second-life battery, optimization

1 Introduction

Vehicle-to-grid (V2G) is defined as the bi-directional electricity transfer between the on-board battery of an EV and the system it is connected to. By enabling vehicles to control their charging behaviour and supply power, V2G technology aims to offer services to electricity grids, whilst simultaneously minimizing battery degradation and inconvenience to EV users. Vehicle-to-grid technology is supposed to increase the potential benefit of the inclusion of electric vehicles in energy systems in comparison with dummy charging or even with smart charging policies [1]. V2G requires additional electrical equipment compared with standard or smart charging, such as an inverter to convert the DC power output from the on-board battery to AC for usage. This conversion equipment is normally integrated into EVSE (Electric Vehicle Supply Equipment), although some manufactures are considering integrating this within the vehicle. Control units are also required for efficient, reliable and safe battery charging and discharging, along with upstream communication protocols to manage these interactions with the electrical systems where the vehicle is connected [2].

An early distinction to be made is that between V2G and "smart charging", also known as "controlled charging" and sometimes going by the acronym V1G. Whilst both smart charging and V2G are able to remotely and intelligently control the rate at which an EV battery is charged, only V2G technology enables an on-board EV battery to discharge power back to the system. In other words, whilst a V2G system can behave as both flexible generator and flexible load, smart charging can only can behave as a flexible load. Smart charging has been the first approach of including and optimizing electric vehicle charging events into different energy systems, and combine these smart charging policies with local renewable generation, energy prices or forecasted demand by means of energy management systems. V2G requires this optimization algorithms to go one step further, they should decide when to charge or discharge the vehicle following different signals (price, demand, grid impact, …) but always keeping in mind the users requirements on the EV battery.

EVs can therefore be seen as a distributed energy source and are able to offer values and services that exceed its primary function as a mean of transportation. In this work, the vehicle-to-building (V2B) application is analysed, where services are provided to the building where the vehicle is connected. V2B can generate value through behind-the-meter optimization to reduce energy costs to building users and maximize self-supply from on-site generation. In order to demonstrate and validate this service and the functions of V2G charging stations one pilot plant will be installed in Barcelona.

It is important to mention that V2G technology is still largely at a development phase and the business case has yet to be proven. Currently, there is a limited number of electric vehicles (EV) in the market capable of providing of bi-directional power flow between vehicle and charging point. There is also limited availability of V2G ready EVSE and plugs. This is likely due to concerns by OEMs over the impacts of V2X on battery aging [3], along with a lack of demand from vehicle users for V2G capability. This presents a "chicken and egg" problem when it comes to moving the technology from the research and development stage to a mass market for bidirectional EVSE and EVs.

The main objective of this work is to evaluate the impact of the V2G technology in the demonstration project regarding performance and costs in comparison with standard charge (plug-in and charge) and smart charge. Moreover, the installation of second life batteries is also evaluated. The installation details is described in Section 1.1. In order to achieve an optimal management of the solution an Energy Management System (EMS) based on optimization models has been developed and it is detailed in Section 1.2.

1.1 Description of the installation

The work done in this paper has been developed within GrowSmarter project [4], the measure is deployed at Nissan headquarters in Barcelona and focuses on the integration of V2B services with renewable energy generation and energy storage systems in buildings. The installation is built on the following elements:

- Installation of 2 V2G charging stations (10kVA).
- Installation of a PV field (10,89 kWp) connected to three hybrid inverters (AC power: 3,6kW each one).
- Installation of three energy storage system (ESS) (12,6kWh).

The building has been monitored and the installation deliver energy to part of Nissan headquarters load which includes the cantina and has a maximum peak of 60kW. To manage the installation, an energy management system (EMS) has been developed and integrated together with a SCADA system (Fig. 1).

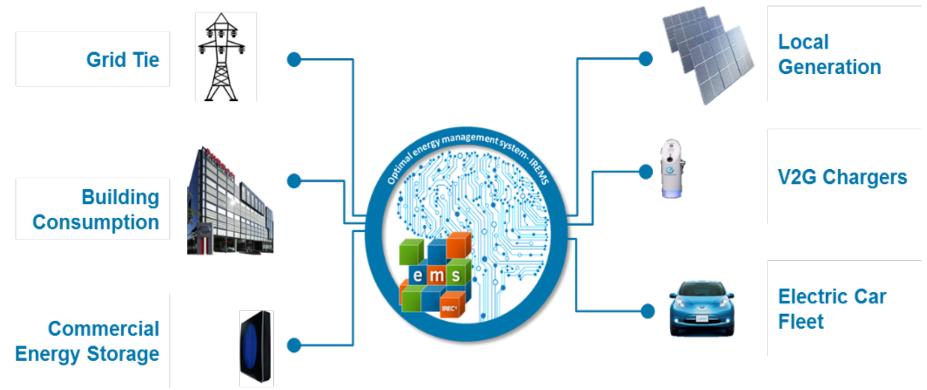

Figure 1: Elements installed and considered in the energy management system

1.2 Description of IREMS

The use of V2G chargers requires specific smart management to exploit its potential. IREMS is an optimization model solution for the smart and dynamic energy management of multiple types of electric vehicle charging infrastructure (smart charge) or V2G systems as well as consumption, generation units and energy storage systems and it will be in charge of managing the whole system.

The optimization module of the energy management system IREMS [5] creates and resolves every 15 minutes a *unit assignment problem* according to the current status of the system, external set-points, and available forecasts. These problems minimize the overall energy cost of the system within a predetermined time horizon of 24 hours and define the behaviour of each element to be managed. Technical constraints for the V2G chargers, the energy storage system, and the photovoltaics module and user requirements are also considered in the optimization problems [6]. To avoid an excessive use of the EV battery for V2B services that may affect the battery lifespan, the optimization algorithm considers a penalty related to the usage of the V2G.

After solving the problem, the manager sends in real time the optimal decisions regarding active power and/or device status (e.g. charge/discharge the V2G) for each controllable element of the system to the real-time module. In turn, the real-time module ensures the power balance of the system every 20 seconds considering both, the instructions given by the optimization module to the controllable elements and the real readings from all the devices. Fig. 2 represents the algorithm concept, data inputs and outputs.

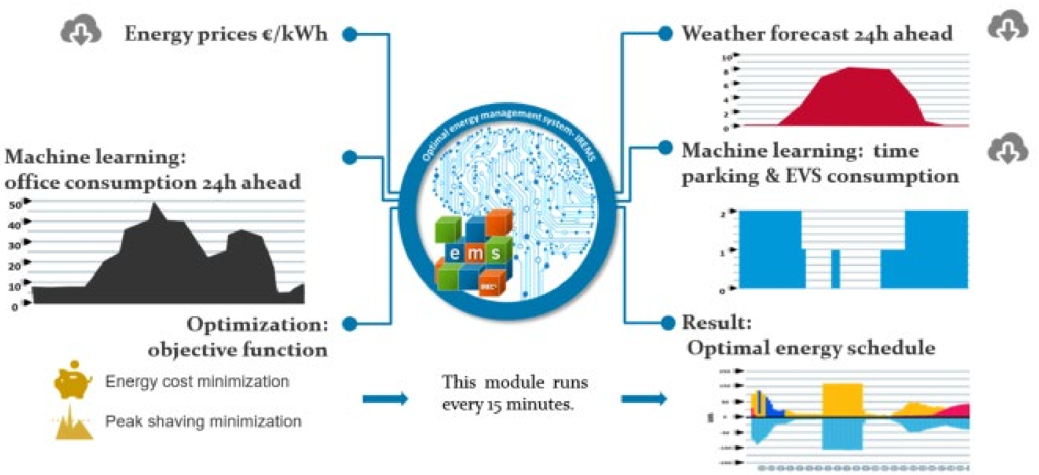

Figure 2: IREMS algorithm concept

2 Methodology

The main objective of this work is to evaluate the impact of V2G technology in the installation, to achieve this objective the V2G technology must be compared with standard charging policies and technologies. In order to perform the comparative analyses of the performance of the system four scenarios are compared (Table 2).

Table 1: Scenario definition

	Consumption & Solar Panels	Dummy chargers	Smart chargers	V2G chargers	Battery 2nd life
Scenario 1	√	√	X	X	X
Scenario 2	√	X	√	X	X
Scenario 3	√	X	X	√	X
Scenario 4	√	X	X	√	√

Simulations of a variety of scenarios are performed for a complete week on an hourly basis with the software GAMS. This study aims to illustrate the real performance, costs and benefits of the installation, so real data has been used for all simulation analysis.

Regarding prices, the price vector for 2018 of the tariff 3.0A, the 3-period tariff contracted has been used. Only the price related to the energy term has been considered, thus all the results presented in this work relate to the weekly costs of energy purchase. It should be notice that this tariff is not the ones that allows the EMS to achieve it maximum potential, that would be a 24h based tariff, but it is the tariff used at the real installation. The load profile and PV production used for the simulations are taken from a week of real data measured in the Nissan headquarters (Fig. 3).

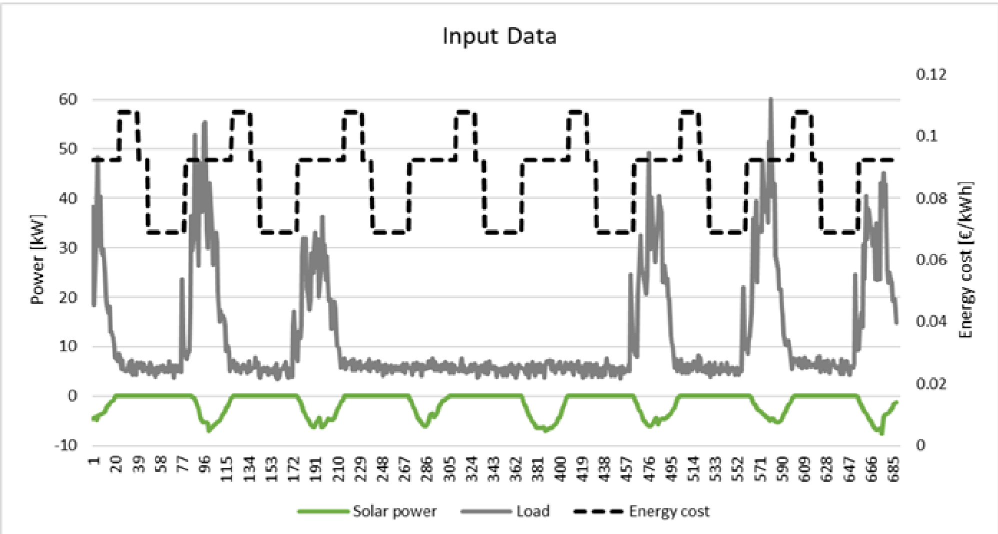

Figure 2: Solar power, load and energy cost of the simulation case.

The assumption taken for the presence of the EVs connected to the chargers (parking periods, initial SOC …) is based on the current EVs usage data from Nissan fleet. Finally, the injection to the grid is not permitted or remunerated so the power surplus production will be minimized and curtailed in order to not inject power to the grid.

The charging strategy assumption for each scenario is as follows:

- Scenario 1: The EV charging events start once the vehicle arrives at the parking and finish once the vehicle is unplugged of fully charged.
- Scenario 2: The EV charge event start following the criteria of the IREMS algorithm, the chargers can be turned on/off or the energy supplied to the EV can increase or decrease during the EVs charge due to the smart charge functionality.
- Scenario 3 and 4: The EV is charged or discharged following the criteria of the IREMS algorithm, both power and energy are decided by IREMS as well as the charger status (on/off).

3 Results

For evaluating the impact of the charging strategies and the different charging technologies in the installation some KPIs have been defined:

- Solar surplus (kWh): energy produced by the local PV generation not used in the building. As has been explained, the injection to the grid is not allowed, so this surplus is curtailed.
- Max power from the grid (kW): maximum value for the grid interconnection.
- Energy cost [€]: total energy cost for the energy bought to the grid.
- Average cost per kWh [€/kWh]: average of the energy cost per kWh taking into that own generation is cost free and price arbitrage done by the EMS.
- Load supplied by V2G [%]: percentage of the total load supplied by the EV battery through the V2G charger.

An overall comparison based on the weekly results from the optimization is provided under this section and it can be seen in the Table 3 below.

Table 3: Results of the simulation

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Solar surplus [kWh]	4,1	0,0	0,0	0,0
Max. power from grid [kW]	55,31	55,31	55,31	40
Energy cost [€]	169,54	164,3	159,99	154
Average cost per kWh [€/kWh]	0,09	0,088	0,084	0,082
Load supplied by V2G	0	0	10,63%	9,38%

As it can be observed, in both second and third scenario, where the chargers includes services and the EMS managing the system the EVs are charged in low price periods and discharged in high price periods doing energy arbitrage, this strategies allows a cost reduction per kWh of 7,8%. In Table 3 and Fig. 5-6 it can be seen also how the solar power surplus is used to charge the EVs instead of been curtailed. Moreover the installation of the second life battery (Scenario 4) allows the system to decrease the peak power and this will facilitate the reduction of the contracted power of the system 27%.

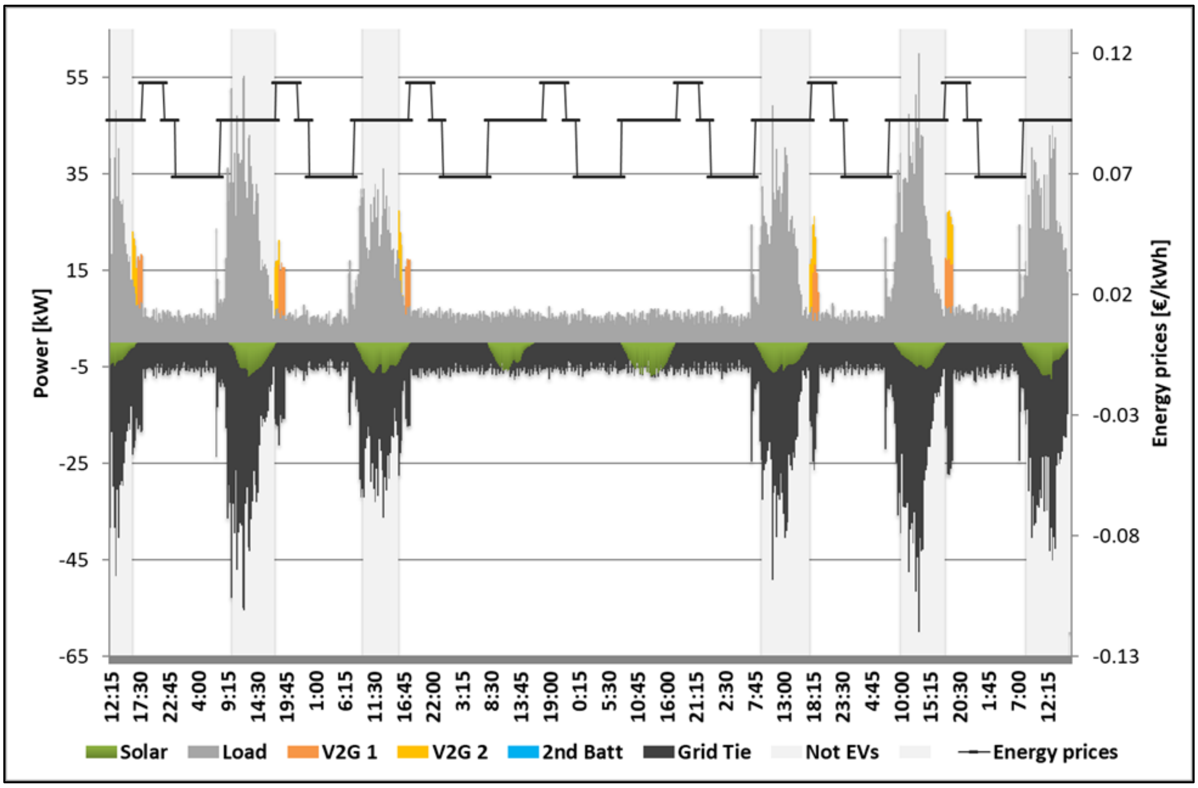

Figure 4: Results of the simulation Scenario 1

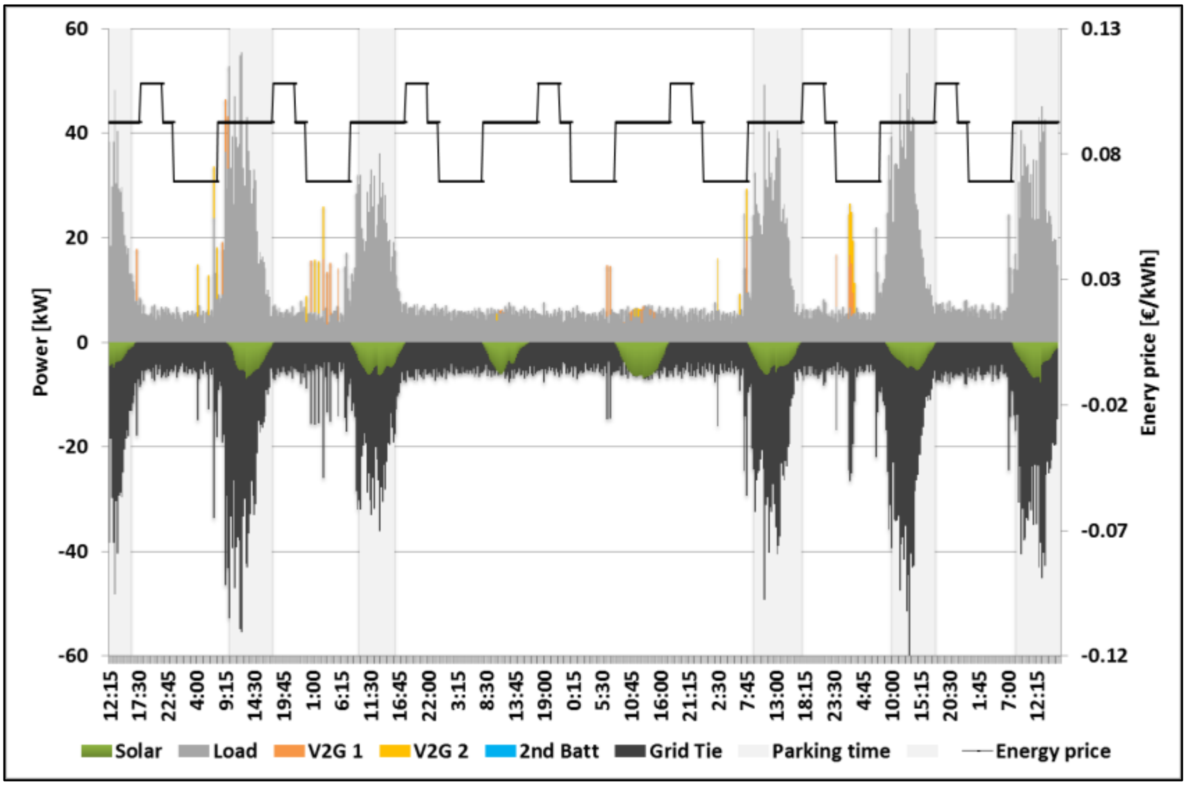

Figure 5: Results of the simulation Scenario 2

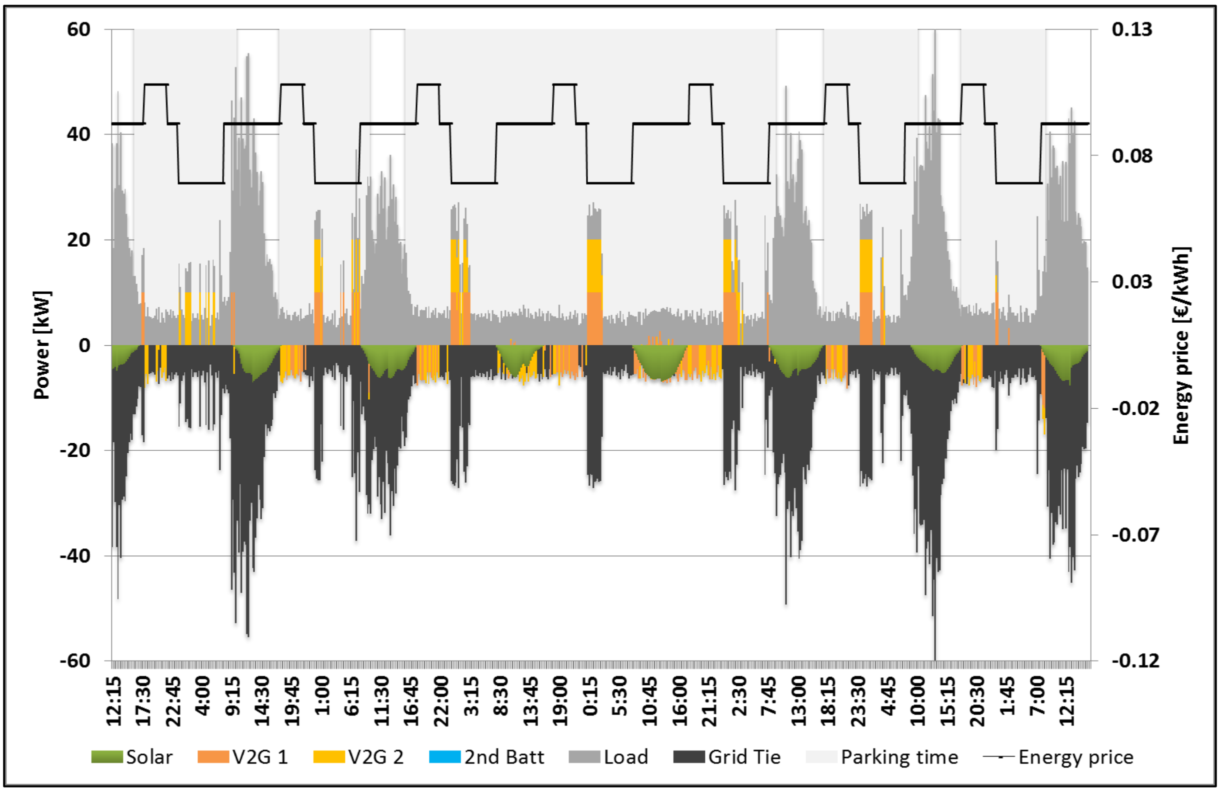

Figure 6: Results of the simulation Scenario 3

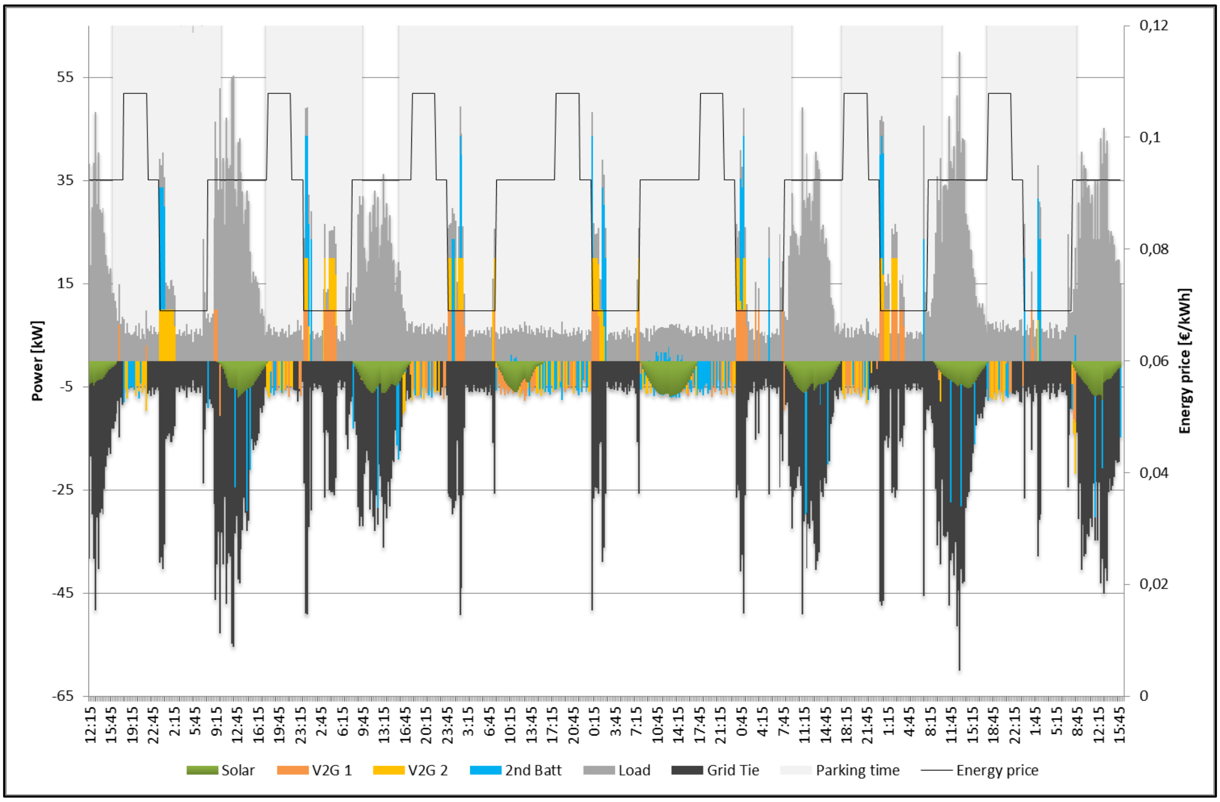

Figure 7: Results of the simulation Scenario 4

Comparing the energy cost of the energy purchased from the grid in the second scenario, the cost had decreased respect the cost of the scenario one due to the smart functionality of the EV chargers. This functionality allows the end user to differing the charge the EV in periods where the energy is cheaper decreasing in this way the cost of charging the EV as it can be seen in Fig. 5. The energy cost has decreased due to there is no curtailment of the renewable resource.

Regarding with scenario 3 and as it can be seen in the Table 1, the cost of the energy purchased from the grid is even lower due to in periods when the energy is expensive the load is supplied by the V2G chargers.

4 Conclusions

The main objective of the work was to evaluate the impact on the installation of V2G chargers together with energy management system, additionally the installation of second life batteries are also evaluated. The results are based on real data from the demonstration site in Barcelona.

Results shown that the EMS allows the system to perform energy arbitrage, decreasing both total costs and cost per kWh. V2G chargers allow cost reduction with respect of smart charge, but it would be needed more analysis to evaluate how the V2G current cost could be amortized and impact on total contracted power costs of the installation.

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