POLITECNICO DI MILANO
Msc. In Electrical Engineering
School of Industrial and Information Engineering

Feasibility study for V2G diffusion using photovoltaic systems applied on Italian parking lots

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Abstract

This document evaluates the feasibility to use a fleet of electric vehicles as a virtual power plant, implementing Vehicle to grid technology to satisfy the energy demand. The main goal of the study is determine the amount of energy required to fully charge an entire fleet of electric vehicles as well as to determine the energy available to be delivered to the grid in high demand periods.

An scheme of a schedule algorithm is proposed, to determine which operation should be performed and the energy resources which can be used in order to supply this requirements.

Lo scopo di questo studio è determinare la fattibilità nel uso della tecnologia *"Vehicle To grid"* al interno dei parcheggi italiani, valutando anche la possibilità della integrazione dei sistemi fotovoltaici per la fornitura della energia necessaria ad ogni momento. L'obiettivo principale di questo documento è determinare la quantità d'energia disponibile, sia per fornire le macchine elettriche che per la rete elettrica dipendendo del'ora del giorno.

Finalmente si propone un algoritmo per lo spacciamento della energia secondo a dipendenza dell'ora del giorno, come i risorsi energetici ad utilizare.

Acknowledgments

First of all, I want to extend my gratitude to Professor Michela Longo for having me as his student in this project, for being always available to help me in what I needed and to take the time to work with me, in this which we believe, is a useful work.

I want to thank also my parents, my aunt and my beloved wife. The are as my engine to go ahead and my motivation to always look for the best. It is because of them I am in here and it is because of them I will continue to pursue bigger goals each time.

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Introduction

The main objective of this feasibility study is to propose and schedule algorithm, which would be able to evaluate and use a fleet of electric vehicles as a virtual power plant, implementing Vehicle to grid technology to satisfy the energy demand. Being able, in the process, to determine the amount of energy required to fully charge a certain vehicle's fleet as well as to determine the energy available to be delivered to the grid in high demand periods. The algorithm should be in grade to decide when to charge or discharge a vehicle or even to not perform any action, depending on the time of the day, the occupancy level and the energy cost. At the same time, some restrictions given by the grid operator and the vehicle themselves should be satisfy to guarantee the correct operation of the installation and at the same time the availability for the owner.

The structure of this document is divided in three main parts, first of all the entire concept of the electric machines growing demand, type of available vehicles and motivation of the new technologies is describe. As a part of this, the concept and motivation of the Vehicle to Grid (V2G) technology is described, citing different authors and previous research done in the same field.

Not all the electric vehicles within the market have the possibility to perform V2G operation, that is why, different models of electric vehicles, capable of performing such a function, are analyzed and described, in terms of their features and characteristics.

In the next section of this work, Photovoltaic (PV) technologies are described, and three study cases are taken into account, all of them within Italy. Performing an statistical analysis, it is possible to determine the amount of power and energy available at a given location, in a daily, monthly or yearly basis, with a given probability. This, intended to determine the availability of energy at certain point in time, and so, determining if it is enough to supply an electric vehicle's fleet or if not, the other components of the installation.

Finally, different case scenarios are analyzed in terms of occupancy of the parking lot, to determine the amount of energy necessary to fully charge the vehicles, as well as the energy available to supply the electric demand present on the electric grid.

The final outcome of this study is an algorithm proposal, to determine the hours at which is possible to supply or withdraw energy to or from the electric grid, based on the occupancy, solar radiation levels and energy demand.

Chapter 1

Vehicle to Grid (V2G) State of the Art - A Review

The main focus of this chapter is to put in context the previous developments made in vehicle to grid (V2G) technologies, as well as their considerations, constrains and advantages, to take them as a starting point for the methods, simulations and analysis performed in this document.

Additionally, some already implemented or ongoing projects are taken into discussed, as well as the available electric vehicles in the market with V2G capability.

1.1 Smart cities in the 21st century

The concept of smart city is a compound of seven fundamental caractheristics:

1. Smart policies
2. Smart governance
3. Smart people
4. **Smart science and technology**
5. **Smart environment**
6. Smart living
7. **Smart built environment**

Within the concepts of *Smart science and technology, Smart environment* and *Smart built environment*, the Vehicle to grid (V2G) technology can be categorized. Since these characteristics of a smart city include sub categories which consider Sci-Tec research and development, sustainable and safe transport systems, Inter/national connectivity infrastructure, sustainable resources management, sustainable/Green energy resources, Hi-Tec construction technology and Advance building technology.

The smart city, status and goals depend on each particular case, and each particular city features. This goals are measured by means of indicators which are based on existing urban and building infrastructure, resources, codes, standards and regulations.

The smart city model, proposed in PAS 182:2014, is intended to create a data driven city, integrating city systems, with operational independence and operational efficiency. The modern infrastructure should be versatile, diversified, normalized and its physical components may vary. In such way, there should be a clear strategy of balancing the development of existing and emerging or planned infrastructure.

In order to achieve the goals and objectives of the smart city planning, multidisciplinary teams should work together (Engineers, architects, politicians, planning authorities, etc), which final outcome should be an integrated economics, urban planning, architectural design and sustainable construction [1].

This feasibility analysis is directed to change existing parking lot infrastructures, including hi-technology control and monitor schemes to develop a charge/discharge schedule, being capable of make decisions and changes based on the real time status of the system, so there is a sustainable and cost efficient scheme to perform energy exchange between the grid and the building and also as a future work, being able of taking an economic profit from such exchange.

1.2 Electric Vehicles (EV) operation modes in smart grids and smart homes

There are different well known and widely studied operation modes which can be performed using electric vehicles as described below:

1.2.1 Grid to vehicle (G2V) operation mode

Is the basic and evident operation mode which can be performed with an electric vehicle. It consists in the simple charging of the vehicle's battery by means of the power grid. It increases the energy demand on but doesn't perform any other operation. The electric vehicle is simply represented as a load to the system.

In figure 1.1 the scheme of this charging mode is presented.

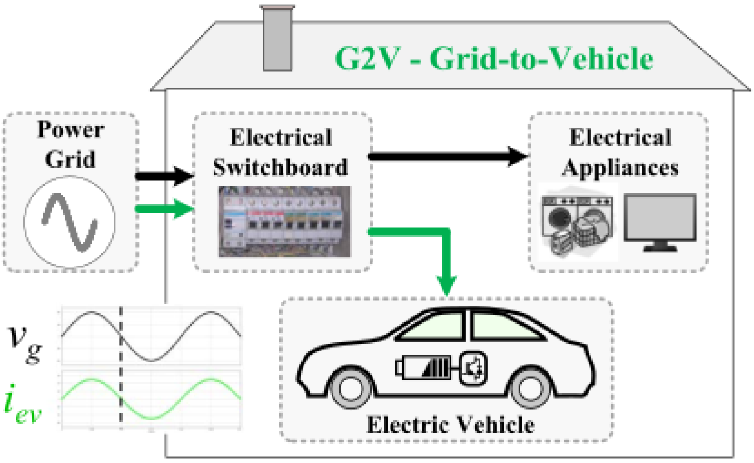

Figure 1.1: Grid to Vehicle operation mode [2]

1.2.2 Bi-directional operation mode - Vehicle to grid (V2G)

As the battery of the vehicle is an energy storage unit, it is possible to send it back to the grid and perform control operations. It can be used to stabilize the load profile and support large-scale renewable energy resources [3].

Figure 1.2 shows the scheme of this operation mode.

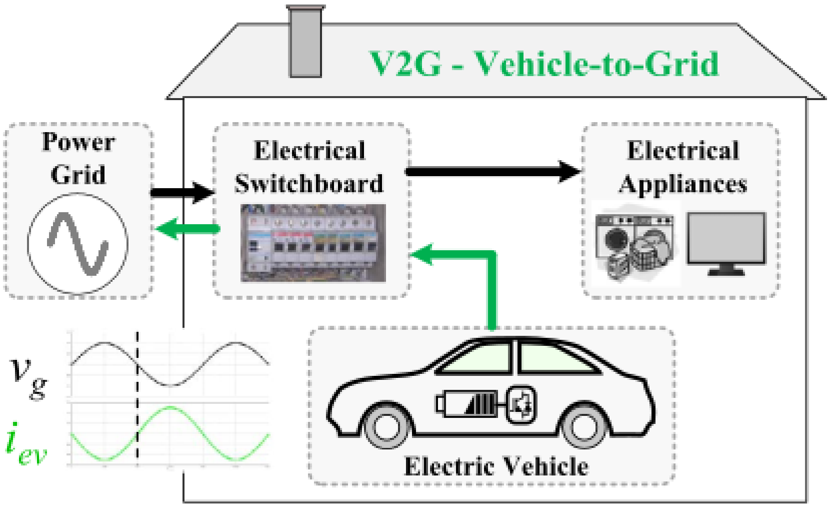

Figure 1.2: Vehicle to grid operation mode [2]

This operation mode, turns the electric vehicle into an active element within the grid, which can perform both electric load function and energy generation.

Off course, for the electric vehicle to be capable of perform such operations, some aggregates should be present into the vehicle's electric infrastructure and some cost functions should be evaluated [3–5].

1.2.3 Home to vehicle (H2V)

This innovative operation mode integrates both G2V and V2G characteristics and controls them in function of the home appliances. This particular operation mode consists in the regulation of the current provide to the vehicle, by measuring the current being consumed by the home appliances, also adding the capability to provide the grid with both active and reactive power when needed [6–8].

Figure 1.3 shows the scheme of the H2V operation mode, both combined with V2G features and G2V features.

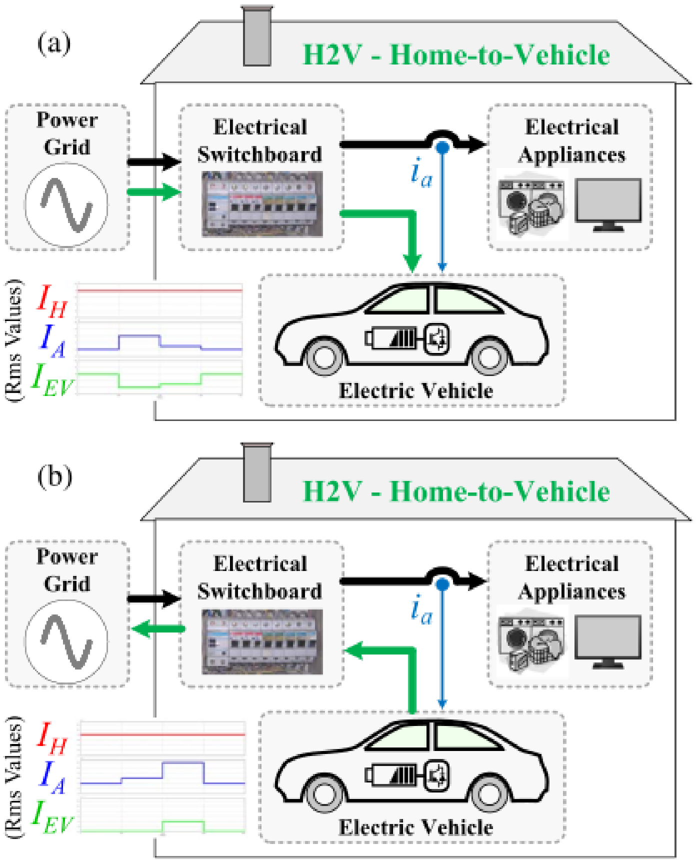

Figure 1.3: Home to vehicle operation mode (a) Combined with G2V (b) Combined with V2G [2].

1.2.4 Vehicle for Grid (V4G)

This operation mode is based on using the electric vehicle as an active component in function of the power grid needs. Being able to control the EV's charger to produce just capacitive reactive power or just inductive reactive.

In this operation mode, the charger can perform also power quality functions, as filtering harmonics present on the grid due to non-linear home loads. The great advantage of this operation mode is that it doesn't make use of the battery itself, therefore it doesn't cause age nor reduces the life span of the battery [9–11].

In figure 1.4 the scheme of this operation mode is presented, performing the function of compensating harmonics and producing reactive power for the grid.

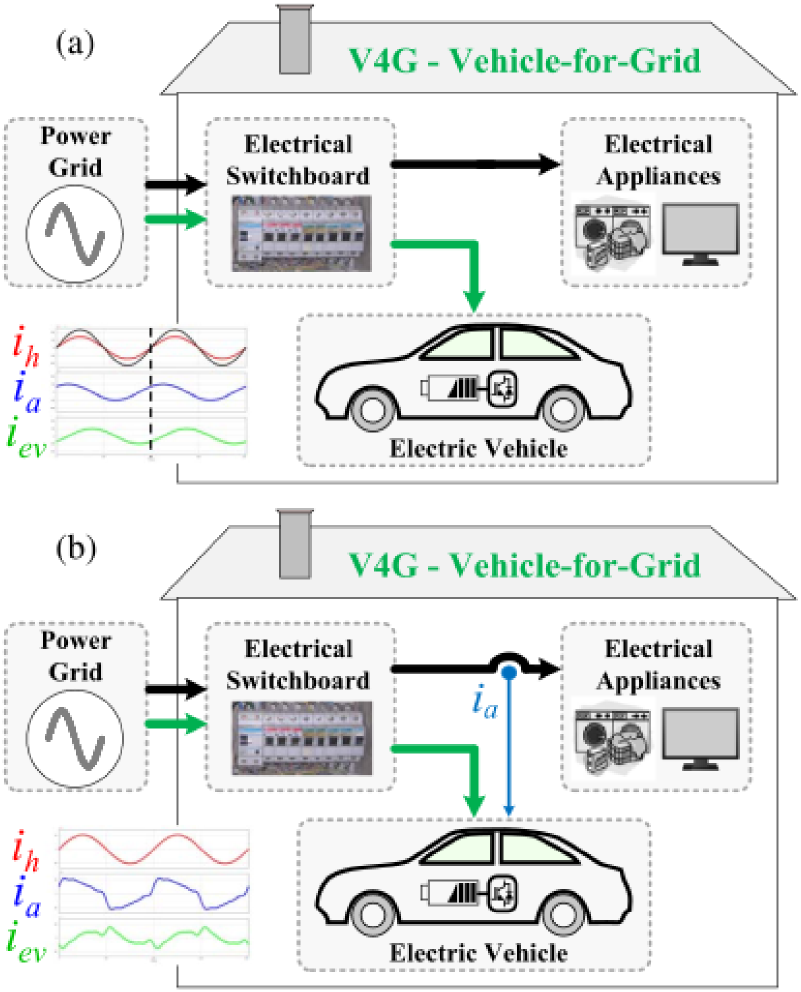

Figure 1.4: Vehicle for grid operation mode (a) Producing reactive power (b) Compensating current harmonics [2].

1.2.5 Vehicle to Home (V2H)

The main idea of this operation mode, is to use the bi-directional features of the EV's charger, to act as an UPS to the house, supplying all the home appliances when needed and providing reliability to the energy supply. In other words, the electric vehicle is used as a voltage sources which is available in case of a power outages [12, 13].

In figure 1.5, the scheme for this operation mode is presented, both operating in an isolated system, as well as operating as an UPS for the house electrical appliances.

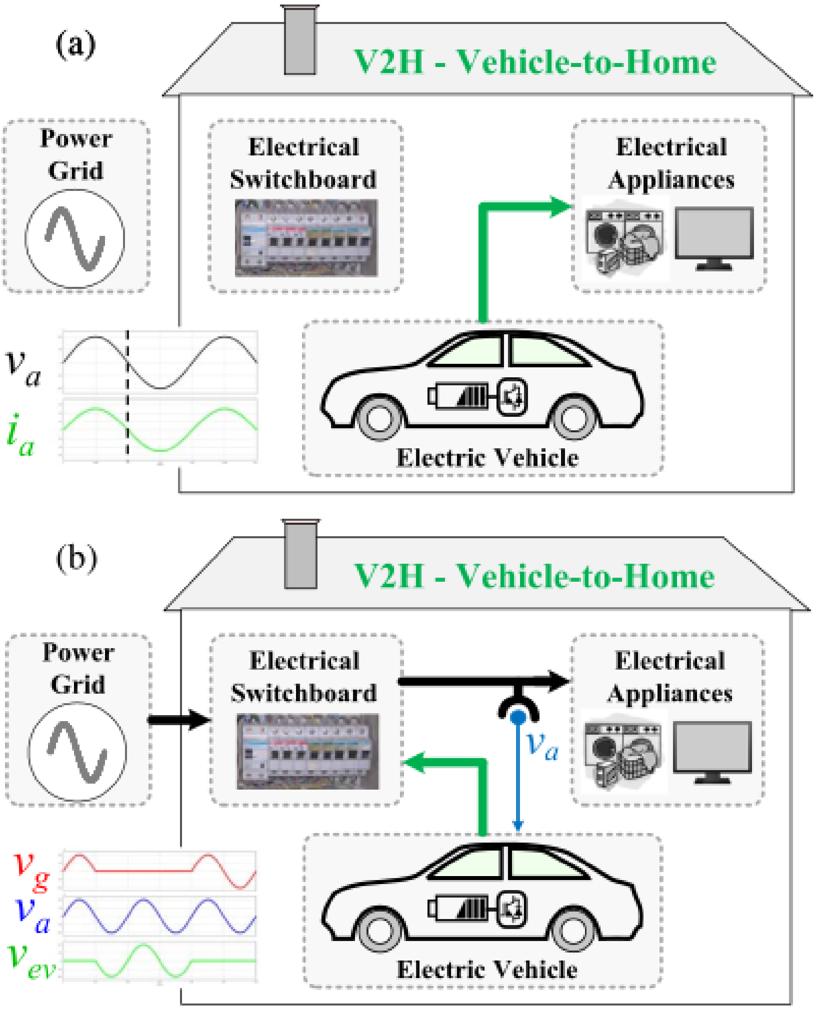

Figure 1.5: Vehicle to home operation mode (a) Operation in isolated mode (b) Operation as offline UPS [2].

1.3 Motivation of the V2G appliances

There are several reasons to think about the implementation of V2G technologies, both technical and economical. In [15], the main reasons are the listed as follows:

- Increasing on the electric vehicles (EV) penetration in the market.
- Load Adjustment on the power grid
- Renewable energy sources coordination on the grid
- Economic benefits for the power grid and EV owners.

The main goal of V2G is to solve the biggest issues in the operation of the power grid, which are mainly load demand fluctuations, causing energy waste and economic losses due to the high cost of operation on peak load power plants and Voltage and frequency regulation on the grid which also implies high operation costs for the entire system [16].

One apparent solution for the energy waste problem could be to supply the electric vehicles (EV's) while the load demand is low and give the storage energy back to the grid when the demand is high, avoiding or at least delaying the entrance of peak load power plants to the system. Saving both energy and money.

As a consequence of this behavior, the EV user can buy energy (charge) while the price of the energy is low and sell it back (discharge) when the price is higher, obtaining economical benefits from this trade [17].

Of course there are limitations on the implementation of this kind of solution. If is true that statistical analysis show that a vehicle stands still almost 20h a day, so the battery could be almost freely exploited in this period of time, is also true that the penetration of electric vehicles on the market is still incipient, so the collective capacity of the EV batteries is not currently suitable to supply the load demand. As a second big constraint, there is the fact that EV's cannot enter or exit freely from the power grid, which could cause serious problems in the grid operation during peak hours, so it makes necessary the implementation of a real-time control systems which makes possible the bidirectional energy flow and at the same time, don't constrain the free usage of the vehicles from the users point of view [18].

1.4 Main constrains of the V2G Operation

In [19] a review of the main constrains in a V2G is performed, identifying the main technical challenges to face in order to implement a system of this kind, listed as follows.

- **Dispersion of the EV's charging load:** Intended to not interfere with the normal operation of the grid and to avoid the investment on new appliances such distribution networks or power plants to supply their own load. Here is where the concept of " Ordered charging" becomes important. A control scheme is required.
- **Optimal Power configuration:** Determines the power which a certain EV can provide to the grid and the charging power required, based on the SoC of the vehicle and the total number EV's present in the facility.
- **Minimization of the operation cost:** Taking into account the cost of the different resources to generate energy and the prices of selling and purchasing energy to and from the power grid.
- **Battery Degradation:** The constant cycles of charging and discharging the batteries, have a direct impact on the lifespan of them and so in the storage capacity. A mitigation of this effect can be achieved by the use of more efficient and cheaper batteries.
- **Change in infrastructure:** The current power grid is not prepared for a massive connection of random EV loads, with different energy requirements, which represent a demand dilemma for the grid operator as well as a huge challenge in terms of communications infrastructure inside the transmission and distribution systems.

Also in [19], the authors propose a basic scheme for V2G appliances integrated with power grid and the involved infrastructure, both inside the vehicle itself and the power grid, as shown in Figure 1.6.

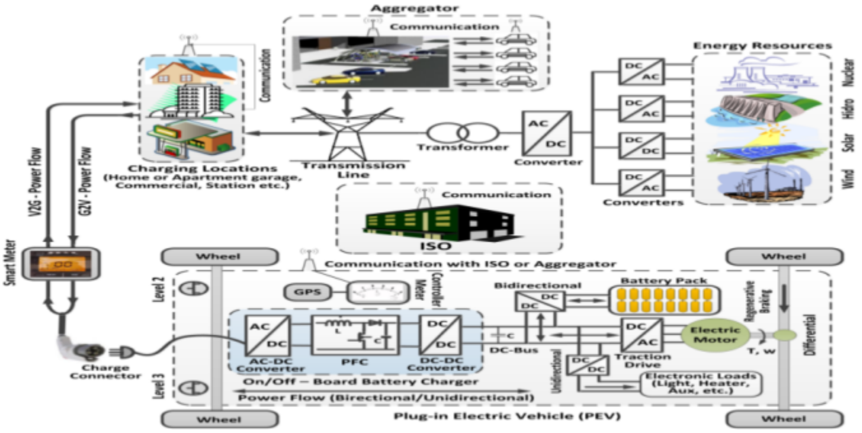

Figure 1.6: General implementation of a V2G system [19]

Another aspects to have into account while integrating a V2G or G2V appliance to the power grid are the voltage variations and overloading which can be present at the connection point.

In [14], the authors analyze the impact of an uncoordinated charging of an electric vehicle fleet within a distribution network. Having as a result very high current peaks on the different buses of the grid.

In figure 1.7, the present current peak is twice the nominal value of the current on the transformers. This can cause serious problems on the protection's coordination and compromise the continuity of the service as well as permanent damages on the electric infrastructure.

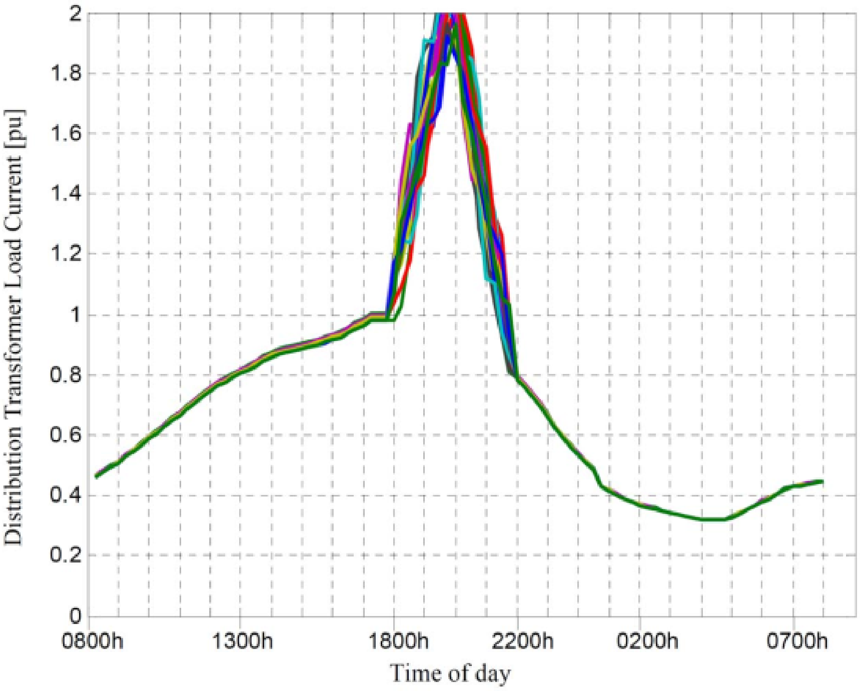

Figure 1.7: Daily load currents due to uncoordinated EV charging in a distribution network [14]

Additionally, there are big voltage drops in the buses of the system, reaching up to 15% variations with respect to the nominal values. This can be specially dangerous if there are voltage sensible equipment connected to these buses, causing loses of high cost instruments. It also can trip voltage protections on the system and alter the power flow of the meshed grid.

Figure1.8 shows the results on the worst case bus found in [14] with and without the presence of electric vehicles on the grid. During the charging of the electric vehicles the differences observed are really pronounced.

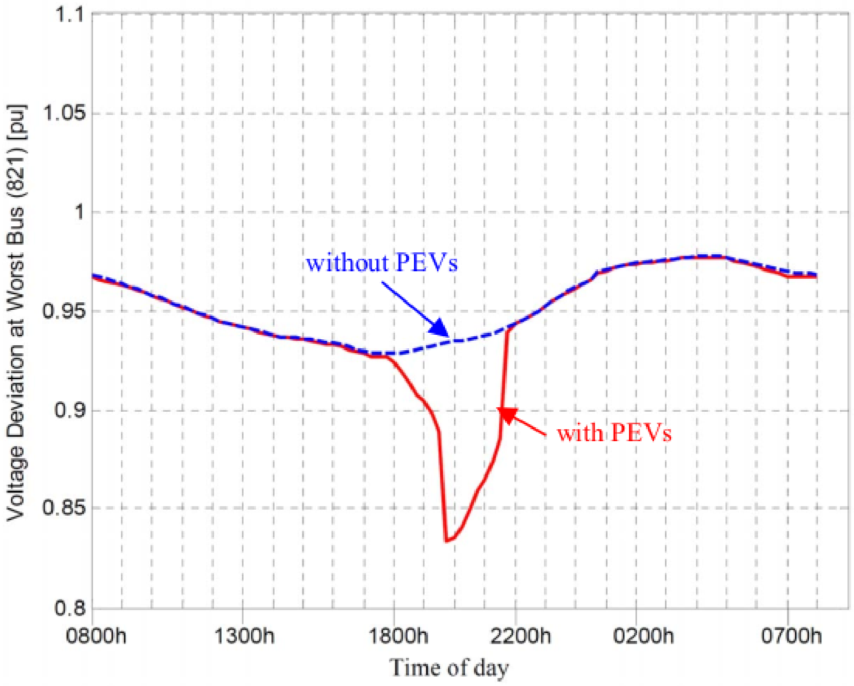

Figure 1.8: Voltage profile at worst bus with EV uncoordinated scheme [14]

1.5 V2G Operation

The V2G operation can be divided in two different operation modes, centralized operation or autonomous operation [15].

1.5.1 Centralized operation

In centralized operation, the EV's charging power and available power are determined based on algorithms taking into account the number of EV's and the state of charge of every vehicle present. This kind of operation can be suitable for dedicated facilities, where the availability of the EV's can be more controlled as for example in corporate parking lots.

There are several studies which relates to this issue and address the problem from different approaches, as the control scheme, impact on the grid due to the stochastic loads/generation resources among others, considering different occupancy scenarios with penetration of PV technologies, which will be the main focus of this project.

1.5.2 Autonomous Operation

In autonomous operation the EV's are scattered in different points making impossible a centralized operation. In this case, the vehicles are provided with an intelligent charger, capable of determine the optimal operation condition based on energy price, reactive power requirements among other factors provided by the grid operator.

Since the objective of this project will be the evaluation of the performance of vehicle to grid appliances within parking lots, the autonomous operation mode is just mentioned as a possible option, but will not be taken into account in the development of this document.

1.6 V2G facilities with penetration of renewable energy sources

The increasing demand on electric vehicles represent a paradigm from the environmental impact viewpoint. While the EV's work with what is considered "clean energy", the origin of that energy could be from non renewable sources as coal, nuclear or hydroelectric power plants which have a considerable impact on the environment.

For 2020, a 30 million EV's are expected to enter on the global market, increasing the electricity demand for charging purposes in 70% to 80%, so carbon emissions generated from the actual conditions of the power plants, will be comparable with the emissions of the current fuel vehicles [20].

In order to eliminate or to reduce as much as possible such an impacts, renewable energy sources arise as a suitable alternative. Nevertheless, an extra problem arises, derived form the intermittent behaviour of the renewable energy sources (RES). V2G technology can be used as a way to solve this problem, using the storage system of the EV's to stabilize the voltage profiles of the grid via intelligent charging strategies [21].

It is also necessary to adapt the traditional grid for the new dispatch strategies as it is studied in [22], where the results show a prospective reduction of the electrical load in approximately 20% due to the penetration of PV systems with respect to the load seen by the grid if the EV's demand increases as expected.

Additional advantages resulting from the studies made in [23] and [24] are the reduction in the intermittent of solar energy and the increasing in the incomes for both grid operators and EV owners.

1.6.1 V2G Analysis in parking lots

The main issue the V2G management systems have to face is related with the non deterministic availability of the EV's, occupancy of the facilities and state of charge of the vehicles. That is why, several stochastic approaches have been proposed in order to overcome this problem and to provide a certain level of reliability of the available capacity and energy management.

In [25] a stochastic model for the parking lot occupancy has been developed to determine the probability of a certain occupancy level along the day. In [26] and [27] intelligent schedule models are proposed in order to keep the stability on the grid based on the available resources inside a parking lot and considering hybrid and pure electric vehicles.

On the other hand in [28] the authors evaluate the impact of the stochastic charging and discharging schemes of both residential and parking lots having V2G systems. Arriving to the conclusion that even with high EV's penetration level and the correct schedule algorithm, the effects on the grid due to this new loads are minimum, postponing an eventual grid reinforcement.

In addition to the studies mentioned above, [29] concludes that the integration of electric vehicles into a smart power grid is not just feasible, but also can contribute by reducing overloads, improving power quality, reducing power outages, injecting active and reactive power and also avoiding new power plants to supply the increasing demand.

There is also an associated cost, related to energy and operational cost which vary wit the time of the day. This cost behaves in a dynamical way depending on the present demand. There is also an additional constraint which is the limit of power exchange with the power grid, defined by the grid operator. [31] develops a scheduling of the vehicles present in a parking lot depending on the cost of the energy and the power limitations.

This model divides the present vehicles on the parking lot in three different categories of priority, depending on the arrival state of charge (SoC), and the price of the energy at the moment of the day. By monitor these variables in discrete time steps, it is possible to propose a cost-effective charging schedule scheme for the vehicles.

1.7 Available Bidirectional electric vehicles

Although the market for electric vehicles is rapidly increasing around the world as cited before, the technology for eventual V2G implementation is not. Currently and available in the market, there are just few models in capacity to manage a bidirectional power flow for vehicle to grid (V2G) or Vehicle to Home (V2H). The main manufactures going towards these standards are Nissan and Mitsubishi, which already have, in partnership with another companies, several ongoing projects intended to scale this technology in the future.

The below listed models are the ones which are in capacity of providing such an implementation and present in the mentioned projects.

- Nissan LEAF: Nissan Leaf characteristics can be seen in Table 1.1.

Table 1.1: Nissan Leaf Technical Characteristics

Battery Capacity [kWh]	Normal Charging[kW]	Normal charging time [h]	Fast Charging [kW]	Fast Charging time [min]	Max speed [km/h]
24	7	2	50	40	145

- Nisan e-nv200: The characteristics for this vehicle can be seen in Table 1.2.

Table 1.2: Nissan e-nv200 Technical Characteristics

Battery Capacity [kWh]	Normal Charging[kW]	Normal charging time [h]	Fast Charging [kW]	Fast Charging time [min]	Max speed [km/h]
24	6.6	4	50	30	123

- Mitsubishi PHEV outlander

  The characteristics for the hybrid Mitsubishi PHEV outlander can be seen in Table 1.3.

Table 1.3: Mitsubishi PHEV outlander Technical Characteristics

Battery Capacity [kWh]	Normal Charging[kW]	Normal charging time [h]	Fast Charging [kW]	Fast Charging time [h]	Max speed [km/h]
12	2.2	6	3.3	4	170

- Peugeot iOn

  The technical characteristics for the electric car Peugeot iOn are listed in table 1.4.

Table 1.4: Peugeot iOn Technical Characteristics

Battery Capacity [kWh]	Normal Charging[kW]	Normal charging time [h]	Fast Charging [kW]	Fast Charging time [h]	Max speed [km/h]
14.5	1.76	11	3.08	6	130

1.8 V2G Implemented Pilot projects

There are several pilot projects around different European countries, all of them intended to measure and validate in the field the already existent research theories of the V2G and G2V technologies. The main scope of the projects is to determine whether or not is viable, economically and technically, the integration of the electric vehicles to the grid in a large scale as virtual power plants.

Some of the more important projects already ongoing are listed below.

1.8.1 Netherlands - Pilot Project

In October 2017, The Italian company ENEL, in a partnership with the Japanese manufacturer Mitsubishi, the dutch grid operator TenneT and the American company Nuvve, launched a pilot project near the city of Amsterdam, in order to evaluate the impact of V2G appliances in the grid. The initial phase of the project consists in the installation of 10 charging columns, 10 kW each, in both commercial and private sites, for a total installed capacity of 100kW, being able to provide electricity on-demand to the grid as well as to charge the EVs.

Mitsubishi motors, provided 10 PHEV out-lander SUVs for the purposes of the project, while Nuvve is providing the control scheme *"Grid Integrated Vehicle Platform (GIVE)"*, which is able to regulate the power flows, optimizing the power offered to the grid as well as guaranteeing the mileage for the EV owner. Additionally, *"New motion"*, a company which manages more than 25.000 charging points around Europe, provides real-time information about charging places position and availability and also energy prices, so the customer can optimize the profit of using the V2G appliances.

The reason behind the selection of Amsterdam as the place for this pilot project is the fact that, in the Netherlands there are currently, about 25.000 Outlander PHEVs, and Amsterdam is one of the cities with the largest percentage of this electric cars [30].

1.8.2 Nissan - Enel partnership in the UK

Trying to meet the goals of carbon (CO_2) emissions for the commitment acquired in the Paris agreement, the UK government in partnership with Nissan, have launched the biggest V2G project ever implemented. In its first phase, 100 vehicles, equipped with V2G technology, owned by private and fleet owners are integrated. The vehicle's models are Nissan LEAF and Nissan e-NV200.

The UK government predicts an increasing demand of electric vehicles, arriving up to 700.000 in 2020, which will require an extra 500 MW of installed power in the grid, which makes more attractive the creation of “Virtual power plants” provided by V2G technology. On top of that, a further Analysis shows that if every Nissan electric vehicle in the UK could be connected to the grid, that would represent 180 MW of new installed capacity, while if the scale is done with all the vehicles present in the country, this contribution would arise to 370 GW, power enough to supply countries like the UK, Germany and France.

The project was launched in 2016 and the results of the first phase are expected for 2019. The outcomes for this preliminary phase are voltage and frequency regulation, as well as the impact on the demand curve that this technology could have and also the stability given by batteries to the renewable energy sources (RES) already present on the power system [32].

1.8.3 Denmark Pilot project -“Parker project”

Parker project is an on-going pilot project and the first of its class. It consists in a real implementation of V2G technology and its intended to address different objectives. The main objectives of the project can be classified in three categories as follows:

1. **Technical and grid applications:** *“The project will study the practical applications of power and energy services on contemporary electric vehicles in order to identify technical, economic and regulatory barriers for these applications and to finally identify viable business cases.”*

2. **Grid certification:** *“specify the technical parameters (grid keys) needed by electric vehicles to provide power and energy services to the grid. Furthermore, the project will produce a Grid Integrated Vehicle (GIV) certificate that demonstrates the ability of electric vehicles to support such parameters.”*

3. **Scalability and reproduction:** *“promote replicability of the investigated applications across geographies, technologies and user groups. Also, Parker will research on the economic and technical impacts of the applications on the power system and markets” [33].*

Launched at Denmark in august 2016, in partnership between ENEL, Nissan, Nuvve, Mitsubishi motors among others, and consisting of an initial fleet of 10 corporate vehicles, Parker project tries to achieve a real approach to the already study theories about smart grid synergies, grid stability, centralized operation, frequency control and impact on power systems.

The resources of the project are an initial founding of DKK 14,731,471 (equivalent to almost 2 million Euros), financed by ForskEL and it is formed by Nissan e-NV200 evalia, Mitsubishi Outlander PHEV, Nissan Leaf and two Peugeot iOn, while for the charging infrastructure is provided with ENEL chargers 1.0 and 1.5 and the control platforms are a product of Nuvve [34].

The project has already produced several outcomes, materialized in published academic papers in topics as power quality [35], frequency control [36], control schemes [37] and field validation analyses [38].

The final results are expected to be fully available in July 2018.

1.9 Italian case and future perspectives

Unfortunately, the Italian scenario for the implementation of the V2G technology is behind the other European countries as listed above. Although ENEL, which is the main company, funding V2G pilot projects around Europe is Italian, there is just one research project ongoing in Italy. Is based in Genova and consists in a very small fleet of 2 Nissan Leaf connected to the grid via a technological platform called Glide. The reason behind the poor development of this matter in Italy is mainly the grid regulation which, for the moment, doesn't allow to connect storage systems to the power grid.

Nevertheless, there are several research projects, validated with academic publications, which analyze the impact on the power grid due to an eventual entrance of the electric vehicles as an active player into the power grid dynamics as shown in [39]. Where simulation techniques are used in collaboration with the computer science engineering department of University of Erlangen-Nuremberg to measure the impact of the electric vehicle integration on the Italian power grid. The main outcome of this work is a prospective schedule for slow and fast charging of the EV's based on the demand patterns present in Italy and the consequent reduction on $C0_2$ emissions.

On this document, complementary research on this matters are going to be developed, including the penetration of PV technology, specially in parking lot facilities for railway stations. The main outcome of this project work is to address the demand problem on different Italian cities and to study the impact of an eventual V2G facilities in railway station parking lots taking into account the occupancy levels and the solar irradiance in the given locations, to cover, in principle, the station energy requirements and if possible to extend the results to surrounding commercial and residential buildings.

Chapter 2

Photovoltaic (PV) - Installation sizing

2.1 PV technologies

Currently there are many technologies for the PV cells arrange but only some commercial ones. In this document, just commercially available types of PV cell or film, any of which might be found in a module or film used on an active solar roof [40]. The following technologies are not consider:

- **Gallium Arsenide cells:** Due to their toxicity and potential carcinogenic properties, these are only used in rare applications such as satellites or demonstration solar-powered cars.
- **Organic-based PV solutions:** Still under research.

On the other hand, there are some available technologies on the market, each one with its particular characteristics.

- **Mono-crystalline silicon PV panels:** These are made using cells sliced from a single cylindrical crystal of silicon. This is the most efficient photovoltaic technology. The manufacturing process required to produce mono-crystalline silicon is complicated, resulting in slightly higher costs than other technologies. Is the most expensive solution but it has the best efficiency.
- **Poly-crystalline silicon PV panels:** Also known as multi-crystalline cells, are made from cells cut from an ingot of melted and recrystallized silicon. The ingots are then saw-cut into very thin wafers and assembled into complete cells. They are generally cheaper to produce than mono-crystalline cells, due to the simpler manufacturing process, but they tend to be slightly less efficient.

- **Thick-film silicon PV panels:** This is a variant on multi-crystalline technology where the silicon is deposited in a continuous process onto a base material giving a fine grained, sparkling appearance. Like all crystalline PV, it is normally encapsulated in a transparent insulating polymer with a tempered glass cover and then bound into a metal framed module.It is used in building integrated photovoltaic and as semi-transparent, photovoltaic glazing material that can be laminated onto windows. Other commercial applications use rigid thin film solar panels (sandwiched between two panes of glass) in some of the world's largest photovoltaic power stations.

- **Amorphous silicon PV panels:** Amorphous silicon cells are made by depositing silicon in a thin homogeneous layer onto a substrate rather than creating a rigid crystal structure. As amorphous silicon absorbs light more effectively than crystalline silicon, the cells can be thinner - hence its alternative name of 'thin film' PV. Amorphous silicon can be deposited on a wide range of substrates, both rigid and flexible, which makes them ideal for curved surfaces or bonding directly onto roofing materials. This technology is, however, less efficient than crystalline silicon, but it tends to be easier and cheaper to produce. If roof space is not restricted, an amorphous product can be a good option. However, if the maximum output per square meter is required, it should be chosen a crystalline technology.

- **Other thin film PV panels:** A number of other materials such as cadmium telluride (CdTe) and copper indium diselenide (CIS) are now being used for PV modules. The attraction of these technologies is that they can be manufactured by relatively inexpensive industrial processes, certainly in comparison to crystalline silicon technologies, yet they typically offer higher module efficiency than amorphous silicon. Most offer a slightly lower efficiency. A disadvantage is the use of highly toxic metals such as Cadmium and the need for both carefully controlled manufacturing and end-of-life disposal; although a typical CdTe module contains only 0.1% Cadmium, which is reported to be lower than is found in a single AA-sized NiCad battery.

  A comparison between some different technologies is provided in Fig. 2.1.

It is necessary to focus in the main aim of this type of projects, which is economic profitability. One of the indicators that define the economic term of the project is the Pay-back time (amount of time necessary to recover the initial investment). In Fig. 2.2 a comparison between different technologies with their pay-back time (estimated in an statistical way) is shown.

CPV stands for *"Concentrated photovoltaic systems"* that are systems outside this study.

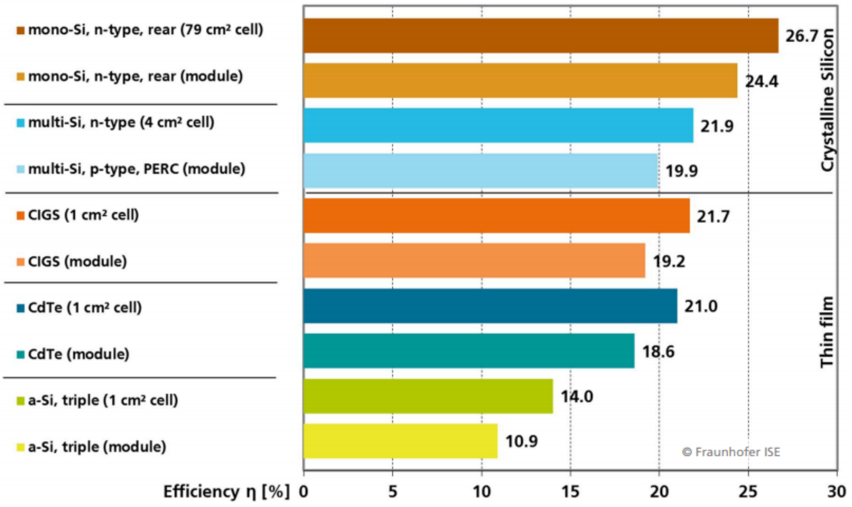

Figure 2.1: Comparison between different PV cell technologies and their efficiency [41]

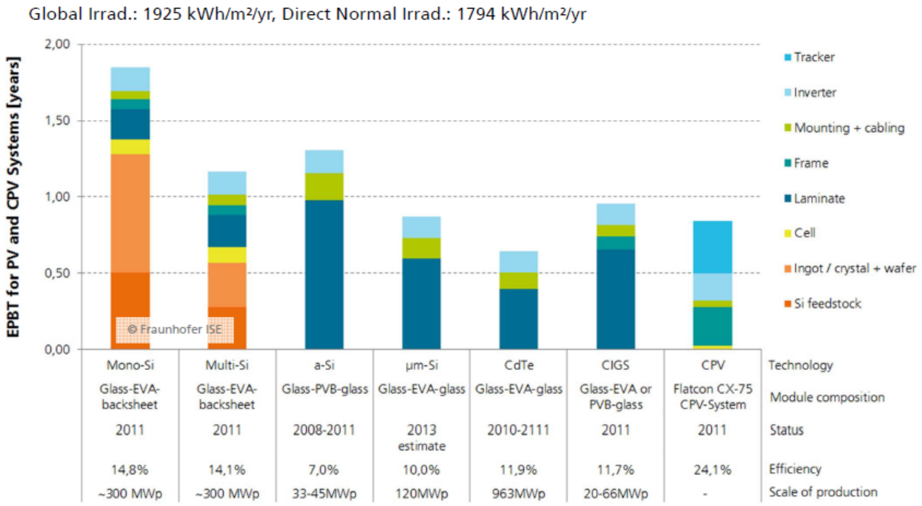

Figure 2.2: Comparison between different PV cell technologies and their payback time [41]

Once this graphs have been presented, it is possible to confirm that the technology that better suits the project is the **Mono- crystalline Silicon Panels**, they have the best pay-back time rate and the best efficiency.

The use of mono-crystalline technology and the best peak power on the market is used, obtaining the description of the device, summarized on table 2.1.

The unitary price of each panel, including installation expenses and direct costs, is of €349,43 with a variable price of €52,41 every 10 years because of maintenance.

Table 2.1: Technical characteristics of mono-crystalline PV panels

P [W]	V_{mp} [V]	I_{mp} [A]	V_{OC} [V]	I_{sc} [A]	η [%]	Temp [°C]
330	37.3	8.85	45.5	9.33	17.2	-45 - 85

2.2 Case scenario: Prospective PV power and energy generation across the Italian territory

The main part of the analysis presented in this document will be carried out for the case of a railway station's parking lot, which further in this document will be used as well to evaluate V2G feasibility in a big scale full electric parking lot (477 parking places). The calculations of available surface, number of panels and peak power of the installations are based on the geometry and physical characteristic of this particular case.

The parking lot at north Italy is an underground parking, composed by 5 levels. 0 level is at ground floor while the other floors are at different underground levels. Therefore, the only surface that can be used to install the panels is ground level.

It is then assumed, that the 70 bays available will be used as a installation surface, which will serve both as a cover for parked cars and as a support structures for the panels. Based on the real plan, the parking surface can stand 616 solar panels with the dimensions described in the previous section. Each panel has a maximum peak power of 330 Wp.

Additionally, the levels of solar irradiation in different latitudes of Italy will be taken into account in order to validate the obtained results. Two more locations are considered as the solar irradiation depends on the latitude and the geography of the zone, giving a first approach to the feasibility of implementing this kind of installations across the Italian territory.

The evaluation to be made in the different locations takes place at the Center and South of Italy. The installation's parameters will remain the same, for the purposes of direct comparison with the obtained results in the city of Bologna (North of Italy).

2.3 Stochastic data analysis

Solar irradiance is intrinsically stochastic, due to the variables related to weather conditions, cloud movements among others.

Is well know that the data collected from solar radiation measurements follows a log-normal distribution from where the probability of having a certain level of irradiance and by consequence, the associated energy production can be obtain easily.

Nevertheless, the available data collected from the Photovoltaic Geographical Information System (PVGIS) [42], shows only the mean irradiance level corresponding to an specific hour of the day, so it is necessary to simulate the probability density function (PDF) around the mean values and the standard deviation among them.

Once the PDF has been estimated for all the months of the year, it result quite easy to obtain an estimated value of the total energy production by month or by year with a certain level of reliability.

2.3.1 Log-normal probability density function (PDF)

The log-normal PDF is quite similar to a normal distribution, apart from the fact that is not defined for negative values. In this case, the relationship between the data and this kind of distribution results quite obvious, since is physically impossible to obtain a level of solar irradiance which is less than zero.

The expression for the log-normal PDF is given by Eq. 2.1

$$f(y) = \frac{1}{y\sigma_y\sqrt{2\pi}}e^{-\frac{1}{2}(\frac{lny-\mu_y}{\sigma_y})^2} \tag{2.1}$$

Where σ_y and μ_y are related to the standard deviation and the mean value of the original data in the following way:

$$\sigma_y^2 = ln[(\frac{\sigma_x}{\mu_x})^2 + 1]$$

$$\mu_y = ln\mu_x - \frac{1}{2}\sigma_y^2$$

Being μ_x and σ_x the mean and standard deviation of the data given by PVGIS database.

In this way, a log-normal distribution can be generated around the mean value of the day or even around the mean value for a certain hour of the day if very accurate results are required.

For the purposes of this project, an analysis around the mean values for each day of each month is considered enough, with the aim of the extrapolation to the monthly values of power an energy production.

Using the expression given by equation 2.2 we are able to calculate the associated produced power corresponding to a certain level of solar irradiance. Nevertheless the probability associated to a certain level of power is not the same to the probability of having a level of irradiance necessary to produce that value of power, since the relation between power and irradiance has a non-linear region as is noticeable in Eq. 2.2.

$$P_{out}(G_t) = \begin{cases} P_n(\frac{G_t^2}{G_{std}R_c}) & 0 < G_t < R_c \\ P_n(\frac{G_t}{G_{std}}) & G_t > R_c \end{cases} \tag{2.2}$$

Associated to each PDF, there is the probability of occurrence for each single value of solar irradiance, produced power and produced energy. For the purposes of this document, just the reliability of each quantity is considered, which means that the obtained probability corresponds to the probability of having a value which is equal or greater than the one under analysis. Where reliability is defined as:

$$R(y) = 1 - F(y)$$

Where $F(y)$ corresponds to the cumulative probability of the log-normal distribution, given by Eq. 2.3.

$$F(y) = \int_{\infty^-}^{y} f(y)dy = \int_{\infty^-}^{y} \frac{1}{y\sigma_y\sqrt{2\pi}} e^{-\frac{1}{2}(\frac{lny-\mu_y}{\sigma_y})^2} dy \tag{2.3}$$

In this way,following the expressions given by Eq.2.1 and Eq.2.3 the reliability for each one of the different quantities can be estimated.

2.4 Power Generation Analysis

The output power of the PV installation, depends on the solar irradiance and the parameters proper of the used PV panels.

For the output power due to a given irradiance, equation 2.2, will be considered [43].

Can be seen that this equation takes into account 2 conditions for the generation of power, depending on the incident irradiance on the surface of the panel, as well as it takes into account the nominal output power of the panel being used.

The other parameters present in the equation, are standard reference parameters obtained in controlled environments as a way of comparison, with the respective values given by [43, 44].

$$G_{std} = 1000[W/m^2]$$

$$R_c = 150[W/m^2]$$

Since the previous analysis is the same for each month of the year, a random month has been chosen in order to show the corresponding obtained PDF's for the solar irradiance, the produced power and the produced energy.

2.4.1 Energy estimation

The results for the Energy are obtained by the application of Eq.2.4

$$E_i = P_i * d_i * t_i \tag{2.4}$$

Considering that each month have, of course, a different number of days (d) and different daylight hours (t).

the reliability associated to the energy produced can be assumed as the same as the reliability of producing a certain power, since the equation which relates the two quantities depends on a linear relation between them and considers as well that the consumption doesn't change too much during a short period of time, which in this case is one hour.

2.5 Obtained results

2.5.1 North of Italy

In Fig.2.3, the different values corresponding to solar irradiance, generated power and generated energy quantities for the month of June are calculated in the following way, as the analysis is the same for every month and the total results are examined in this section as well:

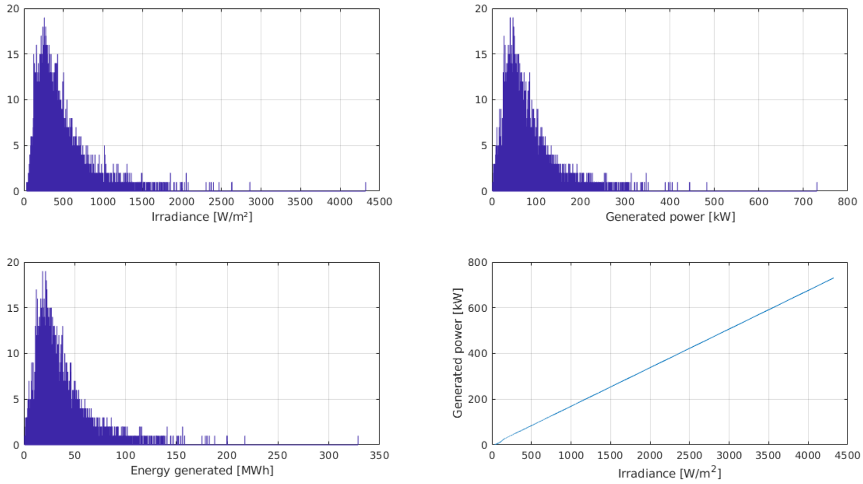

Figure 2.3: PDF's for the month of June at North Italy

Figure 2.3 shows the following characteristics:

- **Solar Irradiance:** Values corresponding to the daily solar irradiance in a single day for the month of June. As has been said before, solar irradiance, produced power and generated energy follow a log-normal distribution, because is physically impossible to have negative levels of this quantities.

- **Produced power:** Values corresponding to the generated power in a single day of June according to the corresponding solar irradiance.

- **Energy produced:** Values corresponding to the energy produced in the entire month of June, having into account the hours of sunlight and the number of days of the month.

- **Irradiance and Generated power relationship:** Describes graphically equation 2.2, with a first non-lineal region,until a certain Irradiance value, while the behaviour starts to be lineal.

In Fig.2.4 the reliability corresponding to daily values of solar irradiance and generated power are shown.

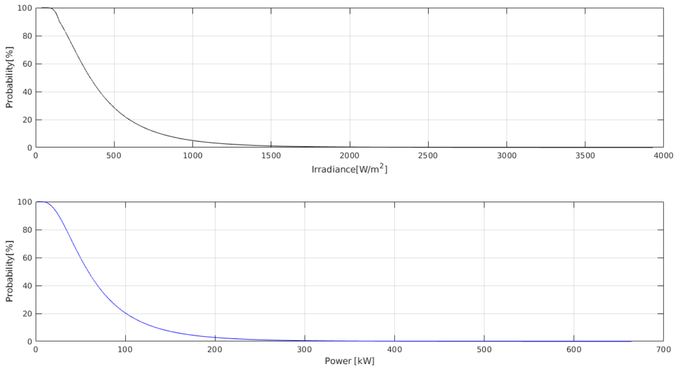

Figure 2.4: Reliability for daily irradiance and generated power

Once considered the output power, it is possible to estimate the total energy produced during a given period of time.

In Fig.2.5 the reliability correspondent to the energy produced during the entire month can be seen. It is worth to notice the units of energy, which is in the order of MWh, not only during the month of July, but also in months with significant differences in terms of daylight hours as well as in solar irradiance levels during the day.

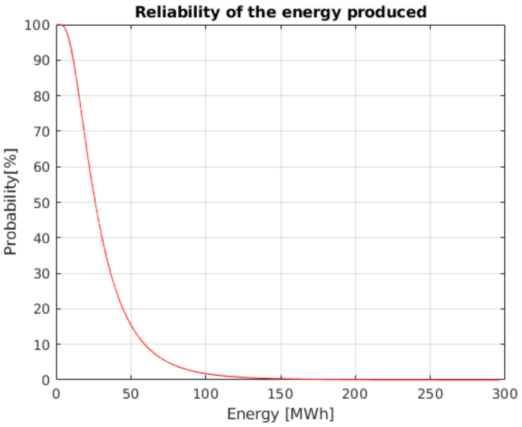

Figure 2.5: Reliability for generated monthly energy

By defining a certain reliability level for the power and so for the energy production, the prospective power and energy production can be estimated in a monthly basis during the year.

As can be seen in figure 2.5, a high reliability level implies a low energy production and consequently a high energy estimation represents low reliability levels. 60% is chosen as the target probability, to have a not so low energy estimation, but at the same time, to do a cost-efficient and feasible implementation for the project.

Figure 2.6 shows the obtained results for the power production during the year, while figure 2.7 shows the results regarding to energy production.

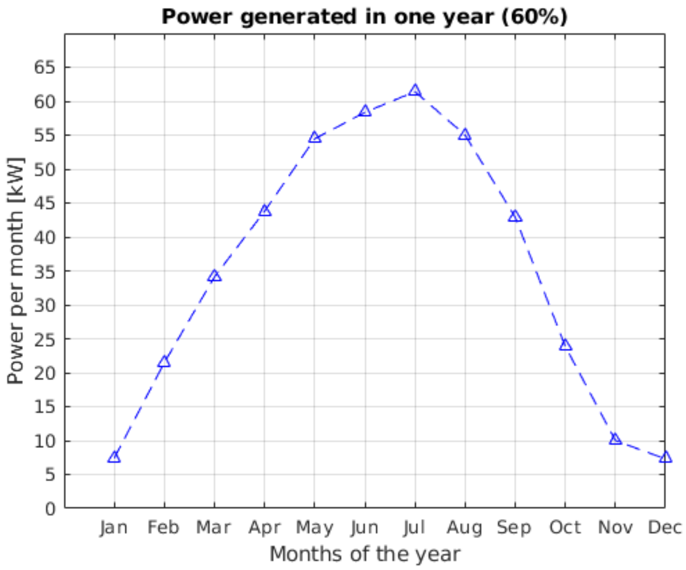

Figure 2.6: Monthly power estimation at north Italy with 60% reliability

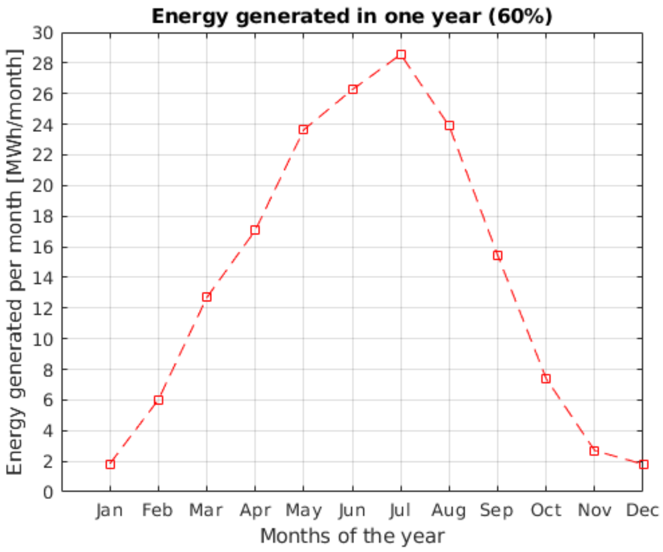

Figure 2.7: Monthly energy estimation at north Italy with 60% reliability

The obtained results are contained in table 2.2 for better appreciation. This Table contains the most relevant results in the studied scenario which are:

- Peak power over the year P_P: This is the power o sizing of the installation as is the highest power expected.
- Mean Energy production E_m: Is the average energy produced in each month of the year.
- Total Energy production E_t: Is the sum of all the energy contributions during the year.

Table 2.2: Obtained results - North Italy

P_p [kW]	E_m [MWh]	E_t [MWh]
61.69	14.04	168.55

2.5.2 Center of Italy

As this region is closest to the equator line, it has higher radiation levels as well as more daylight hours in each month of the year. In consequence the distribution of the data changes slightly with respect to the previous case, as shown in figure 2.8.

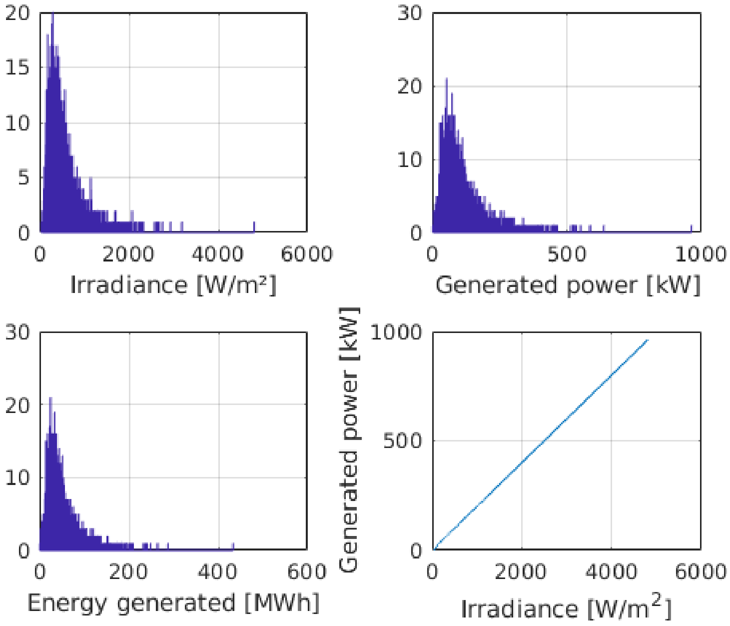

Figure 2.8: PDF's for the month of June at central Italy

As can be seen in figure 2.8, there are higher concentrations of prospective irradiance levels towards higher values. This is reflected offcourse in the generated power as well in the energy, having as well a smaller non-linear region.

The same analysis for the study case of North of Italy was carried out in order to direct comparison between the 2 latitudes. The same reliability level, available surface and PV panels nominal power was used.

The obtained results are shown in figure 2.9, figure 2.7 and are further summarized in Table 2.3.

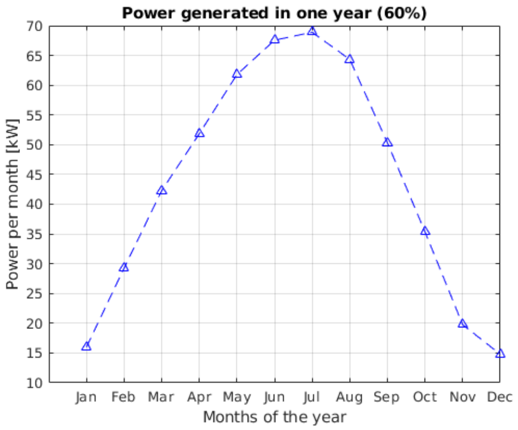

Figure 2.9: Monthly power estimation in the center of Italy with 60% reliability

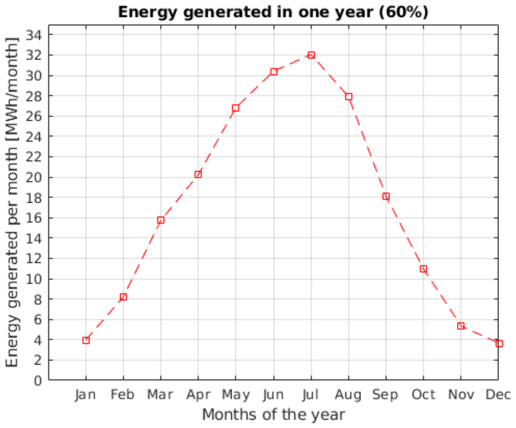

Figure 2.10: Monthly energy estimation in the center of Italy with 60% reliability

Table 2.3 Shows a synthesis of the results in terms of peak power generated, mean energy generated by month and total energy generated during the year. Comparing this results with the ones obtained for the case of north Italy, in average, the installation can produce around 2MWh more by month, representing an increment of 25 MWh per year.

Table 2.3: Obtained results - Center of Italy

P_p [kW]	E_m [MWh]	E_t [MWh]
69.77	16.94	203.37

2.5.3 South of Italy

This part of the analysis is carried out at the very south of the Italian territory. This gives this region very high levels of solar radiation during the year compared with the other two locations under analysis. Figure 2.11 shows higher concentrations of data of the probability density function around values superior form those present in the two previous cases.

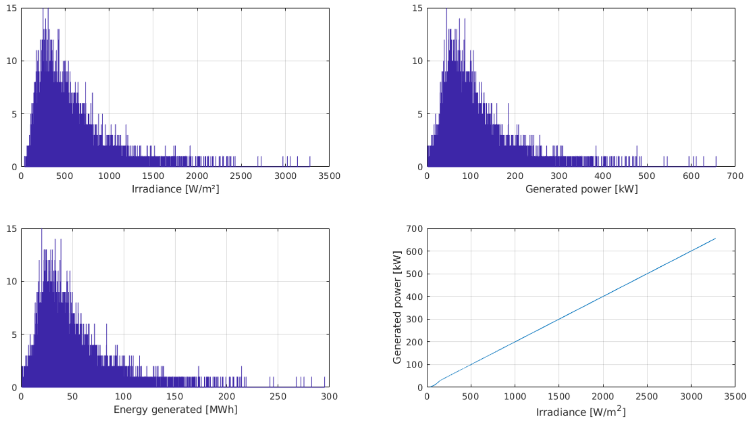

Figure 2.11: PDF's for the month of June at South Italy

The geographical location makes the expected results to be the best of all, which is confirmed in figure 2.12 and figure 2.13.

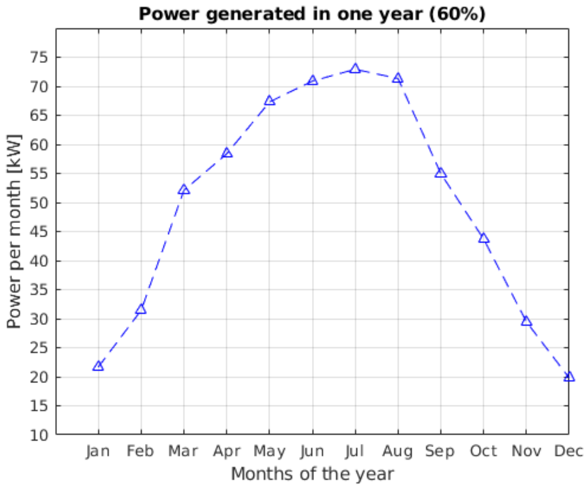

Figure 2.12: Monthly power estimation in the south of Italy with 60% reliability

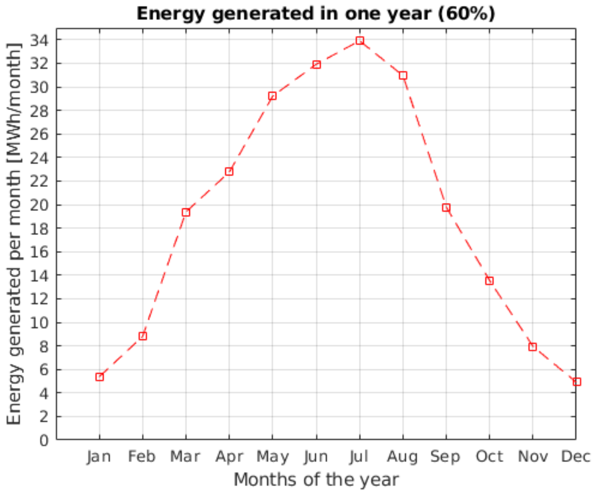

Figure 2.13: Monthly energy estimation in the south of Italy with 60% reliability

Finally, Table 2.4 presents the results obtained in a numerical way, where it can be seen that the average energy production is increased by 2 MWh with respect to the center of Italy and by 5 Mwh with respect to north Italy and so obtaining a value of total energy production, which exceeds in 25 MWh/year and 60 MWh/ year the cases of center of Italy and north Italy respectively, without changing to much the peak power obtained, and so the sizing of the installation.

Table 2.4: Obtained results - South Italy

P_p [kW]	E_m [MWh]	E_t [MWh]
73.27	19.03	228.41

2.6 Results' Analysis

From the previous results can be derived some partial conclusions, as it follows:

- As the peak power obtained is comparable between the three cases is feasible to obtain higher energy production with the same installation sizing, hence with the same infrastructure, investment and operation cost.
- Similar power and energy production can be achieved between the three installations with different reliability levels. So the installation can be sized in order to predict even higher radiation levels and so take advantage of some eventual higher peak power generations during the month or to ensure higher reliability levels in order to produce the same energy.

Figure 2.14 shows the direct comparison among the three study cases, with the same reliability level (60%), showing once again that the southern locations have a better generation capacity with the same features of the photovoltaic installation in every month of the year.

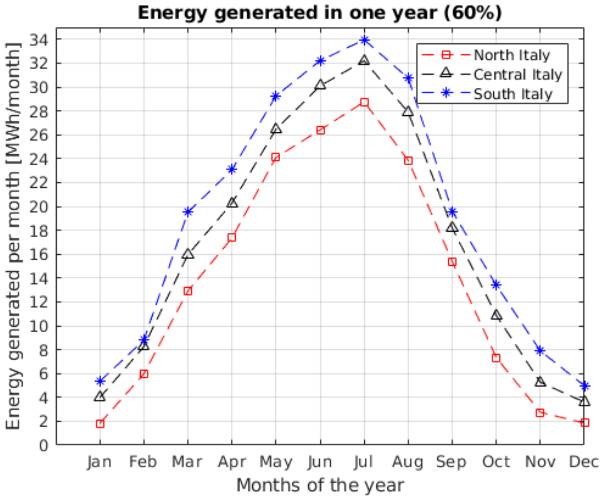

Figure 2.14: Results' comparison at 60% reliability

On the other hand, figure 2.15, shows, how changing the reliability levels to higher values, thus being more accurate on the estimation of the energy production, it is possible to obtain very similar generations during the year by improving the precision on 10% and 15% on the central and south Italy cases respectively, taking as a reference point the results obtained for the north Italy region.

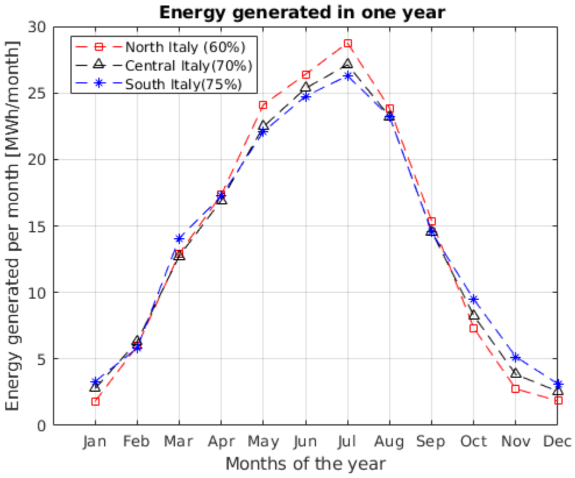

Figure 2.15: Results' comparison at different reliability levels

The total energy production as well as the mean energy production obtained by changing the reliability as described above, are contained in table 2.5.

Table 2.5: Energy Production at different reliability levels

Location	E_m [MWh]	E_t [MWh]
North Italy	14.03	168.45
Central Italy	13.84	166.11
South Italy	14.08	169.06

Chapter 3

Electric Vehicles charging operation and V2G

3.1 Charging operation

In this section the EV's are treated as a simple load, considering the different charging powers and the battery capacity of each vehicle. A comparison between the PV generation and the required energy to fully charge the entire EV fleet present at the parking lot is done in order to determine the feasibility of using renewal resources to supply the additional load generated by the cars.

The characteristics of the PV installation to be taken into account are the ones considered in chapter 2 for the case scenario of north Italy, so the irradiance levels, as well as the prospective energy and power generation.

3.1.1 Daily available power

According to the analysis performed in chapter 2, it is possible to determine the solar irradiation, during a single day in a particular month of the year. Taking the data provided by the PVGis database, is possible then, to calculate the generated power every 15 minutes along the day. Has been shown as well, that the solar irradiance varies significantly according to the month of the year. Figure 3.1 shows four different scenarios corresponding to each season of the year and the available power in function of the solar irradiance along the entire day.

According to chapter 1 and the information about the electric vehicles having the capacity to implement V2G features, the available power in all the months of the year, during most of the daylight hours could be enough to supply the vehicles.

Translating the obtained results in figure 3.1 to energy values, it is possible to determine the amount of kWh which can be supplied to the electrical vehicles demand. The obtained results from this analysis are shown as well for different periods of the year in figure 3.2.

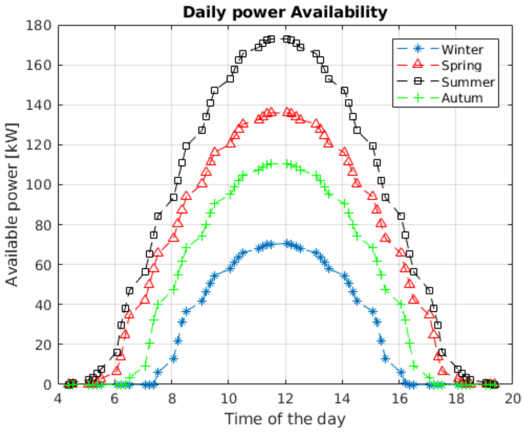

Figure 3.1: Daily Available Power

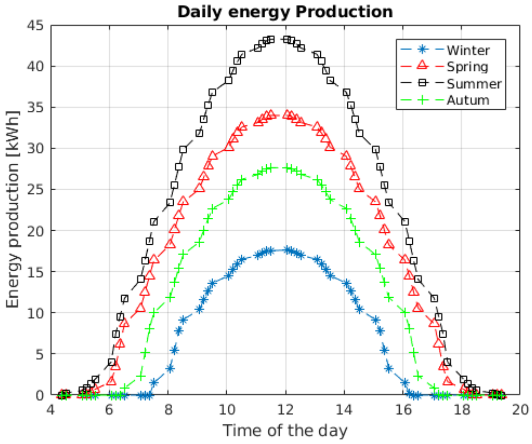

Figure 3.2: Daily Available energy

To determined if the values obtained from figure 3.2 are satisfactory, different facts from the electric vehicles have to be considered as the state of charge and the parking time.

Figure 3.1 and figure 3.2 show the typical expected behaviour of a solar irradiation pattern, with low or zero values at the beginning and the end of the day, while presenting a peak value at noon. The differences among the 3 curves presented are determined by the season, because it modifies the daylight hours during each month as well as the radiation levels presented along the day.

3.1.2 Parking times and occupancy

In order to achieve a more accurate results concerning the times and energy available or required for the charging/ discharging cycles of the EV's, it is necessary to model the parking occupancy according to the actual parking facilities data. In [45] a stochastic model for arrivals and departures has been validated, using a normal distribution approach. The same occupancy model is going to be used, having into account the data collected.

3.1.2.1 Normal distribution Model

The most used statistical model to describe a random variable is the Gaussian or normal distribution. A variable Y is consider to be Gaussian if its probability density function is given by equation 3.1.

$$f(y) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-1}{2}(\frac{y-\mu}{\sigma})^2}; -\infty \leqslant y \leqslant \infty \tag{3.1}$$

Where μ corresponds to the mean value of the data, while σ corresponds to the standard deviation. All the data of the distribution is considered to be contained inside the interval $[\mu - 3\sigma, \mu + 3\sigma]$ with a probability superior to the 99%.

Is particularly useful to define the cumulative probability function, since with this function it is possible to determine the probability of having a given point result y and is described by equation 3.2.

$$F(y) = \int_{-\infty}^{y} f(y)dy = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-1}{2}(\frac{y-\mu}{\sigma})^2} dy \tag{3.2}$$

Using equation 3.1 and equation 3.2 it is possible to model a certain occupancy level of the parking facilities and the given probability which this result is expected to happen.

Figure 3.3 shows the typical occupancy during the month of July of the parking lot facilities, evidencing, a peak occupancy of around 65% during the morning, while in the rest of the day the occupancy level is almost constant around 35% and finally there is a second peak of around 55% during the evening.

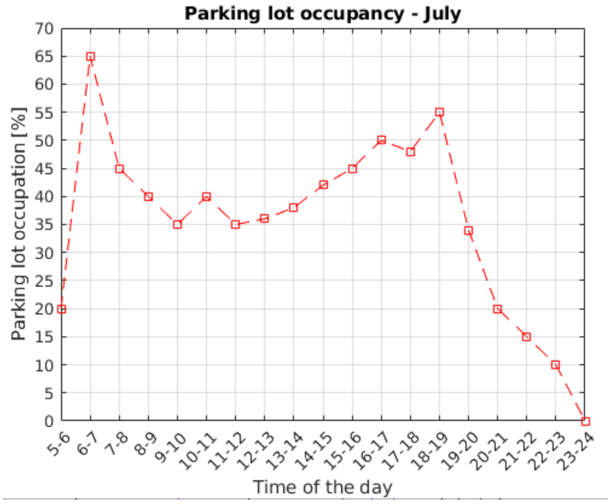

Figure 3.3: Typical occupancy levels during July

On the other hand, different months of the year can be analyzed to describe the regular users' behaviour, and build a more accurate model. Figure 3.4 shows the occupancy levels of the parking facilities during the month of September.

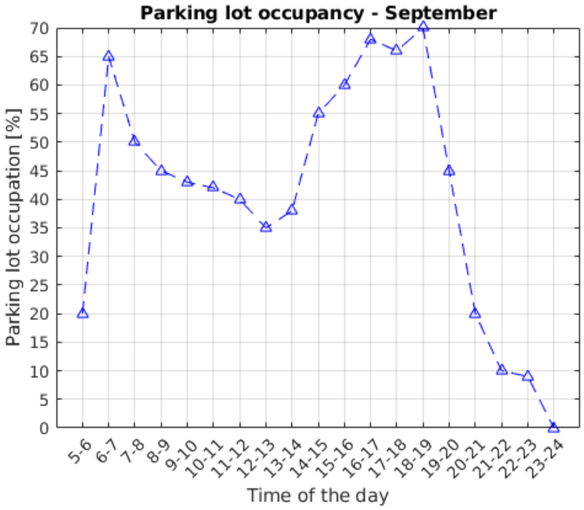

Figure 3.4: Typical occupancy levels during September

In figure 3.4 it is possible to observe the same 65% peak during the early morning and a second bigger peak, compared with the one presented in figure 3.3, but still not so distant form the peak value. This behaviour suggest that the departures time is more casual than the one for the arrivals, as considered in [45].

The study performed in [45] validates the observed behaviour, since the arrivals are modeled with a peak value around 8 am and a standard deviation of 20 minutes, while the departures are modeled with a peak value around the 6 pm with a standard deviation of 40 minutes. Figure 3.5 shows the model obtained in [45].

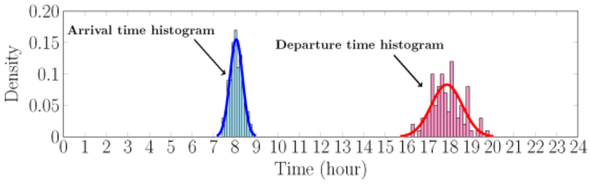

Figure 3.5: Arrival/departure times for/to a railway station [45]

Based on 3.3, figure 3.4 and figure 3.5, the parameters on table 3.1 will be adopted to model the arrivals and departures of the EV's on the parking lot as well as the occupancy levels.

According to table 3.1 it is possible to make a 2D modeling considering as variables the time of the day and the occupancy levels. Where the occupancy levels depend in some degree of the time of the day, but still have a degree of

Table 3.1: Arrivals/departures and occupancy, Normal distribution parameters

Variable	Mean value [μ]	Standard deviation [σ]
Arrival time	7 a.m	30 mins
Departure Time	7 p.m	45 mins
Occupancy/Arrivals	65%	15%
Occupancy/Departures	55%	25%

freedom given by the probability of having different occupancy levels at the same time of the day.

3.1.3 Fleet generator

In order to predict the behaviour of the electric vehicles during the charging period it is necessary to know key variables which play a role in the case scenario to be analyzed. As is evident, the power capacity of the virtual power plant as well as the energy required during the charging periods have an stochastic behaviour depending on the EV owners' behaviour.

In order to simulate this behaviour, it is necessary to know the current occupancy of the parking lot, which kind and number of vehicles are present (i.e Battery capacity and charging power) and the state of charge (SoC) of every vehicle.

According to the electric vehicles characteristics cited in chapter 1, it is possible to divide the available cars in different categories depending on the charging power and battery capacity as it is shown in table 3.2.

Table 3.2: EV cars key characteristics

Car Model	Battery Capacity [kWh]	Normal Charging[kW]	Fast Charging [kW]
Nissan Leaf	24	7	50
Nissan e-nv200	24	6.6	50
Mitsubishi PHEV	12	2.2	3.3
Peugeot iOn	14.5	1.76	3.08

The fleet of cars to be generated, considers the actual occupancy of the parking lot, which means the number of cars present at the facilities at the moment of the energy estimation. The program generates a N x 4 matrix where N corresponds to the current number of EV present as shown in table 3.3.

Table 3.3: EV fleet generator

EV	Battery Capacity [kWh]	Charging power [kW]	SoC [%]	Parking time [h]
1	C_1	P_1	SoC_1	t_1
2	C_2	P_2	SoC_2	t_2
...	...	...	...	...
N	C_N	P_N	SoC_N	t_N

As said before, the battery capacity and charging power of the vehicles are generated randomly for the amount of the vehicles present according to the values in table 3.2, while the range for the state of charge of the arrival vehicles is consider between 10% and 95%. The ideal SoC of 100% is excluded as the vehicle has a minimum consumption form the user's home to the parking lot facilities.

Once the car fleet has been generated, the charging power assigned to each EV is identified in order to know the total power to be provided for full charge of the vehicles.

Having identified the charging power needed for the entire fleet, the SoC of every EV has to be determined in order to know which is the energy necessary to provide, having into account the power restriction given by the vehicle itself and finally calculate the total energy necessary to fully charge each type of vehicle and thus, the entire fleet.

This is achieved by simply taking column four in table 3.3 and following equation 3.3 and equation 3.4.

$$E_i = (1 - SoC_i) * C_i \tag{3.3}$$

$$E_{tc} = \sum_{i=1}^{N} E_i \tag{3.4}$$

Where C_i represents the battery capacity of the correspondent electric vehicle under evaluation, E_i represents the associated energy in kWh necessary to fully charge the vehicle, SoC_i represents the current state of charge of the vehicle and E_{tc} the total energy in MWh necessary to fully charge the entire fleet.

Having calculated the total amount of energy needed for charging the entire fleet, the charging time needed for such an operation can be estimated as well. Based on the number of EV of each type present at the moment and the available charging powers, each vehicle will take a certain amount of time to charge up to 100%, which will be given by a time constant defined as in equation 3.5.

$$\tau_c = \frac{C_i}{N_i * P_c} \tag{3.5}$$

Where τ_c is the time, given in hours, needed to charge N vehicles of type 'i', having a given charging power P_c associated to the kind of EV under charge. Figures 3.6, 3.7 and 3.8 show the expected behaviour of a electric vehicles' fleet considering different occupation levels, according to the time of the day and the data provided by the parking lot staff.

The modeling of the electric vehicles and the charging modes follows the steps given in [46]. Assuming the battery of the vehicle as a capacitor, it is possible to determine the time constant required to charge the battery in function of the power available and so the time required to achieve a certain level of SoC.

In this [46] there are defined 3 charging levels, depending on the power used and the time required to achieve the desired SoC levels. The obtained results in the study are displayed in table 3.4.

Table 3.4: Charging levels and times [46]

Level	Limit [%]	Time [h]	Outlet Unit
1	100	22	110/120V, 15A
2	100	8	240V,70A
3	80	0.5	DC 50kW

Level 1 considers a normal residential monofasic outlet, while level 2 considers a bifasic connection in a non-residential grid and finally level 3 considers a DC outlet of 50kW fast charging system.

Off course the times given in table 3.4 depend on the size of the fleet considered, but it is obvious than the reduction between levels is very large. In this document level 2 (Normal charging) and level 3 (Fast charging) are considered in the following results.

3.1.3.1 Charging Operation - Occupancy scenarios

As seen in figures 3.3 and 3.4, there are different occupancy levels during the day, varying between 20% and 70%. During the closing time of the parking lot are present lower occupancy levels but off course, these are not evaluated since there are not EV's nor sunlight at those hours.

In this section, 3 different case scenarios are going to be analyzed within the given interval, considering a minimum of 20%, an average of 55% and a maximum occupancy level of 70%.

- **20% occupancy**

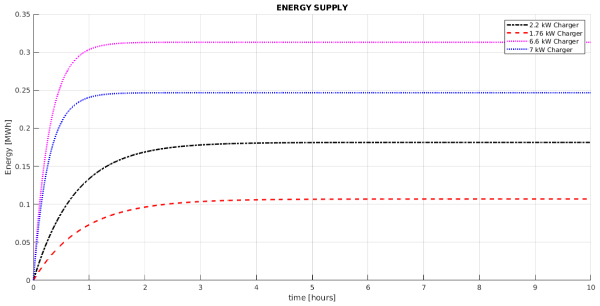

Figure 3.6: Charging time of the electric fleet for 20% Occupancy

Figure 3.6 shows the charging trend of all the vehicles, based on their battery capacity, maximum charging power and number of vehicles present at the parking lot. A total of 95 electric vehicles were taken into account, distributed randomly among the different vehicle types. In particular for this results, there were generated 22 vehicles corresponding to a 12 MWh battery capacity and 2.2 kW of charging power, 14 electric vehicles with a battery capacity of 14.5 MWh and a charging power of 1.76kW, 33 vehicles corresponding to a battery capacity of 24 MWh and a charging power of 6.6 kW and finally 26 vehicles corresponding to a 24 MWh battery capacity with a charging power of 7 kW.

Figure 3.6 shows, as expected, a steeper slope for those vehicles with a higher charging power, while for those corresponding to low charging powers the slope is smoother. This is evident as we can interpret equation 3.5 as the higher the power, the smaller the time constant.

This particular simulation shows a total charging time of around 2 hours, in order to charge entirely this particular fleet of 95 electric cars, corresponding to 0.84 MWh, which can be withdrawn whether from the power grid or from the photovoltaic installation depending on the available power at the time of the day.

- **55% Occupancy**

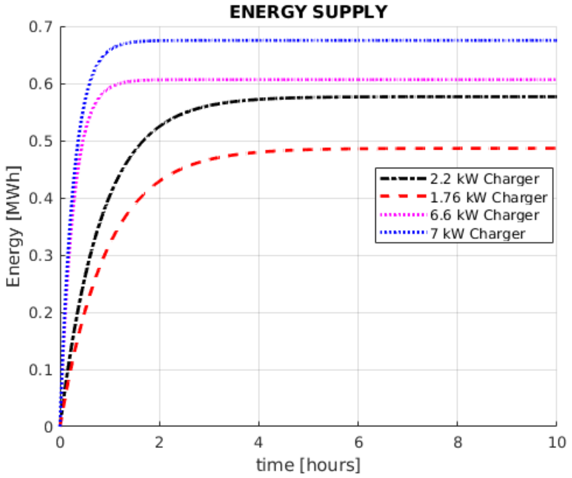

Figure 3.7: Charging time of the electric fleet for 55% Occupancy

Figure 3.7 shows the charging trend of all the vehicles, based on their battery capacity, maximum charging power and number of vehicles present at the parking lot. A total of 262 electric vehicles were taken into account, distributed randomly among the different vehicle types. In particular for this results, there were generated 63 vehicles corresponding to a 12 MWh battery capacity and 2.2 kW of charging power, 59 electric vehicles with a battery capacity of 14.5 MWh and a charging power of 1.76kW, 69 vehicles corresponding to a battery capacity of 24 MWh and a charging power of 6.6 kW and finally 71 vehicles corresponding to a 24 MWh battery capacity with a charging power of 7 kW.

This particular simulation shows a total charging time of around 3 hours in order to charge entirely this particular fleet of 262 electric cars, corresponding to 2.34 MWh, which can be withdrawn whether from the power grid or from the Photovoltaic installation depending on the available power at the time of the day.

- **70% occupancy**

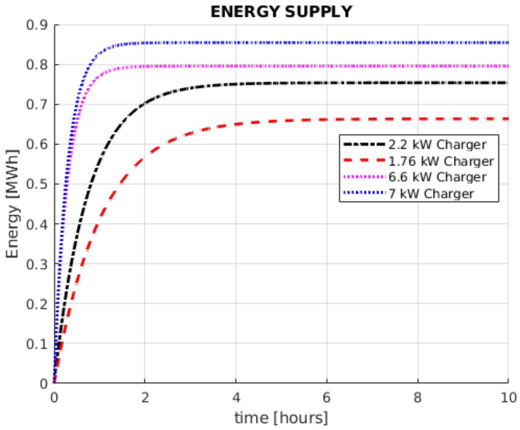

Figure 3.8: Charging time of the electric fleet 70% occupancy

Figure 3.8 shows the charging trend of all the vehicles, based on their battery capacity, maximum charging power and number of vehicles present at the parking lot. A total of 333 electric vehicles were taken into account, distributed randomly among the different vehicle types. In particular for this results, there were generated 92 vehicles corresponding to a 12 MWh battery capacity and 2.2 kW of charging power, 73 electric vehicles with a battery capacity of 14.5 MWh and a charging power of 1.76kW, 84 vehicles corresponding to a battery capacity of 24 MWh and a charging power of 6.6 kW and finally 84 vehicles corresponding to a 24 MWh battery capacity with a charging power of 7 kW.

This particular simulation shows a total charging time of around 4 hours in order to charge an entire 333 fleet of electric cars, providing 3.06 MWh, which can be withdrawn whether from the power grid or from the Photovoltaic installation depending on the available power at the time of the day.

3.1.4 V2G Implementation

In order to implement a V2G feature on the parking lot, it is necessary to know how much energy can be exploited from the electric vehicle fleet present at the parking lot in a certain moment and the required time for the operation. This is done, having into account the model of the EV developed and explained in [46] and previously in section 3.1.3.1.

As has been said before, the virtual power plant represented by the EV's has an stochastic behaviour depending on the EV's users routine. In addition, V2G facilities have to guarantee to the user, the normal operation of his car, which means to guarantee a minimum charging level of the battery at any time the user decides to withdraw his vehicle from the facilities.

3.1.5 Adopted Restrictions

It is necessary then, to define a set of constraints in order to ensure such conditions but at the same time, being able to exploit, as much as possible the energy stored on the vehicles. The set of constrains considered is defined as follows:

1. **Minimum SoC:** A minimum state of charge which will guarantee to the user at any time along the day and which will also take as a transition point from discharging period to charging period during the dynamic schedule of V2G.

2. **Maximum SoC:** Evidently, the limit of the maximum state of charge is reached when the electric vehicle is fully charged. At that moment the control algorithm intended for the V2G, will decide if the car will be placed in a non-charging period or discharging period, based on the load profile and the hour of the day.

3. **Minimum parking time:** A minimum parking time has to be taken into account since to do the exploitable energy estimation and usage more reliable. As some studies have shown, as in [45], the typical standing time of vehicles in parking lots is of around 8 hours, coinciding with a the week working hours. Having this into account, a minimum time of 4 hours stay is considered.

3.1.6 Exploitable Energy evaluation

Evaluating the above mentioned conditions, it is necessary to determine once again, the occupancy of the parking lot and the vehicles which suit the imposed restrictions. Once the vehicles are identified, it is necessary to determine the type of the available vehicles, the state of charge of them and so the prospective energy which can be used.

For each electric vehicle which satisfies the restrictions, the available energy that can be used in order to return to he grid, so for the V2G implementation will be given by eq. 3.6.

$$E_{V2G_i} = max\{0, SoC_{c_i} - SoC_{min}\} * C_i \tag{3.6}$$

Where SoC_c represents the current state of charge of the vehicle at the moment of evaluation, SoC_{min} represents the minimum state of charge which have to be guaranteed to the user and C_i represents the battery capacity of each vehicle present on the parking lot.

And so, the total energy which can be exploited in the parking lot facilities will be equal to the summation of all the individual energy resources, after having identified the the type and the number of EV's corresponding to each particular type of vehicle at the moment of evaluation, as described in equation 3.7.

$$E_{t_V2G} = \sum_{i=1}^{N} E_{V2G_i} \tag{3.7}$$

Where E_{t_V2G} is the total energy which can be exploited at a certain moment of the day, while E_{V2G_i} corresponds to the expression described in equation 3.6.

3.1.7 Discharging Operation - V2G

In order to determine the necessary time to deliver the energy stored on the EV's batteries to the grid, it is necessary to know the total energy to be handle, the power each vehicle can handle and the time constant correspondent to to the operation of each vehicle type.

The time constant to be considered is described in equation 3.8, where P_i corresponds to the power which each EV can handle for the operation while C_i corresponds to the battery capacity of the EV car type i and N_i correspond to the number of vehicles of type i present at the facilities at the moment of evaluation.

$$\tau_{V2G_i} = C_i/(N_i * P_c) \tag{3.8}$$

Is noticeable that there are different time constants, each one corresponding to the different EV types present.

3.1.7.1 Occupancy level scenarios

As well as for the charging operation, different occupancy levels are considered. In particular the study cases of 20%, 55% and 70% are evaluated, to describe the behaviour of the facilities and the prospective amount of energy which can be withdrawn under these particular conditions.

- **20% Occupancy**

  Under simulation conditions, considering an occupancy of 20% of the parking facilities, which mean a total of 95 vehicles with the following random distribution:

- **2.2 kW (Type 1) Vehicles:** A total of 22 vehicles were generated:
- **1.76 kW (Type 2) Vehicles:** A total of 14 vehicles were generated.
- **6.6 kW (Type 3) Vehicles:** A total of 33 vehicles were generated.
- **7 kW (Type 4) Vehicles:** A total of 26 vehicles were generated.

After having evaluated the established restrictions detailed on section 3.1.5, the amount of available cars descended to a total of 19 vehicles available for V2G purposes distributed on the following way:

- **Type 1:** 2 vehicles.
- **Type 2:** 3 vehicles.
- **Type 3:** 10 vehicles.
- **Type 4:** 4 vehicles.

Having a total energy storage of 320.93 kWh which can be exploited for V2G purposes.

Figure 3.9 shows the different trends of discharging corresponding to each type of vehicle, as well as the total time required for the total discharging of the batteries, respecting always the lower limit imposed on the SoC defined in section 3.1.5.

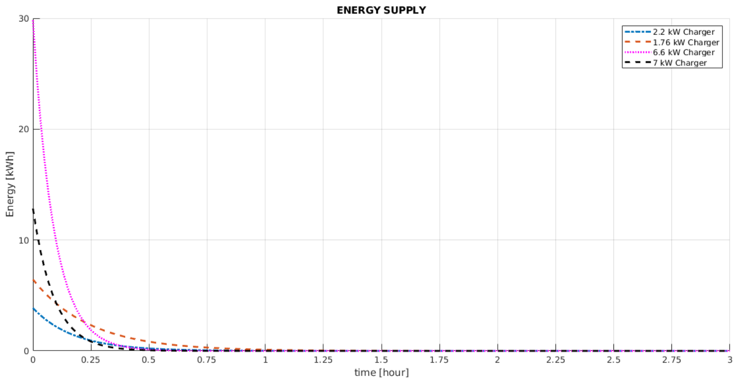

Figure 3.9: Discharging trends for a 20% Occupancy.

On figure 3.9 is clear how the vehicles with larger powers require less time to deliver energy to the grid while those with lower charger powers need some more time in order to perform the same operation. It is noticeable as well that the total discharging time required in the operation is around 0,5 h. Having into account that the restrictions specified a minimum parking time of 4h, a complete charging/discharging cycle could be perform so the entire operation is invisible for the owner of the vehicle. In order to develop a more sophisticated schedule scheme, an algorithm could be developed to alternate between normal, fast or accelerating charging power in order to perform more charging/ discharging cycles on the same time, depending on the energetic requirements.

- **55% Occupancy**

  Under simulation conditions, considering an occupancy of 20% of the parking facilities, which mean a total of 262 vehicles with the following random distribution:

  - **2.2 kW (Type 1) Vehicles:** A total of 63 vehicles were generated:
  - **1.76 kW (Type 2) Vehicles:** A total of 59 vehicles were generated.
  - **6.6 kW (Type 3) Vehicles:** A total of 69 vehicles were generated.
  - **7 kW (Type 4) Vehicles:** A total of 71 vehicles were generated.

  After having evaluated the established restrictions detailed on section 3.1.5, the amount of available cars descended to a total of 60 vehicles available for V2G purposes distributed on the following way:

  - **Type 1:** 13 vehicles.
  - **Type 2:** 14 vehicles.
  - **Type 3:** 16 vehicles.
  - **Type 4:** 17 vehicles.

  Having a total energy storage of 1.49 MWh which can be exploited for V2G purposes.

  Figure 3.10 shows the different trends of discharging corresponding to each type of vehicle, as well as the total time required for the total discharging of the batteries, respecting always the lower limit imposed on the SoC defined in section 3.1.5.

  On figure 3.10 it is noticeable as well that the total discharging time required in the operation is around 1,2 h. Having into account that the restrictions specified a minimum parking time of 4h, a complete charging/discharging cycle could be perform so the entire operation is invisible for the owner of the vehicle. In order to develop a more sophisticated schedule scheme, an algorithm could be developed to alternate between normal, fast or accelerating charging power in order to perform more charging/ discharging cycles on the same time, depending on the energetic requirements.

- **70% Occupancy**

  Under simulation conditions, considering an occupancy of 70% of the parking facilities, which mean a total of 333 vehicles with the following random distribution:

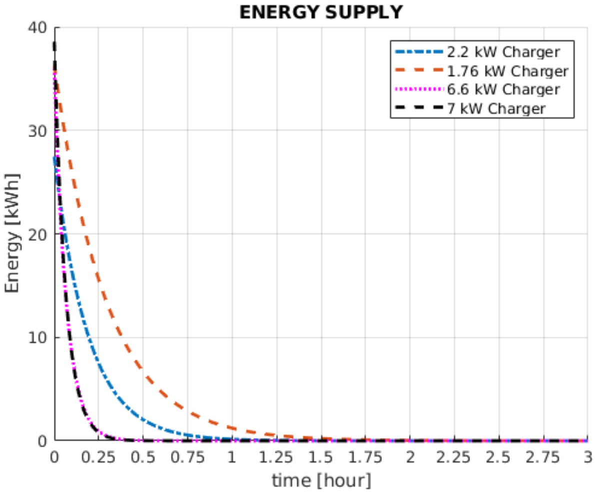

Figure 3.10: Discharging trends for a 55% Occupancy.

- **2.2 kW (Type 1) Vehicles:** A total of 92 vehicles were generated:
- **1.76 kW (Type 2) Vehicles:** A total of 73 vehicles were generated.
- **6.6 kW (Type 3) Vehicles:** A total of 84 vehicles were generated.
- **7 kW (Type 4) Vehicles:** A total of 84 vehicles were generated.

After having evaluated the established restrictions detailed on section 3.1.5, the amount of available cars descended to a total of 64 vehicles available for V2G purposes distributed on the following way:

- **Type 1:** 23 vehicles.
- **Type 2:** 13 vehicles.
- **Type 3:** 17 vehicles.
- **Type 4:** 11 vehicles.

Having a total energy storage of 2.16 MWh which can be exploited for V2G purposes.

Figure 3.11 shows the different trends of discharging corresponding to each type of vehicle, as well as the total time required for the total discharging of the batteries, respecting always the lower limit imposed on the SoC defined in section 3.1.5.

On figure 3.11 it is noticeable as well, that the total discharging time required in the operation is around 1,3h. Having into account that the restrictions specified a minimum parking time of 4h, is not possible to perform a complete charging/discharging cycle with normal charging power. In order to perform an entire cycle, the implemented algorithm should alternate from normal charging to fast charging if this occupancy level is present.

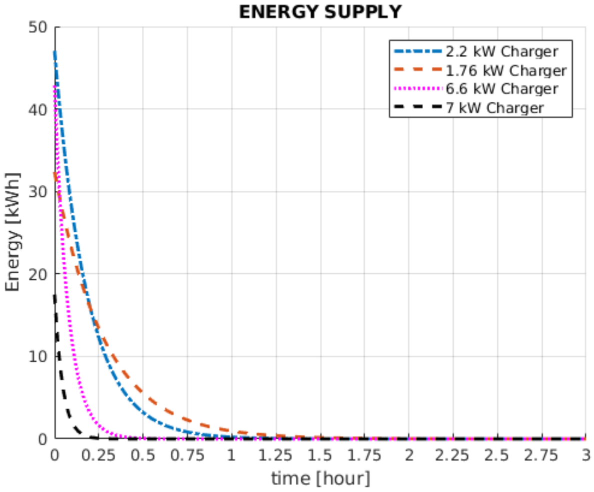

Figure 3.11: Discharging trends for 70% Occupancy

Off course, these given values are not fixed, as the behaviour of the occupancy is not deterministic, but changes with a given probability, modeled with the normal distribution explained before and depending on the user's behaviour.

Nevertheless, they provide a close estimation on the order of magnitude of the energy needed to charge a given fleet under different occupancy conditions as well as an idea of the available energy which can be given to the grid while the fleet is working as a virtual power plant.

3.1.7.2 Fast Charging Operation

As the parking lot installation closes at midnight and the trends in 3.1.2 show people leave the facilities starting around 8 pm, it is necessary to boost the charging process of the cars still present, so the user will leave with a full charge or at least with a charge percentage superior to 70%.

If the time of the day is superior to 6 pm, the algorithm should apply the fast charge power, corresponding to each type of vehicle described in Tables 1.1, 1.2, 1.3 and 1.4.

In figure 3.12 is presented a case, with 46% occupancy of the parking lot represented in 223 vehicles, distributed in the following way:

- 55 type 1 vehicles
- 42 type 2 vehicles
- 65 type 3 vehicles
- 61 type 4 vehicles

This represents an energetic requirement of almost 2 MWh (1.96 MWh), which in the normal charging conditions, will take around 3h. In figure 3.12 is clear, that the charging operation is much faster, mainly in the case of type 3 and type 4 vehicles, since the increment in power from normal charging to fast charging is very representative (from 6.6 kW and 7 kW) to 50kW, while in the case of type 1 and type 2 vehicles, the increment is much lower (from 1.76 kW and 2.2 kW to 3.3 kW and 3.08 kW respectively).

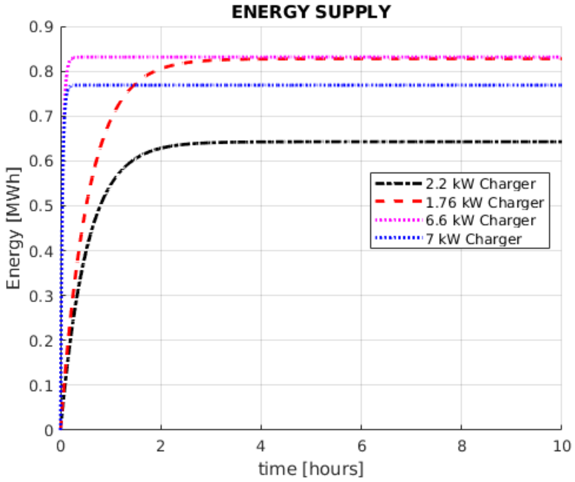

Figure 3.12: Fast charging operation

In this way, it is possible to reduce the charging time and also, in further improvements to the algorithm, it would be possible to alternate between normal and fast charging, during the entire day, if is possible to monitor the state of charge of every single vehicle.

If a majority of type 3 and 4 vehicles is considered, the charging operation could be performed in a really short time, very inferior, even much more less than 1 hour.

3.1.8 Load profiles

The Italian grid operator TERNA, forecast the national energy demand one day in advance and builds an expected demand curve. Additionally, through on-line measurements and signaling systems, the grid operator is able to monitor, in real time, the actual national demand and show the two curves overlapped, so at any time is possible to determine the energy necessary to be dispatched into the grid.

These pair of curves are built using statistics, historical data and demand forecast methods. The accuracy of the forecast is quite good and normally the expected demand is always higher than the actual one. This is having into account a safety factor [47].

Additionally, as the demand is quasi-inelastic, the demand curves changed in magnitude day after day, but they keep the same shape during the day, with a demand peak around 11 am and a second, but lower peak around 8 pm. Figure 3.13 shows the typical shape of the demand profile in Italy.

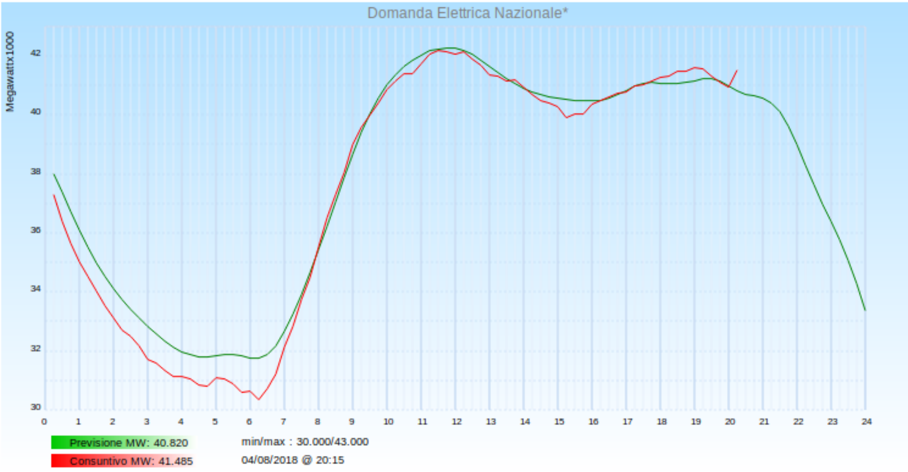

Figure 3.13: Typical demand curve in Italy. Forecast and actual demand

Figure 3.13 shows a very pronounced valley during the early morning, around 1am and 7am. This is particularly convenient given the conditions on this study case, where the highest occupancy levels are present during the early mornings.

While there is a pronounced peak starting from 8am and remaining more or less constant during the day with two peaks around 11 am and 7 pm.

3.1.9 V2G Scheduling

Analyzing the obtained results in sections 3.1.1,3.1.3.1,3.1.4 and 3.1.8 it is possible to formulate an schedule of charge/discharge of the EV's present on the parking lot, having into account the hour of the day, occupancy level at a given time and the prospective energy required and available to either withdraw or provide to the grid.

In figure 3.13, it can be seen that during the early morning, there are required, between 6-8 MWh to flattered the demand curve, so in this period it is convenient to perform the charging operation of the vehicles, to increase the present demand. Considering the best case scenario analyzed, with a 70% occupancy level the facilities can provide around 3 MWh, while in the worst case, the vehicle's fleet can provide around 0.8 MWh.In this period the complete fleet should be charging while the photovoltaic installation should be disconnected from the grid.

On the other hand, during the high demand periods, there is a need to reduce, between 2 MWh to 4 MWh the demand, so in this period is when the algorithm for the schedule of the electric fleet should perform the discharge operation of the vehicles.

Considering the best case scenario, which is an occupancy level of 70%, there is an availability of around 2.16MWh, while in the worst case scenario, which is an occupancy of 20% of the parking lot, the energy available for V2G operation would be around 0.32MWh.

If an average occupancy level scenario is considered, which is around 50% to 55% of the parking capacity, the energy available to provide to the grid is around 1.5 MWh, which can reduce significantly the highest demand peak during the day.

For the rest of the day, when the demand remains more or less constant, the algorithm should monitor, the SoC of every single vehicle, in order to decide whether it is going to be charged or discharged and if this operation is going to be performed through the grid or through the photovoltaic system.

3.1.9.1 Optimized scheduling schemes for V2G

The issue of V2G scheduling has been matter of research in the last few years. In particular, one of the most important topics in this area is the creation of optimized algorithms whic allow to perform an optimized schedule of the single vehicle.

Different schemes have been proposed in centralized scheduling, decentralized scheduling and also in a combination of them. In figure 3.14 a mixed V2G scheduling scheme is presented.

This scheduling scheme can implement different type of algorithms to determine whether a vehicle can be used for V2G or should be assigned to the charging process. The different alternatives to this issue are presented in table 3.5 [48].

In particular, in this document a Binary linear programming strategy is considered for the schedule of charging and discharging of the vehicles and also to alternate between normal and fast charging depending on the occupancy and time of the day.

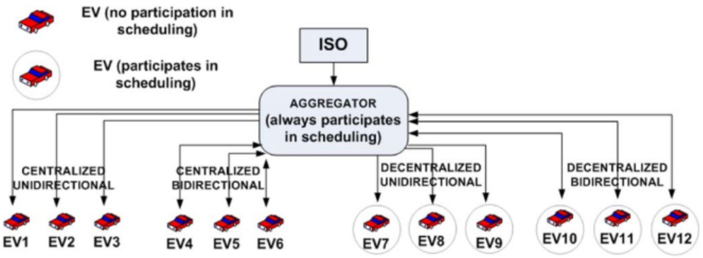

Figure 3.14: System-level view of the V2G scheduling process [48]

Table 3.5: Optimization techniques used for V2G scheduling [48]

Optimization method
Dynamic Programming
Convex Optimization
Binary Linear Programming
Quadratic programming
Game Theoretic Approach
Swarm Particle optimization
Heuristic methods
Mixed Integer Stochastic Optimization
Mixed integer Linear programming
Evolutionary Algorithm
Others

Unfortunately this study doesn't count with the possibility of monitor every single vehicle as all the obtained results are obtaining with simulation tools. Nevertheless, the algorithm can be validated through the results obtained in [45] and showed in figure 3.15.

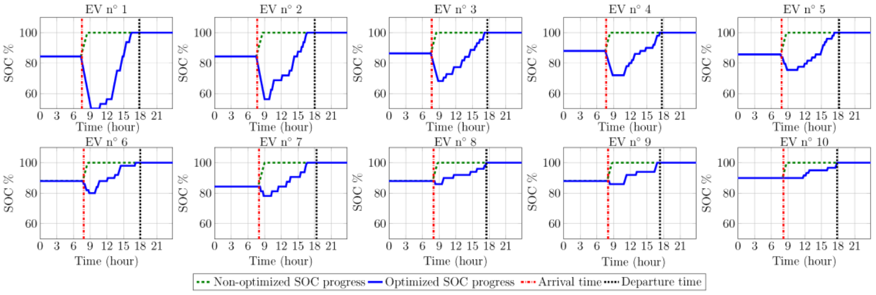

Figure 3.15: Binary programming algorithm obtained results [45]

The results in 3.15 were obtained in a field study, within a real parking lot, where it was possible to monitor the demand profile and the SoC of each vehicle in real time.

3.1.10 Implementation Algorithm

After having evaluated all the different aspects which play a role on the V2G implementation scheme, figure 3.16 summarizes the different steps and conditions, as well as the data required in order to perform a suitable schedule for the charging/discharging cycles.

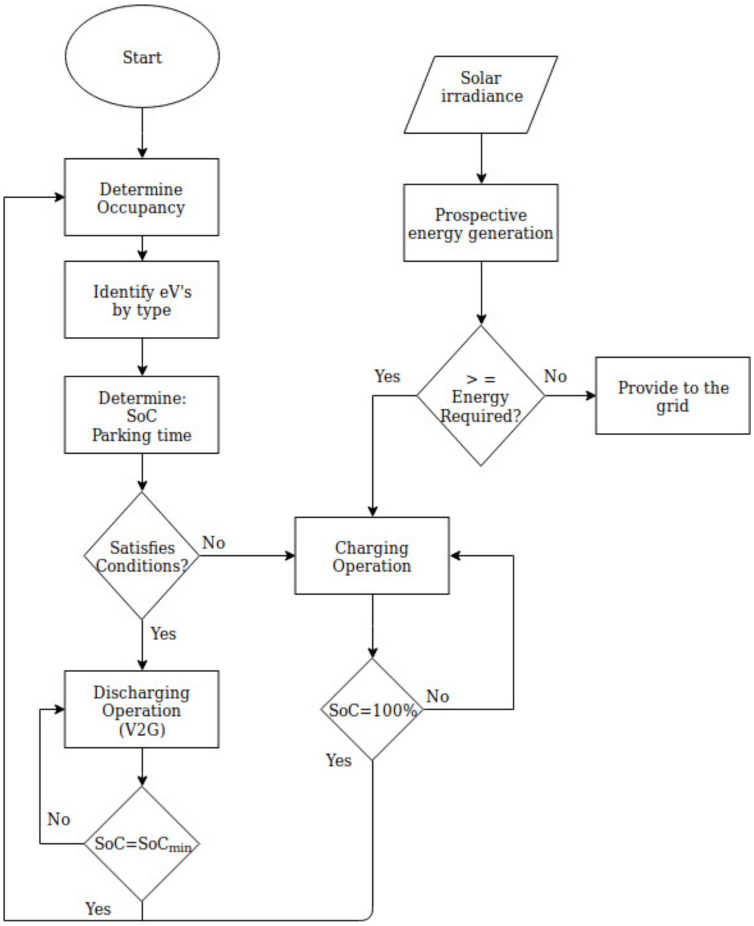

Figure 3.16: V2G Implementation algorithm

3.1.10.1 Description of the algorithm

- **Determine Occupancy:** As described before, the owner of the user is stochastic, so the occupancy of the facilities is a casual variable, modeled according to the normal distribution described before.

- **Identify Vehicle type and SoC:** After having identified the occupancy, it is also necessary to determine the type of vehicles present and their associated state of charge. In that way, it is possible to calculate, both the energy necessary to charge the fleet, and if the vehicles satisfy the conditions to perform V2G operation.

- **Charging operations:** If a vehicle doesn't comply with the established conditions to perform V2G, then is marked to be charged. The charging operation chooses between the PV installation or the electric grid, depending on the energy levels produced at the corresponding time of the day. The algorithm should also determine, in function of the state of charge and the time of the day, if it uses the normal charging power or the fast charging power of the vehicle.

- **Discharging operation (V2G):** If a vehicle satisfies the conditions to perform V2G, the algorithm should decide to perform such an operation or not depending on the time of the day. This discharge operation will be performed until the vehicle reaches a minimum state of charge, guaranteeing always the use of the vehicle.

There is another important factor to be considered in the V2G scheduling and so in the algorithm as described in [45] and [49]. The different energy prices along the day are an important differentiating factor and also the main way to monetize the scheduling scheme. Is then very important to know the different tariffs in the place where the installation is going to be operative.

As it can be evident, the higher energy prices correspond to the hours where the demand is maximum or has a peak, while the low tariffs correspond to the time of the day where the demand is minimum or very low, while in the hours where it remains more or less constant there is a medium tariff.

[49] Proposes a different version of the algorithm, validating the one proposed in this document, as it has the same inputs and have the same considerations, but add an extra loop considering the cost of charging the vehicles at a given time, dividing them into three priority groups.

In figure 3.17 can be seen the different inputs, considerations, conditions and constraints. There are two main differences between the two versions of the algorithms. The first one as explained before, is an added constraint referring to the cost of the energy, while the second one, is that in [49] there is no consideration of photovoltaic systems integrated to the scheduling scheme.

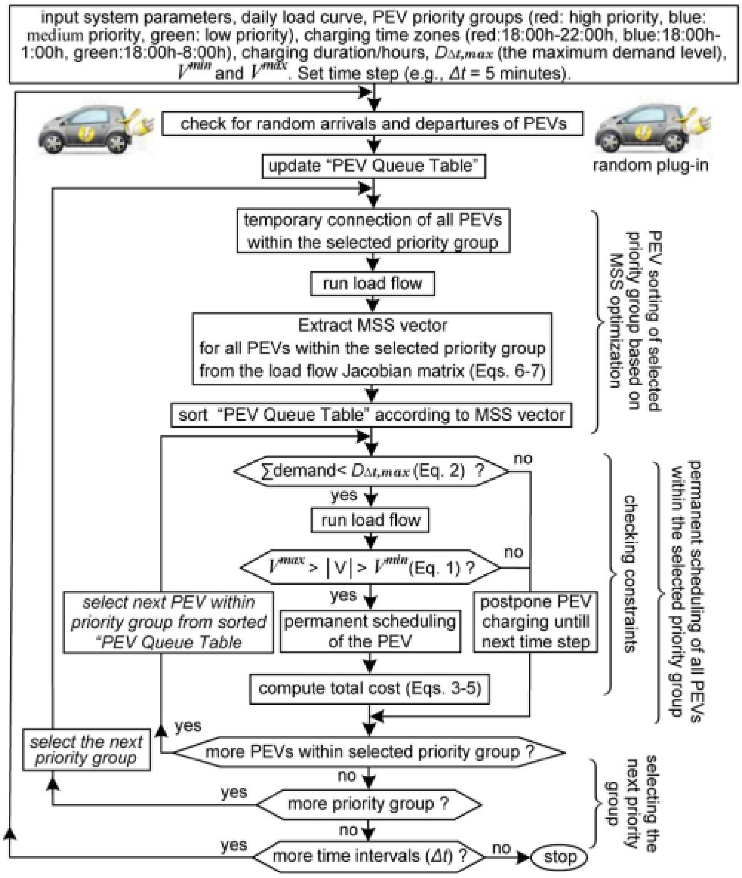

Figure 3.17: V2G Scheduling algorithm considering energy cost [49]

Conclusions

The implementation of an optimal schedule algorithm reduces the operation cost, current peaks and voltage drops within the distribution network. The algorithm is able to satisfy both grid's and internal restrictions in order to guarantee a correct operation of the electrical appliances and protect the power grid and the vehicles present. Is able as well to determine if is necessary or not to boost the charge of the vehicles by applying a fast charge depending on the time of the day and the cost of energy, evaluating casual variables at the same time.

The levels of solar radiation and so the levels of energy production changes with the location and have a certain associated probability. Although it is possible to produce quite large amounts of energy using this technology during the year, the daily levels are not high enough to supply a relatively big fleet of electric cars. The energy available from PV generation could be then used to charge a small portion of the fleet or to supply the local electric appliances.

As the current situation of the parking lots studied, didn't include any of these features, the photovoltaic systems can be implemented to supply a first pilot project of electric cars, performing as well, V2G. The daily available power is enough to supply some units or the electrical appliances of the parking lot as stated above.

Even if the fast charge power, allows to perform the operation in a very short time compared with the normal charging power, its continuous use is not possible, since the higher the charging power, the higher the impact on the life span of the battery and so, more difficult to incentive the owners to allow the V2G operation.

As for the V2G features, it is clear, that a no so large fleet of cars is needed to change the shape of the demand curve. In the best case scenario analyzed, the prospective available energy from just one installation, can produce around 3 MWh. If this result is extrapolated to a macro scale, all over the Italian territory, it is clear, that a real possibility on changing the demand patterns and relieve the grid, are possible just by implementing this features.

As the size of the installation grows, the probability of having bigger numbers of cars connected to the grid at some point of the day increases considerably, increasing as well the reliability associated to V2G plants, which are very stochastic so far.

The biggest challenge at this point for the implementation of V2G technology, not just in Italy, but all over the world, is to find right policies and monetizing schemes, to incentive the EV's owner to connect their vehicles and to allow the operator to perform such activities, having into account the reduction of life span of the batteries as well as the possibility for the user to find its vehicle with low battery levels at a given point during the day.

Appendix A

List of variables

- $f(y)$**:** log-normal probability density function
- σ_y**:** log-normal standard deviation
- μ_y**:** log-normal mean value
- σ_x**:** original data standard deviation
- μ_x**:** original data mean value
- $F(y)$**:** log-normal cumulative probability
- $R(y)$**:** log-normal reliability function
- $P_{ph,n}$**:** Nominal power of the PV panels
- G_{std}**:** Standard solar radiation value
- R_c**:** Reference radiation point
- P_p**:** Peak power
- d**:** Total days in a given month
- t**:** Daylight hours in a month
- P_i**:** Power value obtained at certain instant of time
- E_t**:** Total energy production
- E_m**:** Mean energy production
- E_i**:** Energy required to charge the vehicle
- E_{tc}**:** Total energy required to charge an entire fleet
- C_i**:** Battery capacity of the vehicle

- SoC_i: State of charge of each vehicle
- τ_c: Charging process time constant
- N_i: Available number of cars
- P_c: Charging power of each EV
- E_{V2G}: Total energy available for V2G
- τ_{V2G}: Discharging process time constant

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