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Modelling and analysis of Vehicle-to-Grid Technologies for Power Quality improvement

Supervisor

Prof. Dr. Michela Longo

Candidate

Mohammed Khalil Bendraz – 941073

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Abstract

The transition toward Smart Grids concept promoted the increased reliance on renewable energy sources and Electric Vehicles. Through such concept, and with the help of EVs, it becomes possible to enhance the Power Quality (PQ) of the grid by delivering the energy stored in batteries on-board EVs into the electrical network through Vehicle to grid (V2G) functions. V2G technology's aim is to provide the electrical grid with the surplus of energy stored in EV batteries in order to stabilize the grid, and to compensate for the PQ disturbances that occur in the network and may damage the appropriate function of the loads connected to the electrical network. In this work, an analysis of the PQ events is provided, as well as, a detailed study of the features of each parking area that can be a prospective candidate to host EV charging stations in order to assess the feasibility of V2G in each parking area is made. In addition, we will present two MATLAB/SIMULINK models adopted to simulate the V2G and G2V operations. The first model is a simulation of typical three-phase electric vehicle charger that enables V2G and G2V operations, while the second model is a 24-H simulation of a V2G system adopted in order to assess the feasibility of V2G functions for each scenario.

Key words: Vehicle-to-Grid (V2G), Power Quality (PQ), Smart Grids (SGs), Mobility-as-a-Service (MaaS), Voltage Dips, Electric Vehicles (EVs).

Sommario

La transizione verso il concetto di Smart Grid ha promosso la maggiore dipendenza dalle fonti di energia rinnovabile e dai veicoli elettrici. Attraverso tale concetto, e con l'aiuto dei veicoli elettrici, diventa possibile migliorare la Power Quality (PQ) della rete fornendo l'energia immagazzinata nelle batterie a bordo dei veicoli elettrici nella rete elettrica attraverso le funzioni Vehicle to grid (V2G). L'obiettivo della tecnologia V2G è fornire alla rete elettrica l'eccedenza di energia immagazzinata nelle batterie dei veicoli elettrici al fine di stabilizzare la rete e compensare i disturbi PQ che si verificano nella rete e possono danneggiare il corretto funzionamento dei carichi collegati alla rete elettrica Rete. In questo lavoro viene fornita un'analisi degli eventi PQ, nonché uno studio dettagliato delle caratteristiche di ciascuna area di parcheggio che può essere un potenziale candidato per ospitare stazioni di ricarica per veicoli elettrici al fine di valutare la fattibilità del V2G in ciascuna area di parcheggio è realizzato. Inoltre, presenteremo due modelli MATLAB/SIMULINK adottati per simulare le operazioni V2G e G2V. Il primo modello è una simulazione del tipico caricabatterie trifase per veicoli elettrici che abilita le operazioni V2G e G2V, mentre il secondo modello è una simulazione 24 ore su 24 di un sistema V2G adottato per valutare la fattibilità delle funzioni V2G per ogni scenario.

Parole chiave: Vehicle-to-Grid (V2G), Power Quality (PQ), Smart Grids (SGs), Mobility-as-a-Service (MaaS), Voltage Dips, Electric Vehicles (EVs).

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Glossary:

ANSI: American National Standards Institute
BEV: Battery Electric Vehicle
BTM: Bus Tram Metro
CCS: Combined Charger System
CESI: Centro Elettrotecnico Sperimentale Italiano
DSO: Distribution System Operator
E-REV: Extended Range Electric Vehicle
EV: Electric Vehicle
EVSE: Electric Vehicle Supply Equipment
FCEV: Fuel Cell Electric Vehicle
G2V: Grid-to-Vehicle
ICE: Internal Combustion Engine
ICT: Information and Communication Technology
IEC: International Electrotechnical Commission
IEEE: Institute of Electrical and Electronics Engineers
ITIC: Information Technology Industry Council
MaaS: Mobility-as-a-Service
PHEV: Plug-in Hybrid Vehicle
PLL: Phase-Locked Loop.
PQ: Power Quality
QOS: Quality of Service
SAF: Shunt Active Filter
SAIDI: System Average Interruption Duration Index
SAIFI: System Average Interruption Frequency Index
SEMI: Semiconductor Equipment and Materials International
SG: Smart Grid
SoC: State Of Charge
THD: Total Harmonic Distortion
TSO: Transmission System Operator
V2G: Vehicle-to-Grid
VIGIL: VehIcle to Grid Intelligent Control Platform
UPQC: Open Unified Power Quality

Introduction:

Recently, Electric Vehicles (EVs) have received an increasing attention, as the rapid development of EVs technologies is regarded as a trigger to rely on EVs in the near future. Environmental and social issues such as pollution and harmful CO2 emissions caused by the excessive use of ICE cars are the main key factors leading to the adoption of Electric cars as the most appropriate, sustainable and clean alternative for ICE driven vehicles in the near future. This is driven mainly by the improvement in battery cell technologies that certainly will lead to enhance the performance of the Electric Vehicles in terms of long periods of driving with only one charge a day, as well as the capability of the battery to withstand extreme hot or cold weathers. In addition, the increase reliance on Renewable energy sources to provide energy to the electrical grid is a key factor leading to adopt more sustainable and green vehicles fully powered by clean energy. Therefore, the aim to eliminate harmful pollutants as well as reducing CO2 and greenhouse emissions will certainly be reached effectively relying on e-mobility as well as powering the grid with renewable energy sources.

Nevertheless, the low number of charging stations compared to the high numbers of EVs circulating in the streets is the main concern and can be a hurdle temporarily by slowing down the process of reaching a fully electrified fleet of vehicles in our roads. Thus, establishing more charging stations aiming to serve the high demand of energy from Electric cars connected to the grid will definitely enhance and facilitate the charging process within the charging stations and mitigate the traffic congestions caused by the long waiting times inside the charging stations.

With the establishment of Smart Grids as a new concept transforming the electrical power grid. The islanding operation has emerged as a brand-new idea that is elaborated aiming of supplying a micro grid with sufficient energy provided by local generators and storage. Thus, with the deployment of high numbers of Electric Vehicles into the SGs, electric cars are able to provide ancillary services to the electrical network and they can act as a backup source of energy helping the grid dealing with the high demand of energy from the connected loads. Electric Vehicles can be regarded as a flexible energy supplier, i.e., auxiliary source of energy, and a storage of distributed energy. The additions that EVs will offer to the electric grid would be possible with advanced communication, metering and control techniques. Hence, smart grids will encourage the incorporation of EVs into the electric grid.

Moreover, due to the unprecedented renewable energy sources penetration in smart grid, Power Quality (PQ) has received in an increased attention, as it considered an important key factor in the power systems engineering domain. PQ events such as voltage dips, although they are characterized with short durations, they are capable of degrading the continuity of the service either for affected loads or in the utility mains, and may cost the operators a loss of high amount of money. Therefore, it is mandatory to assess the severity of the occurred PQ events in order to know the exact origin of different voltage dips and then create a mitigation plan performing immediately after the occurrence of an undesired event. With a feasible method to reduce the hazards on the grid due to PQ events, the electrical grid will be able to guarantee a good quality of power delivered to end-users.

For better use of Electric Vehicles within a smart grid context, efficient charging strategies and communication technologies are needed for a safe and reliable charging process. Through Vehicle-to-Grid (V2G) technology, EVs can interact with the grid and feed the electrical network with the surplus of energy stored in their batteries in order to help the grid withstanding additional peak demand of energy as well as mitigating severe power interruptions, outages, and avoiding blackouts. Through V2G, a bi-directional flow of energy between the electric grid and the electric car is made possible. The ancillary services provided by EVs are able to compensate for the PQ events occurring continuously in the grid, i.e., stabilizing the active power and compensating the reactive power of the electrical network.

Knowing the exact number of EVs contemporaneously connected to the grid is mandatory in order to know the amount of power that EVs can inject in the grid taking into consideration that EVs must leave the charging stations with a fully charged battery. In our work, we will perform a probabilistic analysis and assume how many EVs are needed in each charging station situated in various parking areas. In addition, the assessment and analysis we will make for voltage dips occurred in different territorial zones will help us to know the eligible events for compensation process.

The need for high numbers of EVs connected in the same time to the grid and providing enough energy to the network is mandatory in order to guarantee the continuity of the power flow and withstanding the high demand of energy from industrial and residential loads. With the number of EVs nowadays up and running in the roads, it is difficult to guarantee such operations continuously. Therefore, the solution can be provided by the Mobility-as-a-Service (MaaS) concept. MaaS is an umbrella term combining several transportation means, mainly Electric Vehicles that area now mandatory in every car-sharing fleet. The car rental companies are providing electric cars for their customers in order to execute duties that last for a short period, particularly within urban areas. Taking into account that EVs spend most of their times parked in charging stations, it is beneficial that car rental companies provide large EV fleets to their customers and can be driven anywhere with a prerequisite of plug-it in a charging station after the end of the trip. MaaS concept is feasible and can promote the reliance on V2G to provide energy to the grid in order to withstand the high demand of energy from the connected loads.

The rest of the work is structured as follows: the first chapter is a general overview of the Smart Grids, electric vehicles, Mobility-as-a-Service (MaaS), Power Quality (PQ) and Vehicle-to-Grid (V2G) concepts. In the second chapter, a literature review of both V2G and MaaS is provided. The third chapter presents the statistical analysis and classification of Voltage dips, as well as the assessment of the prospective parking areas eligible for hosting charging stations. In the fourth chapter, a detailed description of the models adopted for the V2G concept is provided. Finally, the fifth chapter presents a discussion of simulation results in order to rate the feasibility of implementing V2G functions in different parking areas containing EV charging stations.

1. General Overview:

1.1. Smart Grids:

As the need for new forms of power generation grows, the aim to meet this need with future plans for energy production has become inevitable, meaning that the new forms of power generation and energy distribution should be as clean as possible. Thus, wide research efforts are being made to reconcile power generation technologies with international targets for the environment.
However, the technical challenges involving the distribution of electricity remain relatively the same for Energy, since there should always be a balance between the energy produced and the energy consumed all along the different dots on the power grid.
In this context, Smart Grid has emerged as a new concept for transforming the electric power grid by using advanced automatic control and communications techniques within the supply chain. This system is basically a Two-way digital based electrical network that reduces the unnecessary energy consumption to make it available for all the consumers connected all along the supply chain.
Moreover, this concept complies perfectly with the shift to the production of renewable energies since it advocates decarbonisation, lower energy costs, and larger energy capacity to support renewable energy sources.
The purposes of Smart Grid's design are to enlarge the power system performance, to create controllable assets, security and reliability and decrease operations costs.

- ✓ Application of Smart Grid:

Smart grids are utilized in many fields to provide optimal solutions for many electrical energy production and distribution limitations such as:

- Shortage of power.
- Inefficient Power consumption.
- Power theft.
- Predictable power and voltage fluctuation.
- Power factor degradation.
- Limited access to electricity in some areas.

- ✓ Benefits of Smart grids:

  - Having flexible topology.
  - Lower greenhouse gas.
  - Self-healing
  - Decentralization of control services.
  - Bidirectional communication.
  - Paving the road for electric vehicles.

- ✓ Research activities on smart grids:

In the following some of the recent research programs on Smart Grid definition, design and applications [66]:

-IntelliGrid: launched by EPRI (Electric Power Research Institution), the idea behind this project is to efficiently use the energy flowing in the electric grid.
This program aims to create a solid technical basis for Smart Grids that link electricity with communications and computer control to enhance customer services.

This program aims to create a solid technical basis for Smart Grids that link electricity with communications and computer control to enhance customer services.

-Grid Wise: Initiated by the Department of Energy and industry contributors, established on the idea that a elementary conversion of a power system to an intelligent, self-healing and flexible network with market-based structures for elaborating profits at all levels of the system requires information, communication and control technologies in the whole system.

-SG program: Established by the European Technology Platform in 2005. This program states that the European electricity should meet the demands of customers; also, it should be adaptive to renewable energy sources, providing high security.

- ✓ Smart grid components [2, 6, 66]:

To build such a smart and innovative system, numerous parts need to be incorporated such as energy infrastructure, processes, devices, information and markets into a coordinated and collaborative process that allows energy to be generated, distributed and consumed more effectively and efficiently.

In addition to that, many technologies are being employed within Smart Grid, the most notable are:

Self-Healing: A self-healing smart grid can automatically identify typical problems and quickly rectify them in case they occur. This technology minimizes downtime and financial loss.

Demand Response: In order to match the demand for the power with the available supply in an optimal way, a change in the power consumption needs to be made; this process is known as Demand Response.

Electric Vehicles: Since reducing our carbon footprint is one of the major problems tackled by Smart grids, electric vehicles fit perfectly for this aim, as they have become the main road transportation means as well as an ecological and sustainable substitute for the conventional cars we have nowadays.

Cyber Security: This technology is compulsory for the development of the grid and the processes and components within it. Due to the fact that SGs use advanced communication technologies to connect the entities of the grid. A safe, fast and reliable communication is compulsory for a safe transfer of sensitive data between operators and consumers.

Sensing, Measurements:

Multiple sensors are utilized to record and monitor the performances of the power grid; measurements are periodically made in a form of diagnosis to make sure that sensors are giving coherent results. Measurements are critical to make sure that the grid performance in terms of power stability matches the power quality, power losses and power efficiency standards and requirements. Furthermore, the large number of measurements to be processed should go through quick communication channels in order to give timely responses in case something does not go right.

Control and Automation:

The complexity of smart grids justify the usage of sophisticated control techniques to manage simultaneously all the services and processes taking place within the grid. The tasks can be divided into two categories: a first category of repetitive predictable tasks and another category of random and sporadic tasks. As for the first one, automation is the right way to manage it; however, the second type of tasks is delicate to deal with and needs a merging between advanced control techniques, neuronlike and artificial intelligence to provide a solution for each specific task.

- ✓ Smart grid's impact on power quality [1 - 6]:

Currently, distributed energy resources, especially the renewable ones present a significant problem. In other words, the characteristics of the produced energy are not stable as they fluctuate permanently, and in the renewable energy cases, they depend on external and uncontrollable parameters.
This instability makes them not suitable for direct connection to the electrical network and subsequently need to be rectified by the power electronics set in a SG.

1.1.1. Future Plans of SGs:

The need for smart, decarbonized and efficient energy is imminent now more than ever.
Thus, in the near future we expect to witness the presence of smart grids around the globe.
For this purpose, numerous expansion plans are expected to trigger investments:
In the Net Zero Emissions by 2050 Scenario, the level of grid investment triples by 2030, especially for digital investments and smart grids, which should account for around 40% of total investments in this decade [2 - 4, 7, 66].

Electrical grid investments were expected to reach ~USD 290 billion in 2021, as they were recovering from 2020's pandemic when the funding for the electric sector took a remarkable drop in many countries, especially China. However, 2021's investment topped the 2019 level of ~USD 270 billion to reverse the falling trend. [2, 7, 66].

Before expanding on future plans, let us get a closer and brief look at the state of investments in the electric sector before this year. The 2020 pandemic did not only put our health on the line, taking the life of hundreds of thousands of people around the world, but it has compromised the economic wheel. As a result, ongoing schemes such as smart grids took a hard hit since the investments in electricity networks in countries, where the pandemic weakened the financial situation of energy distribution companies dropped 15% in 2020, to 60% of the 2016 level. [2, 7, 66].

In addition to that, in Europe, grid expansion plans for 2022-2030 provide the basic structure to increase investments, since they are supported by solid economic programs. According to the European Commission's 2030 climate ambition plan released in September 2020, an amount of USD 70 billion is foreseen as investment during 2022-2030. [66].

In the USA, the proposed American jobs scheme includes plans to build a more resilient electricity system in order to achieve carbon free electricity production by 2035. Such measures emphasize on the importance of regulations to mobilize network investments by encouraging connections to the grid, especially for renewable energy projects; boosting up response time; and simplifying procedures to make public land available for electricity infrastructure [66].

The digital revolution in Economy is also reaching the electricity sector as the number of governments, utilities and manufacturers embracing digital technologies is growing tremendously: They utilize them to deploy smart meters, digital substations, smart EV charging infrastructure and also for software solutions such as artificial intelligence [66].

In this scenario, the need for hour-to-hour flexibility in 2050 is four times higher, with batteries and demand response systems providing around 50% flexibility services. However, these solutions would not have much effect on flexibility services without smart grid technologies, for which funding must increase sharply: annual electricity network investments need to nearly triple to an average of almost USD 800 billion by the late 2020s. [66].

Hence, It will be essential to expand, modernize and digitalize electricity networks to pool all available flexibility resources to support the Net Zero Emissions by 2050 Scenario’s rapid low-carbon electricity supply transition.
Moreover, in this scenario, the need for hour-to-hour flexibility in 2050 is four times higher, with batteries and demand response systems providing around 50%. [66].
However, these solutions will not be able to provide flexibility services without smart grid technologies, for which funding must increase sharply: annual electricity network investments need to nearly triple to an average of almost

USD 800 billion by the late 2020s, and investments in digital assets must increase eightfold, at more than twice the speed of total investments in transmission and distribution.
These investments – in assets and software to support smart metering, network automation, EV charging and other applications – should combine connectivity, interoperability and cyber-security, leveraging the internet of things to enhance electricity system management while making utilities' decision-making more informed and efficient. [2, 7, 66].

1.1.2. Integration of EVs in SGs:

- ✓ Electric Vehicles:

EVs are the favored means of transportation for the near future and an evident result of the modernization of the transportation industry. EVs are also the promising solution to global warming issues. The emergence of plug-in electric cars as a subset of battery electric vehicles and plug-in hybrid vehicles is the triggering point to integrate EVs in the smart grid. However, this process is not as simple and smooth as it might sound. An EV connected to the power grid is considered as a regular load; as a result, it is capable of modifying slightly and sporadically the electric network nearby. This suggests using a flexible energy supply management system in order to control the load varying flexibility [3 - 7].

- ✓ Smart grids and EVs:

Taking into consideration the advanced features of Smart grids, such as smart metering, advanced control methods and communication, EVs can play both roles, a flexible energy supplier and a storage of distributed energy. As a result, Smart grid technologies will allow an energy exchange between EVs and power networks.

The technology by which this connection is made is mostly known by Vehicle to Grid (V2G). It refers to the management and control of EV loads by power aggregators or utilities via the communication between EVs and the power grid.
V2G technology can be categorized into unidirectional and bidirectional:

As for the unidirectional, it uses communication techniques between the grid and the electric vehicle to access the charging rate of the EV's battery. Since unidirectional V2G is a one-way technology, the power grid could use it to charge the EVs connected batteries to prevent grid overloading. Subsequently, EV's battery is considered as load or an energy storage from the point of view of the grid.
Thus, bidirectional SGs uses unidirectional principles in both ways, to overcome the grid's overload by evacuating the excessive energy into EVs batteries or for grid support. [3 - 7].

- ✓ EV integration impact on power grid :

The deployment of the EVs into the smart grid can provide many ancillary services to the grid such as reactive power support to improve the operational efficiency, regulating the voltage and frequency and securing the power grid. The additions that EVs will offer to the electric grid would be possible with advanced communication, metering and control techniques. Hence, smart grids will encourage the incorporation of EVs into the electric grid. [3].

- ✓ EVs impact on Power quality & Instability:

Fundamentally, non-linear current consumption of electric current in some types of loads such as R load, RL load influences notably the power quality of the grid. As a result, harmonic distortion can contribute to existing grid issues such as imbalanced operation, reactive power flows and network losses and poor voltage regulation. Considering those, EVs, which are considered as loads from the grid standpoint, should not introduce more power quality losses. However, since EVs are most likely to introduce a tremendous amount of harmonics into the electric grid. A large number of EVs connected to the grid will subsequently increase the introduction of harmonics into the power system, especially during peak hours. [3 - 7].

1.2. The shift to Electric Vehicles (EVs):

The transition from fully driven internal combustion engine vehicles (ICE) or partially driven ICE cars, i.e., Hybrid electric vehicles to fully driven electric vehicles (Battery electric vehicles) is happening worldwide at a fast rate. As the Electric vehicle is growing rapidly, car manufacturers are emphasized that by 2040, EVs will contribute with an approximate 54% of the total sales in the car market [53].

Government leadership and incentives, EV market maturity and readiness as well as the EV charging infrastructure are the key catalysts driving and moving EV adoption into the fast lane.

One of crucial and challenging aim for the European Union is to reduce 80% of the greenhouse gas emissions by 2050. As the transportation sector, mainly road transport is growing year after year, it is considered as the main pollutant and the major source of CO2 emissions. Therefore, regulations have been set to curb the road transport impact on the environment. These regulations considered the transition from ICE vehicles to a clean, green and sustainable alternative, i.e., Electric Vehicles (EVs) [53].

However, without a transition to renewable energies as a source of energy for EVs, the environmental aspirations will be unmatched the sooner. Therefore, Electric vehicles, when powered with renewable energy resources are able to provide significant reduction of greenhouse gas emissions.

A major issue that could be a hurdle to the adoption of the EVs as a clean substitute to ICE cars is the overload of the electrical network that could lead to the use of fossil fuels to compensate the need of the grid. The majority of EV owners mainly choose the evening to charge their vehicles. Therefore, the high number of vehicles connected in the same time into the grid will definitely rise the electricity demand to the utmost level. Consequently, power plants will use fossil fuels to meet the high demands of electricity, resulting in CO2 emissions. Thus, with the concept of Smart grids, EVs turned to be as an auxiliary source of energy to the grid. Through Vehicle to grid (V2G) functions, the EV can feed the grid with the surplus of energy stored on-board their batteries. This will improve the performance of the grid facing the high demand of electricity not only from vehicles that need to charge their batteries but also from the residential and industrial loads. With this cut-edge technology, EV batteries are able to stabilize the active power and compensate the reactive power. In addition, charging stations can be used as a compensator as they receive power from EV on-board batteries and transfer it to the electrical network.

1.2.1. The different types of EVs:

Electric vehicles are classified into several types, each one of the will be described in details in the following.

- ✓ Battery electric vehicles (BEV): They are also called "all-electric vehicles" or "100% pure electric vehicles" since they are powered by electrical energy storage only, which is a rechargeable battery. In other words, BEVs are propelled by an electric motor drawing energy from the on-board battery energy system. The battery is recharged by connecting the vehicle to the grid and/or through regenerative braking system. This type does not have an ICE used as a backup in case of a fully discharged battery. BEVs are considered zero emission vehicles.

  The BEVs driving range is considered between 150 Km and 400 Km. With the development in Battery technologies, the range can be extended further.

  Due to the increase of on-board battery capacity, and government regulation requirements, the growth BEVs is expected to be faster than ever. [54, 57, 64].

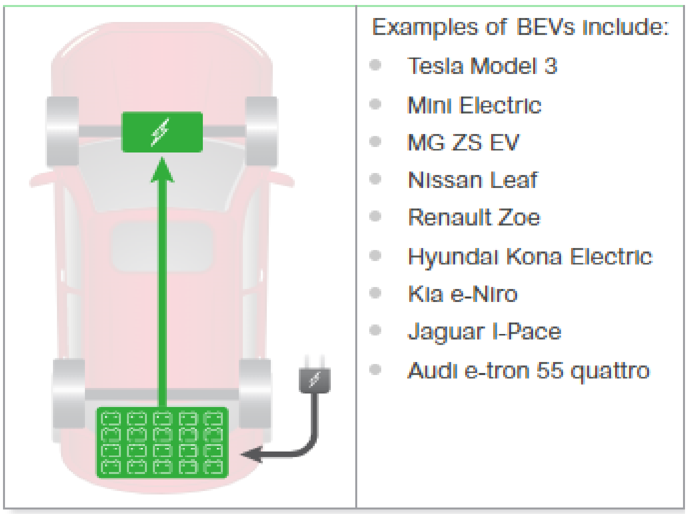

Figure 1 : Battery Electric vehicle [54].

- ✓ Plug-in Hybrid Electric Vehicles (PHEV): This type of EV can be recharged by either plugging the vehicle to an external energy source, or by a petrol/diesel engine. Therefore, a PHEV an engine and electric motor that both can drive the car. Regenerative braking

system can also be used to recharge the battery of a PHEV. In comparison to a regular HEV, a Plug-in Hybrid Electric Vehicle has a larger battery with the capability to plug-it into the grid.
Not only the battery size increases but also the driving range is extended for this type compared to HEV. In other words, using its battery power, a PHEV can drive for an average distance between 30km and 50km before its diesel/petrol engine takes over.
An advantage for PHEVs is regarding the cheaper energy cost since the energy produced by the mains is lower than the one produced on-board. However, most PHEVs do not support fast charging.
Moreover, the battery capacity of a PHEV is considered smaller than that of 100% electric vehicle. [54, 57, 64].

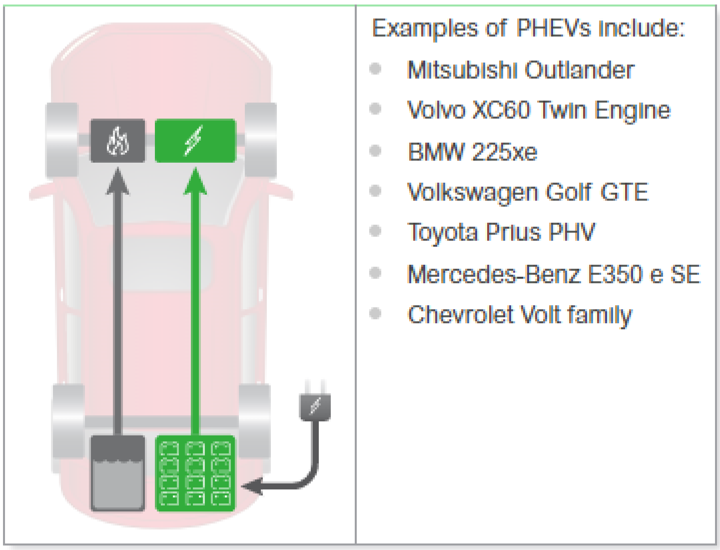

Figure 2: Plug-in Hybrid Electric Vehicles (PHEV) [54].

✓ Hybrid Electric Vehicle (HEV): this type of Electric Vehicle contains both ICE and an electric motor, and both used simultaneously or separately to drive the car. The batteries can only be recharged by a regenerative braking system, which regains the energy lost due to braking to support the diesel/petrol engine during the acceleration. Unlike PHEVs, HEVs can travel at low speed for only a distance between 2km and 4km, after that the diesel/petrol engine turns on. [54, 57, 64].

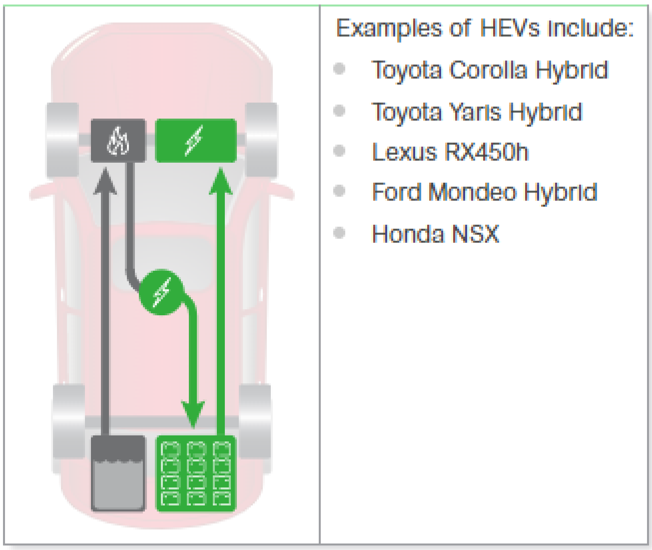

Figure 3 : Hybrid electric vehicle [54].

- ✓ Fuel-Cell Electric Vehicle (FCEV): This type of Electric vehicle is powered by the electric energy that is produced on-board by a fuel cell generator instead of electrical energy stored on the battery. The fuel cell generator produces energy mainly by using oxygen and hydrogen as primary sources. The high cost, short life of fuel cell, and the difficulties in storing hydrogen safely on-board are the main hurdles why FCEVs have only a small share (<1%) in terms of EV production. [54, 57].

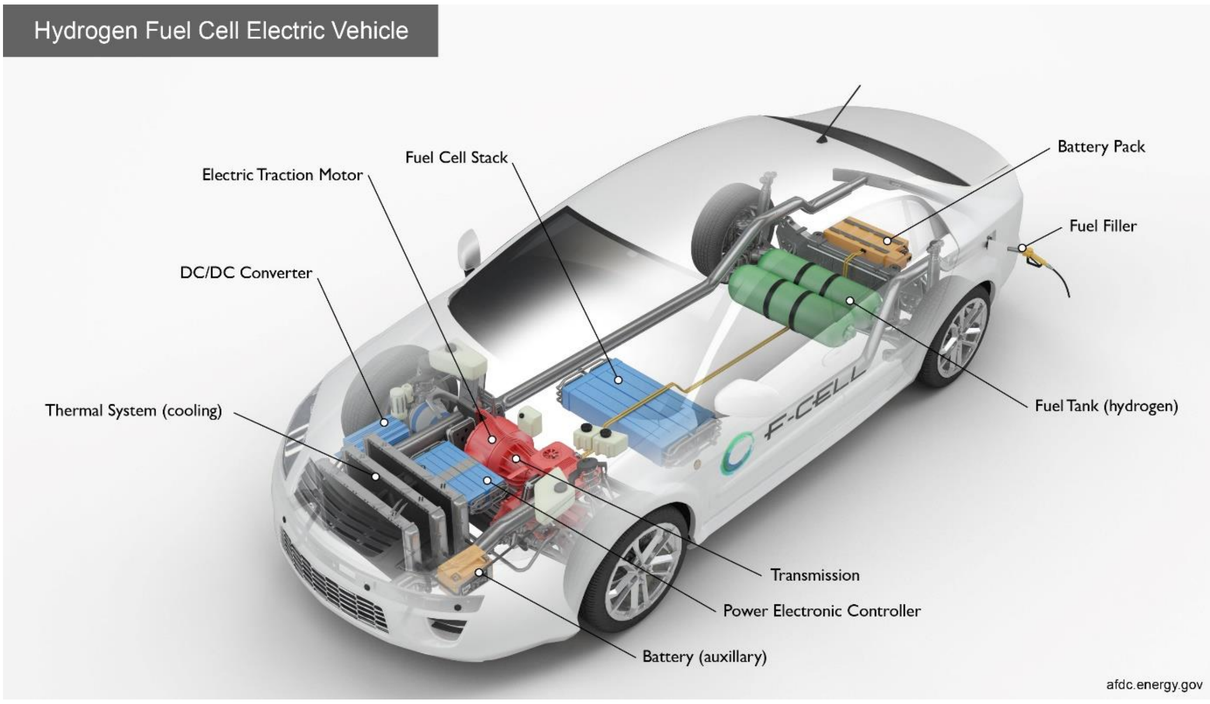

Figure 4 : Fuel-Cell Electric Vehicle (FCEV) [54].

- ✓ Extended Range Electric Vehicle (E-REV): this type of EV runs only on electric power. Yet a small ICE can be used as an auxiliary power unit to extend the range of the vehicle by providing energy to the battery when needed, i.e., when charge drops below a specific level, the ICE becomes able to charge the battery to extend the driving range of the car. [54, 57, 64].

  Since the vehicle runs only on electric power, performance and acceleration of the vehicle are improved.

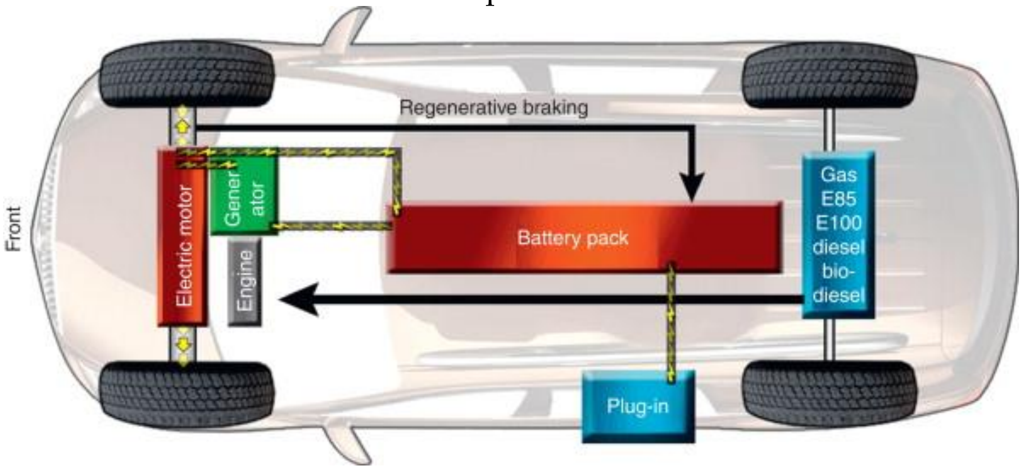

Figure 5: Extended Range Electric Vehicle (E-REV) [54].

1.2.2. Charging modes of EVs:

The international standard ICE 61851-1 defines four modes of Electric Vehicle charging, each of which will be discussed below.

- ➢ Mode 1: Standard socket outlet – domestic application: In this mode, the electric vehicle, through a standard socket-outlet is connected to an AC supply network. According to IEC 61851-1, the rated values must not exceed 16 A and 250 V AC, and 16 A and 480 V AC for single-phase and three-phase installations, respectively. Due to theses power limitations, this mode is considered a slow charging mode as charging time takes several hours. [54 - 58, 64].

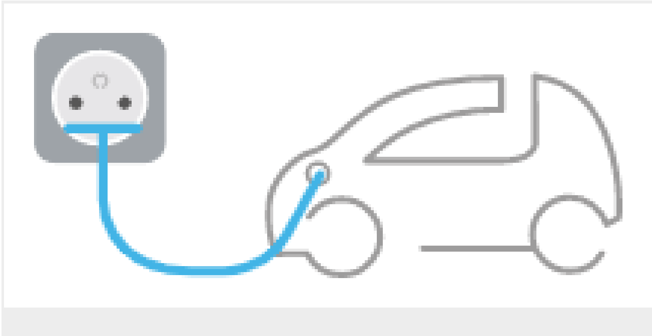

Figure 6 : charging mode 1 [54].

Mode 2: Standard socket outlet with AC EV supply equipment: In this mode, the electric vehicle is connected to an AC supply network via a standard socket outlet. A control pilot function and a system for personal protection against electric shock are integrated into the cable connecting the EV with standardized plug. As mentioned in IEC 61851-1, the rated values for current and voltage must not exceed 32 A and 250 V AC, and 32 A and 480 V for single-phase, and three phase, respectively. This mode is limited to domestic electric applications. [54 - 58, 64].

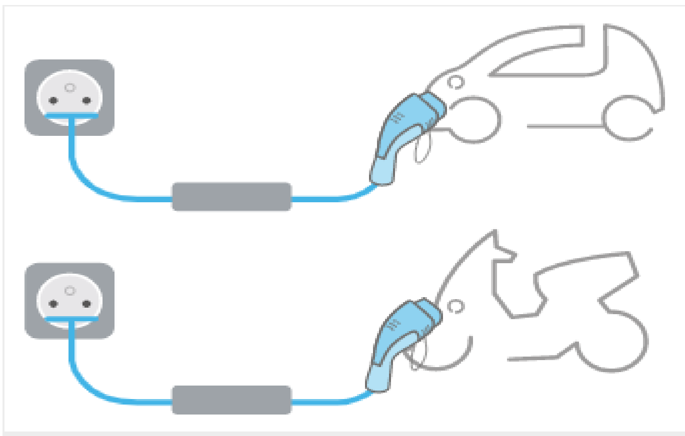

Figure 7 : charging mode 2 [54].

- Mode 3: AC EV equipment permanently connected to an AC supply network. In this mode, the EV is connected to an AC supply network using an Electric Vehicle Supply Equipment (EVSE), which integrates protection and control functions.

  Compared to previously mentioned modes, mode 3 uses instead a dedicated EV charger. Therefore, the power range is higher and spans from 3.7kW up to 22kW AC. This higher range of power enables fast charging of Electric Vehicles.

In addition to the communication between the vehicle and the charging equipment that is made through standard protocols. The pilot wire inside the charging equipment enables the implementation of several control functions, mainly are:

- Verification of the connection correctness between the EV and EVSE,
- The continuous verification of the integrity of the protective conductor,
- Energization as well as de-energization of power supply,
- Transmission of information regarding the maximum allowed current to draw.

Through mode 3, the safety of the property and people is guaranteed with the use of dedicated and independent electrical circuit, which eliminates the risk of an undesired communication with a non-compliant charging station. Furthermore, the control function in Mode 3 manages the charging period of the vehicle as well as it optimizes the electric energy consumption suitably to users' needs. In addition, batteries optimal charging and lifespan are ensured and preserved. [54 - 58, 64].

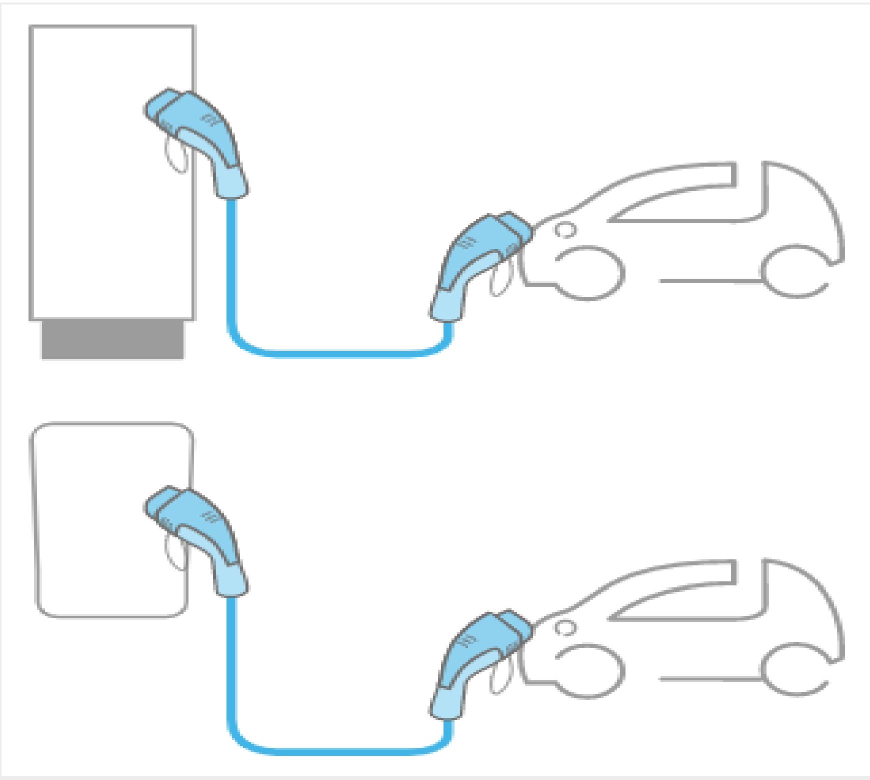

Figure 8 : charging mode 3 [54].

- Mode 4: DC fast charge: In this mode, the charging process is made through a DC EV supply equipment. The EV is connected to the AC network via an off-board charger. The EV charging station delivers power directly to the battery by-passing the on-board charger. In this mode, the EV charging process is much faster than the previous modes with an electric charging power range approximately equal to 24kW.
  The digital communication between the EV and the EVSE is paramount, as it should comply with the requirements set in IEC 61851-24 standard.
  Several rivaling connector standards are widely used in Mode 4, which are, the Japanese CHAdeMO, the European Combo 2 or CCS. The latter has been chosen as a standard to be used in charging stations in European Union. [54 - 58, 64].

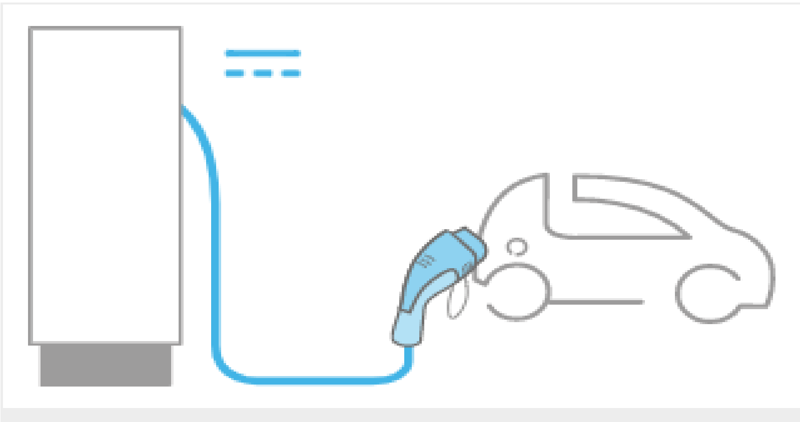

Figure 9 : charging mode 4 [54].

1.2.3. Electric Vehicles Connectors:

The charging station, charging cable and the on-board charger are the three main components to determine the charging speed for the charging process of an EV. In this part of the work, we will outline the different connectors used worldwide. As it is known, Charging cables can be divided according to the region where they are used the most. Nevertheless, it is mandatory to categorize them under AC and DC connectors. AC connectors are defined by IEC 62196-2, while DC connectors are defined by IEC 62196-3.

✓ AC connectors:

- Type 1 connector – SAE J1772:

The three large pins (similar to the power outlet layout at home) and the two smaller pin for the car connection make the J1772 connector easily identifiable. Phase, Neutral and Ground are the three broad pins, whereas, the two smaller pins are used for the communication between the charger and the EV (Pilot Interface).
This type can deliver a power between 3 and 7.4 kW and supports only single phase with a maximum current of 32 A. To avoid disconnection, an extra protection used to lock the connector while charging is adopted. Now, it is mainly used in Japan and USA.
This connector does not support a built-in automatic locking system, and only supports and used for one phase, which is the main advantage for this type. [54, 57, 64, 68].

Figure 10: Type 1 connector – SAE J1772 [68].

- Type 2 connector – Mennekes:

This type became the European Standard after the establishment of the new IEC 62196 in 2003. The connector has a rounded design with a flat edge on the top. It has the same pins distribution as type 1, but it includes two more pins used

as two extra phases that could be needed for three-phase charging.
Mennekes allows a recharge power between 3 and 43 kW and support both single phase and three phases up to 16 A and 32 A, respectively.
The new evolution T2-S of this connector includes additional lock to the connector. Nowadays in France, connector version T2-S is mandatory. [54, 57, 64, 68].

Figure 11 : Type 2 connector – Mennekes [68].

- GB / T Standard:
  This type is developed in China under the supervision of the Guobiao Standardization Commission, and currently it is the only charging connector used in the whole country. The figure below illustrates the pattern of this type and apparently, it is similar to Type2. Yet, the cables inside are reversely arranged, and therefore the two connectors are nor compatible. [68].

Figure 12 : GB / T Standard [68].

✓ DC connectors:

DC charging allows the Evs to charge their batteries faster than AC charging. In fact, there different charger topologies are used worldwide, which are SAE COMBO (CCS), CHAdeMO and Tesla supercharger.

- CCS (Combined Charging System) – Type 1 and Type 2:
  This type combines slow and fast AC, and ultra-fast DC charging in one single connector.
  The figure below perfectly illustrates the shape of this connector. In the case of DC charging, the two lower pins are participating for the charging operation and from the upper part, only the communication pin and the earth conductor are used in order to provide the reference point for the protection systems. CCS is the most popular and common type of DC connectors and it withstands power of up to 350 kW. CCS-Type1 is common in the USA, whereas CCS-Type 2 is widely used in Europe. [54, 57, 64, 68].

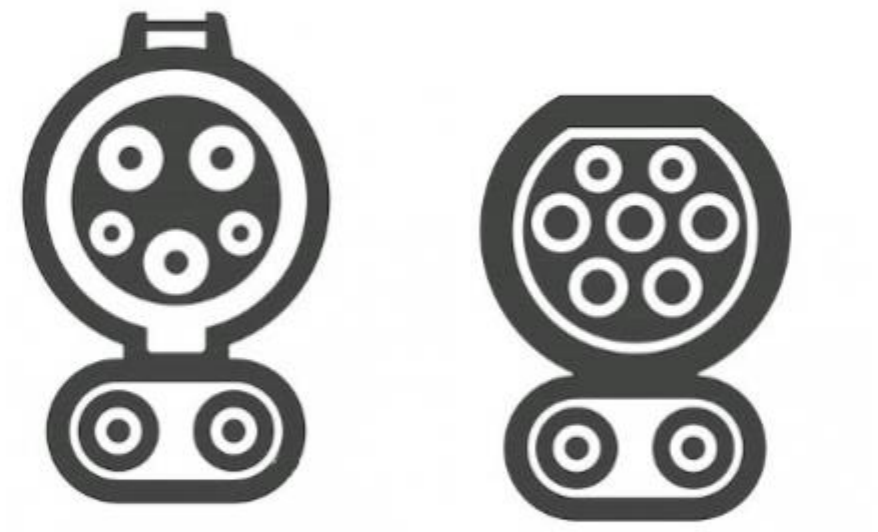

Figure 13: CCS (Combined Charging System) – Type 1 and Type 2 [68].

- CHAdeMO:
  This type is the original DC plug and was developed by five Japanese automakers. Since 2010, the developers of CHAdeMO strived hard to promote this plug as a global

standard. Their efforts partially worked, as the number of chargers with CHAdeMO connectors has been increasing and reaches 44900 chargers (7700 in Japan, 22500 in Europe and 8000 in North America, while 1000 elsewhere) installed in 96 countries as of March 2022.
CHAdeMO is able to deliver up to 62.5 KW and can reach 125 A, yet in 2018, the CHAdeMO Association introduced the 2.0 version of its connector, which allow a charging up to 400 kW. The CHAdeMO association is currently working with China to develop an ultra-fast connector capable of charging up to 900 kW ($600\,\text{A} \times 1.5\,kV$). However, following the European Parliament directive, electric car manufacturers are now abandoning CHAdeMO connectors, as only two electric cars with this connector are currently produced, and one them Nissan, is moving to CCS connectors. Therefore, only Japan and China will adopt this standard in the future. [54, 57, 60, 64, 68].

Figure 14 : CHAdeMO [68].

- Tesla superchargers:
  This type is a 480 V direct current fast charging technology and supports a power at maximums of 72 kW, 150kW or 250 Kw. Tesla operates over 30000 superchargers in over 2564 stations worldwide with an average of 9 chargers per station. There are 1101 stations in North America, 592 and 498 stations in Europe and Asia/Pacific region, respectively.
  Tesla offers adapters for other types of plugs to be used to charge tesla vehicles in stations with a Type 1 CCS or CHAdeMO plugs. [54, 57, 59, 64, 68].

Figure 15 : Tesla supercharger [68].

1.2.4. Charging infrastructures: a discussion.

Charging stations are undoubtedly linked to the adoption of electric vehicles in a large scale. As the EVs market is increasingly growing, charging stations are able to foster it or to be as a hurdle and slow it down. Authorities worldwide must adopt plans to spread EVs and to provide the access to charging stations for EV owners as well as EV fleet owners. Charging stations should be installed in areas where the access is easy, i.e., near homes and businesses, as well as along the roads to facilitate the traveling of EV owners.

Suitable charging stations are feasible for both EV owners and grid operators. From EV owners' perspective, location of the charging station, charging/discharging rates, availability of sockets, free and equitable access to the station are all contributing to the success of a journey as well as the adoption of an electric car. From the departure point, on route, until reaching the destination, Electric vehicle charging stations should provide reliable charging abilities to EV owners and they must meet with their requirements for a successful journey.

On the other hand, Grid operators are expecting from the smart grid concept to bring new improvements to the grid performance as the quality of power being delivered to end-users must be taken into account. In addition, the delivered power needs to be disturbances-free for the majority of the time to guarantee the continuity of the grid service and to feed the loads without interruptions.

The main grid improvement brought by Smart Grids is the integration of EVs through vehicle to grid concept to stabilize the electric network. First aim of buying an Electric car is to drive it to reach a specific destination and charge it when needed. Nevertheless, the emergence of V2G lead to the adoption of EVs to be used as auxiliary sources of energy to the grid, and to provide ancillary services to help the grid dealing with the high demand of energy, mainly during evening when more than 90% of the population are using electricity as well as it is the most preferred period for EV owners to charge their vehicle batteries.

With V2G, electric cars can feed the energy stored on-board to the grid through charging stations. In other words, charging stations are able to play a compensator device role as they can provide the energy drawn from EV batteries to the electric grid in order to compensate Power Quality disturbances that may occur in the electric network.

Moreover, the high number of charging stations being deployed in easy access areas with several charging modes as well as with considerable number of sockets will foster the adoption of EVs.

The lack of charging stations obliged the famous car rental company "share now" to substitute their EV fleet by ICE cars, and subsequently abandoned San Diego market in 2016 [61 - 63]. This was because most of cars are either in charging process or driven by other companies. For this matter, authorities must provide incentives to the prospective EV owners, and establishing more EV charging stations to serve the needs of current and prospective EV owners is the one of the main key catalysts.

One of the main factors behind a successful deployment of EVs is the high number of charging stations being installed and deployed across the areas that statistics have shown the number of EVs already up and running across them. Car sharing companies are considering substituting their ICE vehicles by EVs to contribute to reducing the amount of CO2 emissions. However, a major challenge appears – that is lack of charging stations in some areas.

Share now (established by merging car2go and drive now) is a joint car sharing service of both Daimler AG and BMW. This service is operating in 18 cities across Europe (formerly in North America and Britain). "Car2go" that is now known as "Share now" was operating in North America and more precisely in San Diego, California. The company replaced all his EVs fleet by gasoline and diesel-driven vehicles due to the lack of charging stations on May 1, 2016. The company was convinced to deploy their EVs fleet around the city since it expected 1000 charging stations to be built to serve the high demand of vehicles from costumers, and facilitate the charging process of EVs. Yet, only 400 charging stations were built. Therefore, a percentage of 20% of EVs are not available since they are either in charging process or out of energy. As a result, the company left the city market by the end of 2016 [61 - 63].

From all the 18 cities where share now is actively operating, only four cities (Stuttgart, Amsterdam, Madrid and Paris) have EVs available for car sharing services [62].

Car2go offers only a "one-way car sharing" [62]. This concept enables to the users to begin and end their trips at different locations. The pickup and drop off can be either restricted to traditional rental stations or can be anywhere within the operational area of the company in what is called "*free-floating car sharing*".

One-way car sharing is generally more expensive to run than the traditional round-trip car sharing due to the need for rebalancing the fleet after rentals. Most of one-way car sharing today is based on the free-floating model. [61 - 63].

The idea of adopting EVs to be included in car sharing companies' fleets must be accompanied with incentives to encourage such companies to deploy more EVs around the city. The main incentive is the high number of charging stations to be deployed around the operational areas of the companies. Nonetheless, it remains a problem on how to convince the authorities to build more charging infrastructures since the number of EVs circulating around the city is not significant nor encouraging to do so. Here it appears the "*egg and chicken*" issue. Car sharing companies are not encouraged to deploy more EVs since the actual charging stations cannot support the high demand, and consequently, some EVs will become unavailable for customers due to fact that are either in charging process or out of energy. On the other hand, the authorities are not willing to build more charging stations since up to now, people are not willing to adopt EVs for their daily tasks especially those outside the urban areas.

The mobility-as-a-service (MaaS) concept is relying mainly on EVs (not forgetting that public transport is its backbone). This concept is trying to integrate more transport and technological services in one bundle to become available for users to facilitate their daily tasks and travels and foster the access to multiple services, which will be easily accessible through one application that combines all the services. The car sharing services to be included in this concept are willing to use EVs to provide more variety to the users. In that way, customers can choose between fuel-driven cars or EVs depending on the range, rate, and services provided by each type of vehicles. Yet, the aim of MaaS concept is to integrate more EVs in service to contribute to the vision of more sustainable mobility. The only way to make this vision is to deploy more EVs in urban areas, and through car sharing services, this idea is possible. MaaS concept focusing on encouraging people to abandon the use of their private cars and begin using mobility services provided by this concept. This will certainly decrease the number of cars circulating around the city and thus, mitigating traffic congestions issues and help reducing CO2 emissions.

Information and communication technology (ICT) is playing a key role in connecting multiple devices forming afterwards an advanced and reliable network, in which devices are able to communicate wirelessly and smoothly without human intervention. Regarding transport sector, communication technology is now a vital factor for enhancing the use of vehicles and mainly EVs. A communication technology that is emerging and attracting many attentions is V2X or vehicle to anything [36]. In this work, we will focus mainly on V2G technology that is connecting an EV with the electricity grid. Vehicle-to-grid (V2G) concept, is a bi-directional communication, through which, the energy is flowing from either vehicle to grid (V2G), or grid to vehicle (G2V). Electric Vehicles are considered as a mobile storage of energy as they are able to feed the electric grid with their surplus energy stored in their batteries to help the grid dealing with the high demand of energy during rush times in charging stations. This process is made possible through V2G concept. For better management of this concept, it is highly recommended that owners of EVs start charging their cars during nights or during low-demand periods. In that way, for periods when the energy demand is at its peak level, electric cars can operate as an auxiliary load providing the grid with the surplus of energy stored on-board to deal with high demand of electricity as well as alleviating the issues regarding overloading of the grid, trips of transformers and other components or avoiding blackouts. However, charging and discharging process of the battery will certainly degrade the quality of the battery, and consequently, reducing the age of use of the battery and the electric vehicle itself. Therefore, V2G concept must be accompanied with significant incentives to EV owners provided by grid operators to encourage them utilizing this kind of concept by providing affordable prices on charging process and attractive rates for discharging their batteries.

1.3. Introduction to Mobility-as-a-Service (MaaS):

"Mobility as a Service (MaaS) is a trending mobility concept, which integrates, manages and distributes private and public mobility alternatives using intelligent digital technologies" [45]. The first person spotlighted MaaS concept was Heikkilä in 2014 [34]. Since then, various researches have been published developing this concept alongside several pilot projects conducted in many cities around the globe investigating the usefulness of this concept, and to what extent it meets the needs and aspirations of the customers. Few examples of MaaS pilot projects will be discussed further in this paper. Despite the high number of papers discussing this concept, no common definition of MaaS is found. However, all those definitions share the following basic ideas [47]:

- MaaS aggregates all the mobility services available in the city, and provides integrated ticketing and payment systems.
- MaaS is conceptualized as a range of services available on-demand
- MaaS solutions are provided to customers through a single digital interface.

Urban mobility systems are going through a big transition that will affect the future of our cities [47]. To make this shift a success, MaaS is playing a key role in encouraging residents in urban areas to adopt new tailored mobility solutions. The main features of such mobility solutions are reducing traffic congestion, offering affordable and convenient transport means with accurate and reliable timetable based on the passenger's congestion frequency [46]. Yet, to integrate MaaS in our modern society, several factors such as deficiency of cooperation among stakeholders, digital illiteracy as well as unfavorable governmental policies should be solved. Moreover, investigating the willingness of residents in urban and rural areas to adopt such concept is significant. Not only pilot projects are necessary, which test the willingness of customers through real-life experiments in different cities, but also the investigation of personal and social factors are mandatory for the creation of convenient plans and bundles for future MaaS applications. This research [47] proposes to evaluate travelers' willingness to adopt MaaS solutions. This works aims to define diverse stereotypes groups of travelers to identify potential market possibilities. For this reason, they proposed to conduct an online survey to customers to investigate the influence of different types of personal factors on the future planning and execution of MaaS concept. The questionnaire comprised of four sections: socio-demographic characteristics, personal traits, personal attitudes, and travel habits. This study took place in the city of Madrid. In [42, 43]. They proposed a route choice model under real-time information. This model is updated each time interval from prior time interval data. Such model is vital and significant for car-sharing users since it suggests the less crowded roads in order to reach the destination in a very efficient way, and avoiding traffic jams. "The estimation and updating of such a model allows the MaaS operator to monitor the effects of their dynamic decisions on users' route choice behavior."

Implementation of MaaS concept in urban and rural areas must be accompanied with incentives for both MaaS operators and future customers. This new approach was adopted to achieve collaboration and integration between transport providers and prospective users. Through such approach, the service providers can coordinate and facilitate the needs of their customers [65].

MaaS provides an attractive and convenient solution to help meet the mobility needs of those groups, who no longer want to own a car, either cannot afford purchasing it, or even cannot drive it. To date, MaaS concept is warmly welcome among the younger generation since they are less interested to purchase a car and are more open to the idea of car sharing. However, how this concept can attract older people? Enhancing the community transport services integrated in MaaS concept would be a great motivation for older people to adopt this concept. [29].

1.4. Introduction to Vehicle-to-grid (V2G):

The increasing price of fossil fuels, attention to environmental issues and urban pollution, and the aim to reduce $CO2$ emissions, pushed car users to adopt Electric vehicles as a clean alternative to diesel and gasoline vehicle. In recent years, the number of EVs circulating in the urban areas is gradually increasing. Such increase requires a high number of charging stations to withstand the high demand of energy. In addition, efficient charging strategies and communication technologies are needed for a safe and reliable charging. The vehicle-to-grid (V2G) technology enables the EV to interact with electric grid. Through V2G, EVs can feed the grid with the surplus of energy stored in their batteries to help the grid withstanding additional peak demand of energy as well as mitigating severe power outages and avoiding blackouts. The V2G interaction enables a bi-directional flow of energy between the electric vehicle and the grid. Charging and discharging processes are performed smoothly with V2G concept. During charging, the EV acts as a load and draws power from the grid, whereas in discharging, the EV acts as a power generator and supplies power to the grid by discharging its battery [35]. Regarding the discharging mode, each plug-in electric vehicle discharges its battery according to the needs of the grid.

Vehicle-to-grid (V2G) has the capability to enhance stability, reliability, efficiency, and generation dispatch of a distributed network, thus increasing the entire power grid's performance [19]. Nevertheless, such concept can proliferate only if EV owners participate in it. In addition, charging stations' profit from V2G depends mainly on the willingness of users to adopt such concept as well as their frequency of use. Taking into consideration the fact that the excess of charging and discharging leads to degrade the battery life of an EV, charging station operators must provide attractive incentives to encourage EV owners to utilize V2G services. Charging stations may offer a list of attractive rates for EV owners to discharge their batteries to feed the grid back with the energy stored in such batteries. The users can then select the suitable choice with positive battery utilization and enough compensation. As a result, once the V2G is efficiently utilized, both charging station' profit and user gain increase.

The increased number of EVs connected to the grid will rise the burden on the grid, thus leading to outage and blackout occurrence within the grid, and consequently loss of service continuity, which degrades the quality of power that is delivered to end-users [5, 9, 19]. The introduction of Vehicle to grid concept helps to manage the charging and discharging of EVs within the charging stations and leads to avoid issues that could damage the grid service continuity. In Vehicle to grid function, the EV can be utilized in ancillary services and can be functioning as a secondary reserve for the grid to provide flexibility and reliability. In addition, through a bi-directional V2G, plug-in EVs can adjust their charging and discharging profile, and thus, enabling the stability of the power grid and mitigate the intermittency of renewable energy resources [1, 18, 20].

The adoption of the V2G technology in a charging station will bring several advantages to the grid, mainly; active support of the network as well as the compensation of the reactive power which ensure an effective voltage regulation, and not forgetting the control of the power factor which reduces the dissipation into the grid. Through V2G, EVs can keep their promises alive and most precisely, improving the energy efficacy within a network.

The electrical Network is subject to several short and long interruptions that mainly leads to components trips, outages and blackouts within the grid. Voltage sags and long interruptions have the same impact on the grid continuity service and the power quality. Voltage sags are short interruptions that last from 0.5 cycles to 1 minute [15]. However, their occurrence frequency make them as dangerous as long interruptions that occur from time to time. Voltage dips can cost the grid operators and providers millions of euros every year and their severity depends on their duration, deepness and the where they happened, as well as the class of components connected to loads and the grid whether they are susceptible to such voltage dips, mainly those characterized with long durations and high residual voltages. Therefore, the V2G technology aims through storage on-board EVs to compensate the PQ events (voltage dips), and mainly the suitable ones, i.e., the events that EVs batteries are able to compensate without damaging the batteries on-board. Such events need to be analyzed along with batteries' capabilities. Taking into consideration that the main aim of an Electric vehicle is to transport its owner from point A to point B, the vehicle-to-grid should maintain the performance of the EV and not minimizing its range. Therefore, the grid operators and charging stations should set the limits of the amount of the energy to be drawn from the vehicles' batteries. In [48], they limited the discharging power at 10 per cent. Yet, this amount can be changed and is subject to several factors, such as number of EVs connected to the grid at the same time, State of charge of batteries prior to charging process, amount of energy requested. Nevertheless, the discharging process depends mainly on the willingness of EV owners to adopt such function or not.

Through V2G technology, the EV is seen as the most valuable asset for their owners. The EV can discharge its battery and feed the grid with this energy in hopes lowering the price for everybody. For households, V2G is transformational, i.e., EVs owners have days of worth of electricity parked in their garage. In fact, V2G technology can also be implemented inside private buildings including EV charging stations, EVs owners in such case may be able to use their cars to feed the grid. This energy will be used further to improve the power quality in the building or can be delivered to loads nearby.

To sum up, vehicle to grid technology allows us to see the convergence between the energy side of the world and the transportation side of the world. What that means for every day drivers? --- It means the ability to achieve an almost complete autonomy from both electricity consumption perspective and from transportation perspective.

1.5. Power Quality: General Overview:

Nowadays, due to the significant advantages brought by automation such as the quality and flexibility enhancement for the manufacturing process, the sensitivity of the processes to power quality events has increased for contemporary industries [15].

Power Quality (PQ) is an important key player in the power systems engineering as its main role is to guarantee a good quality of power being delivered to end-users. Since the establishment and adoption of smart grids concept and the unprecedented renewable penetration, power quality field has emerged and has been spotlighted due to several reasons such as the severity of interruptions occurring in the primary distribution network that lead to various issues in the grid, with different level of danger either on the electrical network itself or on the loads connected to it [10]. Moreover, the presence of unconventional consumers such as electric vehicle chargers, data centers as well as several large industrial consumers make the Power Quality concept more relevant to be tackled. The connection of such new entities to the grid creates an overload on the electrical network, which leads to the occurrence of several PQ issues [13, 15, 21].

Power quality disturbances have various hazards on the grid management, as their severity can make the grid management out of service and need an immediate intervention from the operators to mitigate their impact. For instance, the occurrence of a single power quality event such as voltage dips will definitely affect the continuity of the service of the affected loads and cost the operators a loss of high amount of money [21].

The electrical network is exposed to various kind of power quality disturbances with different level of hazards. The categories of these disturbances are voltage sags or dips, voltage swell, transient, harmonic, voltage fluctuations and flicker. Each of which can occur due to several causes, and for better comprehension of their behavior into the grid, network operators must study the various causes that lead to the occurrence of such PQ events, as well as to establish a mitigation plan in order to ease their severity [15, 21].

The use of power electronics as a solution for mitigating Power Quality issues is widely adopted within Smart Grids concept. This effective technical solution will help increasing the energy transmission capacity, voltage stability enhancement, power flow control, and mainly, ensuring a good power quality within accepted boundaries at Distribution Networks [12].

Recently, power converters are used in a wide range in all industries as well as in the residential sector thanks to the highly adoption of local generation and storage technologies within a smart grid concept [8, 11]. These converters such as Energy storage devices are capable of producing Harmonics with high level of risk and lead to the distortion of current and voltage, and consequently, degrading the power quality. The storage devices are playing an important role to promote the smart grids concept by both customers and electricity producers. Nevertheless, these technologies can be inadequate for the electric distribution systems operation [8]. Therefore, their use will certainly create power quality disturbances in the electric network and malfunctioning of the loads as well as degrading the quality of power delivered to end-users.

The significant presence of renewable energy sources in Low Voltage (LV) distribution networks foster the concerns regarding the quality of power. Distribution System Operators (DSOs) are mainly required to curb the severity of PQ disturbances and intervene when needed in order to provide the costumers with high quality of energy and without interruptions.

Moreover, the appropriate management of the grid is becoming more complex due to the high level of penetration of Distributed Generation systems into the Distribution Networks [8]. This operation will eventually degrade the quality of energy provided to end-users connected to LV distribution networks. As a result, the Quality of Service (QoS) standards are out of reach. For this reason, new tools and devices are promoted to be a feasible solution for Power Quality mitigation and compensation. The work in [12], proposes the open Unified Power Quality Conditioner (Open UPQC) to cope precisely with the compensation of PQ issues.

Devices using renewable energy sources are widely used for industrial and residential operations. The continuous use of these devices is increasing and in the meantime, power quality issues in power systems are emerging. The work in [69] proposed specialized passive filtering devices in order to curb the total harmonic distortion in the power network. The use of passive filters will improve the power system reliability, security and efficiency.

Due to the increase of electric vehicles and the emergence of V2G functions, electric vehicle recharging stations are used as compensators to improve the Power Quality of the grid. In [9], the charging stations of electric vehicles using smart controllers are named Smart Parks. These Charging stations are playing the role of shunt active filters in order to improve the quality of power. A large set of EVs connected to the micro grid is able to provide harmonic reduction and power compensation as well as these EVs are considered mobile reserves of energy that could be needed during emergencies. The work made in [9] stated that the smart parks (EV charging stations) are behaving as shunt active filters (SAF), as they produce a harmonic spectrum after injecting voltage and current which cancels the harmonics in the grid due to power electronic loads.

The presence of non-linear electronic loads are the main reason behind instability in a micro grid, since these loads are able to produce harmonics capable of causing malfunctioning of the whole system. [9].

Power Quality issues are able of creating financial burden on the energy suppliers as well as on consumers. In other words, PQ events with low or high duration can affect the correct functioning of the grid and the loads connected to it. Considering industrials, any interruption of any duration will cause to a temporary or permanent undesired function of their operations will certainly lead to monetary losses of different levels depending on the severity of the interruption and its deepness and duration.

In the following, we will discuss in details the various PQ disturbances, and we will focus mainly on the voltage dips since they are the most severe type. Voltage dips are short duration events, nevertheless, their continuous occurrence in the grid promote them as the main cause of malfunctioning of devices.

A. Harmonic voltage:

A harmonic of a voltage waveform is a sinusoidal waveform whose frequency is an integer multiple of the fundamental frequency of the supply voltage. Voltage harmonics are mainly caused by current harmonics. In other words, the voltage source will provide a voltage that will be distorted by current harmonics due to source impedance. Harmonic current flowing through the network impedance give rise to harmonic voltages [15].

Mainly non-linear loads connected to the network such as rectifiers, discharge lighting, and saturated electric machines produce harmonics of the supply voltage [15, 21].

Harmonic voltages can be evaluated:

- Individually through the relative harmonic voltage amplitude ($\mathrm{U_h}$) that is related to the fundamental voltage $\mathrm{U_1}$. With h is the order of the harmonic. Resonances may cause higher voltages for an individual harmonic.
- Globally, with the help of the total harmonic distortion factor THD computed using the following expression [15].

$$THD = \sqrt{\sum_{h=2}^{40} (u_h)^2}$$

The supply voltage THD of all harmonics up to the order of 40 must be less or equal to 8 %. [15].

In the table below, values of individual harmonic voltages at the supply terminals are given in percent of the fundamental voltage $\mathrm{U_1}$. The given values are up to 25, since harmonics of order higher than 25 are usually small, and yet, they are largely unpredictable because of resonance effects.

Odd harmonics				*Even harmonics*	
Not multiple of 3		Multiple of 3			
Order h	*Relative amplitude uh*	*Order h*	*Relative amplitude uh*	*Order h*	*Relative amplitude uh*
5	*6.0 %*	*3*	*5.0 %*	*2*	*2.0 %*
7	*5.0 %*	*9*	*1.5%*	*4*	*1.0 %*
11	*3.5 %*	*15*	*0.5%*	*6…24*	*0.5 %*
13	*3.0 %*	*21*	*0.5%*		
17	*2.0 %*				
19	*1.5 %*				
23	*1.5 %*				
25	*1.5 %*				

Table 1: values of individual harmonic voltages at the supply terminals for orders up to 25 given in percent of the fundamental voltage U1 [15].

B. Transient overvoltage (spike):

Transient overvoltage are short duration surges in voltage between two or more conductors (L-PE, L-N or N-PE), which can reach up to 6 kV on 230 V AC power lines. According to [13] a transient overvoltage mainly result from:

- Atmospheric origin in the image of lightning activity through a resistive or inductive coupling.
- Electrical switching of inductive loads.

Transient overvoltage cause an outright damage to the sensitive electronic devices. Such damage occur when transient overvoltage between L-PE and N-PE exceed the withstand voltage of the electrical equipment.

According to [15], transients with long durations usually have much lower amplitudes. Therefore, it is improbable to have a transient with high amplitude and long rise time. According to ANSI standards [70], transient duration is about one millisecond. The rise time of voltage transient ranges from milliseconds down to a bit lower than a microsecond

Switching overvoltage have generally longer durations as they provide higher energy content, whereas induced overvoltage due to lightning have higher amplitude with lower energy content.

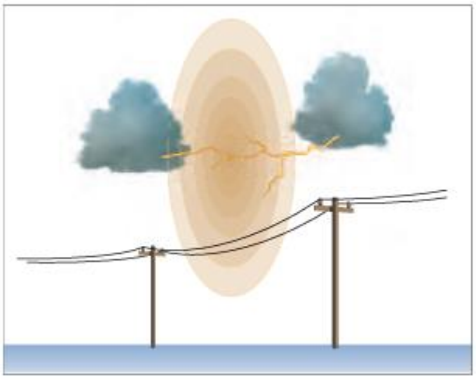

Figure 16: inductive coupling [13].

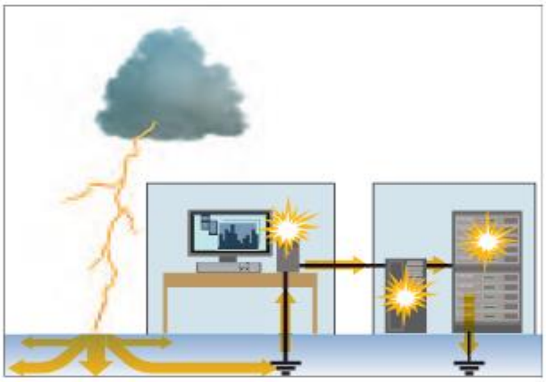

Figure 17: resistive coupling [13].

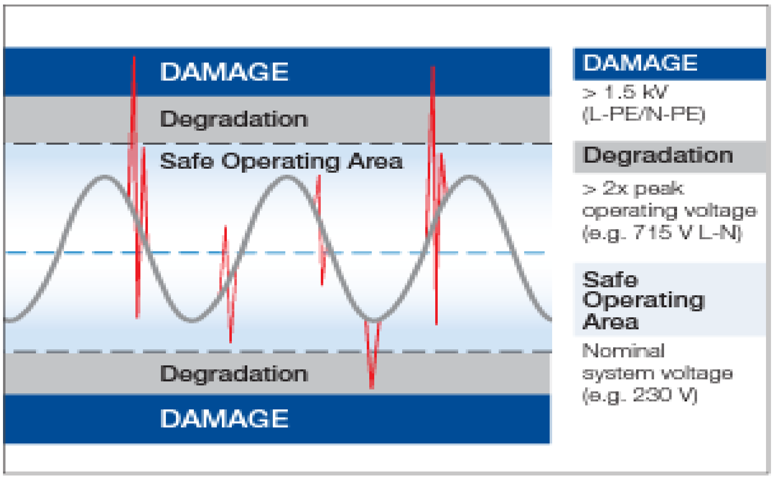

Figure 18: Equipment risk [13].

C. Voltage sags or dips:

Although their short duration, voltage dips are considered one of the main power quality severe issues due to their huge impact on the power grid. According to IEEE 1159 standard, a voltage dip is a decrease in RMS voltage between 0.1 p.u. and 0.9 p.u. at the power frequency for durations of 0.5 cycles to 1 minute [15]. Voltage dips are able to create issues with high level of hazards to end-users since the frequency of occurrence of a voltage dip is larger than any other PQ problems. For better comprehension of the consequences brought with a voltage dip, it is mandatory first to distinguish its nature. Yet, the variety of its root nature makes the process of the identification of the main cause of the voltage dip difficult [15, 21]. Nevertheless, voltage dips main causes include distribution line fault, induction motor starting, and transformer energizing, and not forgetting that the operation of switching the circuit breakers during the reclosing and reconfiguration processes leads to the occurrence of the voltage dips in the utility system. In [21] the authors elaborated a comprehensive modeling and simulation of various Power Quality disturbances. Voltage dips caused by line faults are more serious than voltage dips caused by large motors starting.

Faults leading to voltage sags may occur within transfer switches, transformers, feeder cables, and circuit breakers internal to facilities. In addition, these faults can also appear on the end-user side of the meter. The voltage sag usually starts propagating from the higher voltage levels to the lower ones. Moreover, faults occurring in the network may cause deep voltage sags, and particularly if they occur close to the loads.

For an aerial MV Network, the probability of the presence of a voltage sag is higher compared to underground cables. This assumption is based on an Italian **CESI study** [71].

The figure below shows the distribution of voltage sags causes.

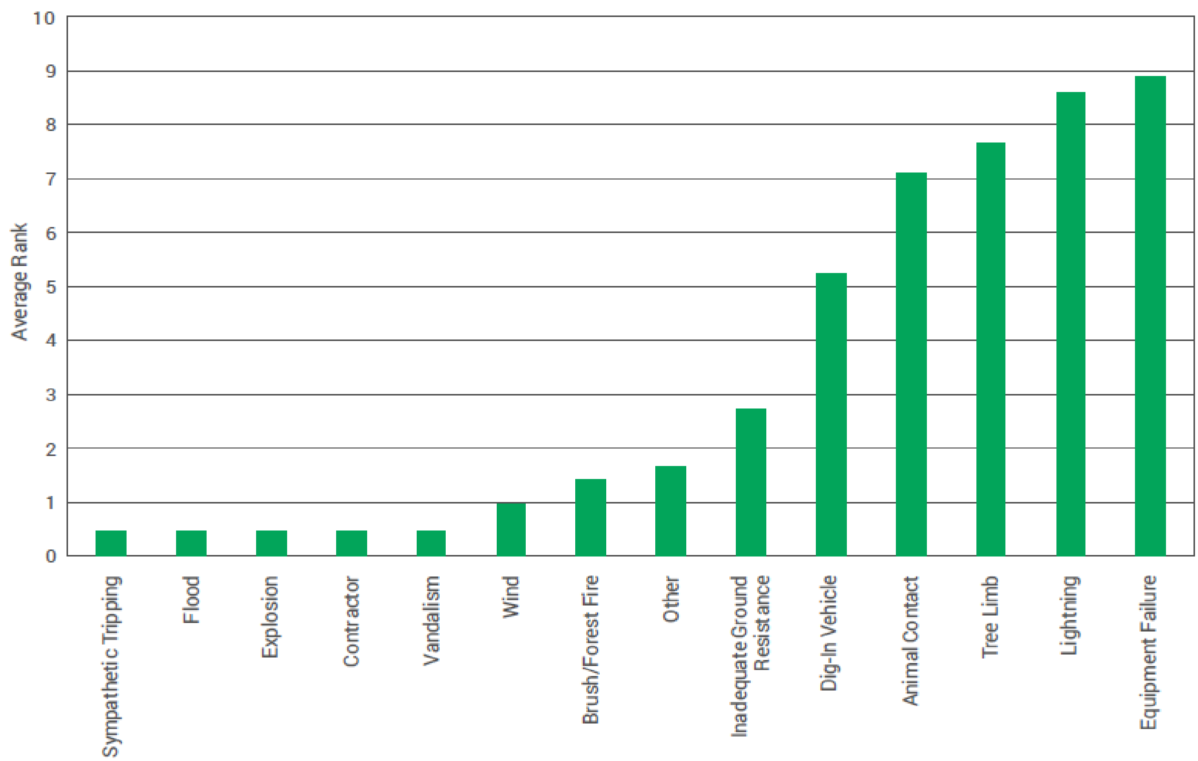

Figure 19: voltage dips main causes [15].

Instantaneous voltage sags lasting less than 100 Milliseconds can be as severe as outages that last for several minutes. Both can have the same impact on the industrial process as they can cost manufacturing facilities high monetary losses since manufacturing plans are subjected and sensitive to several kind of disturbances.

According to [15], voltage sags contribute of more than 60% of poor Power Quality costs. In fact, voltage sag cost less than one voltage supply interruption. However, frequency of occurrence of voltage sag is by far more than voltage supply interruption or any other PQ event.

Control Error, Contactor dropout, voltage flicker and machine mechanisms as well as motor stall and reacceleration are the main results of voltage sags.

Many technical solutions are adopted in order to effectively mitigate the negative impacts due to PQ events (mainly voltage dips) occurrence on the grid. DVR and D-STATCOM are VSI-based compensators that are used mainly for mitigating voltage dips and swells as well as regulating the load voltage [20]. Yet, before choosing the suitable device, it is mandatory for network operators to perform an analysis regarding the voltage dips, through which, a classification of the voltage dips should be made and consequently, number and nature of events eligible for compensation will be known. Having in mind the deepness and duration of voltage dips will lead to perfectly choose the suitable compensation device, its size and its point of connection into the grid in order to not cause any undesired malfunctioning of the connected equipment or the sensitive loads. In this work, we will perform an analytical study of the distribution of voltage dips in the Italian network. The data presented represents different grid interconnection degrees in a way it helps us to understand where the most severe PQ events are occurring. The severity of voltage sags increase with the presence of more sophisticated and sensitive electronic devices.

For statistical purposes, the new version of the standard EN 501608 [72] categorizes the voltage sags according to the immunity curves. Each cell represents a specific set of voltage dips characterized by a particular residual voltage with a certain duration. EN 61000-4-11 and EN 61000-4-34 [72]. state the levels of devices belonging to class 2 and class 3. Based on these levels, immunity curves are perfectly defined.

The table below shows the classification of voltage dips for statistical purposes [15]:

Residual voltage %	*Duration (ms)*				
	10 ≤ t ≤200	*200 ≤ t ≤500*	*500 ≤ t ≤1000*	*1000 ≤ t ≤5000*	*5000 ≤ t ≤60000*
90 > u ≥80	*CELL A1*	*CELL A2*	*CELL A3*	*CELL A4*	*CELL A5*
80 > u ≥70	*CELL B1*	*CELL B2*	*CELL B3*	*CELL B4*	*CELL B5*
70 > u ≥40	*CELL C1*	*CELL C2*	*CELL C3*	*CELL C4*	*CELL C5*
40 > u ≥5	*CELL D1*	*CELL D2*	*CELL D3*	*CELL D4*	*CELL D5*
5>u	*CELL X1*	*CELL X2*	*CELL X3*	*CELL X4*	*CELL X5*

Table 2: classification of Voltage dips according to residual voltage and duration [15].

Cells A1, B1, A2, and B2 are for class 2;
Cells A1, B1, C1, A2, B2, A3, and A4 are for class 3.
Class 2 and 3 are defined by EN 61000-4-11 and EN 61000-4-34.

The sensitivity of equipment and process controls and the susceptibility of semiconductor process equipment to voltage sags are important factors why semiconductor plans require high level and stable power quality for the appropriate working process. SEMI, a semiconductor manufacturer company has developed the **SEMI F47** [73]. Voltage sag immunity curve, which becomes a worldwide standard as the IEEE 1564 recommends the **SEMI F47** to be used as a standard for PQ purposes [15, 21, 68, 73].

SEMI F47 requires that semiconductor-processing equipment should tolerate sags to 50%, 70% and 80% of equipment nominal voltage for a duration of up to 200 milliseconds, 0.5 seconds, 1 second, respectively. The table below shows these requirements in details [15].

Voltage sag duration				Voltage sag
Seconds (s)	Milliseconds (ms)	Cycles at 60 Hz	Cycles at 60 Hz	Percent (%) of equipment nominal voltage
<0.05 s	<50 ms	<3 cycles	<2.5 cycles	Not specified
0.05 to 0.2 s	50 to 200 ms	3 to 12 cycles	2.5 to 10 cycles	50%
0.2 to 0.5 s	200 to 500 ms	12 to 30 cycles	10 to 25 cycles	70%
0.5 to 1 s	500 to 1000 ms	30 to 60 cycles	25 to 50 cycles	80%
>1.0 s	>1000 s	>60 cycles	>50 cycle s	Not specified

Table 3: SEMI F47 voltage sag duration and percent deviation from equipment nominal voltage [15].

In addition to SEMI F47 curve, there is also ITIC curve that can be useful as standard for immunity curves [74].
An equipment is considered immune to voltage dips if its values are above the immunity curves. The figure below perfectly illustrates this feature as the black solid line is set as a buffer zone between the immunity curve (red part) and the unaffected region in which the equipment is continuously working without interruptions [15].

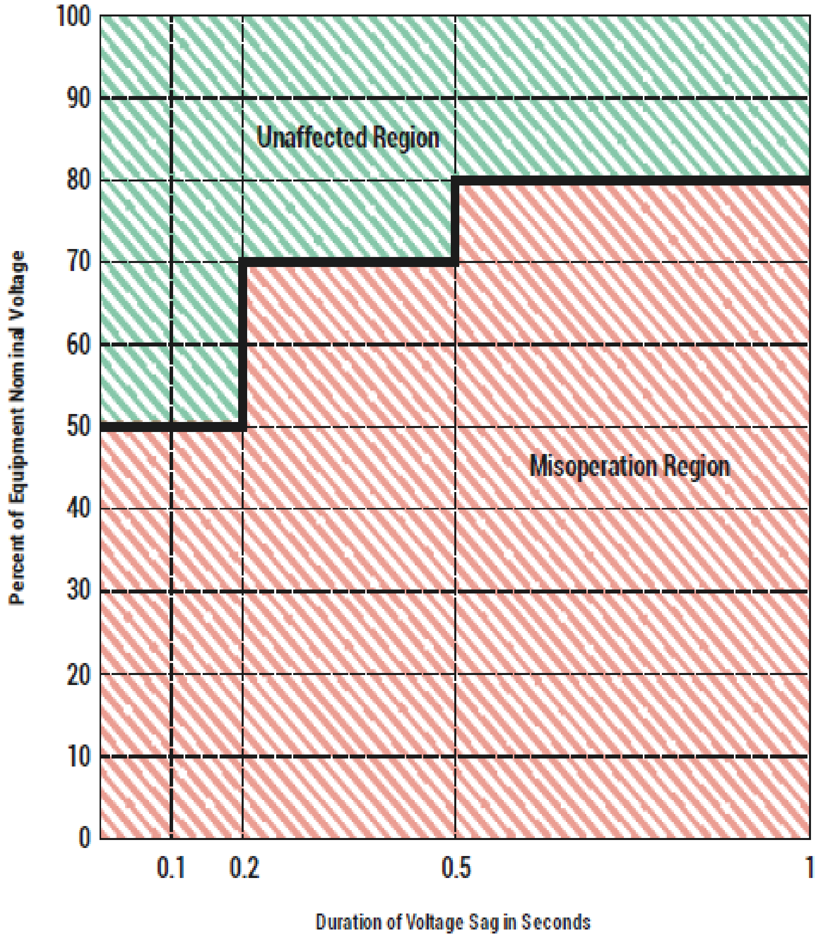

Figure 20: SEMI F47 immunity curve [15].

D. Voltage swell:

Voltage swell is defined by IEEE 1159 standard as the increase in RMS voltage level between 110 % – 180 % of nominal voltage at the power frequency for a duration range between 0.5 cycles and 1 minute. Voltage swell is a short duration voltage variation phenomena, and is the opposite of voltage sag [15, 21].

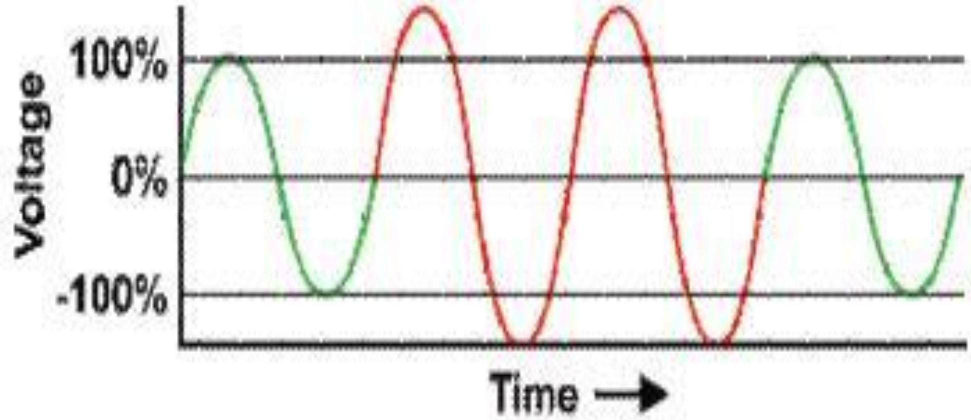

Figure 21: voltage swell [15].

In general, voltage swells are divided into three categories.

Voltage swell	***Magnitude***	***Duration***
Instantaneous	*1.1 to 1.8 pu*	*0.5 to 30 cycles*
Momentary	*1.1 to 1.4 pu*	*30 cycles to 3 seconds*
Temporary	*1.1 to 1.2 pu*	*3 seconds to 1 minute*

Table 4: voltage swell categories.

The voltage dips characteristics of interest are the residual voltage, which is the minimum RMS voltage value and duration. Voltage swell instead is characterized by the maximum RMS voltage value and its duration.
Voltage swells do mainly occur between conductors or between conductors and ground. Taking into consideration the neutral arrangement, overvoltage between healthy phases and ground may result due to faults to ground [15, 21].
According to IEEE 1159-1995, the remaining voltage is used to describe the voltage swell magnitude, and therefore, the voltage swell magnitude is always greater than 1.0 p.u. For instance, when the line voltage is amplified to 150 % of the nominal value, it is due to a swell increase to 150 % [15].
Another reason for voltage swells is the de-energization of a very large load. The sharp interruption of current can generate a large voltage corresponding to the formula. $V = L\frac{di}{dt}$ [15]. Where L is the inductance of the line and di/dt is the change in the current flow.
Furthermore, the energization of a large capacitor bank can also lead to a voltage swell (it most often causes oscillatory transient).

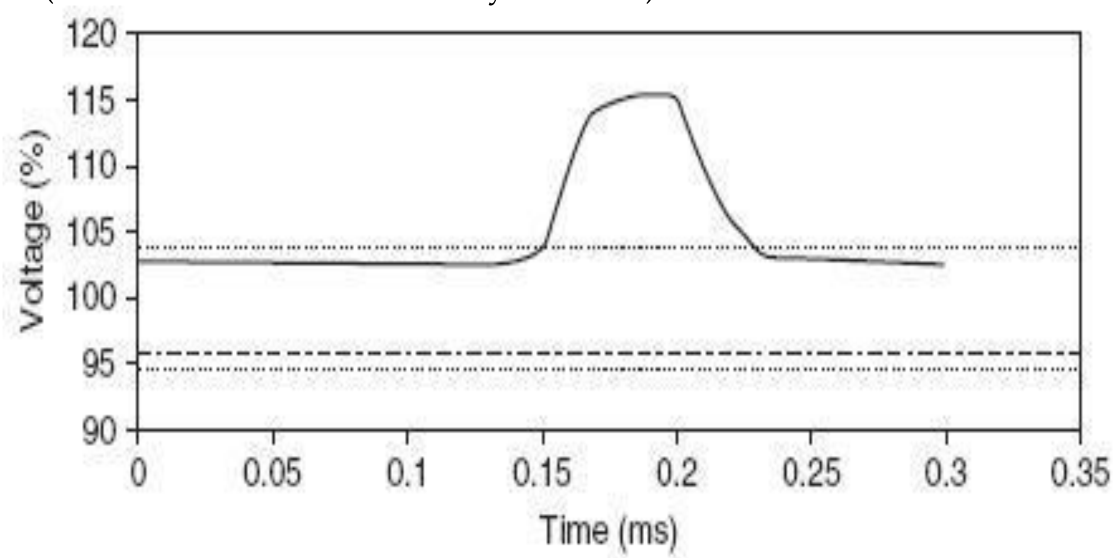

Figure 22: instantaneous voltage swell due to SLG fault [15].

Despite the fact that voltage sags are more frequent, voltage swells effects are nevertheless more destructive. The accumulative effects of voltage swell may cause breakdown of the equipment on the power supplies of the equipment. In addition, voltage swell may lead to an overheating that could eventually cause a failure of the hardware as well as control problems [15, 21].

E. Voltage fluctuations and flicker:

Voltage fluctuations and light flicker are mainly caused by large power fluctuations at frequencies less than 30 Hz. End-use devices such as large dc arc furnaces and welders, reactive power compensators, and cycloconverters are capable of creating large variations in the system voltage at a frequency of 30 Hz. These variations eventually lead to voltage flickers.

If reactive power compensators are not properly applied and controlled, they will have a direct impact on the system voltage and lead to flicker problems since these compensators have allowed large loads that create large flickers to be directly fed from the mains [15, 21].

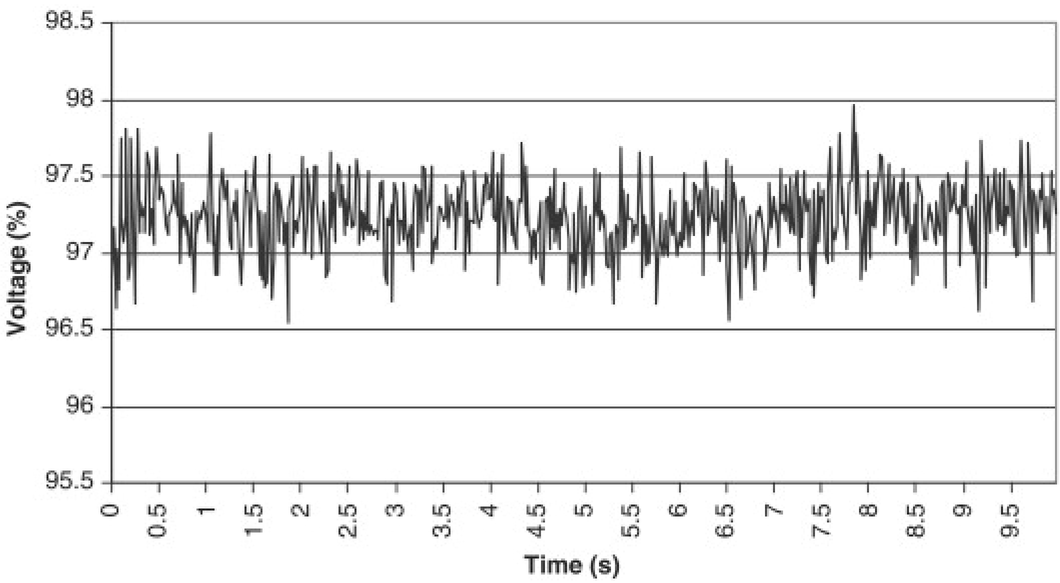

Figure 23: Single-cycle rms voltage fluctuations due to a large dc arc furnace [15].

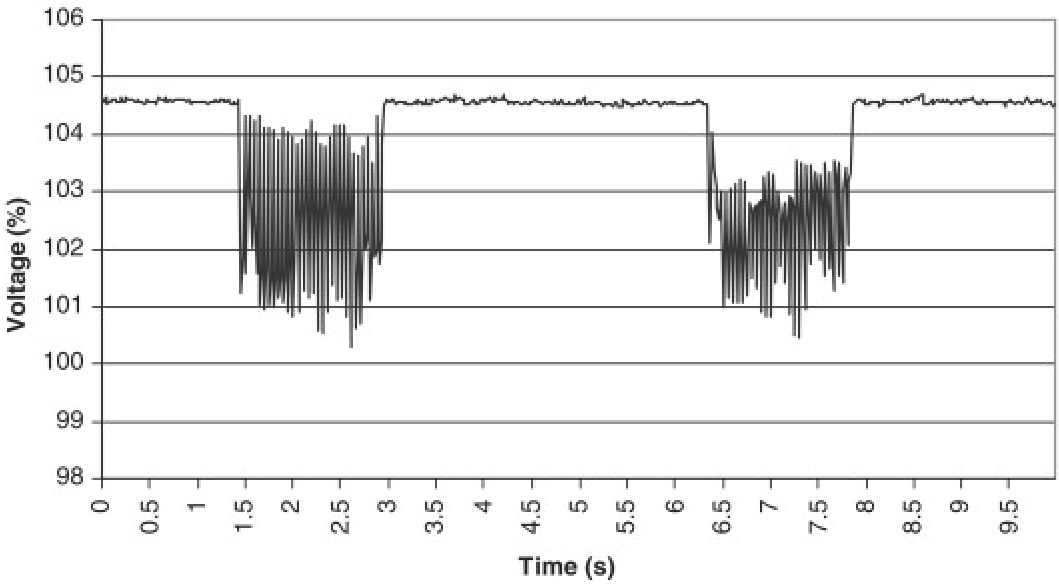

Figure 24: Single-cycle rms voltage fluctuations due to a large dc welder [15].

2. Literature review:

2.1. Mobility-as-a-Service (MaaS) review:

First introduction of Mobility as a Service (MaaS) concept is attributed to Heikkilä. The concept was discussed during the 10th ITS European Congress in Helsinki in 2014. After a year, in 2015, MaaS alliance was established and who disseminated such concept and presented it during the 22nd ITS world congress in Bordeaux. Since then, several literatures spotlighted such concept, and multiple pilot projects took place in several cities worldwide to investigate to what extent MaaS could enhance the conventional urban mobility. In this section, we will discuss the results of several previous researches and pilot projects. To offer an attractive MaaS bundle, the researchers in [34] focused on passenger travel time from train door to the taxi stands in railway station, taking into account many factors such as distance, width of the platform, frequency of congestion inside the station. In addition, they consider the usefulness of establishing a wide area of taxi stands where ridesharing cars can stop. In such area, the arrival order of passengers can be ignored as the number of vehicles is higher, and so passengers do not have to wait for their rides. Therefore, the accuracy of estimating the arrival time of passenger is essential. If the arrival time is well estimated, then the car can pick up the customer in just few minutes after coming out from the station. The investigation of social factors is essential for better implementation of MaaS services. In [47], they proposed a research to evaluate travelers' willingness to adopt MaaS solutions. This study aims to split prospective travelers into different stereotype groups bases on their personal factors such as socio-demographic characteristics, personal traits, personal attitudes as well as travel habits. Mobility as a service plays a vital role in integrating various mobility solutions in a suitable and sustainable manner in both urban and rural areas. The research in [45] presents a pilot project conducted in Alto Minho region. This research discussed how MaaS concept is being implemented in such region and it increased the quality of life of local residents. This paper also spotlighted several pilot projects took place in different rural regions across Europe, mainly North Denmark, Scotland, and Groningen-Drenthe area in Netherlands. Those pilots conducted in different manners but the aim was common, which is to increase the quality of life in such areas as well as offering local residents attractive and affordable mobility solutions to be used while performing daily tasks. For urban areas, [44] presents a use-case took place in the city of Budapest in late 2019. In this pilot project, several mobility operators such as public transport, taxi, car sharing and bike sharing providers were included. Partners of such pilot decided to test every transportation sector, to evaluate how they fit their future MaaS application in the city. The objective of Budapest pilot is to reach full integration in the application from booking to payment passing by routing and ticketing. Budapest pilot project was part of MaaS4EU consortium, which conducted in Manchester, Luxembourg and Budapest.

After the first introduction of MaaS concept in 2014 during ITS Europe Congress, [33] it starts to gain popularity and attention. As a result, several demonstrations of MaaS have been tested, e.g. UniGo in Gothenburg, Sweden; Whim in Helsinki, Finland; SMILE in Vienna, Austria. Moreover, in [33], most researches show that young to middle age and middle-income earners living in urban areas are likely to be the first adopters of MaaS solutions. Such generation is less likely to purchase and own a car, and instead are more open to the idea of car sharing. In [75], researchers implemented a MaaS study in the city of Rome. In this study, researchers followed a multi-step methodology and it is divided in four main steps. The findings were presented and elaborated along with the service main features through a Canvas Business Model. Consequently, eligible customer groups interested in adopting MaaS are mostly young people.

Several MaaS applications were conducted worldwide. Yet, each application had different background working environment and aspects to be considered, even though they all have a common aim. The objective of [31] is to elaborate a quantitative method to analyze and evaluate customization settings of existing MaaS applications. They evaluated 20 MaaS applications. As a result, the found that route setting of journey planning function, functions to provide additional information and services, are the mandatory ones. Consequently, the Italian application 'MyCircero' obtained the highest grade.
In [32], they considered the factors that could have an impact on choosing an on-demand car service, it is revealed that convenience of car models and services are the critical factors for end-users as opposed to cos-savings when choosing a MaaS service over personally owned vehicles. In [42], they examined how the inclusion of transport services in MaaS bundles affects changes in mode use. In this study, MaaS bundle adoption is analyzed by applying binary logistic regression. The results of this research suggest MaaS bundles include unlimited access to the Bus, tram and metro (BTM) and trains even travelers who primarily and solely use car will then utilize BTM services. "The results for the current car owners indicate that for 83.4% of the offered bundles, they respond that they will not make any changes to their owned cars. Shedding the second car has some more potential (15.1%), while only 1.5% indicates to shed all cars. Lease car riders even have a higher inclination to keep their cars: to 97.2% of the offered MaaS bundles they respond that they still need their lease car." "The results in [42] suggest that currently MaaS has a very low potential to reduce car ownership. The results further indicate that current Public transport (PT) users, in particular travelers who now mainly use PT and bike, have the highest inclination to adopt a MaaS bundle". In this research, they propose a pay-as-you-go MaaS system, in which they integrate all transport services in a single digital platform, to see whether it will be an incentive for car owners to shed their cars and start using MaaS services. The research in [30], contributes to a better understanding of how different pricing schemes affect customers' subscription decisions and bundle configuration choices. In order to increase the still limited understanding of end users' adoption decision process, they formulated and estimated a model of MaaS subscription choice and bundle configuration decisions, extended by the choice and willingness to pay for extra features of the service. This will help understanding how each customer is valuing each feature and element in this innovative service. Beyond the pricing, the market share of MaaS may also depend on the basic functionalities of the platform, mobility needs and attitudes of customers.

The work in [23], explores how membership in different car-sharing service types affects vehicle ownership. They performed a comparison between car-sharing services offering one-way service (flee-floating) using two seater cars with two-way car-sharing services. The integration of EVs in car-sharing services will certainly help reducing the burden of owning an EV. In [24], they analyzed whether it is optimal to use EVs in the car sharing market, and investigate the environmental impact of pulling these vehicles from market. Car sharing systems have an important impact on transport in major cities. They can reduce the number of cars circulating in the city, thus, avoiding traffic congestions and resulting in more sustainable cities. In [47], they present an analysis of a free-floating car sharing (FFCS) system in the city of Madrid, with a comparison to a similar study in the city of Hamburg.

2.2. Vehicle-to-Grid (V2G) review:

The vehicle to grid concept is adopted to allow the integration of pluggable EVs with the Grid in a secure and reliable way. According to [35], the main components of such concept are EVs, aggregator and power grid. In this part of the work, we will introduce some previous works and applications related to this cut-edge communication technology.

Through V2G, the energy stored in EVs batteries is supplied back to the grid to fulfill additional peak demand and mitigate the severity of outages [40]. The charging and discharging processes are made easy through such concept. During charging, the EV acts as a load and draws power from the grid, whereas in discharging, the EV acts as a power generator and supplies power to the grid [35]. In [40], they present an intelligent vehicular communication system to V2G interaction. In this article, they propose a resource efficiency framework for selecting suitable EVs to fulfil load demands in Vehicle-to-Grid communication networks. For better management and organization of Charging and discharging process within this concept, a control platform must be included that manages the schedules of both operations. In [38], they present a VehIcle to Grid Intelligent control (VIGIL) platform, which is a comprehensive communication and control platform developed for managing efficiently vehicle to grid systems and electrical network taking into consideration car park requirements as well as users' needs. Even in V2G concept, the most desired process from EV owners is to charge their batteries. However, before the execution of either charging or discharging process, each plug-in EV has to respond to grid needs, which depend mainly on market demand and requirements. Regarding this matter, [41] presents a study case in

which Plug-in EVs were located in a parking lot to charge or discharge the battery depending on market signals and needs.
Vehicle to grid concept enables a bidirectional power flow between EVs and charging stations. Therefore, the EV can inject energy by discharging its battery, which can enhance the profit and "feasibility" of the charging station. However, an excess of charging and discharging process is degrading the battery life of an EV. For this matter, EV owners will need attractive discharging rates and incentives to show their willingness to use V2G concept in both directions. In [36], they propose a menu-based pricing scheme to offer attractive incentives for prospective users. In this scheme, when the harvested renewable energy is small, the users have higher incentives and willingness to adopt V2G services.
The need for an efficient real-time communication system is vital to enable a proficient data transaction between the entities for a better power flow from EVs to the electric grid or vice versa. The work in [39], discusses the impact of realistic communication systems on charging stations at multiple nodes of the sub-feeder in an electricity grid distribution system. They introduced the IEEE 802.11 MAC protocol, which is used by EVs to transmit their data packets to a charging station aggregator. This protocol is using the distributed coordination function to enable such transmission function. Furthermore, in this article [52], they analyzed the **ISO 15118** interface standard used for E-Mobility charging and discharging applications, identifying advantages and disadvantages from the infrastructure used in the market and to propose a new strategy aiming to adapt metering infrastructures for vehicle-to grid energy trading platforms.
Another important feature of V2G technology is the ability of vehicles to make charging reservations before reaching charging stations. Such a feature can reduce the waiting times and congestions within stations. The work made in [49], proposes a Mobile Edge computer Geared V2X for e-mobility ecosystem (we are focusing only on V2G) for making charging reservations, by considering EVs' arrival times and the expected charging time at the charging station for a better prediction of the status of charging stations. In this paper, they introduced a cloud-based global controller that has connections with both charging stations and EVs. Through the aggregator, the EV is able to know where to charge and can forward afterwards its charging reservation request to the chosen charging station. MEGEE has shown its communication efficiency under the Helsinki city scenario, with the feature of sustainably support communication demand from increasingly introduction of EVs.
The high penetration of EVs in the grid introduces concerns and challenges for power system operation due to uncoordinated EV charging process in grid-to-vehicle mode [27, 50]. Consequently, voltage deviations, power losses, and overload of power lines and transformers emerged as severe results of uncoordinated charging within charging station. In this study [50], a

comprehensive day-ahead scheduling framework is developed for an e-mobility ecosystem including EVs, charging stations and retailers for both operations vehicle to grid and grid to vehicle. In [51], they discussed a model of smart control system operating under two different control strategies. They focused on the power grid and their aim was to provide equal load across all charging stations. Then, they proposed a second strategy targeting EV user. Such strategy aimed to direct the driver to the nearest charging station. In [37], a new wireless bidirectional grid interface has been presented.

In addition, high renewable generation can lead to cheap electricity during peak loading hours. In this case, when smart charging demand reacts to the cheaper energy prices, it can lead to a very high peak load in the network. In this case, the operator is willing for peak shaving while consumers/generators desire peak charging. In [28], they explicitly answered this dichotomy.

Having an accurate and timely estimation of the total energy demand of EVs defines effectively the interaction between EVs owners and the electrical power grid, taking into consideration several aspects such as traffic flow, power demand, and available charging infrastructures around the city. This could be beneficial to implement Vehicle-to-Grid technology in a reliable and efficient way. In this study [48], a novel estimation model is proposed and applied to the real-world data of the New-York city taxi fleets in order to obtain the total energy consumption of EVs for different time intervals, in the case where all yellow taxis were substituted with a specific type of electric vehicle. Simply put, knowing the range, speed, distance, and battery capacity, it is possible and feasible to calculate the energy consumption of each route individually.

To improve the reliability and profitability of V2G operations, this research study [25], designed an efficient EV charging and discharging scheduling strategy. In that way, EV users will know in advance how many sockets available and for how long they can use it to charge their batteries. Such scheduling strategy helps EV owners to make charging reservations efficiently. Consequently, this strategy mitigates the congestion issues within charging stations.

Secure communication is a major concern in vehicle to grid network for energy and data exchange. EVs may face many privacy and security risks due to the high cooperation of network communications and due to the high amount of data exchanged between V2G entities. As a result, EVs under attack will not be able to be active for participation in energy trade-offs. Therefore, reliable and secure protocols are necessary to provide the security and privacy of the communications between V2G entities as well as to achieve the higher performance within V2G network. In [27], they propose a blockchain-based secure energy-trading scheme, which provides identity privacy-preservation and mutual authentication in V2G networks. In [26], a privacy-preserving charging-station-to-vehicle (CS2V) energy-trading scheme is presented. This scheme is built on block chain technology, which provides security and transparency.

Vehicle to grid function integration concerns not only the above-mentioned goals, but also the power quality (PQ) assessment and improvement. The use of the storage on-board EVs plays an important role in enhancing, stabilizing and improving the electrical grid in a way it becomes able to withstand the high demand of electricity. The integration of V2G technology helps to stabilize the active power and compensate the reactive power through compensation devices such as D-STATCOM or DVR. The compensating power and energy coming out from Electric vehicle batteries aim to compensate the power and energy losses in the grid that are due to short interruptions such as voltage dips. In [14], an electrical model of Ohio (USA) rural electrical system is created to analyze the impact of different EV charging scenarios on the electrical grid. The model's aim is to quantify the electric energy delivered (kWh) versus peak demand (kW) at the distribution and wholesale (generation and transmission) levels. In [20], they applied V2G technologies in order to compensate the most probable disturbances that are likely to happen in the primary distribution Network. The compensation process is performed through D-STATCOM and DVR that receive the power stored on-board EVs. Moreover, in [75], they proposed an AC/DC and DC-DC bi-directional electric vehicle on-board charger able to provide harmonic compensation for increasing number of non-linear loads as well as it performs the reactive power compensation for household loads.

As we stated above, the V2G function is able to stabilize the active power and compensate the reactive power in case of a reactive power reference is established. In [16], they designed an EV battery charger to control the active power as well as for the compensation of the reactive power, taking into consideration the battery power as a reference.

The increased number and utilization of EVs leads to an increase of demand of more reliable and efficient power supply. The V2G function will grant to the grid the capability to withstand the high demand of energy from the EVs connected in the same time to the grid. In [19], they performed an assessment on the reliability of the distribution system after the injection of high amounts of power stored on EV batteries through V2G function. Reliability indices such as SAIFI and SAIDI were analyzed and assessed. Their improvement gave the green light to implement V2G technologies.

In [18], a novel-phase-detector-based controller for an AC-DC power electronic inverter is proposed to investigate the effects of reactive power compensation on the battery's State-Of-Charge (SoC).

The choice of the compensation device to be used into the grid is not an easy process to perform. An investigation of voltage dips' characteristics must be carried out in order to choose the suitable device that is able to compensate such disturbances without leading to malfunctioning to other devices installed in the grid. Moreover, the investigation of the features (deepness, duration and number) of the voltage sags, as well as the territorial zones where they occurred that are mainly represent different grid interconnection degrees is of paramount importance to know where to adopt vehicle to grid functions and which are the PQ events suitable for compensation using EV batteries. The work made in [20], shows that only PQ events characterized by short duration and restrained undelivered energies, very bothersome in terms of service continuity are eligible for compensation. Furthermore, in [20], they assumed that EVs could only compensate the PQ events of the network with many EVs connected in the same time.

3. Analysis of Voltage Dips and Assessment of Parking areas.

The use of Electric vehicles is practical for the Improvement of smart grids. Through V2G functions, energy stored in the batteries on-board EVs is fed back to the grid in order to help the electric distribution network to withstand the Power quality events such as voltage sags and large interruptions depending on the working environment.
Taking into consideration the number of charging stations that will be provided in different areas around cities, it is necessary to evaluate the feasibility of the V2G function, and whether it can be a solution to the smart grid concept. Such evaluation is conducted to investigate the ability of V2G function to balance the demands of the grid with the available supply. To evaluate the feasibility of adopting such concept to compensate the reactive power in a network, stabilize the active power, and to balance the demand and supply of the grid, it is necessary to evaluate first the Power Quality (PQ) events. In other words, ranking the events based on their duration, deepness, and their numbers, as well as classifying such voltage sags corresponding to different territorial zones presenting different grid interconnection degrees. The second analysis will concern the EV ability to carry out the ancillary services (V2G function) for the electric distribution grid. For that

reason, a preliminary analysis is necessary, through which performance indicators are set and defined to investigate to what extent the EV is able to perform such services. The process of defining the performance indicators and setting their values is mandatory to reach the aim of the compensation system, which is supplying an electric load without causing malfunctioning and minimizing the compensating energy and power.

Furthermore, an analysis will be conducted to evaluate the technical features of several parking situated in different areas in order to investigate their abilities to be equipped with EV charging stations to provide V2G functions. With the help of such analysis, it becomes easier to approximate the number of EVs the parking will host, and consequently, the number of EVs connected contemporaneously to the grid will be known. Therefore, the exact amount of power drawn from a set of EV batteries and delivered to the grid is known. Through this process, the amount of power drawn from an individual EV battery is defined in a way that avoids the degradation of the battery performance.

The work made in this chapter is shaped in this way: first section is regarding the distribution of the voltage dips in the time span between 2015 and 2020. Data of voltage dips will be classified based on duration and residual voltage according to **EN50160** [72] standard. The data gathered are recorded in various areas with different grid interconnection degree. The second part will be dedicated to an energy analysis in order to define the performance indicators to be adopted for the investigation of the ability of EVs to provide ancillary services within the grid. The third part is about an analysis of the charging station in different parking areas. Referring to the scope of our work, this part will help us to investigate the number of EVs connected contemporaneously to the grid [15, 21].

3.1. Distribution and Classification of Voltage Dips:

In order to determine the most probable events eligible for compensation using storage on-board EVs, in this part of the work we will analyze profoundly the distribution of the voltage sags occurred in the Italian electrical network in the time span 2015-2020. The voltage sags shown in this part are gathered between 2015 and 2020 from different territorial zones presenting different grid interconnection degrees. Corresponding to **EN50160,** voltage dips are classified based on their duration and residual voltage.

Before proceeding to the classification process, it is mandatory to define the immunity areas of the appliances connected to the network in order to disregard the PQ events that do not cause any hazards nor interrupt the appropriate working of the appliances. According to European Standards EN61000-4-11 and EN6-1000-

4-34 [72], the immunity curves of classes 2 and classes 3 equipment are reported in Figure below.

According to EN61000-4-11 and EN6-1000-4-34, standards, class 2 includes domestic and office electric devices connected to the public distribution network. Class 3 appliances instead are belonging to the industrial environment. With this in mind, and during a set of voltage dips events, an equipment is considered immune to voltage dips if its values surpass the curves of immunity (see the tables below and colored cells). Therefore, it is mandatory to determine from the total number of voltage dips, the exact number of voltage dips that can create severe issues for both class 2 and class 3 devices. In addition, it is compulsory to determine the voltage dips that EV batteries are able to mitigate without causing any malfunctioning to the grid, EV battery, as well as end-users' devices.

According to EN50160 standard, the tables below show the results of voltage dips distribution in relation to their deepness (residual voltage) and duration. In addition, the voltage dips occurred in different grid interconnection degrees in the period between 2015 and 2020 in the Italian electrical network are recorded and collected by "Terna S.p.A.", which is the Transmission system operator (TSO) of Italy [67].

In this study, Voltage dips involving two or three phases are grouped and referred to as poly-phase, while voltage dips involving only one phase are referred to as single-phase.

380 – 220 kV										
Duration (ms)										
20 – 200		200 – 500		500 – 1000		1000 – 5000		5000 – 60000		
Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Residual voltage %
131	95	5	7	1	1	2	0	0	0	90 > u ≥ 80
122	107	6	6	0	0	2	0	0	0	80 > u ≥ 70
79	63	3	10	1	1	0	0	0	0	70 > u ≥ 40
15	3	0	1	0	1	0	0	0	0	40 > u ≥ 50
2	1	0	0	0	0	0	0	0	0	5 > u
349	269	14	24	2	3	4	0	0	0	Total
618		38		5		4		0		

Table 5: distribution of voltage dips according to residual voltage and duration in a network of 380 -220 kV during 2015.

150 - 132 - 120 kV Nord										
Duration (ms)										
20 – 200		200 – 500		500 – 1000		1000 – 5000		5000 – 60000		
Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Residual voltage %
369	148	22	9	7	1	2	1	0	0	90 > u ≥ 80
222	146	12	16	0	2	2	0	0	0	80 > u ≥ 70
196	148	11	11	0	4	0	1	0	0	70 > u ≥ 40
37	37	3	8	0	4	0	0	0	0	40 > u ≥ 50
0	2	0	0	0	0	0	0	0	0	
824	481	48	44	7	11	4	2	0	0	Total
1305		92		18		6		0		

Table 6: distribution of voltage dips according to residual voltage and duration in a network of 150 -132 - 120 kV during 2015.

380 – 220 kV										
Duration (ms)										
20 – 200		200 – 500		500 – 1000		1000 – 5000		5000 – 60000		
Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Residual voltage %
98	57	2	2	0	2	0	1	0	0	90 > u ≥ 80
94	59	2	5	2	1	0	0	0	0	80 > u ≥ 70
76	64	0	2	0	0	0	0	0	0	70 > u ≥ 40
13	15	1	0	0	0	0	0	0	0	40 > u ≥ 50
1	1	0	0	0	0	0	0	0	0	5 > u
282	196	5	9	2	3	0	1	0	0	Total
478		14		5		1		0		

Table 7: distribution of voltage dips according to residual voltage and duration in a network of 380 -220 kV during 2016.

150 - 132 - 120 kV Nord										
Duration (ms)										
20 – 200		200 – 500		500 – 1000		1000 – 5000		5000 – 60000		
Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Residual voltage %
177	109	1	8	1	4	0	0	1	0	90 > u ≥ 80
226	118	9	11	1	1	2	0	4	0	80 > u ≥ 70
222	105	12	21	0	6	0	0	0	0	70 > u ≥ 40
51	43	2	1	0	3	0	0	0	0	40 > u ≥ 50
4	0	0	2	0	0	0	0	0	0	5 > u
680	375	24	43	2	14	2	0	5	0	Total
1055		67		16		2		5		

Table 8: distribution of voltage dips according to residual voltage and duration in a network of 150 -132 - 120 kV during 2016.

380 – 220 kV										
Duration (ms)										
20 – 200		200 – 500		500 – 1000		1000 – 5000		5000 – 60000		
Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Residual voltage %
106	69	3	3	0	1	0	0	0	1	90 > u ≥ 80
87	48	2	4	2	1	0	0	0	0	80 > u ≥ 70
64	41	0	2	1	0	0	2	0	0	70 > u ≥ 40
9	3	0	0	0	1	0	1	0	0	40 > u ≥ 50
0	0	0	0	0	0	0	0	0	0	5 > u
266	161	5	9	3	3	0	3	0	1	Total
427		14		6		3		1		

Table 9: distribution of voltage dips according to residual voltage and duration in a network of 380 -220 kV during 2017.

150 - 132 - 120 kV Nord										
Duration (ms)										
20 – 200		200 – 500		500 – 1000		1000 – 5000		5000 – 60000		
Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Residual voltage %
144	75	7	1	1	0	0	0	2	0	90 > u ≥ 80
185	84	5	2	1	0	1	0	1	0	80 > u ≥ 70
172	83	10	4	3	1	0	1	0	0	70 > u ≥ 40
27	7	0	3	0	0	0	0	0	0	40 > u ≥ 50
2	0	0	1	0	0	0	0	0	0	5 > u
530	249	22	11	5	1	1	1	3	0	Total
779		33		6		2		3		

Table 10: distribution of voltage dips according to residual voltage and duration in a network of 150 -132 - 120 kV during 2017.

380 – 220 kV										
Duration (ms)										
20 – 200		200 – 500		500 – 1000		1000 – 5000		5000 – 60000		
Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Residual voltage %
104	50	1	1	1	0	1	0	0	0	90 > u ≥ 80
82	41	3	0	0	1	1	0	0	0	80 > u ≥ 70
52	22	3	5	0	1	0	0	0	0	70 > u ≥ 40
22	9	1	1	0	0	0	0	0	0	40 > u ≥ 50
1	0	2	0	0	0	0	0	0	0	5 > u
261	122	10	7	1	2	2	0	0	0	Total
383		17		3		2		0		

Table 11: distribution of voltage dips according to residual voltage and duration in a network of 380 -220 kV during 2018.

150 - 132 - 120 kV Nord										
Duration (ms)										
20 – 200		200 – 500		500 – 1000		1000 – 5000		5000 – 60000		
Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Residual voltage %
205	104	5	8	1	1	0	0	0	0	90 > u ≥ 80
167	104	6	4	3	2	0	0	0	0	80 > u ≥ 70
154	85	6	2	0	1	0	1	0	0	70 > u ≥ 40
27	15	2	1	0	0	0	0	0	0	40 > u ≥ 50
0	0	0	0	3	0	0	0	0	0	5 > u
553	308	19	15	7	4	0	1	0	0	Total
862		34		11		1		0		

Table 12: distribution of voltage dips according to residual voltage and duration in a network of 150 -132 - 120 kV during 2018.

380 – 220 kV										
Duration (ms)										
20 – 200		200 – 500		500 – 1000		1000 – 5000		5000 – 60000		
Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Residual voltage %
63	38	2	4	1	1	0	0	0	0	90 > u ≥ 80
49	37	0	2	1	1	0	0	0	0	80 > u ≥ 70
31	28	1	1	2	0	0	0	0	0	70 > u ≥ 40
3	3	0	0	0	0	0	0	0	0	40 > u ≥ 50
0	0	0	0	0	0	0	0	0	0	5 > u
146	106	3	7	4	2	0	0	0	0	Total
252		10		6		0		0		

Table 13: distribution of voltage dips according to residual voltage and duration in a network of 380 -220 kV during 2019.

150 - 132 - 120 kV Nord										
Duration (ms)										
20 – 200		200 – 500		500 – 1000		1000 – 5000		5000 – 60000		
Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Residual voltage %
130	93	2	11	0	1	0	0	0	0	90 > u ≥ 80
174	86	5	9	1	2	0	0	0	0	80 > u ≥ 70
159	105	4	7	0	1	0	0	1	0	70 > u ≥ 40
43	15	2	4	0	1	0	0	0	0	40 > u ≥ 50
1	0	0	0	0	0	0	1	0	0	5 > u
507	299	13	31	1	5	0	1	1	0	Total
805		44		6		1		1		

Table 14: distribution of voltage dips according to residual voltage and duration in a network of 150 -132 - 120 kV during 2019.

380 – 220 kV										
Duration (ms)										
20 – 200		200 – 500		500 – 1000		1000 – 5000		5000 – 60000		
Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Residual voltage %
62	22	2	1	0	0	0	0	0	0	90 > u ≥ 80
30	23	1	0	0	0	0	0	0	0	80 > u ≥ 70
43	15	2	1	0	1	0	0	0	0	70 > u ≥ 40
5	2	1	0	0	0	0	0	0	0	40 > u ≥ 50
0	0	0	0	0	0	0	0	0	0	5 > u
140	62	6	2	0	1	0	0			Total
202		8		1		0		0		

Table 15: distribution of voltage dips according to residual voltage and duration in a network of 380 -220 kV during 2020.

150 – 132 – 120 kV Nord										
Duration (ms)										
20 – 200		200 – 500		500 – 1000		1000 – 5000		5000 – 60000		
Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Single-phase	Poly-phase	Residual voltage %
239	137	6	15	0	3	0	5	0	0	90 > u ≥ 80
264	176	2	7	1	0	0	1	0	0	80 > u ≥ 70
278	229	5	16	2	9	1	2	0	0	70 > u ≥ 40
81	33	2	2	1	1	1	0	0	0	40 > u ≥ 5
1	0	1	0	0	0	0	0	0	0	5 > u
863	575	16	40	4	13	2	8	0	0	Total
1437		55		17		10		0		

Table 16: distribution of voltage dips according to residual voltage and duration in a network of 150 -132 – 120 kV during 2020.

From the tables above and according to the two standards, EN 61000-4-11, and EN 61000-4-34, as well as immunity curve figure (20), we can determine the number of voltage dips that can threaten the service continuity of class 2 and 3 devices. N is the total number of voltage dips, while N_2 and N_3 represent number of dangerous voltage dips for class 2 and 3, respectively.

Referring to tables above, N_2 is considered the number of voltage dips inside the white and orange cells, while N_3 is the number of voltage dips inside white cells only.

Class 2 immunity

\+ Class 3 immunity

As it is above-mentioned, data are collected from two different grid interconnection degrees, which are "380-220 kV" and "150-132-122 kV Nord". Therefore, we will determine the voltage dips relying not only on the immunity curves but also on the grid interconnection degrees where they occur.

The tables below are made to simplify our approach.

	Year					
	2015	***2016***	***2017***	***2018***	***2019***	***2020***
N	665	498	451	405	268	211
N_2	186	179	128	121	71	70
N_3	40	36	23	47	12	12

Table 17: voltage dips distribution between 2015 and 2020 in a network of 380-220 kV.

	Year					
	2015	***2016***	***2017***	***2018***	***2019***	***2020***
N	1421	1145	823	908	857	1519
N_2	477	486	320	305	347	675
N_3	122	154	64	64	83	160

Table 18: voltage dips distribution between 2015 and 2020 in a network of 150-132-120 kV.

From table (17), it is visible that the number of voltage dips has experienced a positive sharp decrease in the period between 2015 and 2020. The year of 2015 recorded the highest number of voltage sags ($N = 665$), while the year of 2020 had the lowest number of voltage dips ($N = 211$). Even though, 2015 had the highest number of voltage dips recorded, the years of 2016 and 2020 had the highest percentage of dangerous voltage dips for class 2 devices with 35.98% ($N_2 = 179$) and 33.18% ($N_2 = 179$) for 2016 and 2020, respectively. In addition, the years of 2016 and 2018 recorded the highest percentage of voltage dips that could cause an undesired malfunctioning of class 3 devices with 7.32% ($N_3 = 36$) for 2016 and 11.6% ($N_3 = 47$) for 2018.

The year of 2019 recorded the lowest percentage of dangerous voltage dips for bot class 2 and class 3 equipment with only 26.5% ($N_2 = 71$) and 4.5% ($N_3 = 12$), respectively, from the total number of voltage dips recorded ($N = 268$).

From table (18), the number of voltage dips has experienced some fluctuations during the time span between 2015 and 2020, as it decreased from $N = 1421$ in 2015 to N = 1145 and N =823 in 2016 and 2017, respectively. After that, it fluctuated in the two following years with N = 908 and N = 823 in 2018 and 2019, respectively until it reached its peak in 2020 with N = 1519.

The years of 2016 and 2020 recorded the highest percentage of dangerous voltage dips for both class 2 and 3 equipment with 42.5% ($N_2 = 675$) and 13.5% ($N_3 = 154$) in 2016, while 44.5% ($N_2 = 486$) and 10.5% ($N_3 = 160$) in 2020. On the other

hand, the year of 2018 had the lowest percentage voltage dips that could be harmful for the correct working of an equipment belonging to both class 2 and class 3 with 33.6% ($N_2 = 305$) and 7.1% ($N_3 = 64$) from the total recorded voltage dips ($N = 908$) in that year.
From the above-mentioned data, we can understand that the number of voltage dips depends mainly on the territorial zone that represents a specific grid interconnection degree. In addition, the distribution density of voltage dips presented on tables above promote the fact that the different grid interconnection degree may influence the quality of power delivered to end-users.
The above analysis will help us to identify the most probable events eligible for compensation using V2G functions. Such analysis shows that the most probable events have a duration between 20 ms and 200 ms with a residual voltage between 90% and 80%. However, according to the immunity curves definition, these events are not dangerous neither for class 2 nor class 3 appliances and thus, we will disregard and exclude them from the compensation.
Instead, the voltage dips with a deepness less or equal 70% and a duration of up to 500 ms are capable for presenting hazards to both class 2 and class 3 devices. In addition, these events will be considered eligible for compensation using V2G functions.
Regarding single-phase voltage dips:
For the 380-220 kV level, the maximum number of long and deep voltage dips, i.e., voltage dips with a duration superior than 500 ms and a residual voltage less than 70%, for each node was equal to 4. On the other hand, for 150-132-120 kV level, the maximum number deep and long voltage sags was equal to 14.
Regarding poly-phase voltage dips:
For the 380-220 kV level, the maximum number of long and deep voltage dips, i.e., voltage dips with a duration superior than 500 ms and a residual voltage less than 70%, for each node was equal to 6. On the other hand, for 150-132-120 kV level, the maximum number deep and long voltage sags was equal to 16.

Figure (25) and (26) graphically represent the maximum number of single-phase and poly phase voltage dips detected at each grid interconnection degree (voltage level) with a residual voltage of up to 90% and with any duration.

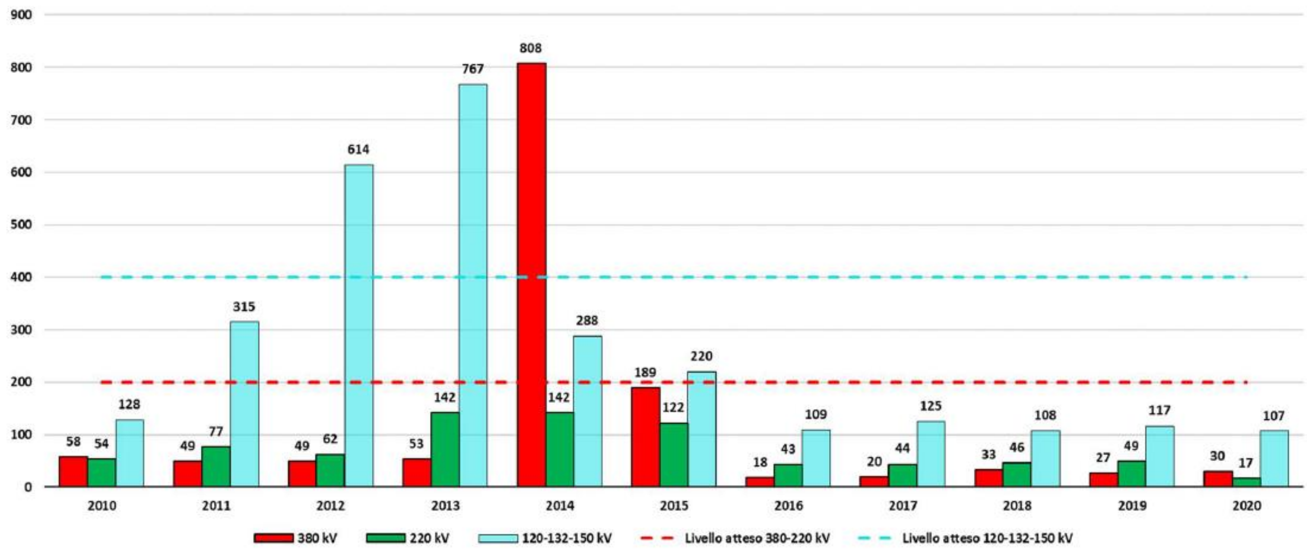

Figure 25: single-phase voltage dips registered in the period 2010-2020 [67].

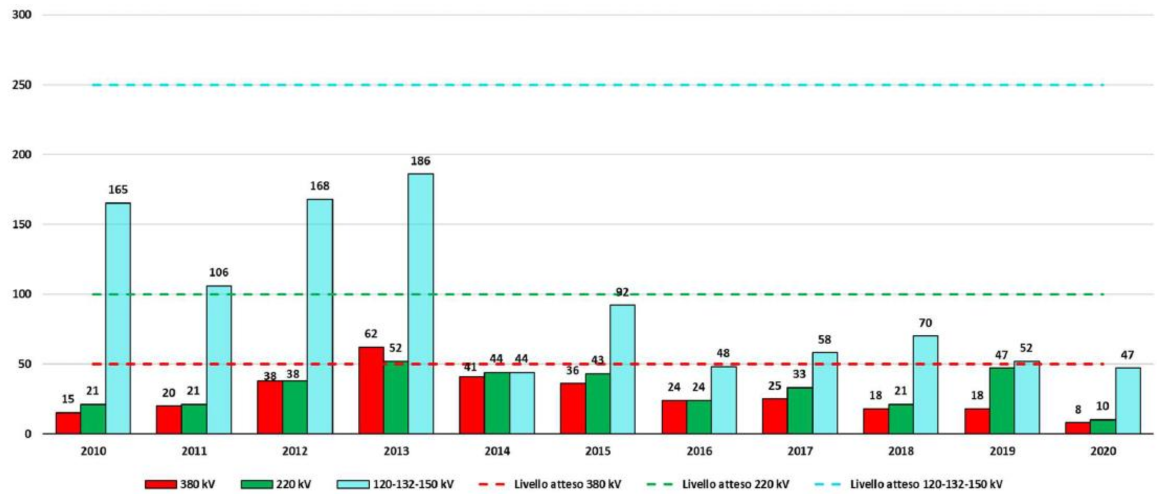

Figure 26: poly phase voltage dips registered in the period 2010-2020 [67].

Figure (27) and (28) show the details of the historical trend of single-phase and poly phase voltage dips detected at each grid interconnection degree (voltage level) with a residual voltage less than 70% and a duration superior than 500 ms.

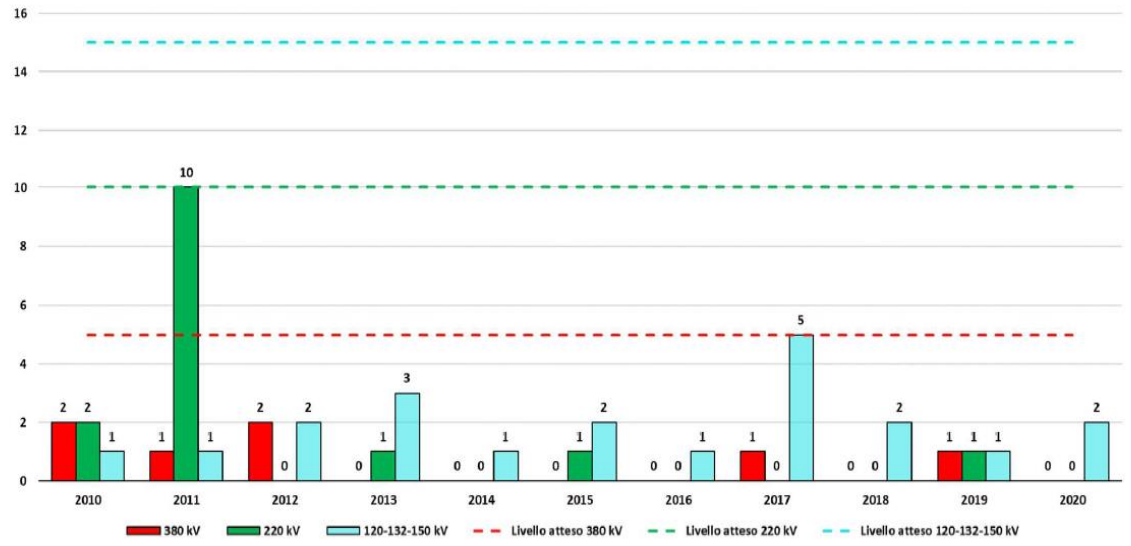

Figure 27: single-phase voltage dips in the period 2010-2020 with a duration superior than 500 ms and residual voltage less than 70 percent [67].

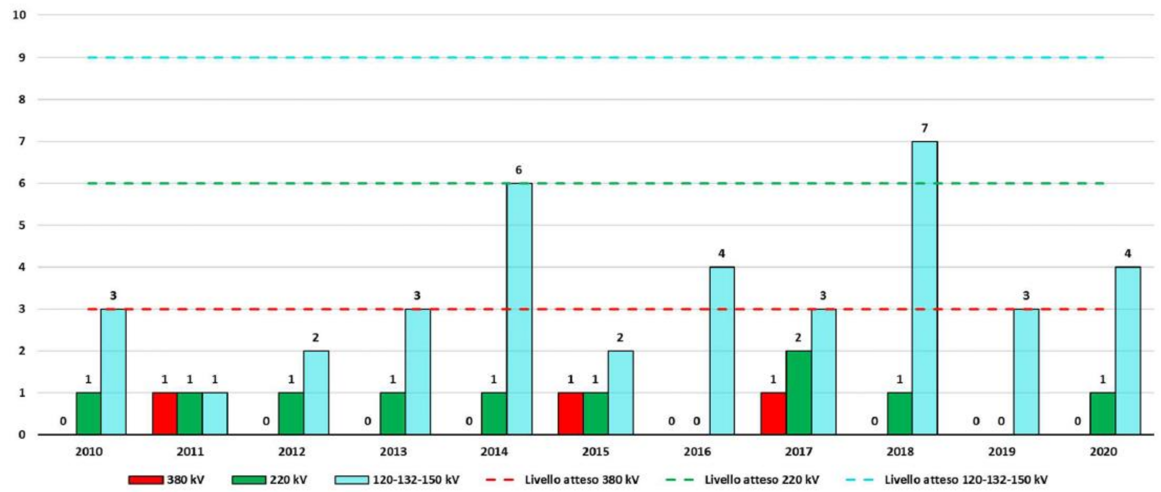

Figure 28: poly phase voltage dips in the period 2010-2020 with a duration superior than 500 ms and residual voltage less than 70 percent [67].

3.2. Analysis of Parking Areas:

In this part of the work, we will perform an analysis on each parking area that can be a potential candidate to host EV charging stations. Through such evaluation, the ability of the parking areas to provide V2G functions will be assessed in order to choose the suitable ones based on each parking features.
The integration of V2G can be possible if it serves the needs of both EVs and grid operators. For future smart cities concept, Electric vehicles are an important key player as their role is not only reducing the high amount of CO2 emissions but also to benefit the Electric grid with energy stored on-board EVs by feeding the grid with this energy directly from their batteries.
However, a major challenge such as lack of charging stations is slowing down the process of adopting EVs in major cities to provide ancillary services for the grid. The concept of smart cities consist not only of privately owned EVs to be used for V2G functions but also the Electric vehicles owned by rental companies that can be adopted for car sharing services. Costumers with subscription in a MaaS concept that encompass various means of transportation including Electric vehicles, will have the opportunity to use such vehicles for duties that do not require long times of driving instead of public transport. Taking into consideration that Electric vehicles spend more than 17 hours of their time parked or under charging process [53], EVs provided by rental companies are useful to reduce the burden of the overload on the grid caused by charging other privately owned EVs. In other words, customers rented an Electric vehicle for one way only can leave the car in a parking area with a prerequisite from the rental company to plug-it in a charging station to be ready for the next costumer. In the meantime, such EVs will discharge their batteries to balance and stabilize the grid. Yet, this concept is subject to various factors in order to know the exact amount of energy to be drawn from the batteries on-board to no degrade the vehicles performances.
The rapid spread and integration of EVs within the smart cities can be seen only if the host cities are able to accommodate them. Cities must provide several parking areas equipped with charging stations able to feed the batteries of Electric vehicles and to receive energy stored on-board EV batteries when needed. The location of parking areas able to host high number of EVs a day can be outside the center or the edge of the city. In addition, those parking areas can contribute for reducing the traffic congestions in major cities, taking into consideration the long periods of EV charging process.
In this part, we will assess the parking areas of Airports and Malls, as well as parking areas situated in metro stations and not forgetting the city district parking places.

3.2.1. Park and Ride:

For big metropolitan cities, parking areas are able to reduce the traffic congestion that can be created due to high number of vehicles coming from outside. Such parking areas are situated in the edge of the city and more precisely near to subway stations or other types of transportation stations. The number of parking lots is higher taking into account the high number of car owners that they prefer using public transportation means instead of their cars.
The following are the data chosen to assess the ability of this type of parking.

- The opening time of the parking: usually the opening period for a park & ride is related mainly to the working time of the transportation service. For this case, it is from 6 am until 1 am, 7 days on 7. Therefore, each vehicle has a maximum of 19 Hours of parking per day.
- Total capacity of the parking: due to the nature of car flow coming from hinterland, the parking size can vary. With this in mind, total capacity of a park & ride is from 1000 vehicles to 1500 vehicles.
- The proportion of parking lots equipped with EV charging stations: 10 %. This value is low because daily commuters are usually coming from long distances with preference of ICE vehicles over Electric vehicles.
- Probability to find electric cars: 70%.

Taking into consideration the above-mentioned data, the number of electric vehicles that can be in the same time connected to the grid during the opening period is 70 and 105.

3.2.2. Mall Centers Parking:

Nowadays, contemporary cities are obliged to build large mall centers encompassing many shops for different purposes. Taking into consideration that large malls are usually situated far from city center or in the extremity of the city, people need to reach them by car. Therefore, mall center parking must provide high number of parking lots able to host huge car flow.
The following are the data chosen to assess the ability of this type of parking.

- The opening time of the parking: the parking opening period is mainly related to the duration in which the mall shops are open. Usually, the parking opening time is from 8 am until 10 am, 7 days on 7. Therefore, each car has a maximum of 14 Hours of daily parking.
- Total capacity of the parking: the size of the mall and its proximity to the city center are contributing to assume the exact capacity of the parking.

Thus, the total number of parking lots can be from 1500 vehicles to 2000 vehicles.

- The proportion of parking lots equipped with EV charging stations: 35%. This value is higher than the previous one for two reasons. Mall visitors spend more than 8 hours in the shopping center, which is a sufficient time to charge 100% of the battery of an electric vehicle. Moreover, for Vehicle to grid operation, the customer will perfectly identify the exact time to execute this function, taking into consideration that EV owners need a battery of 100% before driving their vehicles. Therefore, for this type of parking, charging and discharging operation are identified and set perfectly with the shopping time of customers.

- Probability to find electric cars: 80%.

Taking into consideration the above-mentioned data, the number of electric vehicles that can be in the same time connected to the grid during the opening period is between 420 vehicles and 560 vehicles.

3.2.3. Airports parking Areas:

For airports, the size of parking areas varies and depends on airports proximity to the city as well its size and the airplanes traffic flow in it. For this study, we will consider an airport serving national and international flights and able to host high number of vehicles.
The following are the data chosen to assess the ability of this type of parking.

- The opening time of the parking: Airports parking is open 24 Hours 7 days on 7. Therefore, each car has 24 hours of maximum daily parking.
- Total capacity of the parking: the size of the airport and its proximity to the city are mainly contributing to the capacity of the parking. Therefore, the total number of parking lots is between 4000 and 4500.
- The proportion of parking lots equipped with EV charging stations: 40%. This value is higher than the previous ones because car rental companies in the airports are offering various types of cars in their fleet including EVs, which are already plugged in to the network. This is not only related to the cars found in the airports but also the cars provided by the same car rental company that can be driven by the costumers from the city to the airports and can be left in a parking lot with a prerequisite from the company to

plug-it-in to the grid. with this in mind, it is obvious now why the percentage of EVs to be found in that type of parking is higher, which mainly depends on the rental companies car fleet since they can offer EVs with incentives to use them as an alternative to other transportation means.

- Probability to find electric cars: 90%.

Taking into consideration the above-mentioned data, the number of electric vehicles that can be in the same time connected to the grid during the opening period is between 1440 and 1620 vehicles.

3.2.4. On-street charging stations:

Position of charging station in the city, traffic flow, type of charging provided by station operators are making on-street charging stations more flexible and data vary from a station to another.
Nevertheless, the following are the data chosen to assess the ability of this type of parking.

- The opening time of the charging station: as the previous type, on-street parking with charging stations opens for 24 hours, 7 days on 7. Therefore, each car has 24 hours of maximum daily parking.
- The number of charging stations in a district: 25 to 30 charging stations. This number depends mainly on the population density as well as the traffic flow in each district.
- Probability to find an EV: 80%.
- Availability of sockets in each charging station: the availability is mainly dependent to the number of sockets already in a charging station, as well as the type of the charging mode provided by the operators, which identifies the charging time of each vehicle. The traffic flow in each district contribute to the availability of the sockets as well. For instance, in a district with high traffic flow, the availability of a free socket cannot exceed 50%. On the other hand, a district far from city center with 25 to 30 charging station, sockets availability is from 50% to 100%. Moreover, the charging time of an Electric vehicle is also an important factor contributing for the availability of the sockets. Therefore, in general the probability to find an available socket ranges from 50% to 100% corresponding to the area.

Taking into consideration the above-mentioned data, the number of electric vehicles that can be in the same time connected to the grid during the opening period ranges from 10 vehicles to 24 vehicles.

4. Vehicle-to-Grid (V2G) models:

With the increase number of electric vehicles being deployed all over the globe, the electrical grid has experienced several issues regarding the quality of power being delivered to the loads connect it to a micro grid. The vast deployment of EVs and their use as a sustainable substitute to ICE driven vehicles has contributed to the improvement of the environment, and their frequent use will certainly lead to decrease the households CO2 emissions. However, the large number of electric cars connected contemporaneously to the grid will create an overload on the electrical network, and will degrade the performance of the network and may lead to several interruptions of the power in a way that decreases its quality.

Moreover, in a micro grid, where industrial and residential loads are connected, and in addition to a large number of EVs charging their batteries for several hours, the need for a diesel generator is mandatory to support the grid encountering the high demand from the loads. The use of such generator that is not a clean source of energy will be a hurdle against reaching low CO2 emissions. Therefore, new technologies are emerged to improve not only the performance of the grid but also using them as clean source of energy that can be used when needed. Through Vehicle to grid technology, it becomes possible that EV on-board batteries are opted to be used for ancillary services for the electrical network. EV batteries are considered as storage devices capable of feeding the grid with the necessary energy when needed, i.e., Electric Vehicles will discharge their batteries to compensate the reactive power and stabilize the active power due to the occurred interruption in the micro grid. For a better benefit from the Electric vehicles main feature, it is necessary first to choose carefully the Power Quality events eligible for compensation.

Regarding the analysis of voltage dips, the period between 2015 and 2020 was considered. From the tables above containing the distribution of voltage dips, we will concentrate on the events with a residual voltage lower than 70% and a duration of up to 500 ms since they are dangerous and cause severe effects on both class 2 and 3 appliances according to [(fig (20)]. Other dangerous Voltage dips with longer durations, i.e., durations superior than 500 ms are not considered in this study since the storage capacity of the battery installed on-board EVs would not withstand their compensation.

The number of vehicles available for compensation will certainly determine the real feasibility of the Vehicle to grid functions for every parking prospective scenario. In other words, some charging stations of public parking areas can be connected directly to the primary distribution network due to the high demand of power from such stations. Therefore, the exact number of EVs necessary for

compensating PQ events depends on the discharging power during a V2G function, deepness and duration of the considered voltage dips.
The smart grid concept has brought the idea of supplying a micro grid with enough energy with the help of local generators and storage (islanding operation). Thus, through V2G, we can connect the exact number of EVs to supply the loads during a short event. Consequently, the airport parking areas as well as large size shopping center can be suitable candidates to host charging stations for EVs, as these charging stations will offer V2G functions. For both scenarios, we can compensate for events with deepness lower than 70% and with a duration up to 500 ms in order to limit the power of both parking areas lower than the boundaries set by the regulators.
In the following, we will introduce the models adopted for a vehicle to grid simulation. The first one simulates the charging and discharging operation between an AC source and a battery that plays the role of an Electric vehicle. Explanation of every block used in the model will be provided through this part in order to make the models more comprehensible.
The second example shows a 24-hour simulation of a vehicle-to-grid system. Such system is used in order to regulate the frequency on a micro grid in order to compensate for events occurring during 24 hours. This model is adopted in order to apply our approach of implementing vehicle to grid in charging stations installed in parking areas situated in airports and malls. The reason why we choose only airports and malls is that the data of voltage dips presented in this report is related to the primary distribution network, and the charging stations in public parking areas including airports and malls are connected to such networks.
In addition, airports and malls can meet the smart grids aspiration of creating a permanent and sustainable energy source for islanding operations, as the source of energy will be fully delivered through batteries on-board EVs.

4.1. Three-phase Electric Vehicle charger model:

The model adopted here is related to the connection between the grid and the vehicle. In the input, we have a front-end converter [figure (29)], which is also known as an active rectifier that converts AC grid voltage to DC and maintains a constant voltage across the DC bus. The control block diagram of the three-phase front-end converter is used to regulate 800 V DC across the bus.
In addition, we have a bi-directional buck-boost converter used to control the battery current during charging and discharging operations [figure (29)].
The display blocks show the active power and reactive power after each operation as well as the battery input fluctuations. In addition to that, several scopes are put

to visualize the DC voltage changes, battery results, Grid's voltage and current after the execution of each operation [figure (37)].
The control bloc diagram of the front-end converter is used to regulate the dc voltage across the dc bus [figure (32)]. The current measurement block is used to measure the inverter current. The three-phase bridge is built using IGBTs [figure (35)].

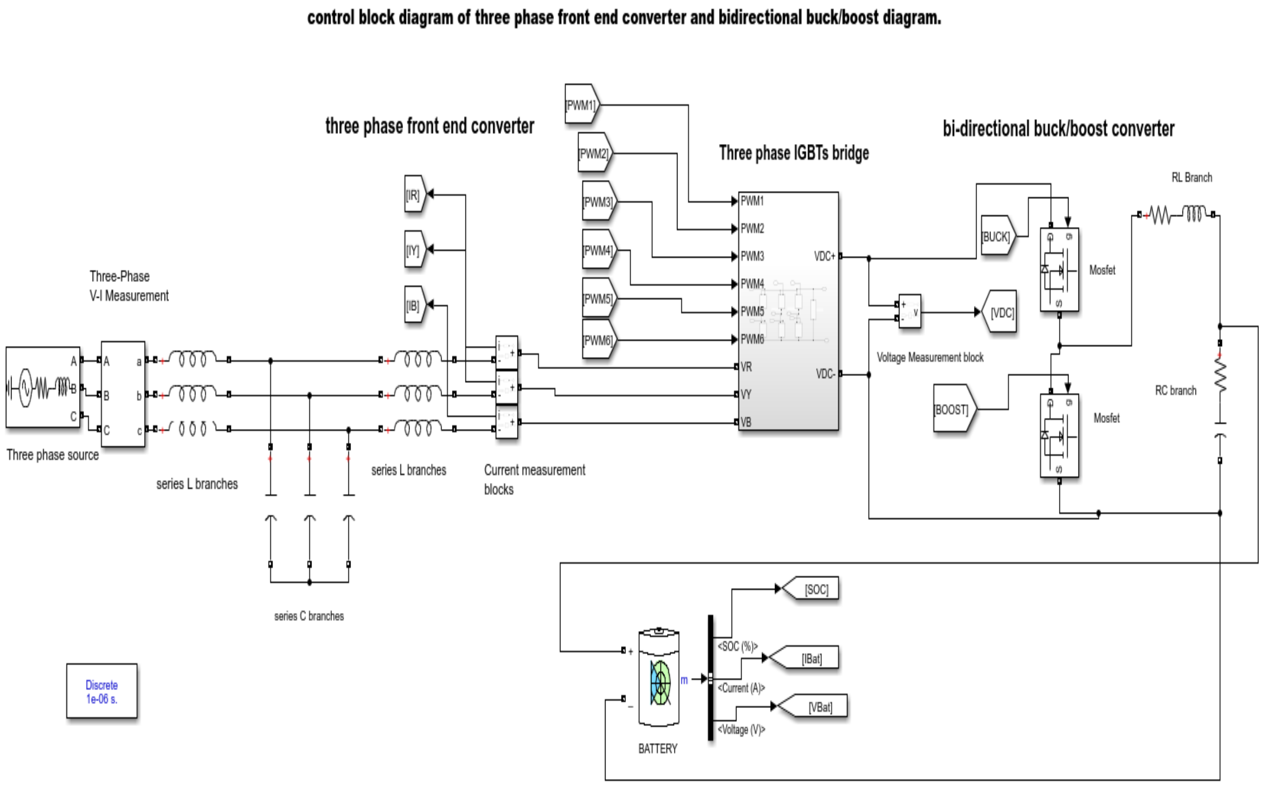

Figure 29: circuit topology of a three-phase electric vehicle battery charger.

The graph above illustrates our basic circuit topology of three-phase electric vehicle battery charger. As it is seen, the input consists of three-phase front-end converter. Such converter is adopted to convert the AC grid voltage to a DC voltage. In addition, the converter plays an important role in keeping the voltage across the DC bus more steady, i.e., constant.
The active front-end rectifier is an AC-DC converter and chosen since it has a low THD input current and it is capable of handling a bi-directional power. In addition, the control block diagram adopted for this converter is used to regulate the 800 V DC across the bus.
On the other side of the control scheme, there is a bi-directional back-boost converter used to control the battery current during charging and discharging operations.

The control block diagram used for buck-boost converter is able to regulate the battery charging and discharging current.
The grid voltage is chosen equal to 415 V RMS at a frequency equal to 50 Hz. The filter topology adopted is an LCL filter with inductances at both sides have a common value of 5 mH each, and capacitances with a value of 30 μF each. The source resistance and inductance values are chosen very small, as R = 0.8929 mΩ, while L = 16.58 nF.
With the three-phase Voltage Current (VI) measurement block, we are only measuring the voltage and NOT the current. Immediately after the Three-phase VI measurement block, we inserted an LCL filter. The inductors used for this filter do have the same values for both sides, i.e., source inverter inductors are equal to inverter side inductors.
In order to measure the inverter current, we inserted three current measurement blocks, one for each phase.
For the inverter bridge, we used IGBTs with an RC branch representing the DC bus. The Resistance value is equal to 1 mΩ, while the bus capacitance is equal to 5600 μF.
For the buck-boost converter, we used MOSFETs, as well as a filter inductance, which is equal to 20 mH. The output capacitance is equal to 0.625 μF.
The battery used here as a DC source and considered as the equivalent of an electric vehicle connected to the electric grid. The battery nominal voltage is 360 V with an initial State of Charge (SoC) set at 50%. The rated capacity is equal to 300 Ah, and the battery response time is set equal to 1s.
The switching frequency of both converters is set equal to 10 kHz with a total rated power equal to 10 kW.
For the three-phase bridge, it is built using IGBTs with an RC branch connected in series representing the DC bus. The PMC port is a connection port adopted for subsystems. The initial voltage used in the DC bus is equal to 800 V. The three-phase bridge and the LCL filter are connected through current measurement blocks. Then we added a voltage measurement block adopted to measure the DC bus voltage.

The figure (31) illustrates the 6-pulse three-phase bridge adopted for our simulation. The bridge consists of 6 IGBTs, each of which has an internal resistance equal to 1 mΩ and a snubber resistance set at $1e^5\Omega$. In addition, there is a DC bus, as the resistance and bus capacitor presents this bus with an RC branch. The capacitor initial voltage is set equal to 800 V. This voltage will be regulated by our schemes illustrated in the figures below.

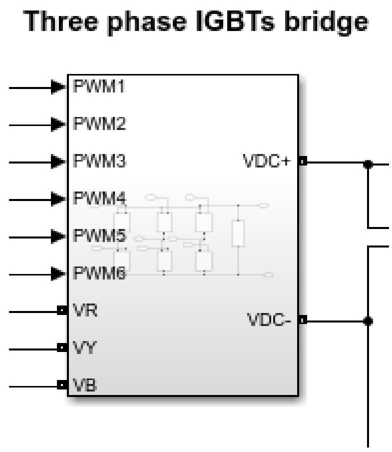

Figure 30: three- phase IGBTs bridge block diagram.

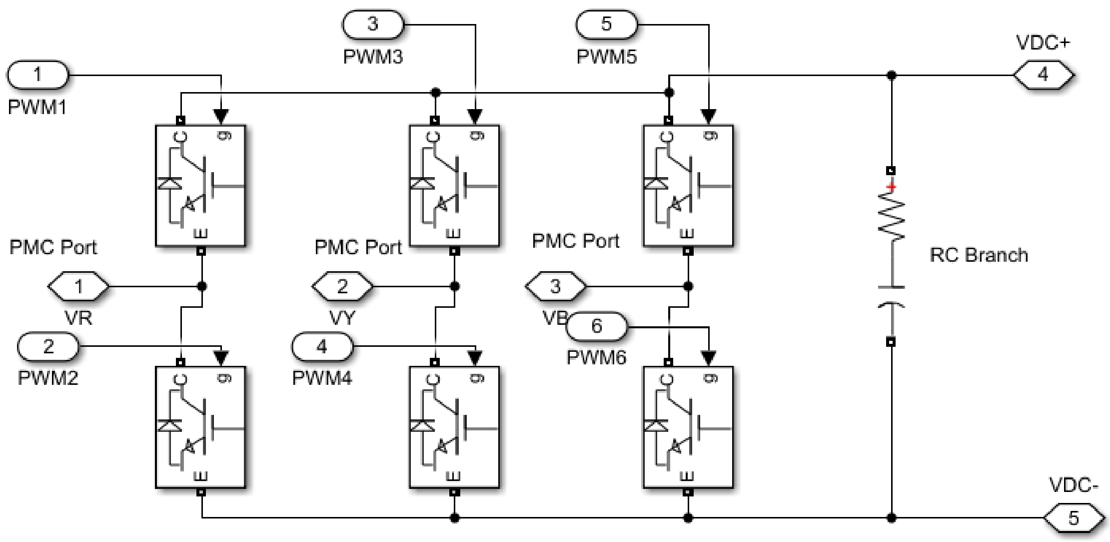

Figure 31: three-phase IGBTs bridge scheme.

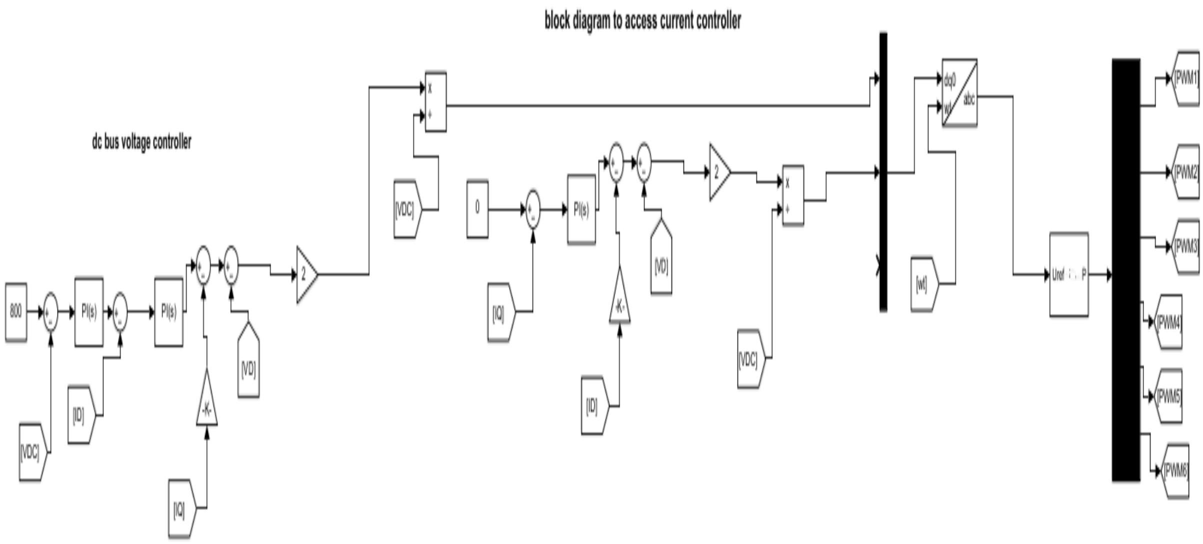

Figure 32: controller blocks diagram: Voltage and current controller blocks.

The DC bus voltage controller is designed in order to regulate the DC bus voltage that is set equal to 800 V as it is depicted in the scheme in the graph above. This value is initially set in the DC bus of the three-phase bridge as the capacitor initial voltage. For this controller, two PI controllers are used. The first one with P = 0.5 and I = 5, while the second gain has P = 25 and I = 500. P refers to Proportional, whereas I is Integral. The first gain used here has a value equal to "2*π*50*10e^{-3}", while the second gain value is set equal to 2. The second controller is designed in order to control the current of the inverter. For this controller, we choose a PI controller with P = 25 and I = 500. The output of this controller is not subject to any limit. A PWM Generator (2-level) is adopted since it controls the switching devices of our generator that is a three-phase bridge (6 pulses). The PWM generator has a frequency set at 10 kHz.

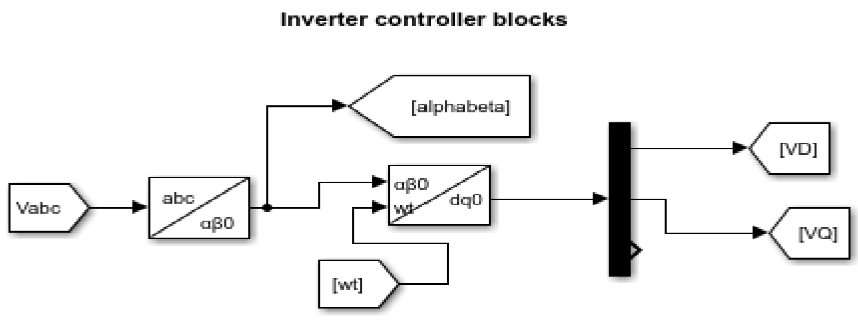

Figure 33: inverter controller blocks.

The alpha beta block in this inverter controller will used as an input to the Pll, as the figure below depicts.

The “abc to αβ0” block performs a Clarke transformation from a three-phase (abc) signal to an αβ0 stationary reference frame. The “αβ0 to dq0” block is used since it executes a transformation from a αβ0 stationary reference frame to a dq0 rotating reference frame. The input “wt” is responsible of the angular position of the rotating frame, as this “wt” is the output of the Pll controller.

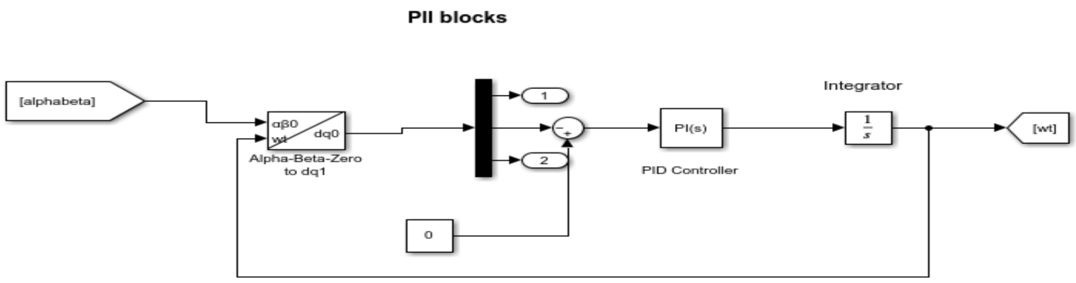

Figure 34: Pll blocks.

The output of the Pll as shown in the figure above has to go to the current transformation block; the “wt” block is the responsible of such connection, as the “wt” is considered as the output of the Pll. The current reference in this controller is set equal to 0. The controller used here is of Type PI. P (proportional) = 10 and I (Integral) = 50000. For the output saturation parameters, the output of this block is not limited. An integrator with initial condition equal to 0 is used.

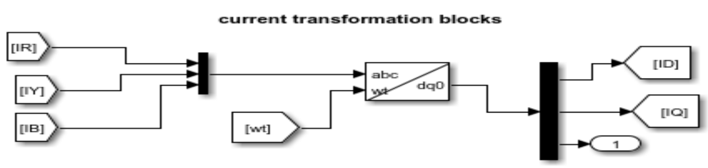

Figure 35: Current transformation Blocks.

The “abc to dq0” block is used here in this controller since it performs a Park transformation from a three-phase (abc) signal to a dq0 rotating reference frame. Similarly, in the inverter controller, the “wt” block is set as input and responsible for the angular position of the rotating frame.

The current reference used here in this block [Figure (36)] is set equal to 30 for V2G operation or -30 for G2V operation [Figure (61)]. A DC-DC PWM generator is used with a switching frequency equal to 10 kHz. The controller used here is of type PI. P (proportional) = 0.005 and I (Integral) = 10. For the output saturation parameters, the output is limited between 0 (lower limit) and 0.95 (upper limit). The time domain used here is continuous.

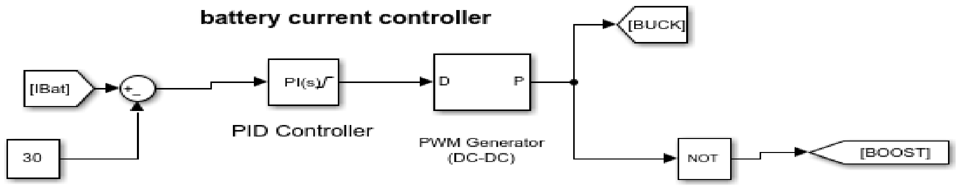

Figure 36: Battery current controller.

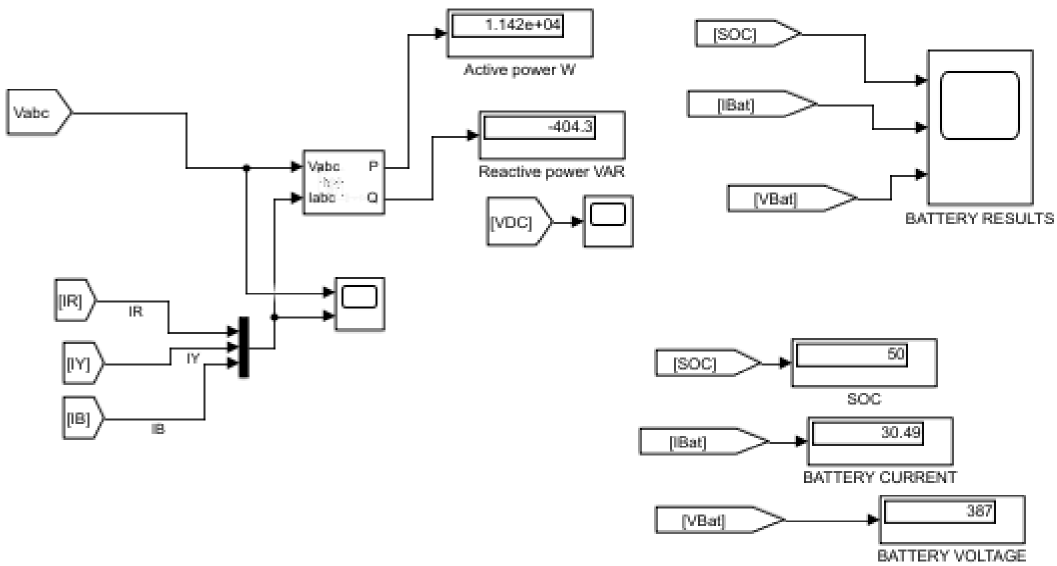

Figure 37: Visualization blocks for results.

4.2. 24-H simulation of Vehicle-to-grid (V2G) system model:

The model adopted in this part of the work is related to a 24-hour simulation of a vehicle to grid system. we used this model to perform the frequency regulation process on a micro grid in order to reduce the severity of the PQ events occurred in the electrical network and to compensate for the events (voltage dips) that may lead to the malfunctioning of the class 2 and class 3 equipment connected to the grid.

Regarding our approach explained in 3.2, this model is adopted in order to visualize to what extent we can reach a feasible compensation of reactive power and stabilization of active power of the grid through a V2G function. In addition, after the analysis of voltage dips, it becomes possible now to assume the approximate number of EVs to be used for the compensation.

As explained in 3.2, the number of EVs in each parking area is subject to several factors, mainly, the number of charging spots inside the parking area, opening time of parking areas as well as the probability to find an EV.

For on-road charging stations, we added also the availability of electric sockets factor that is subjected mainly to the traffic conditions on the roads. Nevertheless, for simulation and simplification purposes, we assumed 100 EVs as the maximum number of electric vehicles connected to the grid and charging their batteries for different periods of the day and different durations in order to benefit the maximum from the V2G function.

The model presented in this part of the work represents a micro grid that is fed through a diesel generator, in addition to a PV farm and a wind farm. The diesel generator is the main power generator in this micro grid with an active power equal to 15 MW. The renewable energy is produced by a combination of Photovoltaic (PV) and wind farms.

In our model, two renewable energy sources are feeding the grid with clean energy. The first one is a Photovoltaic (PV) farm that produces energy according to three main factors; the size of the area covered by the Photovoltaic farm, the effectiveness of the solar panels as well as the irradiance data. The second clean energy source is the wind farm that produces the electrical power following in accordance to wind level. There is a linear relationship between the wind farm and the wind level and it can be explained as follows; when the wind reaches its nominal value, the wind farm starts producing power and feeding the grid with its nominal power. Yet, when the wind speed exceeds the maximum wind value allowed, then the wind farm trips from the grid.

The diesel generator used in this model is the basic generator of energy to the grid. Such generator helps balancing the power consumed and the power produced.

The diesel generator is used as the main power provider for the following reasons. PV farms and wind parks are both subject to various fluctuations in terms of the efficiency of their power. In other words, regarding the PVs, the output of the solar photovoltaic arrays is not steady during the whole day, as it varies with time. In addition, this output changes depending on the climate condition, as it varies during summer and winter, as well as during the rainy days, particularly for a continuous rainy period. In general, solar irradiance, temperature changes, orientation and Tilt angle, Dusts and shading are the main factors affecting the performance of PV modules.

Moreover, the unstable productivity of the wind power stations makes it a hurdle to be adopted as a main source for the energy. As stated above, the wind parks do have a linear relationship with the wind and thus, the production alters and fluctuates yearly, either leading to an underproduction of the power or overproduction that the operators are not able to store. More precisely, the energy production in a year can only be guessed and not computed.

Therefore, relying on a diesel generator as the main power source is feasible in order to guarantee more power being delivered to the grid, and balancing the high demand of power with the power produced by the renewable energy sources and the diesel generator.

A load composed of a residential load and an asynchronous machine is connected to the grid through a three-phase two windings transformer with a nominal power equal to 20 MVA. The primary rms phase-to-phase voltage is equal to 25 kV, whereas the secondary rms phase-to-phase voltage is equal to 600 V.

The asynchronous machine used here represents perfectly the impact of an industrial inductive load on our micro grid. In addition, a square relation between the rotor speed and the mechanical torque controls this asynchronous machine.

Regarding the residential load, a specific power factor is set in order to control the consumption profile of our residential load.

The V2G system adopted here is installed between the secondary side of the three-phase transformer and the residential/industrial load adopted for the grid. A detailed description of the block schemes will be provided below.

Through the V2G system, we will be able to control the charging and discharging of the batteries on-board the EVs chosen for each scenario. In addition, we can use the available power stored on-board to stabilize the active power and compensate the reactive power degradation due to the occurrence of severe PQ events during 24 hours.

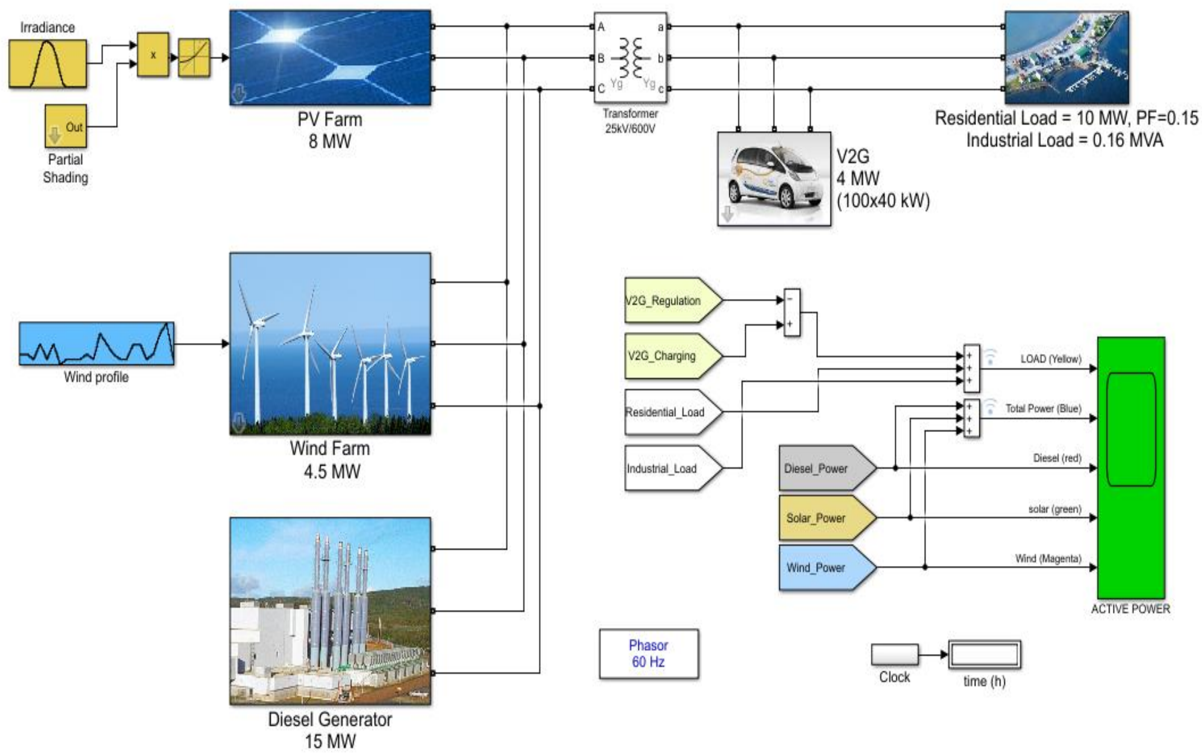

Figure 38: 24-Hour V2G main system.

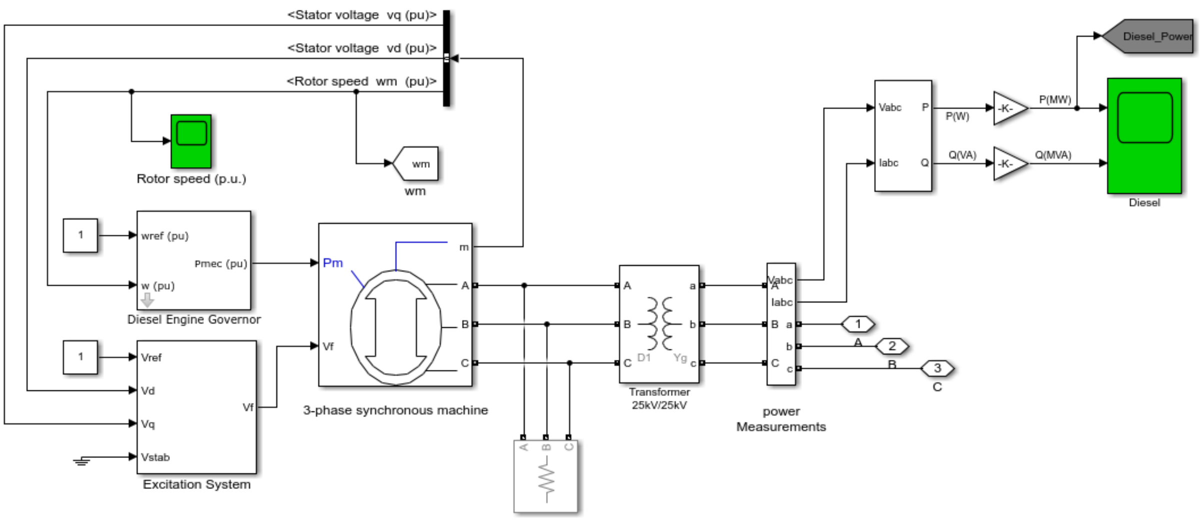

Figure 39: Diesel generator scheme 15 MW.

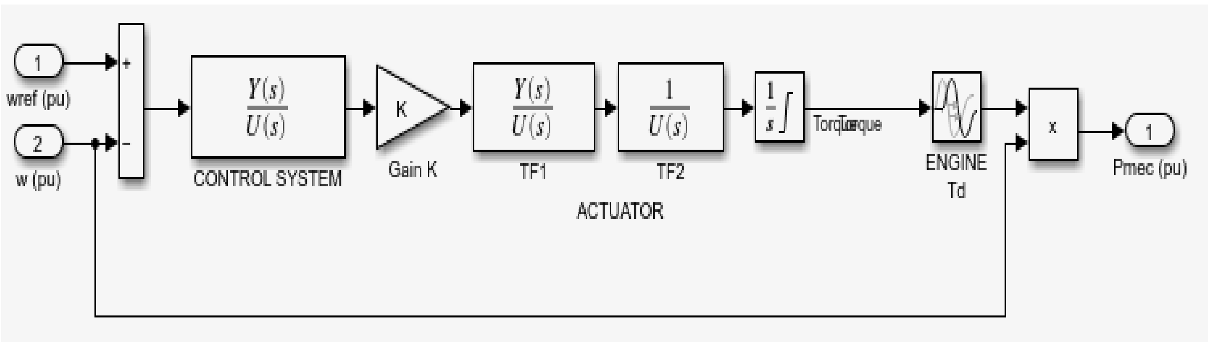

Figure 40: diesel engine governor.

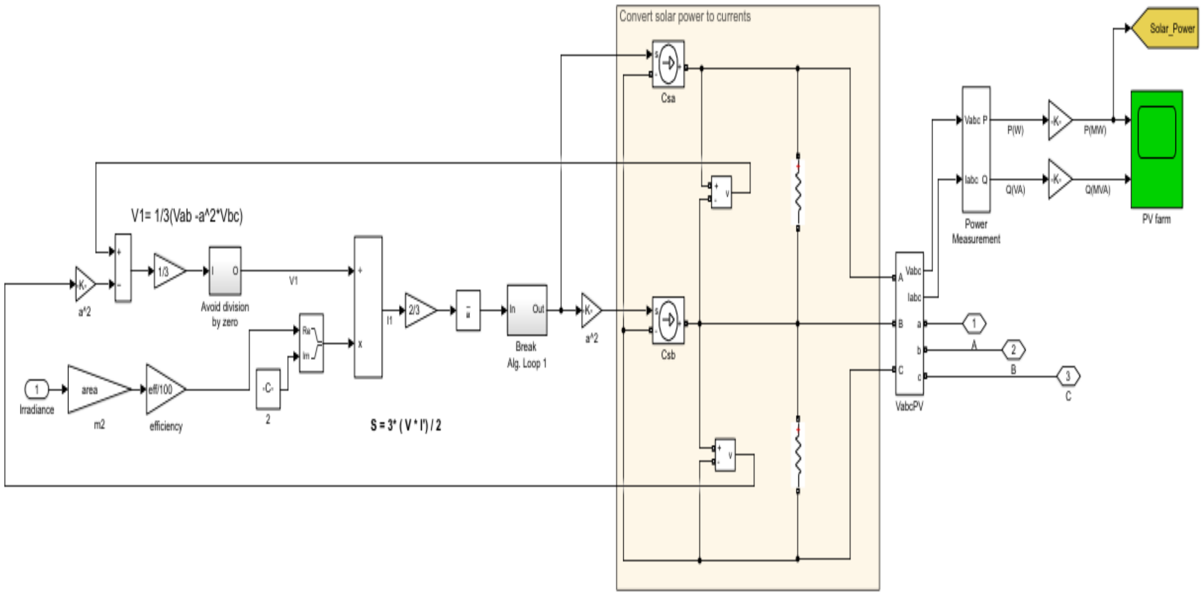

Figure 41: Photovoltaic regulation model scheme.

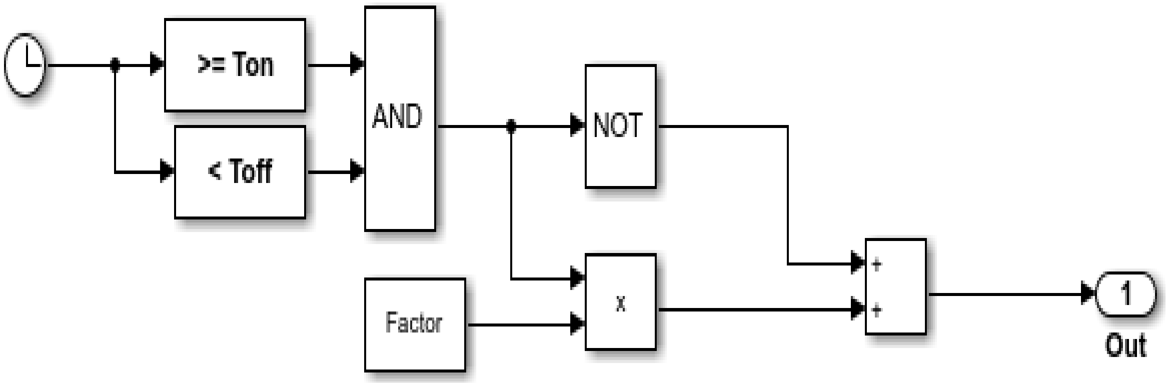

Figure 42: Partial shading scheme.

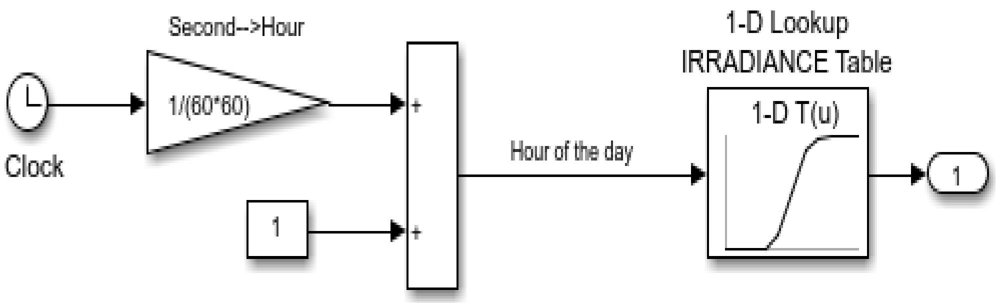

Figure 43: irradiance blocks scheme.

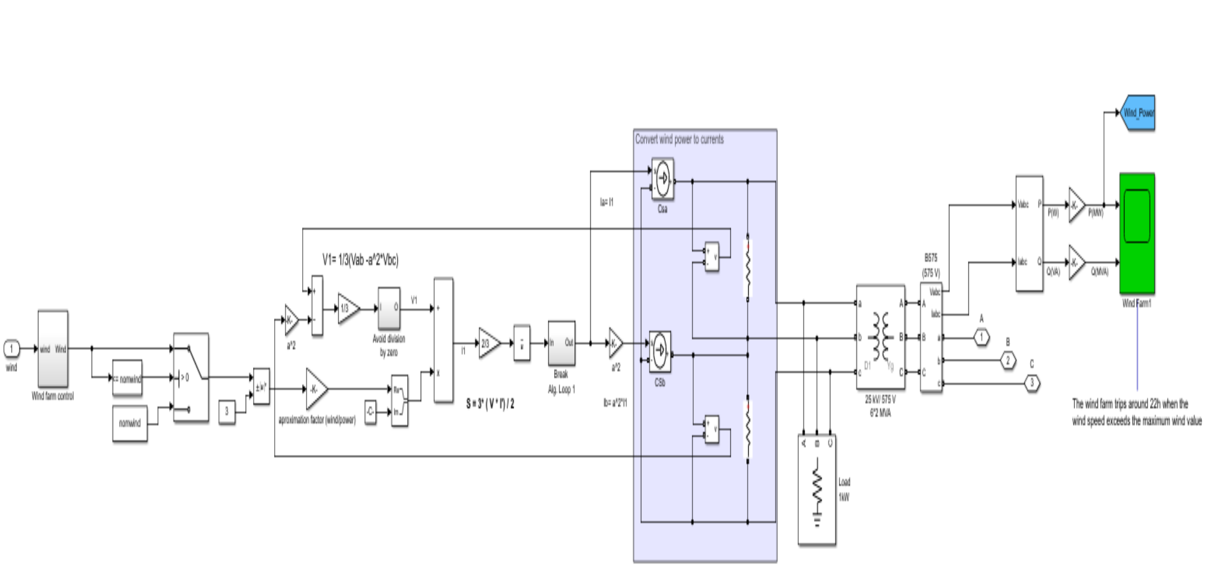

Figure 44: wind farm model scheme.

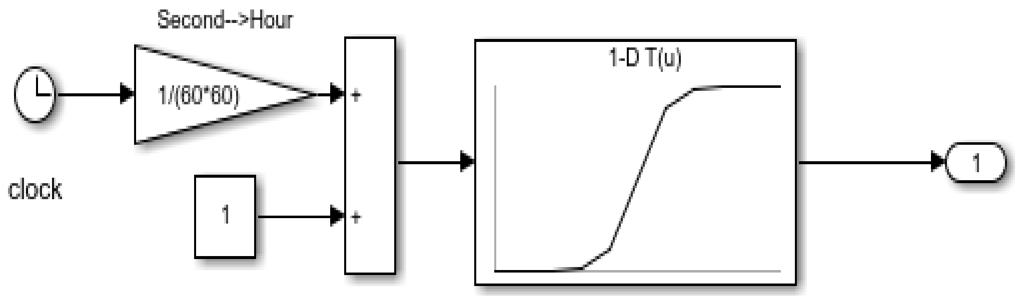

Figure 45: wind profile.

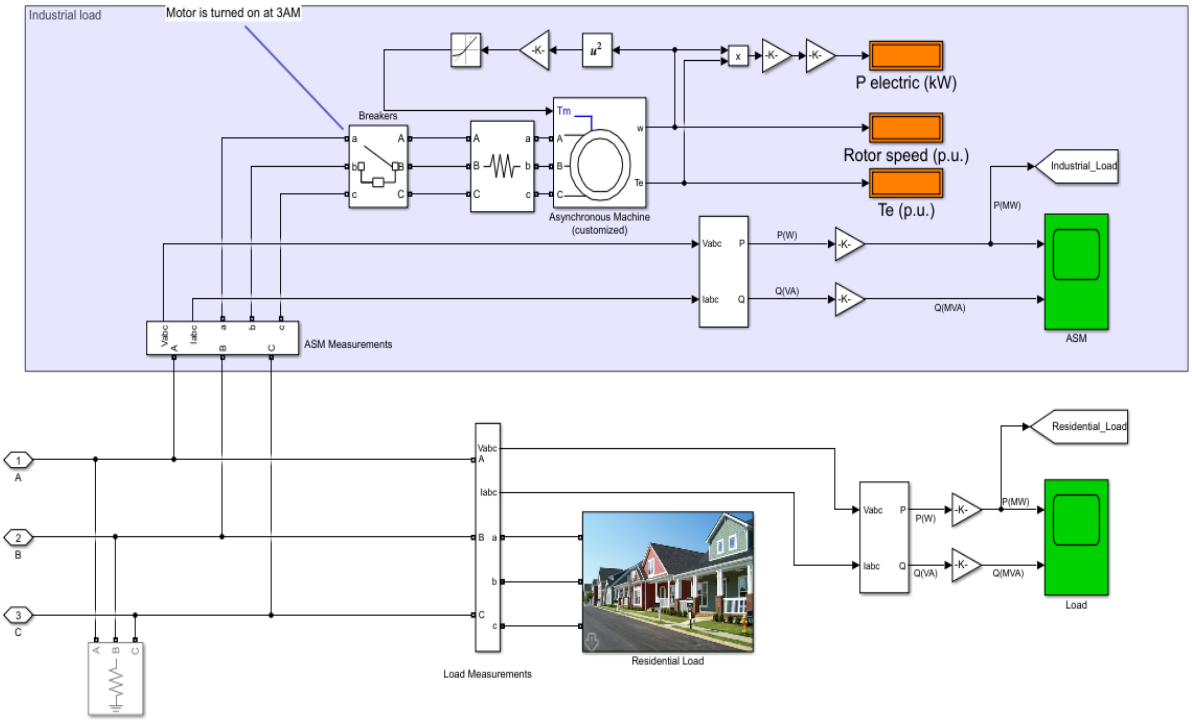

Figure 46: scheme of the industrial load + residential load.

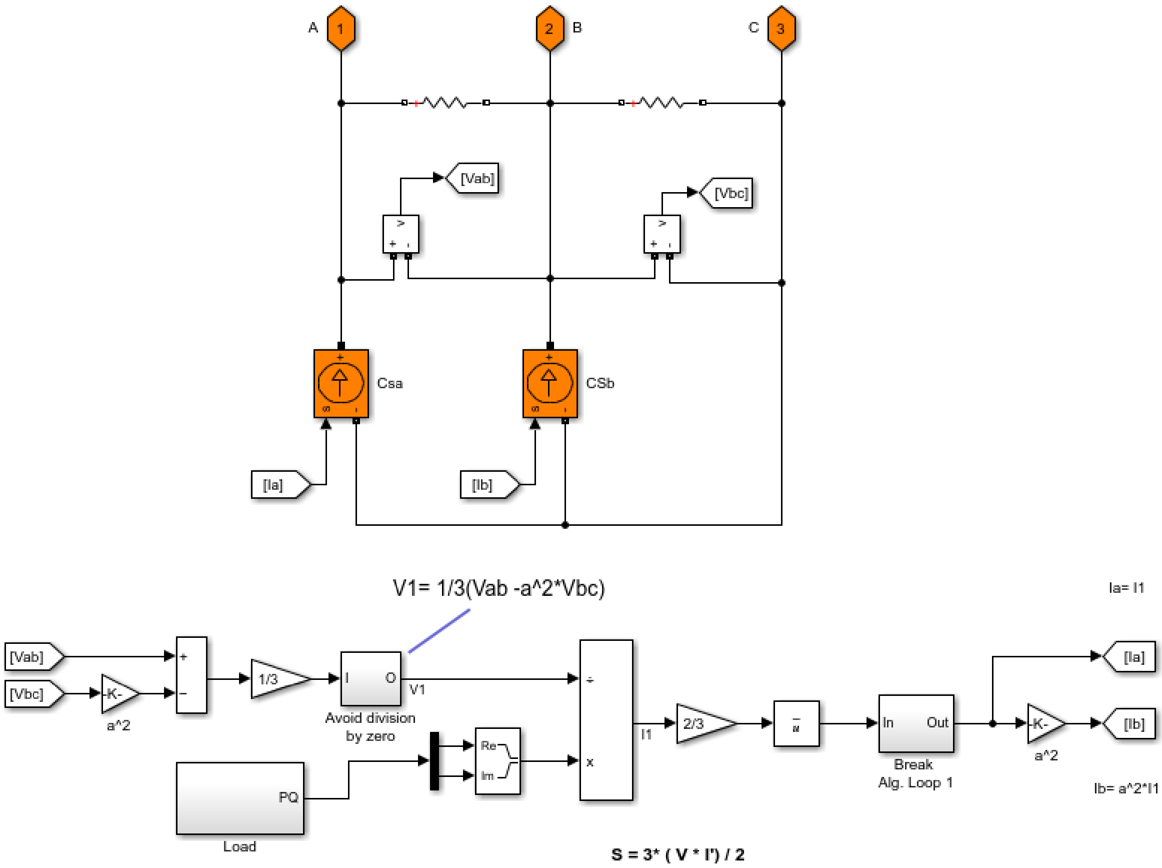

Figure 47: residential load scheme.

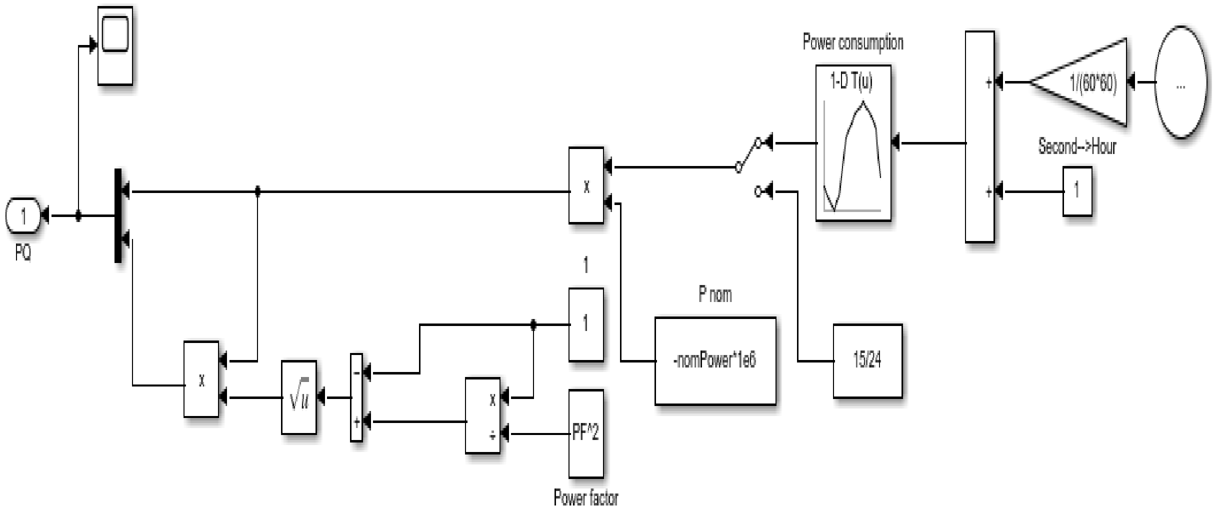

Figure 48: PQ load.

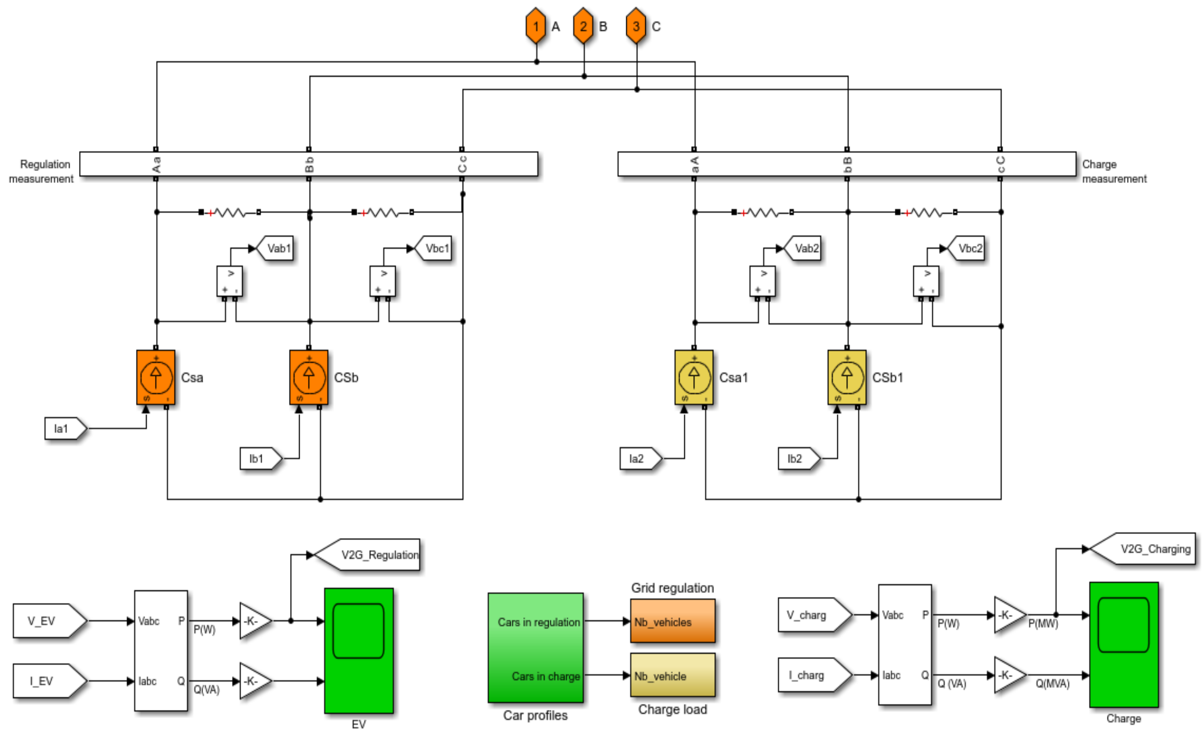

Figure 49: V2G system scheme.

The figure above depicts the blocks used to build the V2G system. As it is shown, the blocks in the top are used for regulation and charging measurements.
The results of regulation and charging can be visible through the scopes.

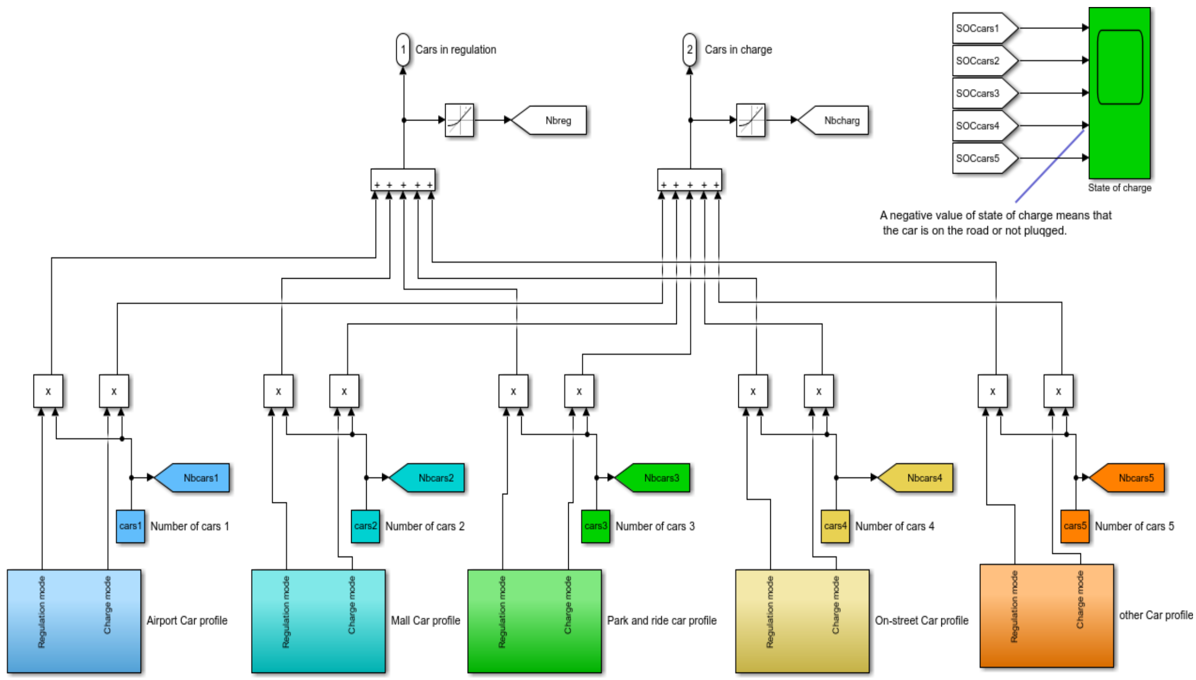

Figure 50: several car profiles blocks.

This figure illustrates how the car profiles are measured to know how many EVs are in regulation or in charging process. The scope used in order to visualize the SoC of each car profile.

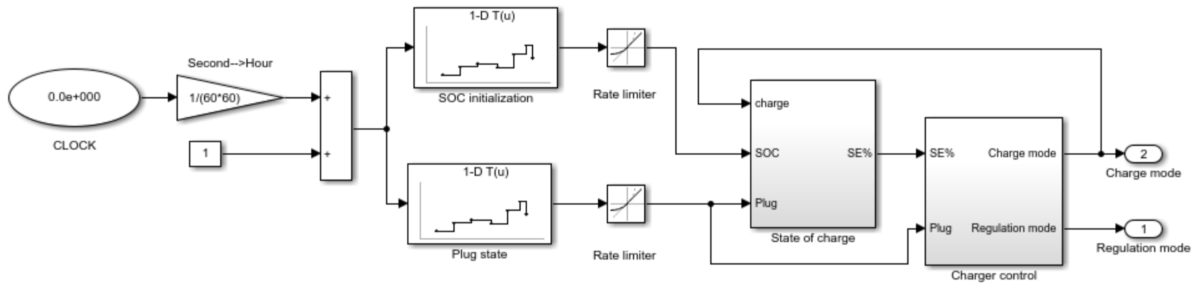

Figure 51: car profiles scheme.

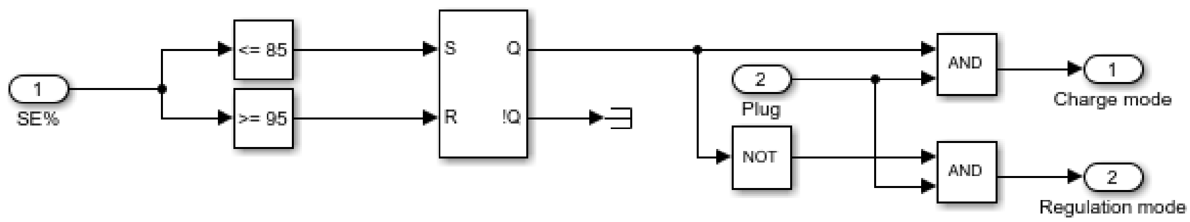

Figure 52: charger control scheme.

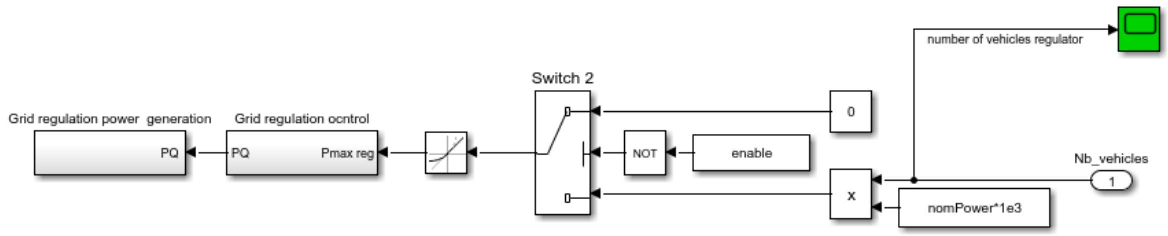

Figure 53: Grid regulation scheme.

This figure perfectly illustrates the blocks used for EVs regulation by the grid. The scope is adopted in order to show the number of EVs in regulation throughout the day.

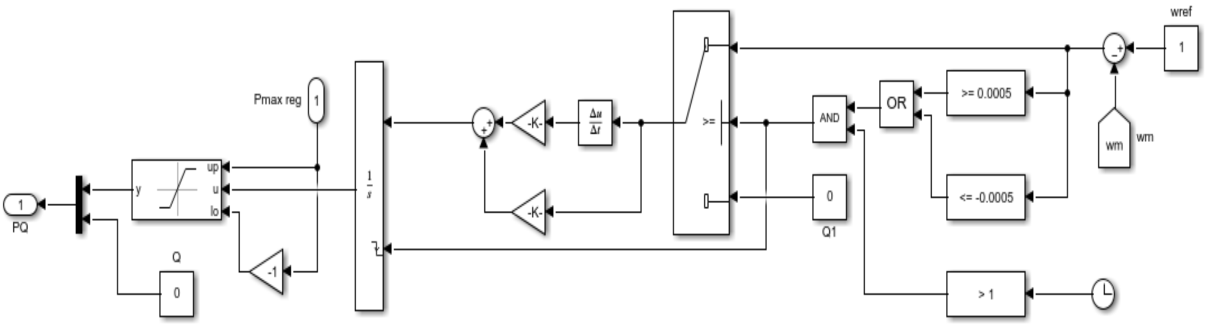

Figure 54: Grid regulation for control scheme.

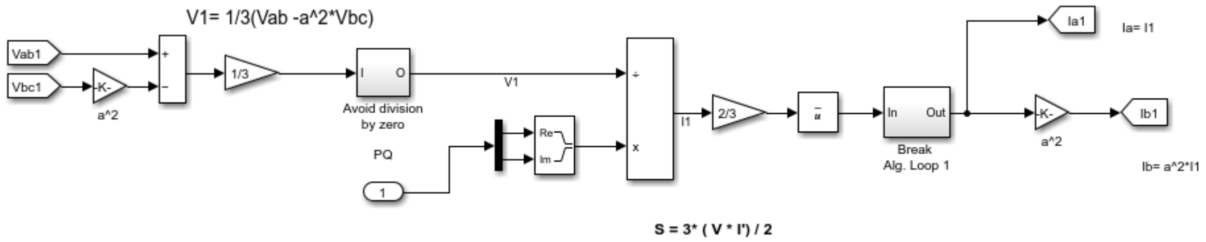

Figure 55: Grid regulation for power generation scheme.

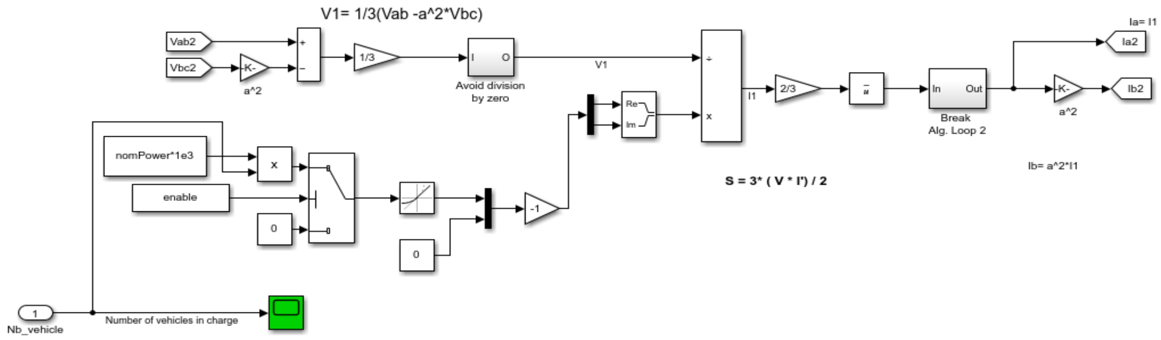

Figure 56: charge load scheme.

This figure shows how we can determine the number of EVs eligible for the charging process. The scope used to illustrate the number of EVs connected to the grid in each time of the day.

5. Simulation and Results Discussion:

5.1. Simulation results of the first model:

5.1.1. Vehicle to Grid (V2G) operation mode:

As the figure (36) depicts, the reference value is positive and equal to 30. Therefore, the active power is positive during the simulation process as the figure (37) shows, which means that the power is flowing from vehicle's battery to the grid. Thus, we are working in the vehicle to grid (V2G) mode.

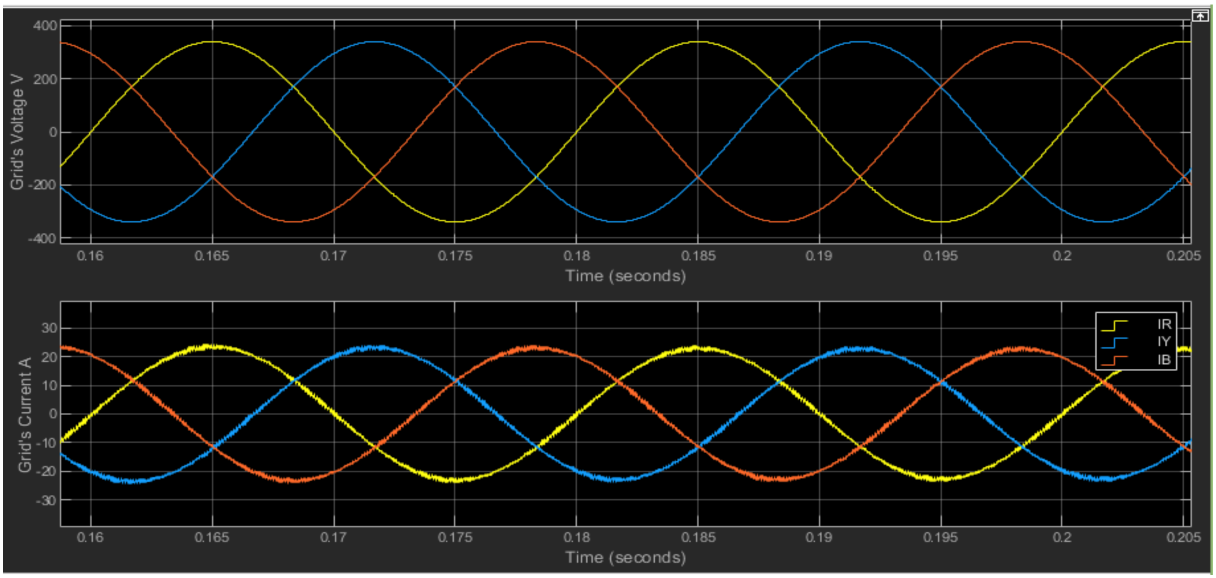

Figure 57: Grid's voltage and current waveforms for a V2G operation.

As the graph above illustrates, the Grid's voltage and current are aligned in phase, which means we are injecting power stored on-board vehicle's battery to the grid.

From the figure below, we can see that the DC voltage has experienced a heavy increase from 800 V to approximately 862 V at the beginning of battery discharging. After that, The DC voltage starts dropping gradually until it restored its initial value at the end of simulation time.

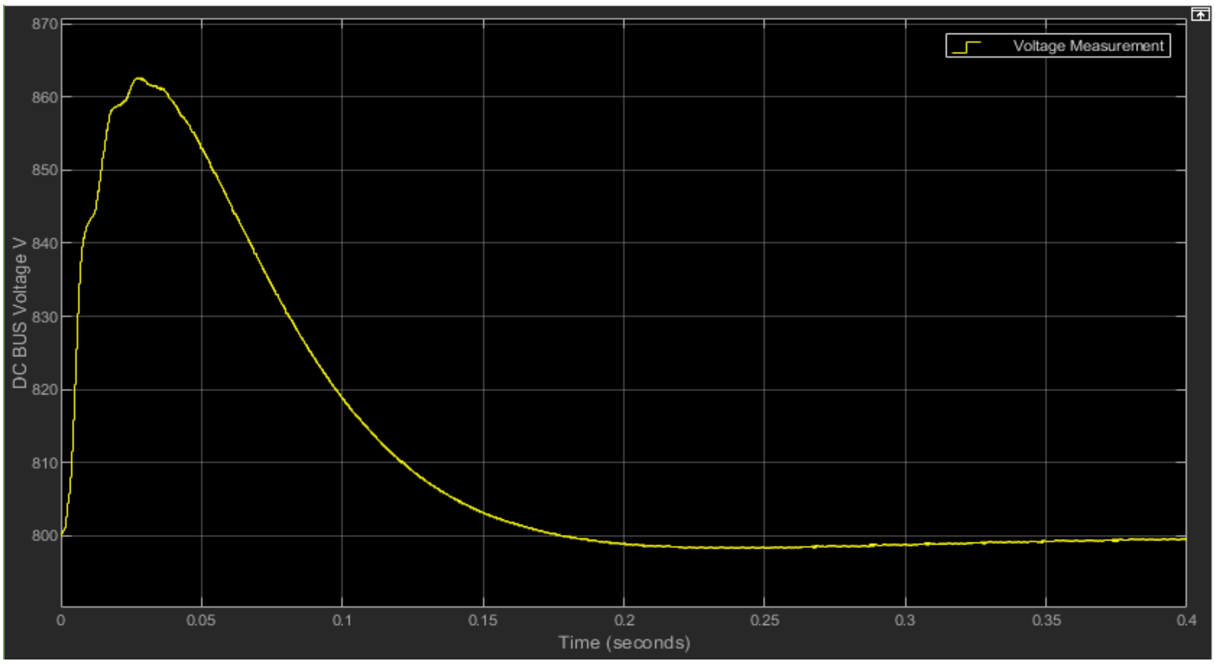

Figure 58: Step response of AC/DC converter, DC Bus voltage waveform during a V2G operation mode.

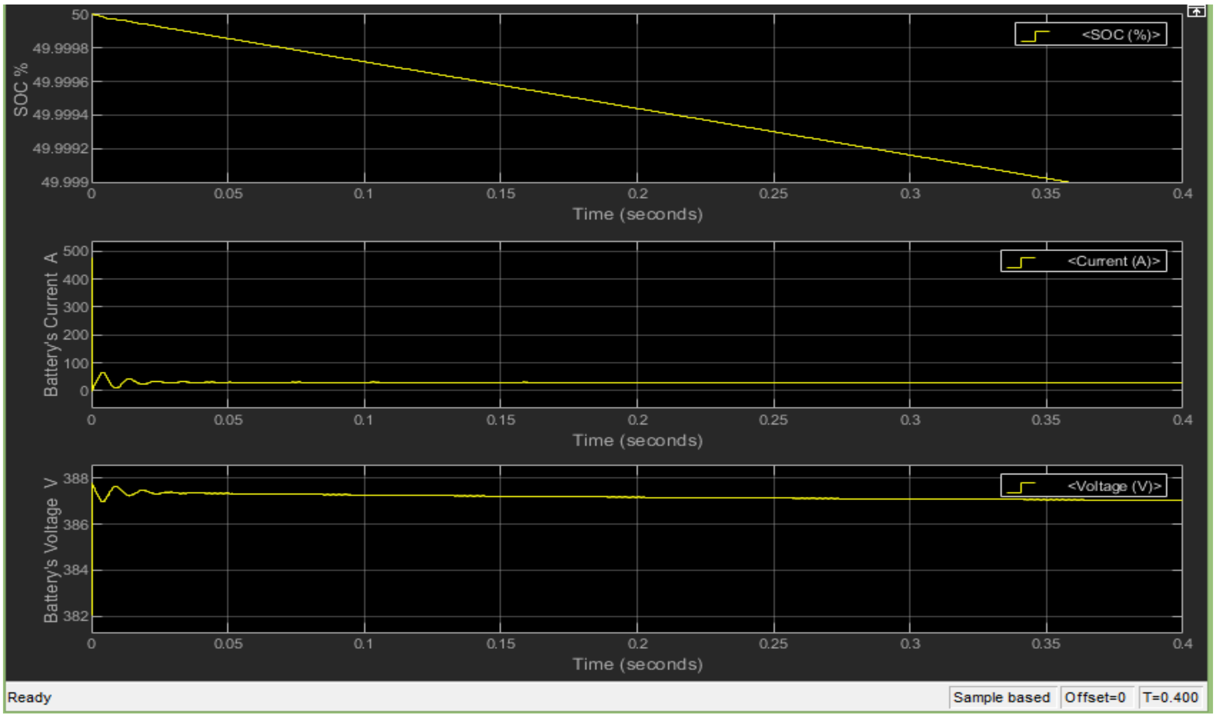

Figure 59: Battery inputs waveforms.

The first waveform perfectly in figure (59) shows the Battery State of Charge (SoC), and as it is illustrated, the battery is discharging. The second waveform shows that the current increases and experiences some fluctuations, and after a time = 0.05 s, the current stabilizes at a value equal to 30. 49 A RMS as it is visible in the figure below. In addition, the voltage of the battery has experienced some fluctuations before it stabilizes at a value equal to 387 V RMS until the end of the V2G operation period.

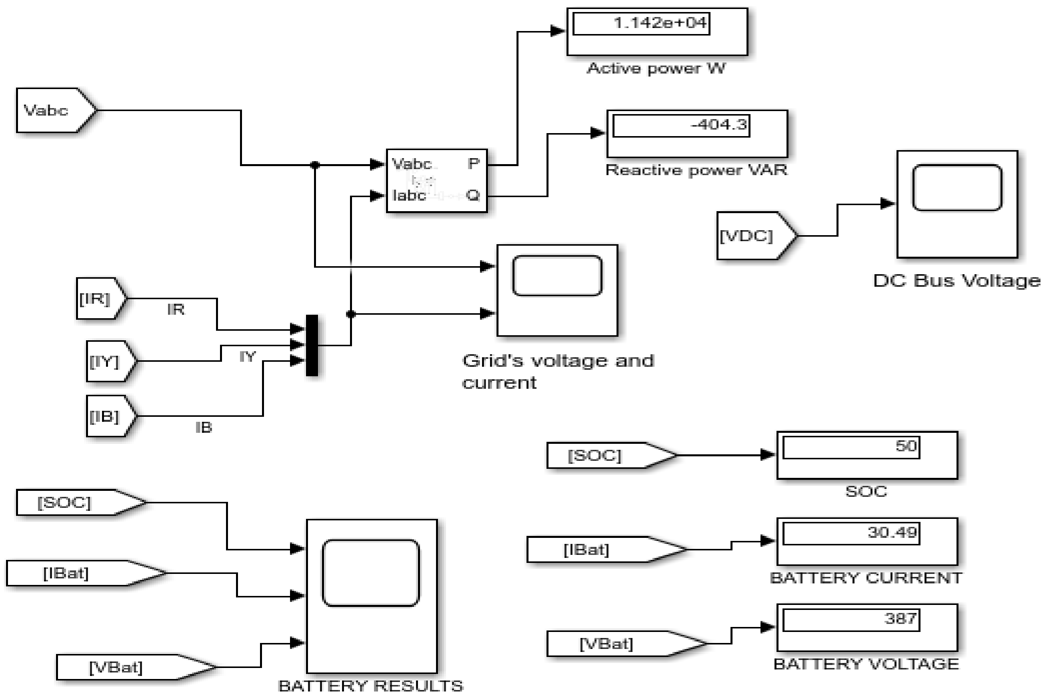

Figure 60: display blocks continuously exhibiting the values of different inputs.

5.1.2. Grid to Vehicle (G2V) operation mode:

As the figure below depicts, the current reference becomes negative and its value set at -30, so the active power now will be negative as seen in figure (61). As a result, the power is flowing from grid to vehicle, i.e., G2V operation mode.

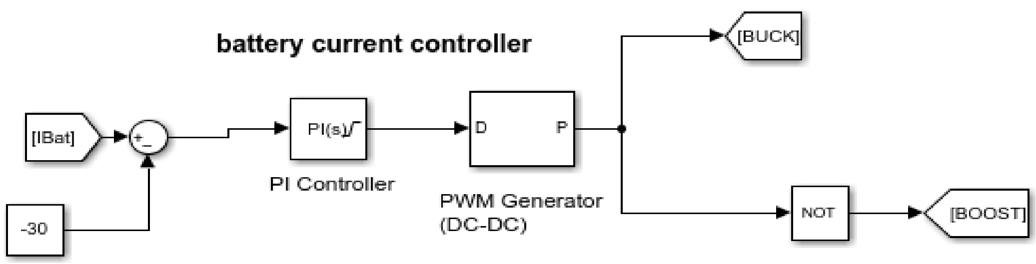

Figure 61: Battery current controller.

The figure below perfectly illustrates the grid to vehicle operation mode. The voltage and current waveforms are aligned out of phase, which means we are injecting power from grid to feed to the vehicle's battery.

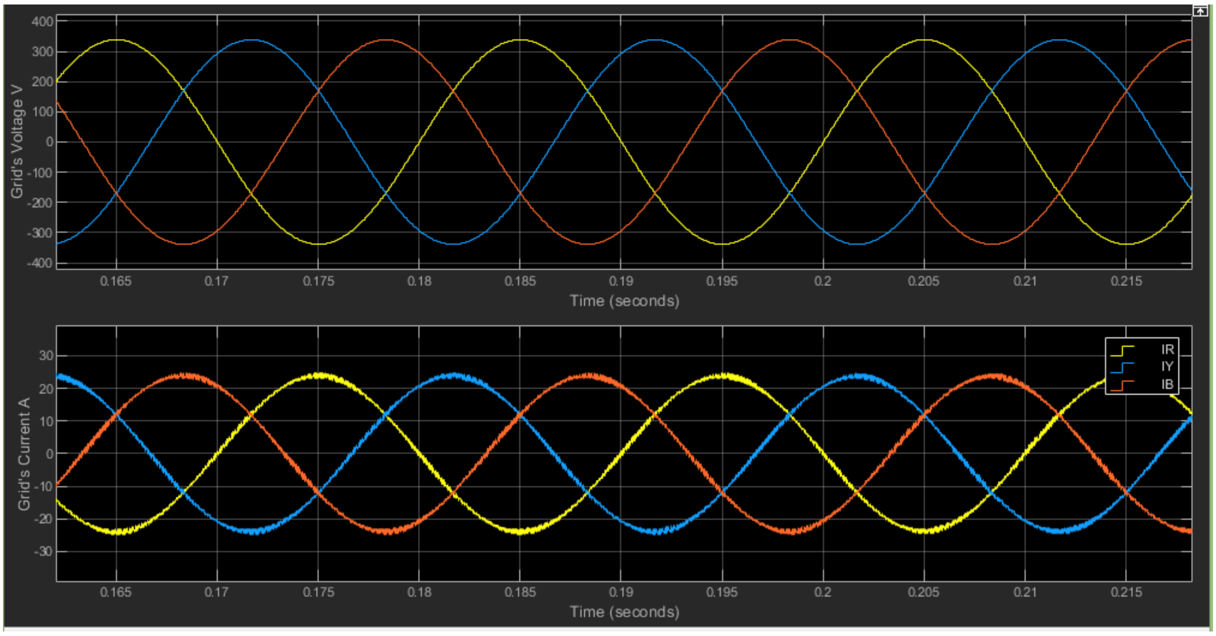

Figure 62: Grid's voltage and current waveforms during G2V operation mode.

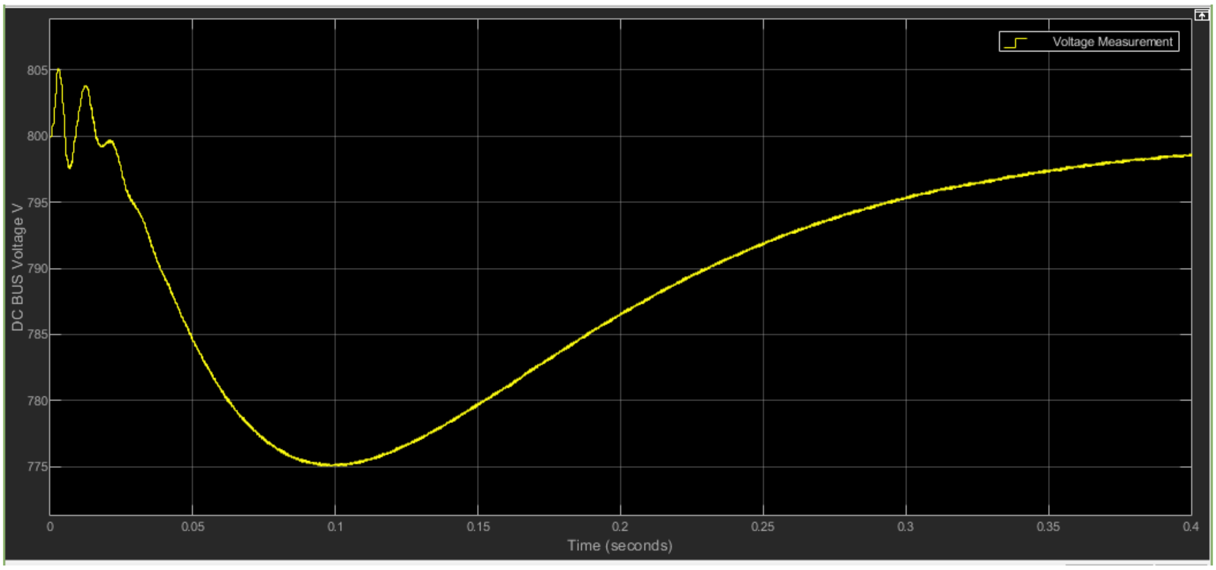

Figure 63: Step response of AC/DC converter, DC Bus voltage during a G2V operation mode.

From the figure above, at the beginning of the simulation, the DC voltage fluctuates before it drops from 800 V to 775 V at time = 0.01 s. Then, the voltage starts increasing exponentially until it returns to its original output value. It took about 300 ms for the voltage to restore its initial value.

The first waveform perfectly in figure (64) shows the Battery State of Charge (SoC), and as it is illustrated, the battery is charging. The second waveform shows that the current experiences some fluctuations in the beginning of the battery charging process, and after a time = 0.05 s, the current stabilizes at a value equal to -29.53 A RMS, as it is visible in the figure below. In addition, the voltage of the battery has experienced some fluctuations before it stabilizes at the beginning of the charging process and after a time = 0.05 s, the voltage stabilizes at a value equal to 387 V RMS until the end of the V2G operation period. The figure below exhibits the values explained here.

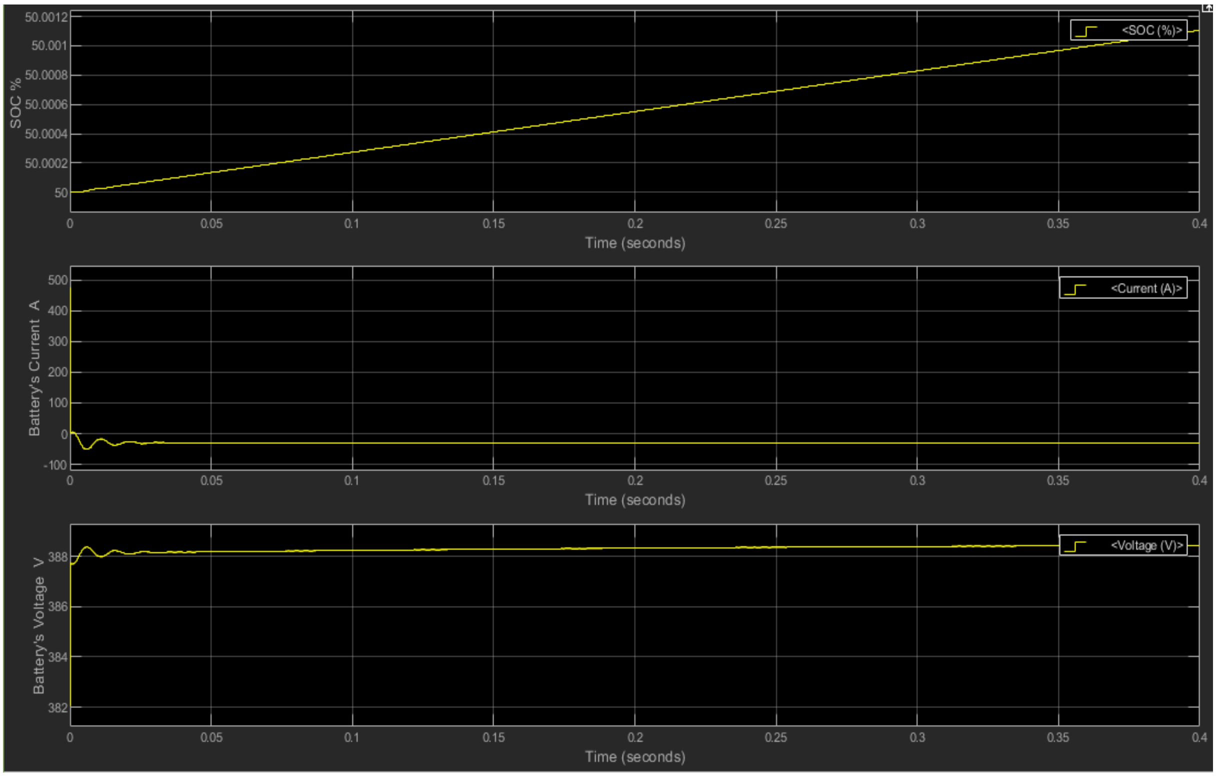

Figure 64: Battery input values exhibition.

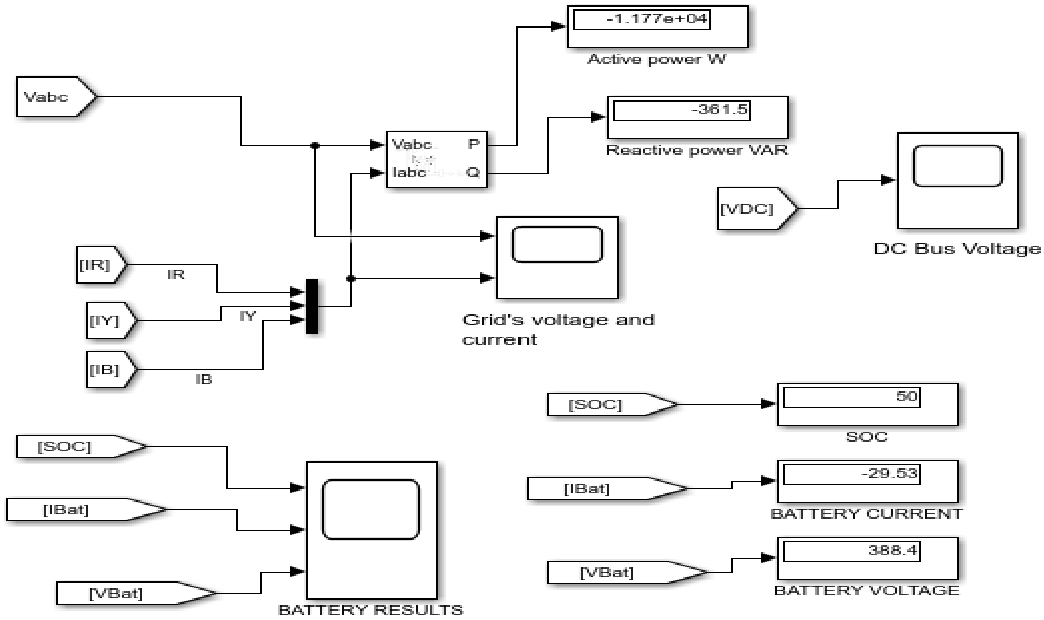

Figure 65: display blocks exhibiting the input values during the G2V operation mode.

5.2. Simulation results of the second model:

The figure below shows the active power generated by the stations and the power consumed by the loads. The Blue waveform illustrates the total power generated by the three sources, as in the beginning of the day, it starts from 6 MW, after that it rises until it reaches its peak at approximately 12.72 MW during the evening and then drops during the night to only 8 MW. The yellow line representing the load power follows the same tendency.

As we mentioned 4.2, the diesel generator is our main provider of the energy for our grid. Therefore, it generates the highest amount of power starting from the beginning of the day. The amount of the power fluctuates during the morning and drop to exactly 4 MW at midday. Then, the power rises until it reaches its peak at a power value equal to 12 MW. After that, the power drops and reaches 8 MW by the end of the day due to the low consumption during the night.

Regarding renewable energy sources, both PV and Wind power stations generated lower values of power compared to the conventional diesel generator. The PV farm power generates zero power in the beginning of the day, while Wind parks power starts from 1.7 MW at the beginning of the day and then fluctuates throughout the morning. The active power generated by both farms increases and reaches a power equal to 4MW at midday. After that, wind power fluctuates again and reaches its peak during the whole day and hits 4.2 MW in the evening and then drops to approximately 1 MW by the end of the day. PV power instead drops sharply until 0 MW for the rest of the day.

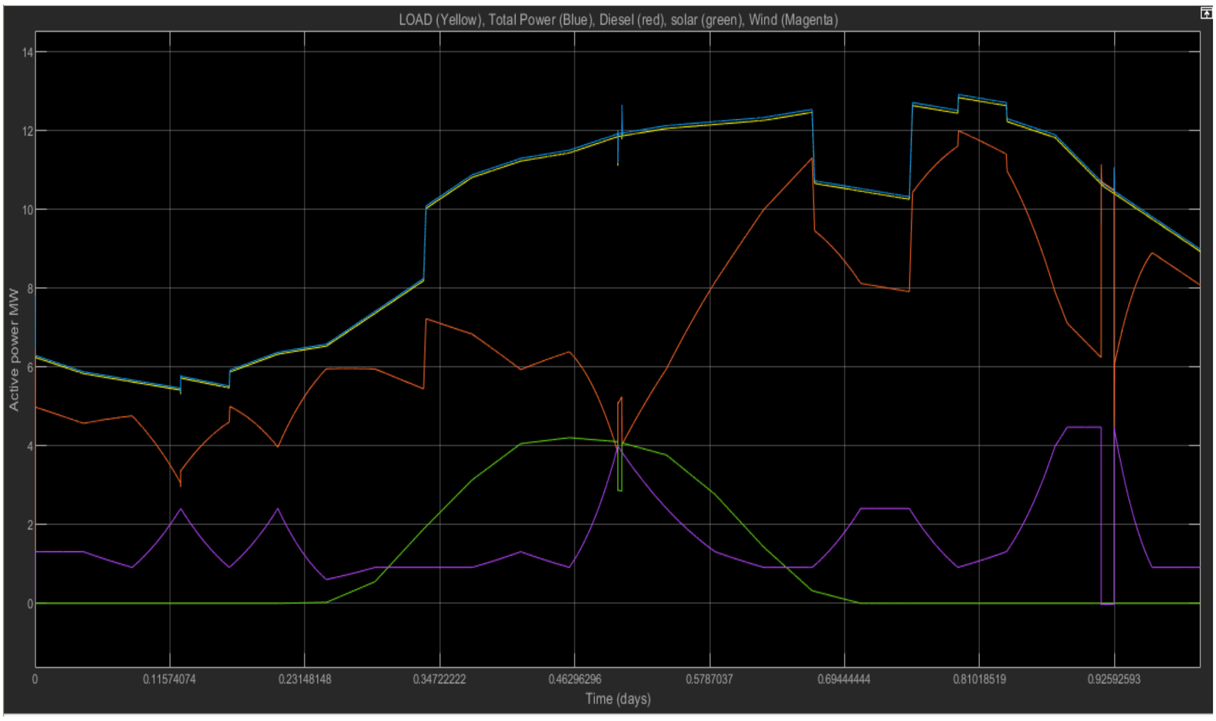

Figure 66: Total active power, load active power and each generator active power.

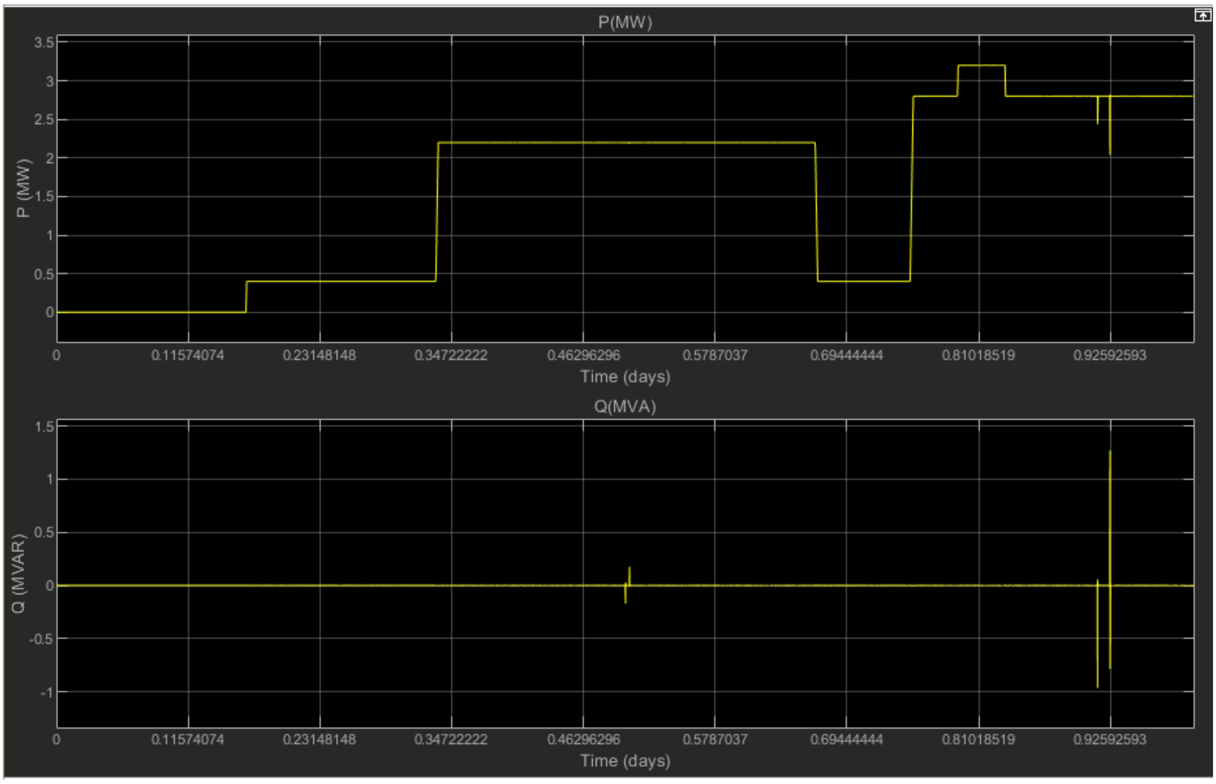

Figure 67: Electric Vehicle at charging process active and reactive power.

The graph above [Figure (67)] illustrates perfectly the active and reactive power consumption by EVs connected to the grid. The active power consumption is low in the first hours of the day and increases throughout the day until it reaches its peak in the evening at a value equal to 3.2 MW. The reactive power consumption instead remains steady the whole day until it overshoots in the last hours of the day.

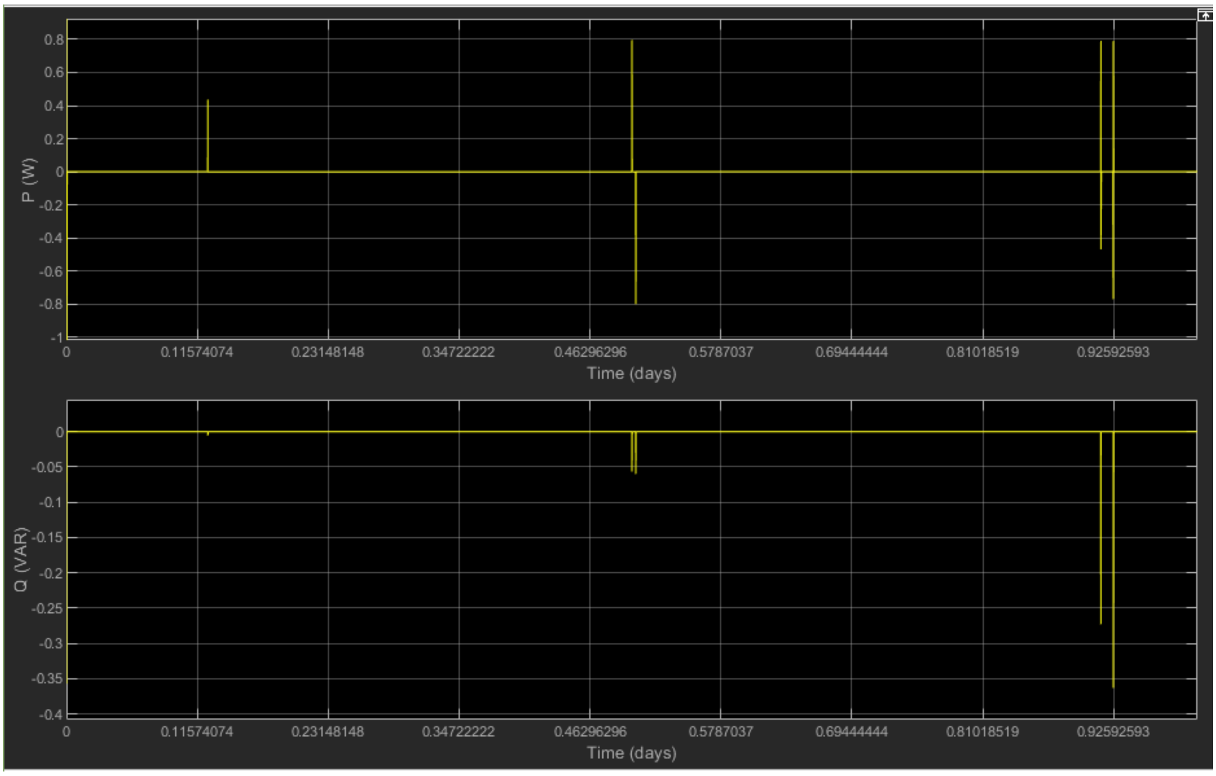

Figure 68: EV at regulation active and reactive power.

The active power as depicted above is subjected to some fluctuations during the day, as it remains steady for the most time and reaches its peak at midday and in the evening.

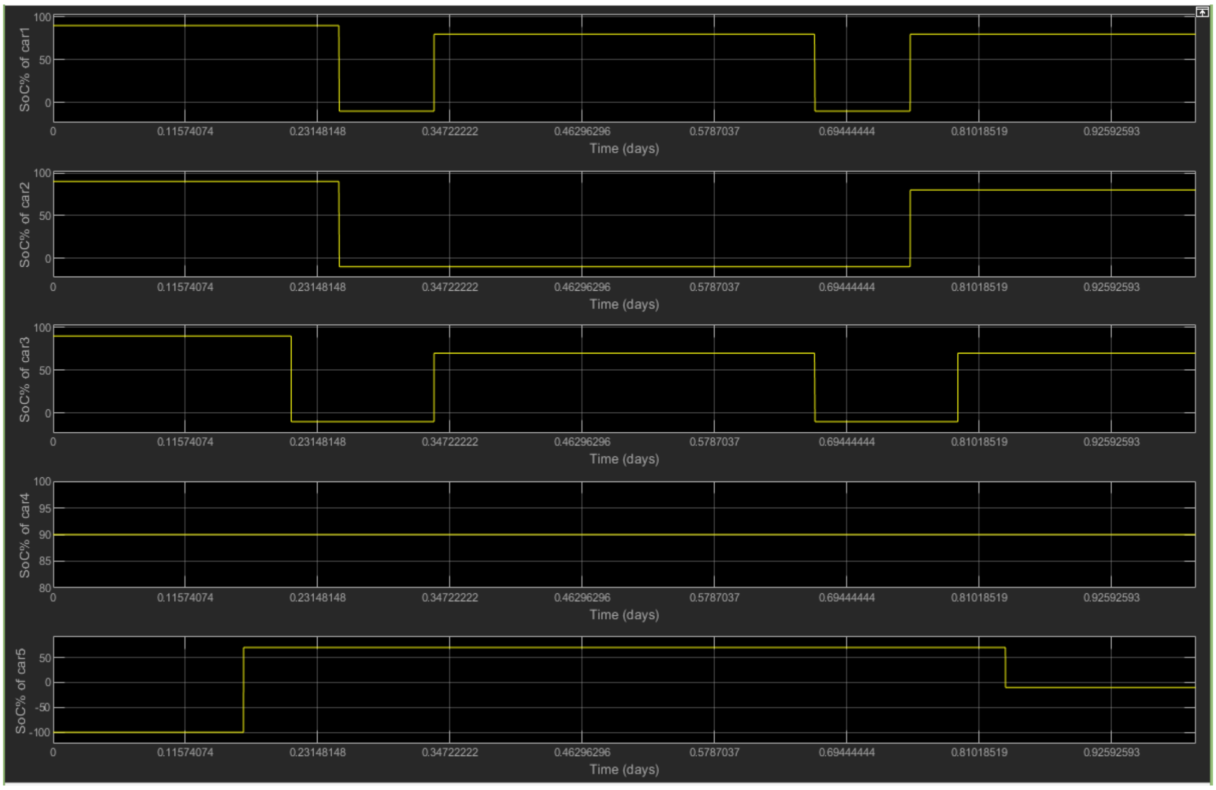

Figure 69: State of Charge of all car profiles.

The figure above illustrates the State of Charge of each car profile. For most of car profiles, the battery is close to 100% from 11 am until 6 pm. During the evening, the majority of cars are connected to the grid. Therefore, the SoC of all profiles are high during the evening.

During the afternoon, SoC of all car profiles is above 50% except the second car profile that represents the Mall scenario. This is because the majority of Mall visitors do prefer spending their time in shopping centers starting from midday, and taking into consideration the fact that they are coming from hinterlands, their EV batteries SoC will definitely be at the lowest level. In general, the SoC of each car profile represent the suitable times for the adoption and implementation of V2G functions. The evening and the early morning are the most appropriate times for a V2G function because in the morning, the majority of the cars are parked and will be driven by their owners starting from 5 pm, while for the evening, the majority of the cars are fully charged, so it would be possible for the operators to perform the V2G operation. Airports, park and ride, and on-street scenarios are the most flexible choices for a V2G function since they can permit the implementation of this operation at different times of the day. Mall scenario instead depends permit it only during the morning or the first hours of the evening since most of the malls close at 10 pm or even before.

In general, and due to the fact that EV owners are ready to pick up their cars starting from 4 pm from any parking area, we assume that from the early hours of the morning until 1 pm is the perfect time for the implementation of a V2G function because all the cars parked in any parking area are plugged into the sockets, and their owners are welcome to allow the V2G function at that time.

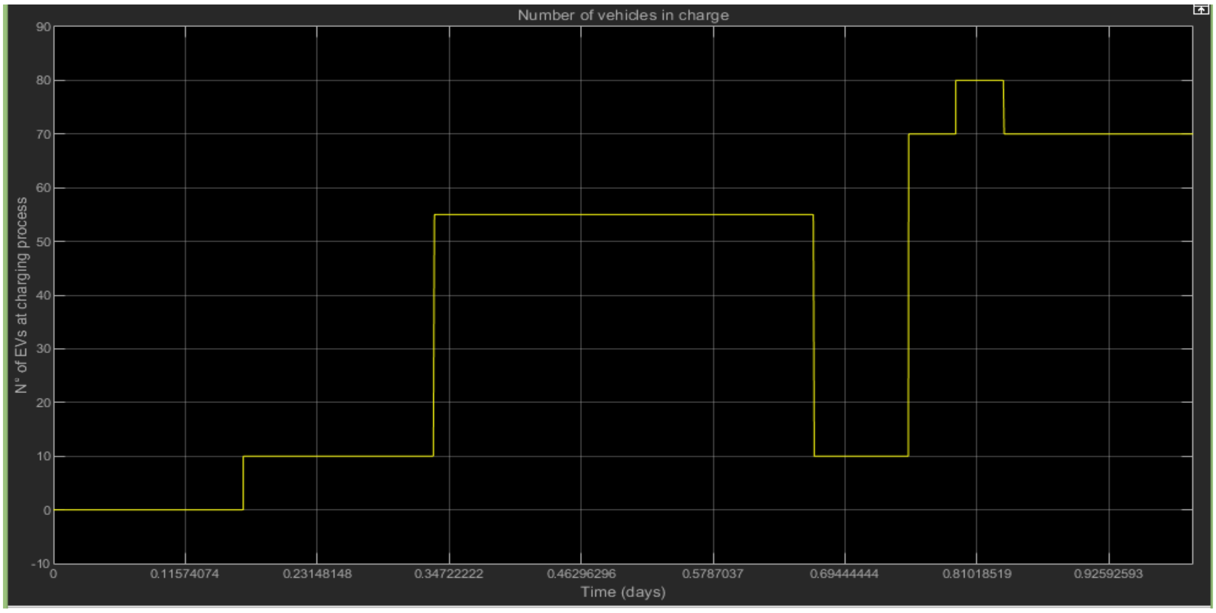

Figure 70: Number of EVs at charging process.

At the beginning of the day [Figure (70)], most of the cars are fully charged and are driven, and starting from 10 am, the number of cars under charging process increases until 55 EVs and then drops and rises again until it reaches 80 EVs in the evening. For the rest of the day, 70 EVs are connected to the grid.

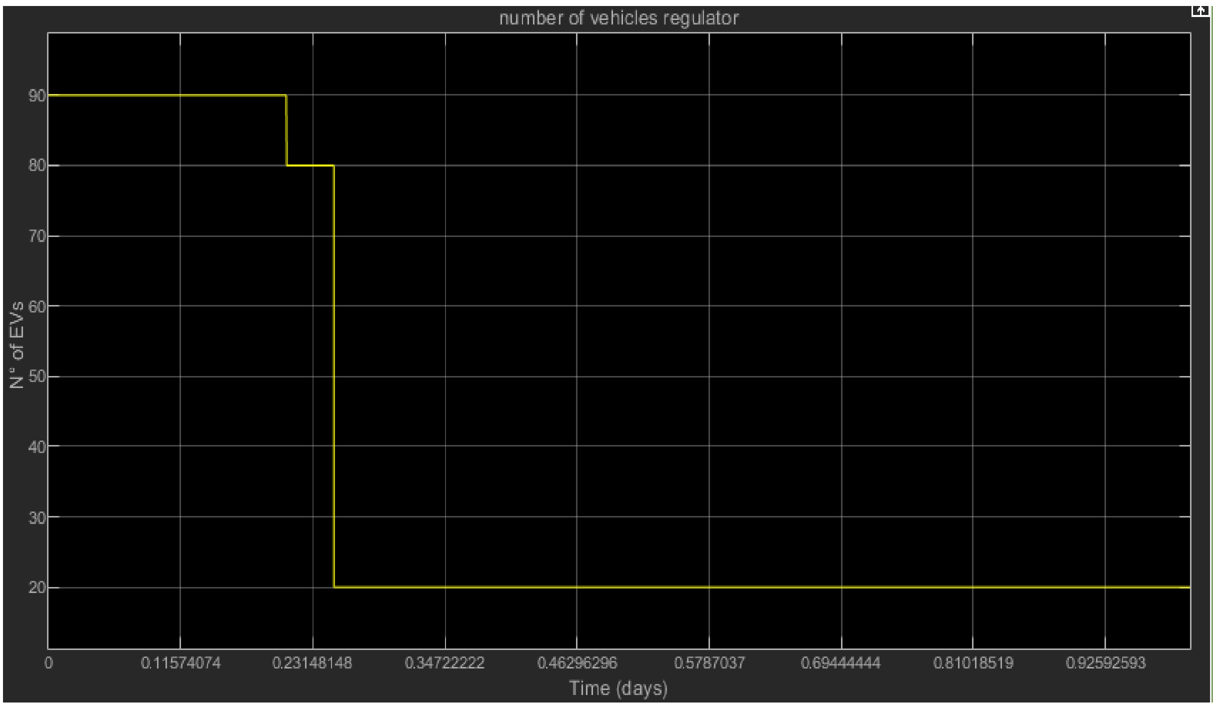

Figure 71: Number of EVs at regulation process.

The figure above [Figure (71)] illustrates that the beginning of the day is perfect time where the majority of the cars are in regulation process. Throughout the day, the number of EVS at regulation process drops until it becomes constant for the rest of the day.

The active power given by the wind power stations [Figure (73)] is variable during the day due to the wind speed. The power reaches its peak in the evening at 4.5 MW and then drops to only 1 MW for the rest of the day. The reactive power is constant the whole day and reaches 2 MW by night. Instead Active and Reactive power of PV farms remain 0 the whole day [Figure (72)].

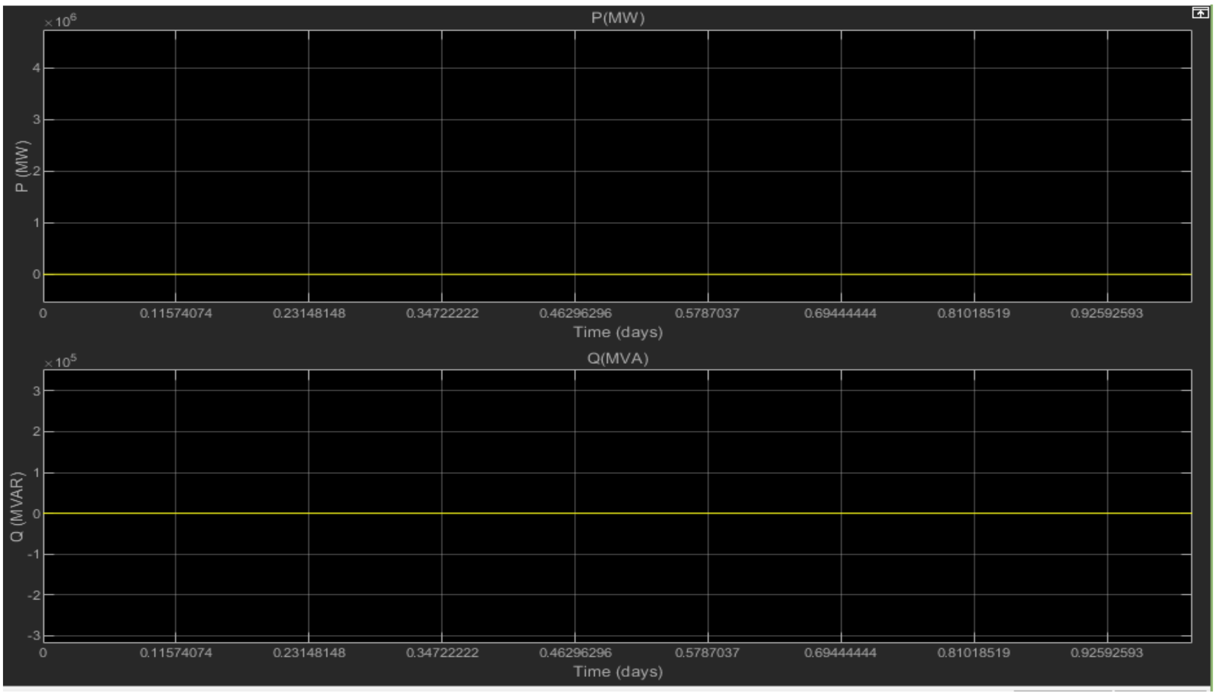

Figure 72: PV farm active and reactive power.

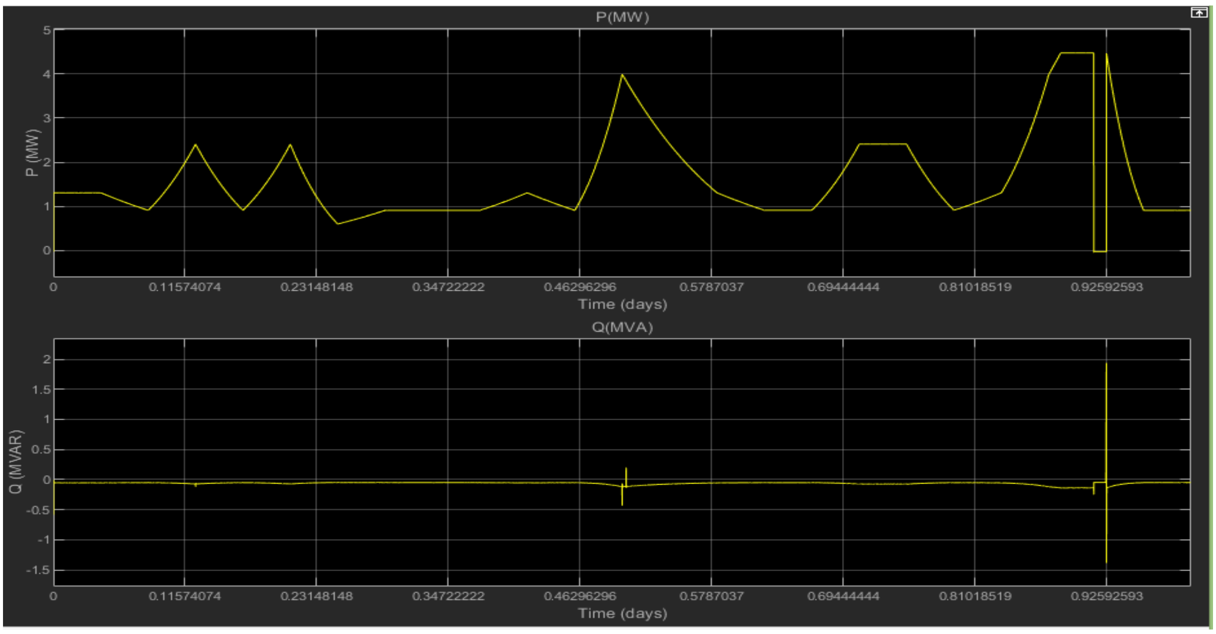

Figure 73: Wind power station active and reactive power.

The diesel generator is the main provider of energy. The active power generated varies the whole day. It reaches its peak in the evening when the demand of power is at its highest level. The max active power reaches is approximately equal to 12.5 MW, while the min active power is 5 MW. Reactive power instead is zero the whole day [Figure (74)].

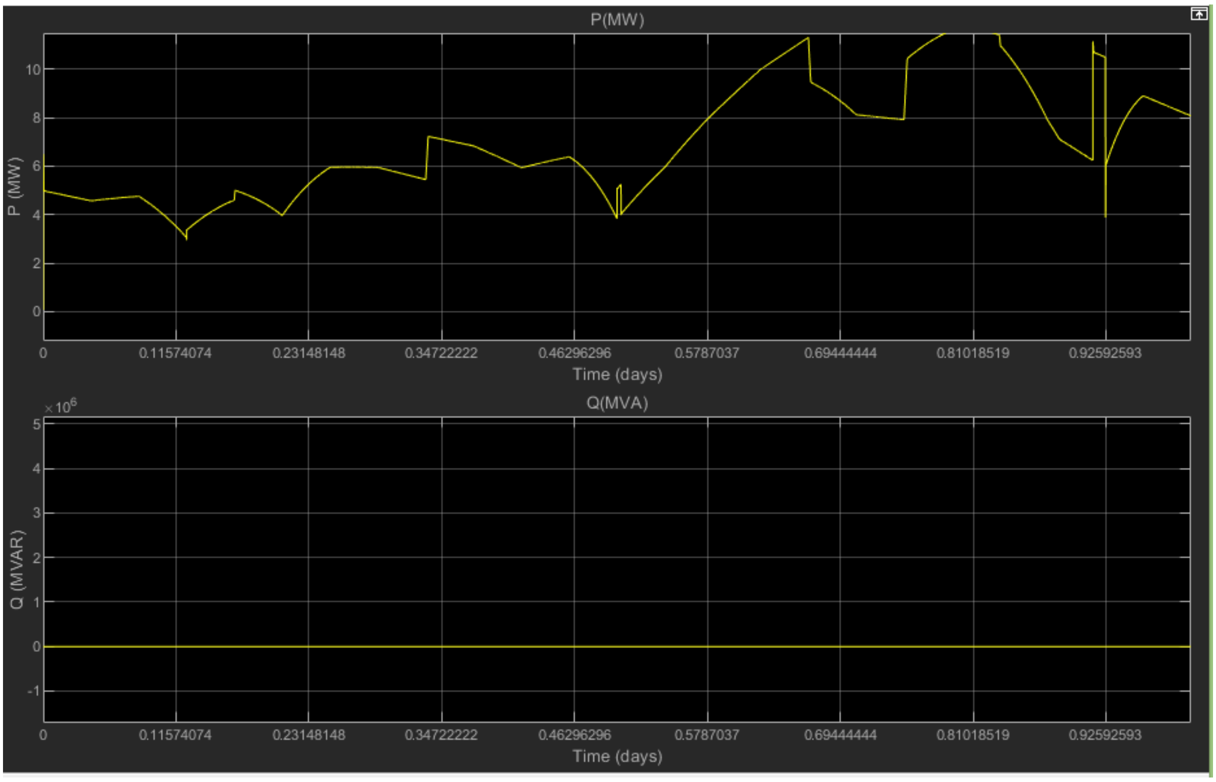

Figure 74: Diesel Generator active and reactive power.

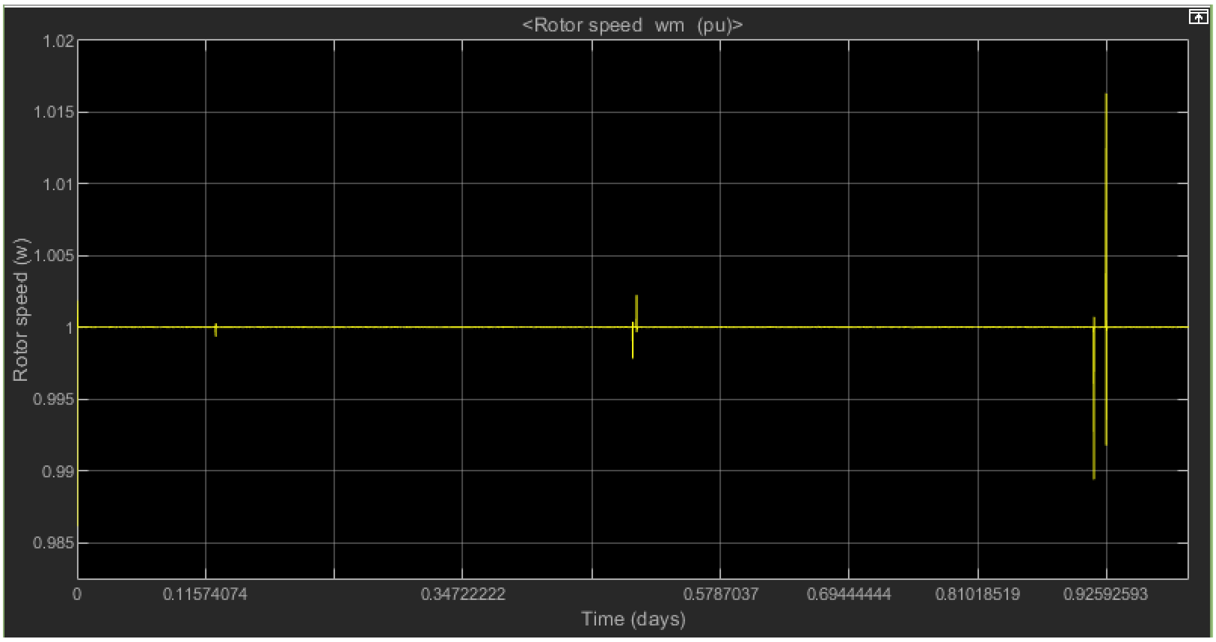

Figure 75: Rotor speed.

The rotor speed remains constant the whole day, and increases during the night to 1.017 rpm as figure (75) depicts.

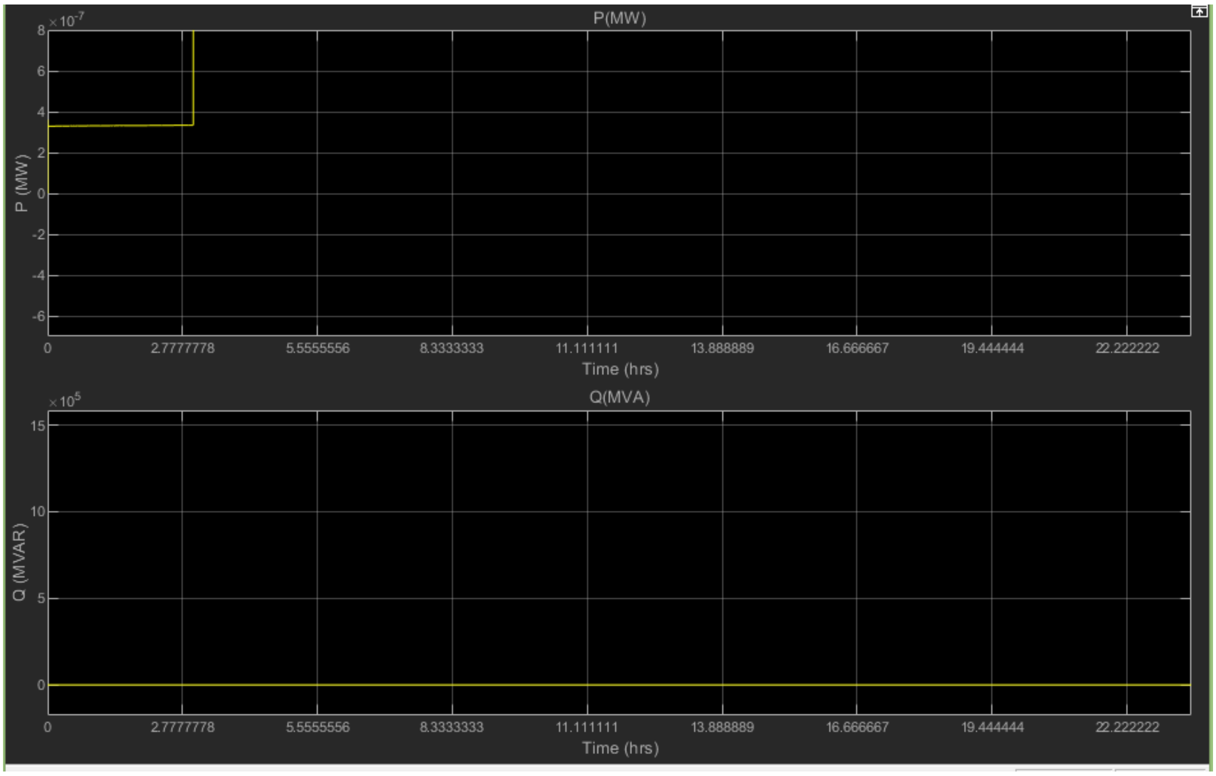

Figure 76: Asynchronous machine active and reactive power.

The industrial load power consumption [figure (76)] equals 3.7 MW in the morning and increases heavily to 8 MW for the rest of the day. The reactive power consumption instead remains steady the whole day.

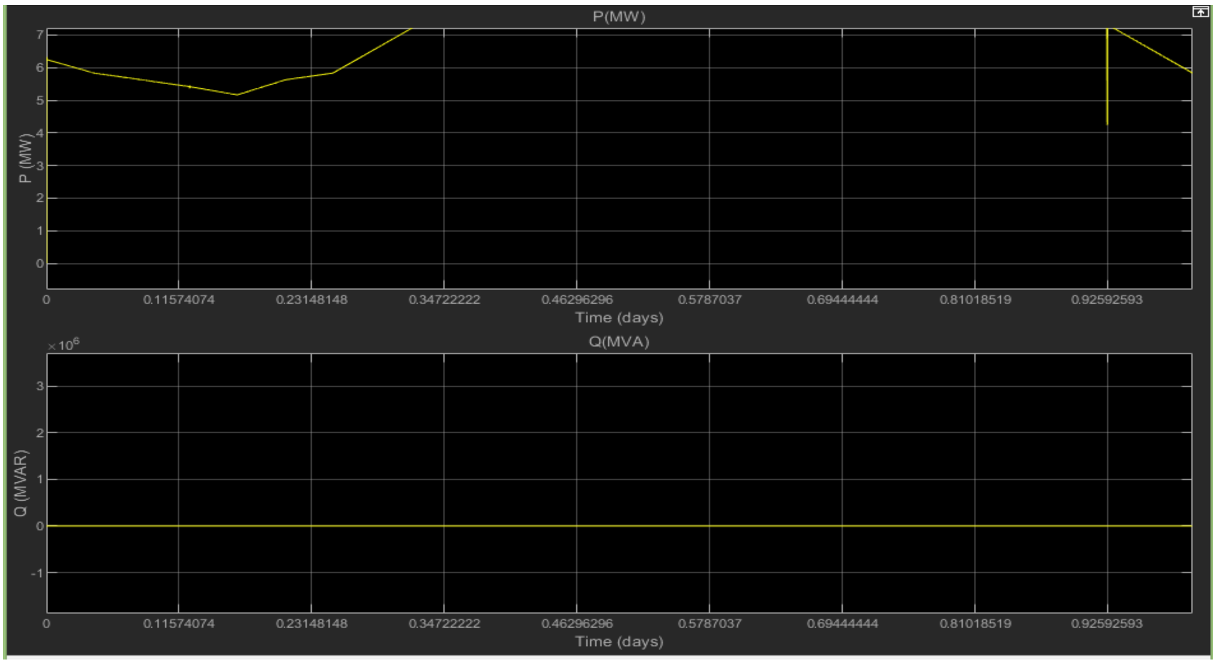

Figure 77: residential load active and reactive power.

The residential load power consumption [Figure (77)] starts at 6 MW in the morning, then it increases higher than 8 MW for the whole day. In the evening and night, it drops again to 6 MW. Similarly to the industrial load, the reactive power consumed here is 0 and remains constant throughout the day.

Conclusion:

The total power generated by the three sources and consumed by the loads reached their peaks during the evening. The power consumption of the electric vehicles connected to grid are following various car profiles, mainly, Airports, malls, park and ride, on-road charging stations, each of which consumes different amounts of energy during the day. Nevertheless, the total active power consumed by the 100 EVs connected to the grid fluctuates throughout the day and reaches its peak in the evening when the number of EVs connected to the grid increases. The SoC figures show that the majority of EVs do have a SoC between 80% and 100% during the evening, as it is the best time for V2G functions. This assumption fits perfectly the airport scenario where the access timing to parking areas served with charging stations is 24 hours. Therefore, implementing V2G functions in an airport parking is feasible due the abovementioned assumption as well as the due to high numbers of vehicles that can be contemporaneously connected to the grid, during either night or day. The feasibility of mall car profile is subjected to many factors, mainly the opening time of the malls that is linked with opening hours of the stores inside it. The morning and the evening are the appropriate times for a V2G function. For the park and ride scenario, the SoC of the EV batteries varies throughout the day, as during the early hours of the day, the afternoon, and the last hours of the evening, most of the vehicles do have a SoC between 80% and 100%. Taking into consideration that EV will drive for long periods after they pick up their cars, the owners will need to find their batteries ready to drive and with a SoC of 100% level. Therefore, the suitable time for a V2G operation is during the morning where the majority of vehicles are parked. However, for on-street charging stations, the SoC of all vehicles remains constant the whole day, which will give the chance to the operators to allow the vehicle to grid function in any time throughout the day.

6. General Conclusion:

In this work, we proposed two V2G models aiming to assess the feasibility of vehicle to grid concept for enhancing the performance of the electric grid. The first model was a simulation of a three-phase charger connecting the electric with the battery that represents an Electric Vehicle. Through the simulation process, we have visualized the battery charging (G2V) and discharging (V2G) operations as well as how the battery inputs (SoC, Current and Voltage) are changing during V2G and G2V operation. In addition, the scopes depicted the waveforms of Grid's Current and Voltage, as their alignment relationship is feasible to know in which operation mode we are witnessing.
The second model is about a 24-hour simulation of a vehicle to grid system. A diesel generator, and PV and Wind power stations are the main sources of energy delivered to the grid, each with a specific rated power. Through the simulation results, we have seen how the power delivered by each power station fluctuates throughout the day, and the diesel generator acts as the main energy source during the whole day due to high demand of power from the residential and the industrial loads. The total power generated by the three sources and consumed by the loads reached their peaks during the evening. The power consumption of the electric vehicles connected to grid are following various car profiles, mainly, Airports, malls, park&ride, on-road charging stations, each of which consumes different amounts of energy during the day. Nevertheless, the total active power consumed by the 100 EVs connected to the grid fluctuates throughout the day and reaches its peak in the evening when the number of EVs connected to the grid increases for the all the scenarios. From the SoC figures, we can assume that the airports and on-street charging stations will allow the V2G functions to be performed during the whole day. On the other hand, the feasibility and implementation of V2G function for park and ride as well as for malls is subject to various factors, and mainly, the number of EVs connected to the grid in different times of the day. From SoC figures, the suitable times for a V2G operation are the early morning hours, the afternoon, and the evening for park and ride scenario, while the early morning and the evening are the appropriate times for the mall scenario.
Electric Vehicles do have several promises, not only toward the environment, but also regarding the improvement of electrical grid by stabilizing the active power and compensating the reactive power that are exposed to several Power Quality event such as voltage dips, which are dangerous for the long term of the service continuity of the grid and also for the loads connected to it. The deployment and establishment of parking areas able to host EV charging station will certainly promote the feasibility of a V2G function, as the parking areas in airports, malls, metros as well as on street can host high number of EVs a day and allowing V2G

functions in order to deliver the power drawn from batteries on-board EVs to the grid to be used for other purposes.

The statistical classification of voltage dips according to EN50106 standard is purposeful in a way it helps distinguishing the severe voltage dips that could lead to undesired operations of the grid. In addition, this statistical classification will contribute to the exact assumption of the number of EVs necessary for a V2G operation.

However, the high demand of electricity from the increase number of EVs as well as from the connected loads, and with the fluctuated power generated by renewable energy sources, the reliance on diesel generator and fossil fuels is inevitable and requires time to make the grid become fully independent from such power sources. This will create a hurdle toward reaching a sustainable and green power delivered to the end users, and will slow down the process of electrifying the transportation means.

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