Bachelor’s thesis at the Lucerne School of Engineering and Architecture

Title	**Modelling and Cost/Benefit Analysis of Bidirectional Charging of EVs**
Student	**Pérez Noguera, Javier**
Bachelor’s degree program	**Bachelor in Energy and Environmental Systems Engineering**

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Abstract German

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Abstract English

This bachelor thesis analyze the cost/benefit of the bidirectional charging of EV’s, which can provide flexibility using the charging and discharging mode of the batteries

Place, date 09/06/2022-Luzern

Abstract

Renewable energy sources have been penetrating on a large scale during the last few years. They are increasing so quickly to reduce the power generation of conventional generation plants, reducing carbon emissions; moreover, electrification in the transport sector is increasing internationally, increasing the integration of EVs in the grid, elevating the energy consumption in the grid systems of all the countries. Fuel cars are being replaced by electrical vehicles increasing the demand for electricity and creating new challenges and opportunities for the operation of the grids. These opportunities must be valued exhaustively, considering different stakeholders' environmental impact and economic benefits. The EV'S can be a useful tool capable of providing an extensive range of flexibility in the operation of the grid in the ancillary services, moreover, contributing to reducing the importance of the conventional plants of generation and creating a new sustainable market that is more accessible and variability. In the current project, three different cases related to frequency control are studied, i.e., three different simulations to assess the feasibility of providing frequency control; therefore, different usage schedules and battery levels of the EV fleet will be used.

Keywords: TSO, V2G, EV’s, simulation, model, ancillary services, frequency control, scenario.

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1. Introduction

As we all know, society is currently undergoing significant technological changes. This change implies the emergence of new opportunities and solutions that could be integrated considering their social, economic, and ecological balance. This project deals with EVs and their repercussions on the electricity grid by providing ancillary services.

Essentially, this project focuses on integrating the EVs by providing ancillary services, specifically **frequency control**, for which it is necessary to explain the specific requirements to be able to participate in the control market.

With the principal purpose of defending the hypothesis of the potential opportunity of EVs, graphs and data provided by the system operator Swissgrid will be shown with the data obtained from the simulation to defend the benefits and to define the feasibility of the project in order to provide frequency control.

Finally, due to the integration of new technology such as EVs, which may or may not be viable to provide ancillary services, it could directly influence the market by creating more accessible and competitive prices with the objective of obtaining maximum benefits providing these services.

1.1 Problem

As mentioned before, the increase of EVs connected to the grid means an increase in electricity consumption which can be a problem for the correct functioning of the electricity system [1]. For this reason, this project studies the integration of EVs, as it can reduce the problems of saturation of power lines due to the storage capacity of the batteries and can provide the necessary flexibility to control the different points of the network and improve the quality and operation of it.

Since the project is about integrating electric cars to provide ancillary services, a simulation as realistic as possible is needed, i.e., how a fleet of cars would act, taking into account their battery charge level to regulate the grid's frequency. This situation involves assuming certain variables and considering the battery level the cars will have throughout the simulation.

The frequency regulation depends on the response time of the different technologies that are part of the regulation pool; therefore, due to their flexibility, EVs could reduce the response time for the regulation between consumption and generation.

1.2 Objective V2G

The vehicle-to-grid concept consists of using the bi-directional battery of an electric car which, when connected to the charge station, depending on the previous data history and the state of charge, provides flexibility to the grid in order to ensure and improve the services to be offered by the system operator.

We have to ensure that the EV's can provide more flexibility in the fast response time and the efficiency of charging and discharging the batteries; apart from this, it is possible to evaluate the idea of using the batteries for storing the energy. We can achieve a society with more sustainability by optimizing and integrating new network opportunities and technologies with all these advantages. These are the reasons of the integration of EV's .

In order to summarize the objectives of V2G:

- Define the mobility behavior of the EV's (using different resources, defend and create a realistic scenario).
- Create a Simulink model relating the power reservation available depending on the scenario created and the power offered for the frequency control.
- Analysis of the data and results of the simulations.

2. Literature review

2.1. Overview of the electrical system in Switzerland

Around 800 companies are involved in Switzerland's production, distribution, and supply of electricity [2].

Switzerland currently has a 6700 km long electricity grid throughout the country, as shown in Figure 1

It also has 147 substations to raise or lower the voltage and facilitate the transport of electricity and 12000 pylons to facilitate its distribution and transport. This infrastructure is why the Swiss power grid is one of the most stable globally due to its infrastructure and the amount of investment that is continually being made to improve it [2].

As we can see in Figure 1 obtained from the website of Swissgrid, there are different levels of voltage around Switzerland to distribute the electricity and provide electricity to the whole country.

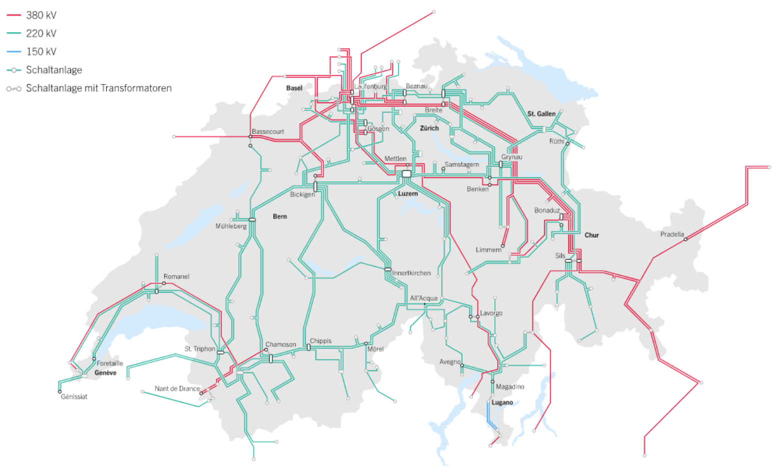


Figure 1: Actual grid system Switzerland 2022

The Swiss electricity network also has different measurement points which are used to simulate different electricity flows in order to provide a quick response to any irregularity or problem in the network; in addition, it is not only limited to Switzerland because the country has connections with different countries in Europe with which energy exchanges take place, which is: Germany, Italy, France, and Austria.

The countries which trade energy with Switzerland are listed in Figure 2:

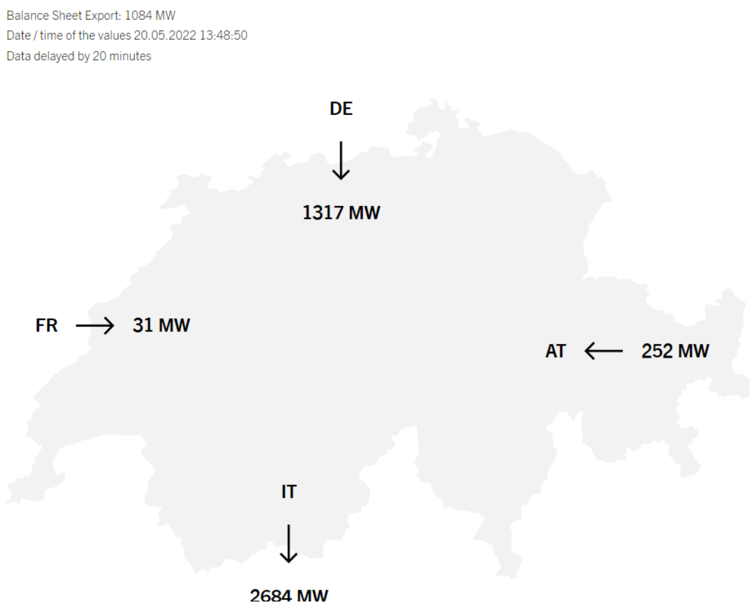


Figure 2: Trade energy in Switzerland with other countries of Europe

As we can see [3], Switzerland exchanges energy with the countries around it. Switzerland's energy generation mix is illustrated in Figure 3.

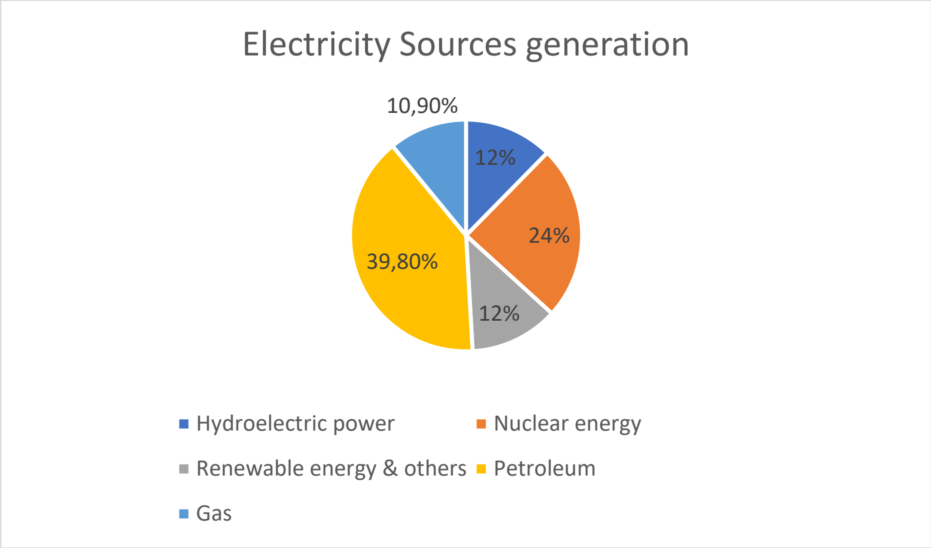


Figure 3: Profile of electricity generation Switzerland

The energy generation profile is divided into 5 different resources; however, Petroleum and Nuclear resources are the most used for energy generation, without taking into account the different exchanges of energy with the countries of Figure 2 [3]

2.2 Ancillary services and aggregation of EV

Due to the flexibility offered by the batteries of the EV's, they could provide diverse types of ancillary services, such as storage capacity, charging for battery optimization, or discharging as an energy supplier to the grid.

In order to be able to evaluate the different opportunities which the electric car could offer, it is necessary to have an overview of the different ancillary services, taking into account their technical requirements and current situation.

2.2.1 Ancillary services of the TSO

Transmission grid operators (TSO) are entities responsible for the flawless operation of the grid independent of the electricity market, assuring and guaranteeing the quality and safe operation of the grid operation. In the case of Switzerland, the TSO is Swissgrid.

Swissgrid [1], as TSO, relies on the following ancillary services to maintain safe and reliable operation of the grid:

- Frequency control
- Voltage support
- Compensation for active power losses
- Black start and island operation capability
- System coordination

- Balance group management
- Operational measurement

All these ancillary services [4] must follow the technical specifications of the European Network of Transmission System Operators for Electricity ENTSO-E (UCTE)

This report aims to focus on the Frequency control systems and the new possibilities we can integrate into the grid, improving the services of the TSO.

2.2.2 Frequency control

The **grid frequency** is an essential variable to stabilize the entire grid and assure the quality of each consumer's energy consumption. Usually, the frequency is the same in the whole system during regular operation. However, the difference between nominal and the possible real frequencies can be a maximum deviation of ±200 mHz [5] following ENTSO-E [4](European Transmission System Operators) requirements.

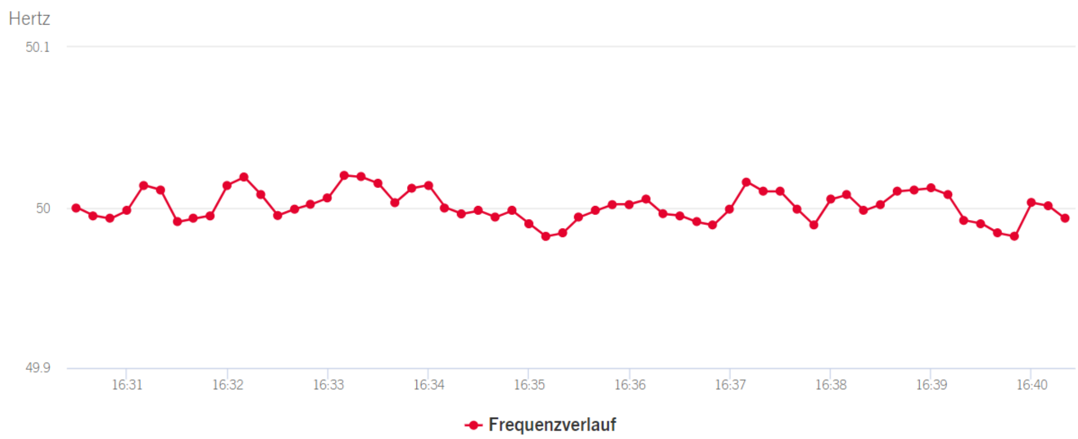


Figure 4: Example of the frequency grid in Switzerland 23/03/2023

In general terms, Swissgrid has a reserve of power plants that are keeping the availability during the day, assuring the capacity to provide energy to the grid in a short time or reduce the amount of energy fed into the grid.

The Swissgrid has three frequency control stages to ensure energy control:

- Primary control.
- Secondary control.
- Tertiary control.

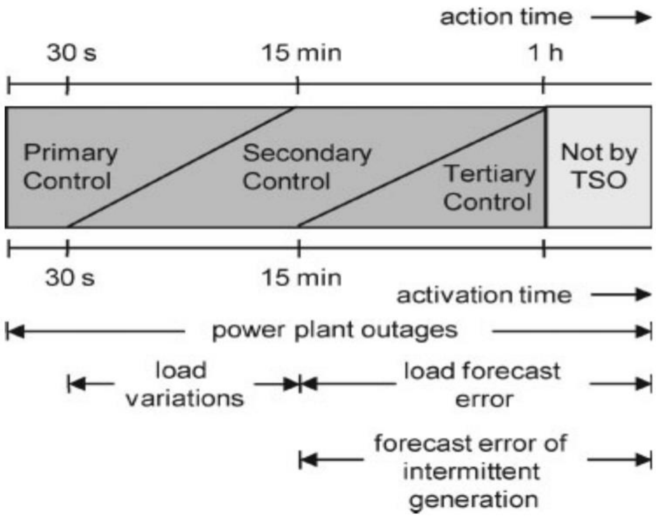


Figure 5: Time Activation of the frequency control [6]

The stability of the frequency is one of the most relevant aspects of the grid [7] on account of:

-A significant number of machines can be damaged because of a frequency change so quickly or have a high or lower frequency.

-The time measurement of the grid of many machines depends on the time, which is included the frequency in the electrical network (for instance, the oven clocks)

In Figure 6, Figure 7 and Figure 8,It is possible to understand the difference between energy consumption and production when it is not balanced and appears with different values of frequency depending on the situation:

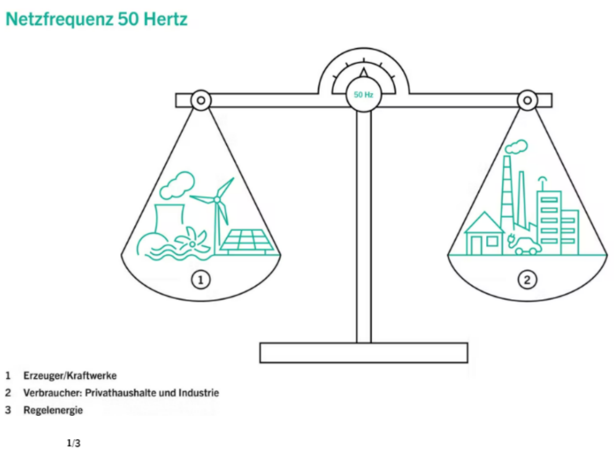


Figure 6: Balanced energy production and consumption [8]

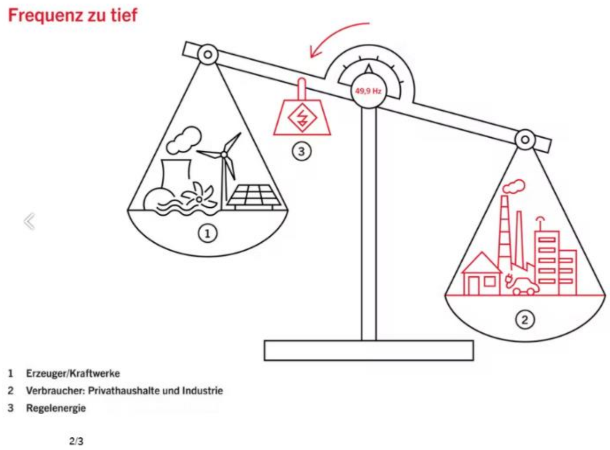


Figure 7: More energy consumption than production [8]

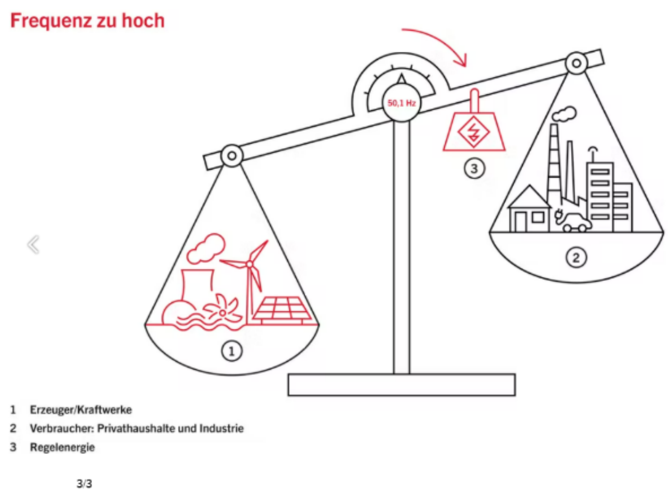


Figure 8: More energy production than consumption [8]

Depending on the frequency variation we may have, positive or negative, it will be necessary to increase or decrease the power generation, as we can see in the diagrams provided by Swissgrid.

As we can see in Figure 6, there is a balance between consumption and generation, so the frequency remains at 50 Hz; however, as we can see in Figure 7, as there is more consumption than generation, there is a difference in the balance, the frequency decreases and falls below 50 Hz. Finally, in Figure 8 we have more generation than consumption, so in this case, there is also a difference in frequency, which increases with respect to 50 Hz.

With the V2G concept in mind, as I mentioned earlier, the aim is to provide the ability to respond to frequency variations, so when electricity consumption is greater than generation, the EV's battery will provide electricity by discharging to balance consumption and generation. Otherwise, when more generation is higher than electricity consumption, the EV's battery will draw electricity from the grid to balance consumption and generation.

2.2.2.1 Primary frequency control

The main objective of the primary control is to rectify the frequency with a quick response to re-establish the balance between energy consumption and production. Oftentimes, Turbine regulators are used for restoring the balance mentioned before.

If the frequency variation exceeds the permissible limits of the frequency control, the primary control is activated like an automatic response. The controllers take control of the power generation to balance the energy consumption with the generation.

Swissgrid forms part of the FCR cooperation mentioned before as ENTSO-E, which exchange frequency control stocks with each other. In the Table 1: Table of members and

TSO of the different countries It is possible to see the different countries that form part of the Cooperation:

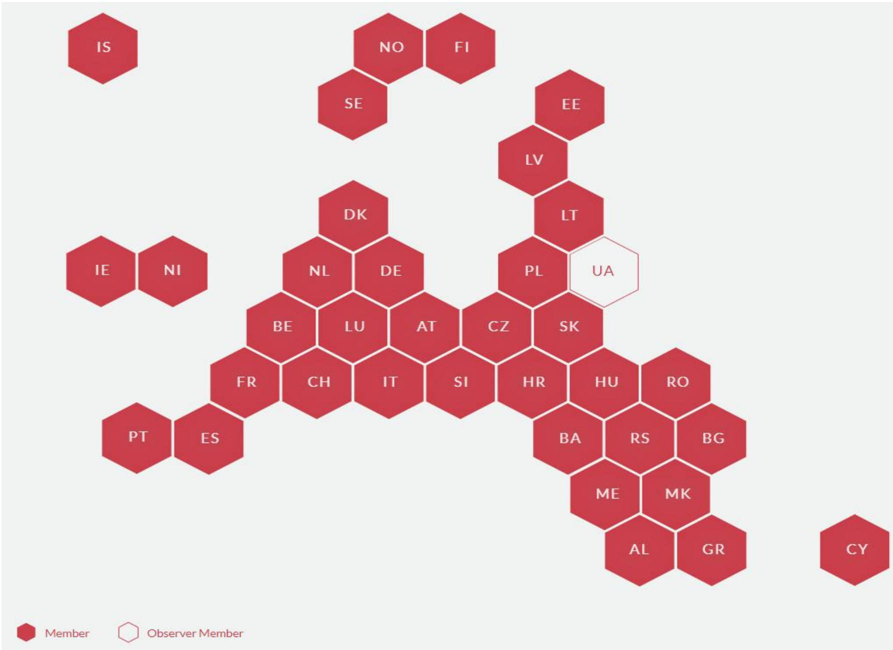


Figure 9: ENTSO-E Member Companies [9]

COUNTRY	COMPANY	COUNTRY	COMPANY
Austria	APG/VUEN	Iceland	Landsnet
Albania	OST	Italy	Terna
Bosnia and Herzegovina	NOS BIH	Lithuania	Litgrid
Belgium	ELIA	Luxembourg	Creos Luxembourg
Bulgaria	ESO	Latvia	AST
Switzerland	SWISSGRID	Montenegro	Crnogorski elektroprenosni sistem
Cyprus	CYPRUS TSO	Northern Ireland	SONI
Czech Republic	ČEPS	Netherlands	TenneT NL
Germany	TransnetBW/TenneT DE/Amprion/50Hertz	Norway	Statnett
Denmark	Energinet.dk	Republic of North Macedonia	MEPSO
Estonia	Elering AS	Poland	PSE S.A
Spain	REE	Portugal	REN
Finland	Fingrid	Romania	Transelectrica
France	RTE	Serbia	EMS
Greece	IPTO	Sweden	SVENSKA KRAFTNÄT
Croatia	HOPS	Slovenia	ELES
Hungary	MAVIR ZRt	Slovak Republic	SEPS
Ireland	EirGrid		

Table 1: Table of members and TSO of the different countries [9]

2.2.2.2 Secondary frequency control

After the primary frequency control, we have the secondary frequency control, which has the same objective, to assist and maintain the frequency control of the network at 50 Hz. [1]

Secondary frequency control uses secondary control reserves for generation regulation in a control area.

The correct exchange of energy flow between the different control areas is ensured with the secondary control reserves. In addition, if there are frequency deviations in the control area, we can re-establish the frequency and restore the reserves provided for the primary control. Once activated, its duration could be up to 15 minutes; once this time has elapsed, the tertiary control would finally restore the frequency to 50 Hz, which is not going to be included in this bachelor thesis.

2.2.3 Control Energy Market

Due to the different energy storage technologies and the costs involved, there are a great variety of options. In order to be able to participate in the control energy market, it is necessary to meet the requirements and be pre-qualified by Swissgrid.

When providers are pre-qualified, and the requirements are completed, they can offer their services at a specific price on an internet platform, considering the cost of the services and the maximum benefit they want to obtain. Once the offer has been entered at each given time and the period in which the offers can be entered has ended, a matching point is obtained [10].

The matching point [11] (where the supply and demand curve crosses) is the price at which the services offered will be paid; all services offered with a higher price than the matching point will be rejected. This price is called the clearing price.

Figure 10: Control energy market

If frequency variations exist:

-**Activation of the primary frequency control** means activation of the reserves, but not additional remuneration for the frequency control

-**Activation of the secondary and tertiary control** means activation of the reserves and additional remuneration for the frequency control.

Intending to improve the energy control market by integrating new technologies and forms of small-scale energy, Swissgrid has created Equigy.

Equigy [12] is a platform based on blockchain technology to aggregate the different technologies on a small scale as batteries of EV's connected in a house.

Thanks to Equigy, it is possible to introduce more suppliers, which contributes to the decarbonization of the energy control market and helps to create a more reliable and secure electricity system. However, the objective of Equigy is the integration of small customers, the main difference between Equigy and this bachelor thesis is the customer for the integration of V2G. In this bachelor thesis the customer considered is a company with a fleet of EV¡s, which suppose a great capacity of energy compared to individual customers with small amounts of energy to provide, although, the idea is the same for both cases.

2.2.4 Technical specification for the participation of Ancillary services

As mentioned earlier, in order to have the possibility to participate in the market of ancillary services, the providers have to follow specific requirements.

This project will explain the requirements to participate as a reserve in primary frequency control and secondary control; in order to do so, it is necessary to obtain a pre-qualification as an ancillary service provider (ASP) [5]; once the pre-qualification is obtained, the ASP will be allowed to participate in the market to provide the ancillary services [7].

It is important to note that if an ASP, once prequalified, fails providing the related services, and breaches the contract, it could be fined and even excluded from future participation in the market. Therefore, to integrate EV's as providers of these services, compliance must be ensured to avoid the problems mentioned above, i.e., It is necessary to ensure that it satisfied all requirements and, therefore, operational readiness.

"*In case of limited energy sources, such as batteries, additional test have to be performed in order to prove that unit can provide the prequalified power for the specified time range of each product*" [13].

After obtaining the pre-qualification, all the resources are classified as:

- **Virtual plant:** defined by Swissgrid "*A virtual generating unit refers to group of smaller power plants of usually different technology types that can also be in different geographical locations*". These resources are validated separately, and it is referred to as small-scale resources.
- **Conventional plant:** defined by Swissgrid "*Conventional generating unit refers to bigger power plants connected to the transmission grid found in one location and comprising different generators or groups of generators*". These resources are validated together if the generators are equal, referred to as great power plants.

When the prequalification is obtained, is available for the next 5 years as a maximum, after this, the technical tests must be prequalified for the next years.

Finally [7] in the pooling, the ASP can create virtual units taking into account their capabilities and possibilities with the sub-units (virtual plants) is very relevant to make sure that the energy that they are providing for the reserve is correctly or in the other case they can receive penalties.

2.2.4.1 Technical specification primary control

The reserve power volume for primary power control in Switzerland is currently approximately 70 MW, with a maximum frequency deviation of ±200 mHz according to the ENTSO-E [14] [5].

In order to enter the bid and offer services, they must be in blocks of a minimum ± 1 MW, i.e., any additional blocks must be added in blocks of ±1 MW. The market in Switzerland in relation with that is divided into 6 periods of 4 hours and is closed at 8:00 CET (D-1) [7].

As I mentioned, the maximum frequency deviation according with the ENTSO-E is ±200mHz, so the supplier must ensure that it can provide the total bid capacity that it has decided to bring to the market.

In relation to the response time, the requirements to be followed as published by Swissgrid are as follows [5]:

- in case of a frequency deviation of at least ±200 mHz, at least 50 % of the full capacity shall be provided after 15 seconds maximum.
- in the case of a frequency deviation of at least ±200 mHz, 100 % of full capacity
- in the case of a frequency deviation of at least ±200 mHz the activation of the total capacity shall increase at least linearly in the range from 15 to 30 seconds
- in the case of a frequency deviation of less than ±200 mHz, the corresponding activated capacitance shall be at least proportional in the same time behavior as mentioned in paragraphs (a) to (d) above.

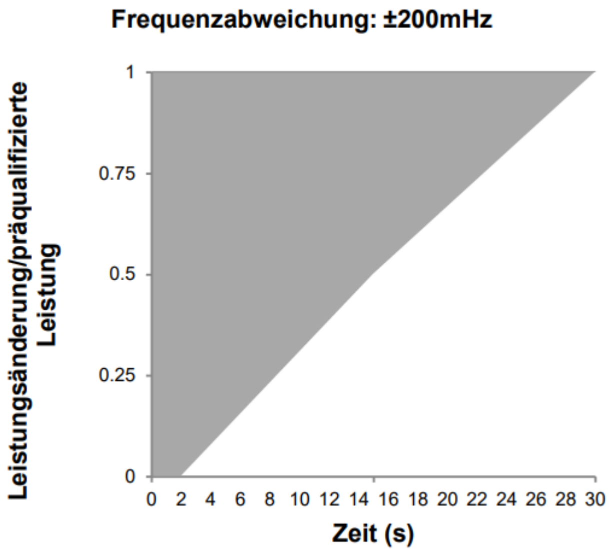


Figure 11: Behavior of activation Primary control reserve with a frequency deviation of 0.2 Hz [5]

A dangerous situation could arise if one of the following conditions were to occur:

- frequency deviation ≥ ±50 mHz for more than 15 minutes
- frequency deviation ≥ ±100 mHz for more than 5 minutes
- frequency deviation ≥ ±200 mHz

For the 15 minutes criteria, a relation is established between the usable storage capacity and the pre-qualified capacity:

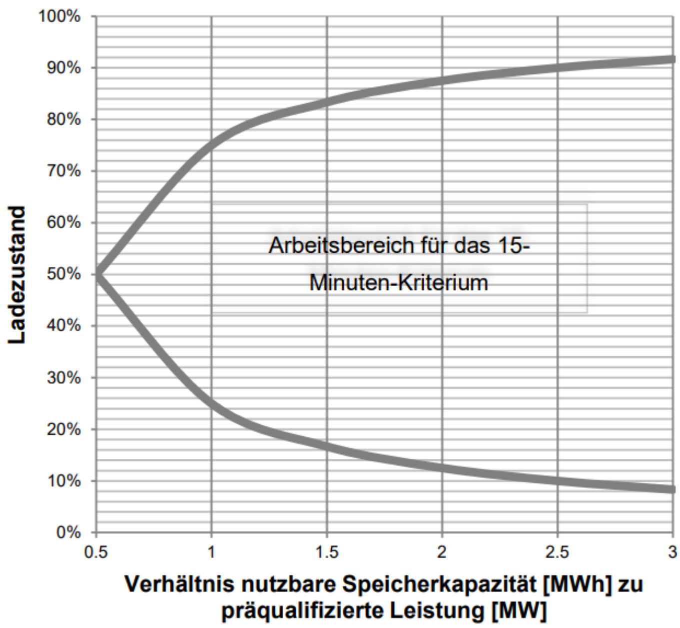


Figure 12: 15 Operating range for the 15-min criterion [5]

$$SoCmax = \frac{E - 0.25h \cdot Ppq}{E} \qquad SoCmin = \frac{0.25h \cdot Ppq}{E}$$

E: usable energy storage (MWh) Ppq: prequalified capacity (MW)

Only in one of the dangerous situations of risk mentioned before behind Figure 11 the ASP will be available to leave the criteria followed in Figure 12 which is to establish a relation between the energy storage (MWh) and the prequalified power (MW); in addition, once one of the risk states has been activated, the supplier must ensure that energy storage will be restored for a maximum of two hours after the end of the risk state.

2.2.3.2 Technical specification secondary control

For secondary frequency control it is necessary to obtain pre-qualification as for primary control and pass a series of tests specified by Swissgrid [15].

In order to be able to provide secondary control services [16], the supplier shall offer bids in blocks of +- 5MW, any additional bids by the supplier shall be +-1 MW.

Procurement for secondary frequency control should be every week, i.e., suppliers should be able to secure power services for one week and the power reservation for secondary control are approximately 390 MW per week in Switzerland?.

	Swiss volume	**Tender Period**	**Maximum Bid Size**	**Bid capacity**	**Duration**
Primary control	70 MW	6 periods (each period of 4 hours)	25 MW	At least ±1 MW Increments of±1 MW (Same bid capacity for 4 hours)	minimum 15 min
Secondary control	390 MW per week	Weekly	100 MW	At least ±5 MW Increments of ±1 MW	15 min
	Usable energy capacity of a battery	**Revenue**	**Technical specification**	**Product duration**	**Procured time**
Primary control	5%<x<95%	Revenue for the volume of power offered in the bid	Prequalification is required	Daily product	Two days before real-time operation (d-1)
Secondary control	5%<x<95%	Revenue for the volume of power offered in the bid and energy supplied for the control	Prequalification is required	Weekly product	Tuesday of the preceding week

Table 2: Primary and secondary frequency control features

2.2.4 Background and supporting data of frequency control

As we know, the frequency control of the grid is necessary, and as I have explained before, it is required to have suppliers that ensure and provide the required reserves to be able to achieve the balance of the grid; therefore in the pool, the suppliers offer their services and depending on the price and the volume they offer, the corresponding contracts will be produced.

Therefore, it is a free market in which, achieving the pre-qualification obtained before, we could integrate the electric cars' batteries to perform at more competitive prices. This can be assured by the data provided by Swissgrid, which shows the volume of tenders offered and the amount of energy used.

Nowadays, the participation of different providers in the control energy market has been increasing due to the importance and market possibilities offered to the different providers [1].

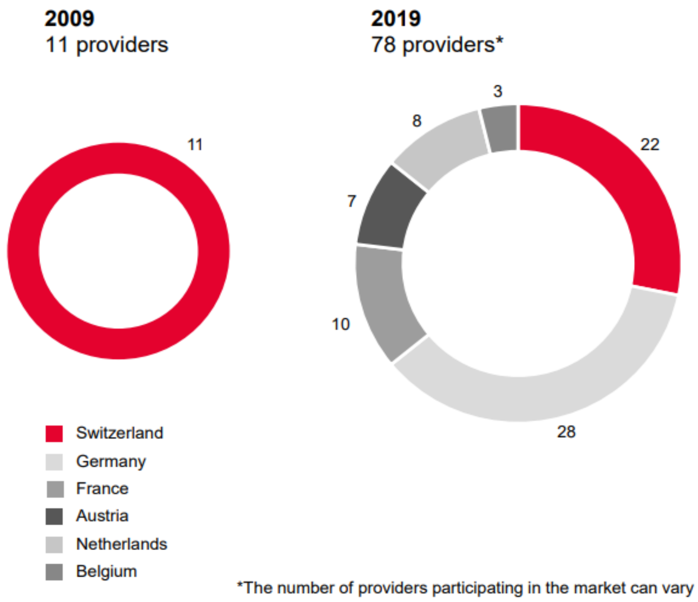


Figure 13: Comparison 2009 and 2019 amount of providers frequency control [1]

According to the increment of the renewable energy, self-consumption energy, and new technologies, a new useful situation is presented by the new technologies which we can provide new services to contribute to the quality and flexibility of the grid operation.

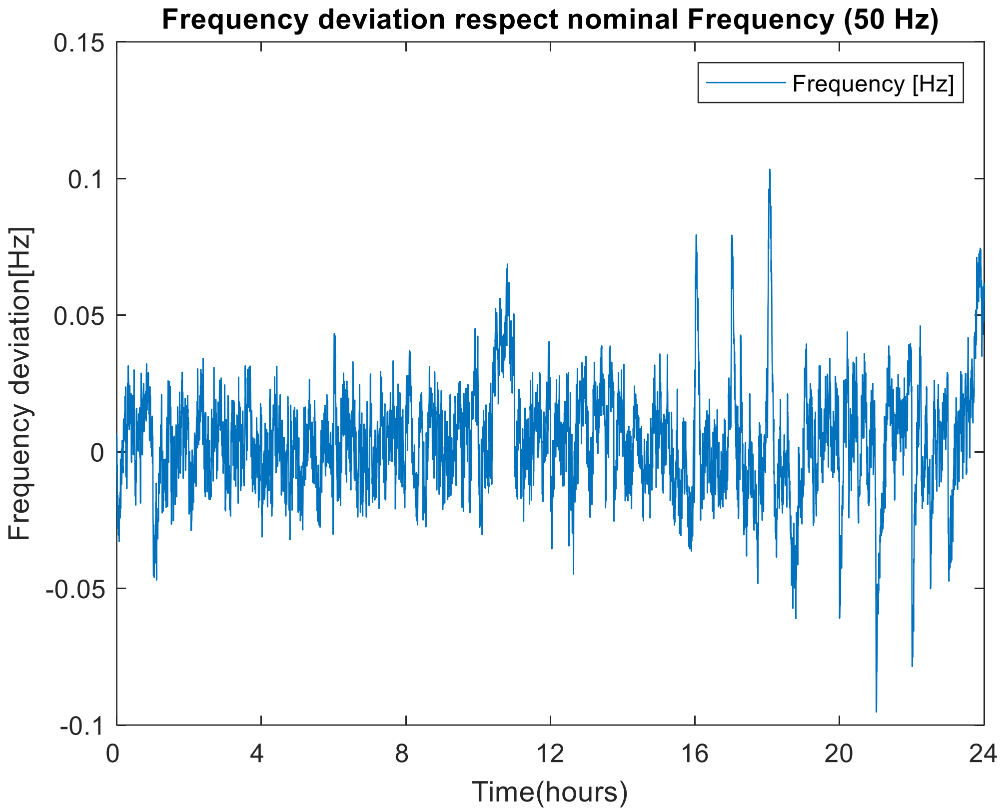


Figure 14: Frequency deviation of one day

In the Figure 14 we can see the variation of the frequency with respect to the time. Over time, it can be observed how the frequency differs from the nominal frequency punctually and recurrently, being the most recurrent range of variation being between 0.05 and -0.05 approximately (Considering 0 is the nominal frequency 50 Hz, the range variation is [50.05;49.95]). Due to the Figure 14 we can see the importance of monitoring and control these variations as they occur throughout the day.

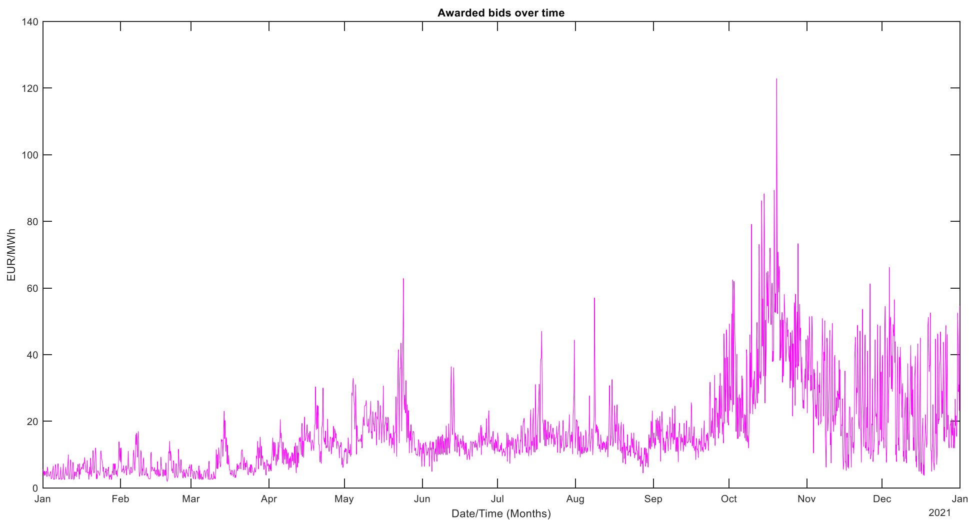


Figure 15: Awarded bids over time

In the Figure 15, we can see the increase over one year of the bids awarded in terms of frequency control; this implies that there is an increase in prices, which means that the market is growing in order to solve the problem and ensure the quality of the network since as time goes by, the electricity system increases. We can also consider that price variation occurs depending on the year and that there is a significant price fluctuation.

Finally, in order to support the idea of EV’s, in the following graph taking into account the historical data, we can obtain how often deviations occur and the maximum deviation, in order to have an idea about the amount of energy that the EV’s should provide as we must subtract it from the amount of benefit that we would get by using them as frequency control.

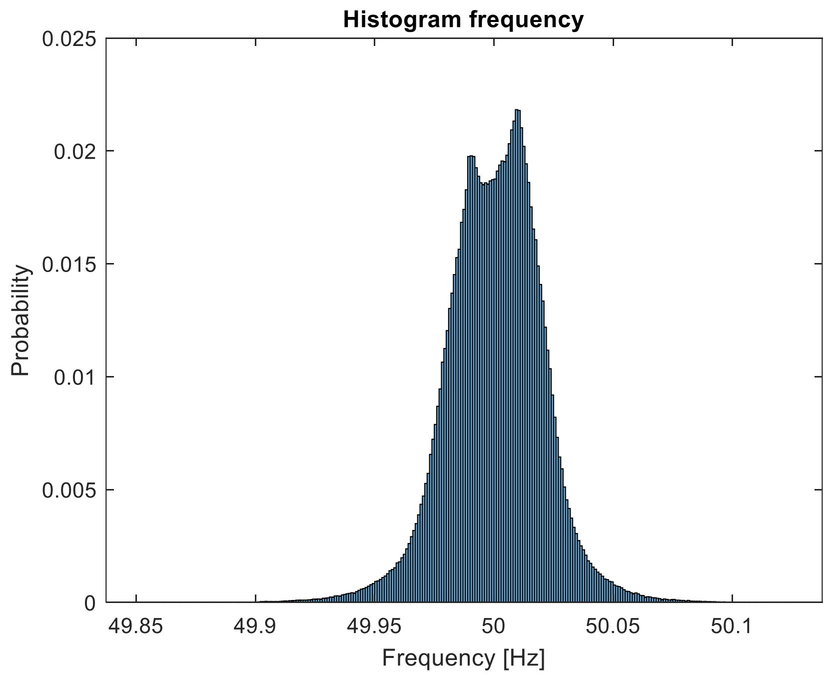


Figure 16: Histogram frequency vs probability

As we can see, most of the variations occur between approximately 49.95 and 50.05 Hz, which means variations of 0.05 Hz with respect to the nominal.

Considering where most of the frequency variations are concentrated, the energy to be supplied or taken from the grid by the EV's should not be significant amounts of energy, which we will study in the simulation.

3. EV'S AS A RESOURCE TO PROVIDE GRID SERVICES AND FLEXIBILITY

As I mentioned earlier, the demand for electric cars and their use increased across Europe [17] as can be seen in the Figure 17 and Figure 18:

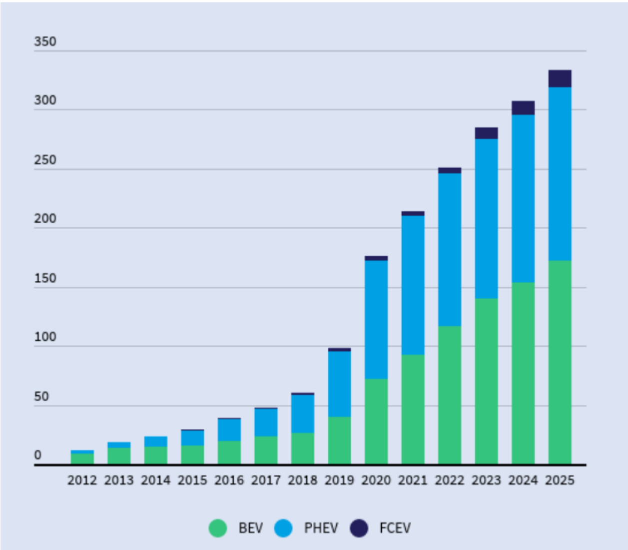


Figure 17: Number available EV in Europe

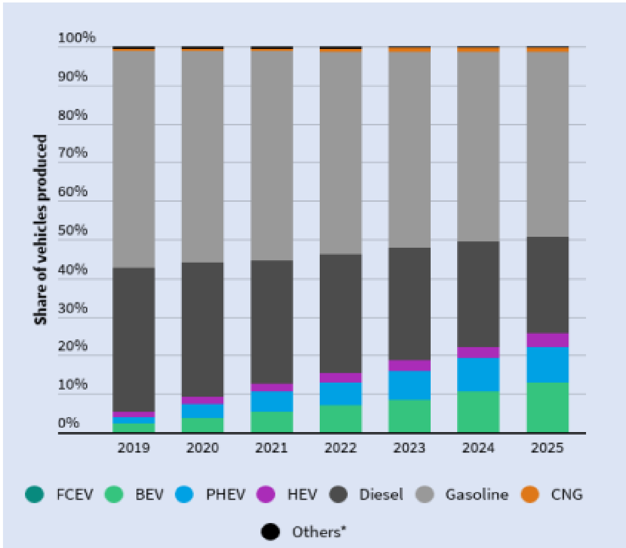


Figure 18:EU production of vehicles per type in 2025 in share of total production

With the aggregation of EV's, we have the possibility of increasing the flexibility of using the EV as an electricity supplier (discharging), optimal loads (charging), or energy storage (batteries) [18].

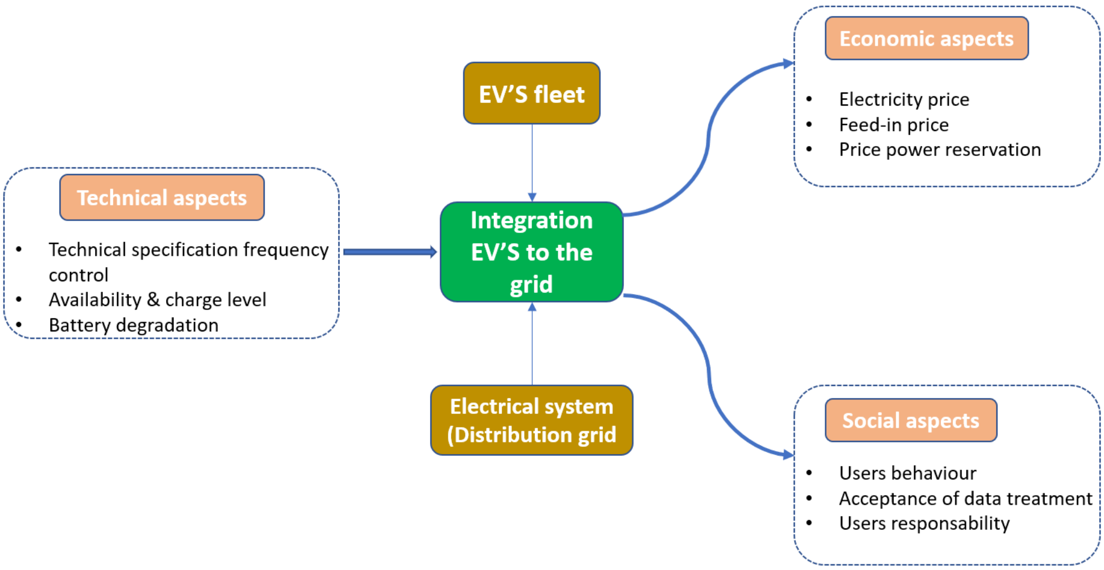


Figure 19:Aspects of the integration of EV's

As shown Figure 19, the possibility of integrating EV's is a reality; however, many factors must be taken into account to be able and make it feasible to integrate into the grid. Technical, economic, and social factors are equally important because they directly or indirectly influence the services that EV's can offer.

3.1. Benefits of the aggregation EV's

Nowadays, the amount of EV's integrated into the grid is increasing in order to contribute to creating a society more sustainable, reduce greenhouse gases, the environmental impact, the global warming in comparison with the last years.

In the following table [19], the different forms of energy storage characteristics are analyzed and compared. In the table, we can also see the different costs of storage in which EV's appear, which helps to compare the technology studied in the project to the rest. The data corresponds to US values.

Storage technology	Cost of storage		response time	Round trip efficiency (%)	Cost to match U.S. V2G capacity ($bn)	Other notes
	$/kW	$/kWh				
V2G	0	0-40	A few seconds	70-85	N/A	By far the cheapest system, diffusion process long and complex, depends on consumers
Hydrogen	1500-3200	260-540	Second to minutes	40	$6200	Lowest efficiency and high capacity costs
Purpose-built batteries	1100-2500	500-800	A few seconds	70-90	$7020	Without secondary use, battery energy capacity is very high cost
Flywheels	870	4800	A few seconds	94	$41,200	Highly efficient but cost limits overall energy capacity, preferred for short-term storage
Power-to-gas	850	N/A	Seconds to minute	50	$2300	Low efficiency,gas infrastructure must preexist, contributes to gas-related emissions
Compressed air energy storage	900-1300	40-109	9-12 minutes	70-90	$2800	Dependent on local geology to compress air into, proven technology
Pumped hidroelectric	1400	68	A few seconds to minutes	70-82	$4300	Most prevalent storage, but geographically dependent, environmental implications

Table 3:Comparison between the different forms of storage

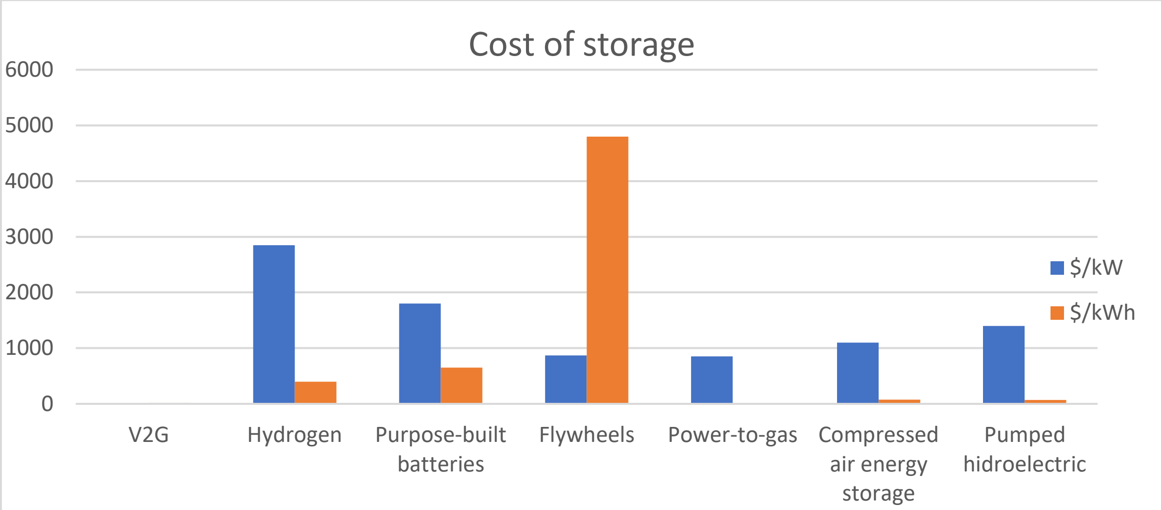


Figure 20: Comparison between the different forms of storage

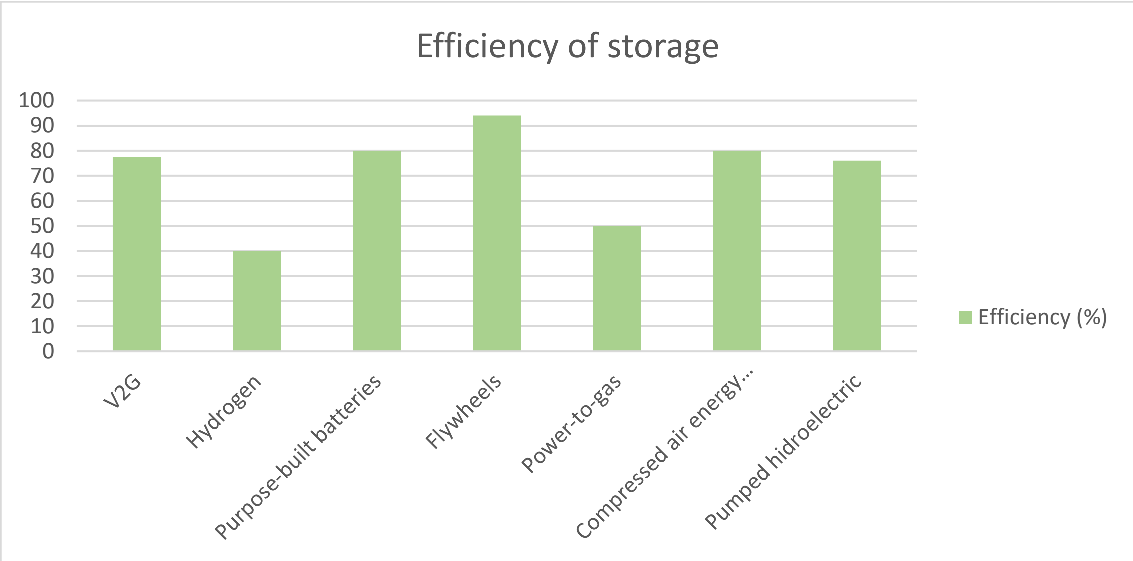


Figure 21: Efficiency different forms of energy storage

* The value taken to represent in the figure 20 and 21 is the average between the maximum cost and the minimum cost.

As we can see, the V2G is the best option taking into account the cost of storage; moreover, efficiency can be considered a good option since it is between 70-85 % [16], despite the other technologies, which can offer better efficiency, have more economical cost.

The different forms of storage of energy that are exposed in Table 3:Comparison between the different forms of storage, and is considered only the economic and efficiency factors; moreover, in Figure 20 the cost of the batteries of V2G in comparison with the other forms is insignificant.

Considering the characteristics of the EV's that [20] are connected to the grid to charge the batteries, we have different valuable tools:

Optimal loads
Possibility of adjusting the level of charging depending on the amount of electricity that is necessary to consume to achieve the balance between the production and consumption when the frequency is >50 Hz
Electricity supplier
Possibility of providing electricity when is necessary to the grid to achieve the balance between the production and consumption when the frequency is <50 Hz and batteries have enough energy discharge.
Energy storage
Using the batteries of the EV'S for storage energy of the grid, with the possibility of having an optimal load or electricity supplier in a future.
Flexibility of the bidirectional batteries
The ease of charging and discharging the battery means it is easy to achieve the various benefits mentioned above.
Economic benefit
Depending on the historical data of frequency, we will obtain an estimation of the total benefit and cost for providing this services

3.1.2 Objectives and research questions

This project aims to create a Matlab (Simulink) model capable of defining the economic viability of using EV's to provide frequency control, taking into account the deviations that may exist due to consumption and production.

Therefore, several factors must be considered in this model, contributing to the economic viability analysis.

The Simulink model must evaluate the availability of the EV's and their charge level to decide whether it is possible to offer the frequency control services, as the EV's have a limit to charge and discharge energy. In this way, it is possible to calculate the cost and revenue of offering the services considering the factors mentioned above.

I have defined 4 objectives which I have followed in order to define my model:

Objective 1: Data specification of the model & diagram of simulation
What are the variables necessaries and characteristics of the EV'S fleet for the integration into the grid? What are the assumptions of this model?
Objective 2: Total cost regulating the frequency with EV'S
What is the total cost of electricity when the EV's take electricity from the grid considering the tariff of Luzern?
Objective 3: Total revenue of feed-in electricity to the grid

What is the total revenue feeding-in electricity to the grid considering the tariff of Luzern?
Objective 4: Total revenue of provide frequency control
What is the total revenue of providing frequency control from Swissgrid?
Objective 5: Total benefits/results of using EV'S providing frequency control
What is the total result after considering the revenue and the cost of the simulation?
Objective 6: Analysis of the different simulation
Comparison and demonstration of the validity of the model

The first step was to define the input data in order to make the corresponding assumptions and assign values.

Once the values have been entered, we make the logic diagrams indicating the different steps to be carried out in the simulation.

After defining the objective 1, we know the steps of the simulation and all the input values are entered, so, it is possible to calculate the total cost due to the electricity consumption of the EV's; however, we must discount the revenue that we can get from feed-in energy into the grid from the cost mentioned above.

Considering the bid capacity is possible to obtain the total revenue by providing reserve power for the frequency control market and thus finally obtain the net profit from the simulation.

With this set of objectives, it is possible to define the total costs and revenues of providing frequency control depending on the frequency variation obtained from historical data.

4. SIMULATION MODEL

4.1 DATA SPECIFICATION

In order to determine the feasibility of the project, I have used the MATLAB program together with Simulink tool to carry out the simulation of different scenarios as close to reality as possible. To do this, it has been necessary to make various assumptions and define the input data, the data which vary over time, and the output data which we are going to use to be able to draw conclusions from the model. All these data are data obtained from numerous studies and bring the simulation as I mentioned above closer to reality.

In order to do a great definition of the data specification, I considered 3 factors:

-Type of data: It can be constant because there is no variation during the simulation; Variable data history over time, is varying during the simulation but it is an input value; Variable over time is varying during the simulation but it is a result of the simulation.

-Input/output: depending on if it is necessary data to initialize the simulation or is the data we want to obtain as a result.

-Assumptions: constant defined in the script of Matlab due to the information obtained from different resources.

In the table below, we can see the data in relation to the frequency:

Data	Type of data	Input/output	Assumption
Nominal Frequency	Constant	Input	50 Hz
Frequency	variable data history over time	Input	-
Frequency deviation	Variable over time	Output	-
Maximum frequency deviation	Constant	Input	0,2 Hz

Table 4: Frequency data for the simulation

The frequency data history makes it possible to determine the variation at each point in time; the data frequency values are available every 10 seconds.

Knowing that the nominal frequency of the grid is 50 Hz and the maximum deviation is 0.2 Hz, it is possible to determine the power to be regulated at each moment by the EV'S fleet.

The historical frequency data are shown in Figure 14: , Once the frequency deviation output has been obtained, considering the availability of the EV's, we will calculate the power to be regulated.

The following data to be defined are the characteristic data of the EV fleet and its batteries:

Data	Type of data	Input/output	Assumption
Efficiency discharge	Constant	input	0,9
Efficiency charge	Constant	input	0,9
Battery Capacity (kWh)	Constant	input	Depend on the profile defined for the fleet*
State of health (SOH)	Constant	input	1
Biding capacity (MW)	Variable data history over time (vector of 24 constants value for every hour in one day	input	Depend on the profile defined for the fleet*

State of charge (SOC)	Variable data history over time (vector of 24 constants value for every hour in one day)	Input	Depend on the profile defined for the fleet*
Plug state	Variable data history over time (vector of 24 constants value for every hour in one day	input	Depend on the profile defined for the fleet*
Charge factor	Constant	Input	0,5
Charge (kw)	Constant	Input	5
Number of cars	Constant	Input	Depend on the profile defined for the fleet*
SOCcars	Variable over time	Output	Depend on the profile defined for the fleet*
EV availability	Variable data history over time (vector of 24 constants value for every hour in one day	Input	Depend on the profile defined for the fleet*

Table 5: Data specification EV's

** The data which depend on the profile defined by the EV's fleet are data that I will define later, as different scenarios will be simulated as realistically as possible.*

Table 5 defines the different variables and assumptions that are part of my model. As for the data type, the input values are defined together with the output values, which may vary during the simulation.

Two different charging levels (SOC and SOCcars) will be established in the model. This is because the SOC will be the variable composed of 24 load state values for each hour of the day, which will initialize the simulation.Once initialized, the SOCcars will be the output variable responsible for collecting the state of charge variations during the simulation.

If the EV's are disconnected from the charging point or are not available, the program will lose the data on the level of charge; however, if they are available or connected again, the level of charge value to be taken to continue with the simulation will be the SOC defined as input value.

The input data that is variable data history over time is data that I have to define in the Matlab script; however, different factors must be taken into account which will directly affect the simulation; one of the most important factors is the behavior of the drivers of the EV's fleet, due to the fact that is depending on the behavior, the level of charge and availability of the EV's will be affected directly, and this will affect the bid capacity we want to offer at each hour of the day.

Considering the importance of making a definition as close as possible to reality in terms of availability of EV's taking all factors into account, as mentioned above, another important part for defining this model, is the bid capacity which the EV's fleet will be able to offer.

In this case, the assumption is the capacity of Bid that I am going to provide to the grid with my entire fleet that will be filtered using a comparative value explained in the Figure 24 and Figure 25 Defining the bid capacity for one day, I will be able to see the state of charge of the battery, how is changing during the day and the cost that we expect due to the frequency deviation which We are responsible for providing energy in order to balance the energy consumption and production.

I considered that the market starts at 00:00 due to the historical frequency data obtained, so, the input data that I defined in my model are in **4.3 Simulation case 1 4.4 Simulation case 2 4.5 Simulation case 3**

The numbers of the bid capacity are taking into account the more realistic scenario, It must be considered how many cars I will have available throughout the day since, during the morning and midday, the car will probably have less load or even not be connected.

As I mentioned before, the bid capacity is classified in 6 periods of 4 hours. Therefore, another requirement that has been taken into account is to use a bid capacity in the six different periods but be the same in the 4 hours in which it starts.

The last data to be specified are the electricity prices, which are listed in the following table:

Cost/Revenue	Price	Units
Electricity tariff cost	0,1789	CHF/kWh
Tariff revenue feed-in	0,09	CHF/kWh
Revenue Power reservation	13,7	CHF/MWh

Table 6: Price of cost/revenue electricity

The cost of the electricity tariff and the price for supplying electricity to the grid is variable depending on the region of Switzerland, in this project the values of the canton of Luzern have been considered.

The revenue price for power reservations is the average of the historical data at which they were paid each hour over a day.

Finally, the values we need in order to determine the potential of the V2G are the cost and the revenues:

Data	Type of data	Input/output
Cost of charging batteries	Sum of a variable over time	Output
Revenue of discharging batteries	Sum of a variable over time	Output
Revenue of providing frequency control	Sum of a variable over time	Output
Total benefit	Sum of a variable over time	Output

Table 7: Economic variables

4.2 DIAGRAMS OF SIMULATION

Once the necessary input and output data of the model had been defined with the relevant assumptions, I defined a series of diagrams and general schemes in order to be able to carry out the simulation.

The simulation could be divided into six logical schemes:

-The Figure 22 refers to calculating the **power cost regulation**, which allows us to obtain the net cost by considering the energy withdrawn and supplied to the grid with the prices defined above.

- The Figure 23 concerns **evaluating the state of charge** of the batteries and the variation during their simulation.

-The Figure 24 concerns evaluating the **possibility of Bid** depending on the battery capacity and the level of Charge.

-The Figure 25 concerns evaluating with the **possibility of Bid** of the previous diagram if the bid capacity we are Introducing as an input is possible or not.

-The Figure 26 concerns evaluating the total **revenue obtained from the Bid capacity**

-The Figure 27 calculates the Total benefit considering the **total revenue** obtained from the bid capacity and the **cost power regulation**.

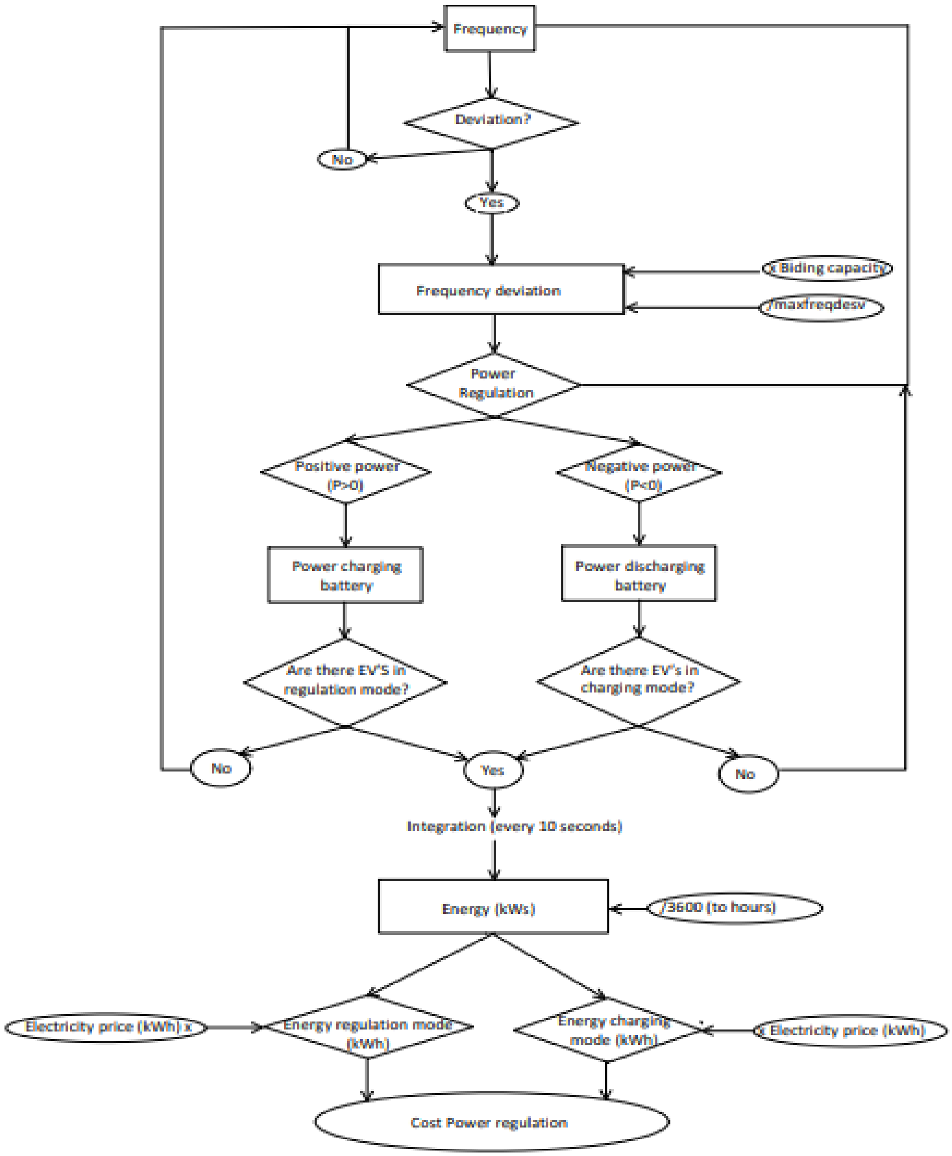


Figure 22: Calculation of power regulation

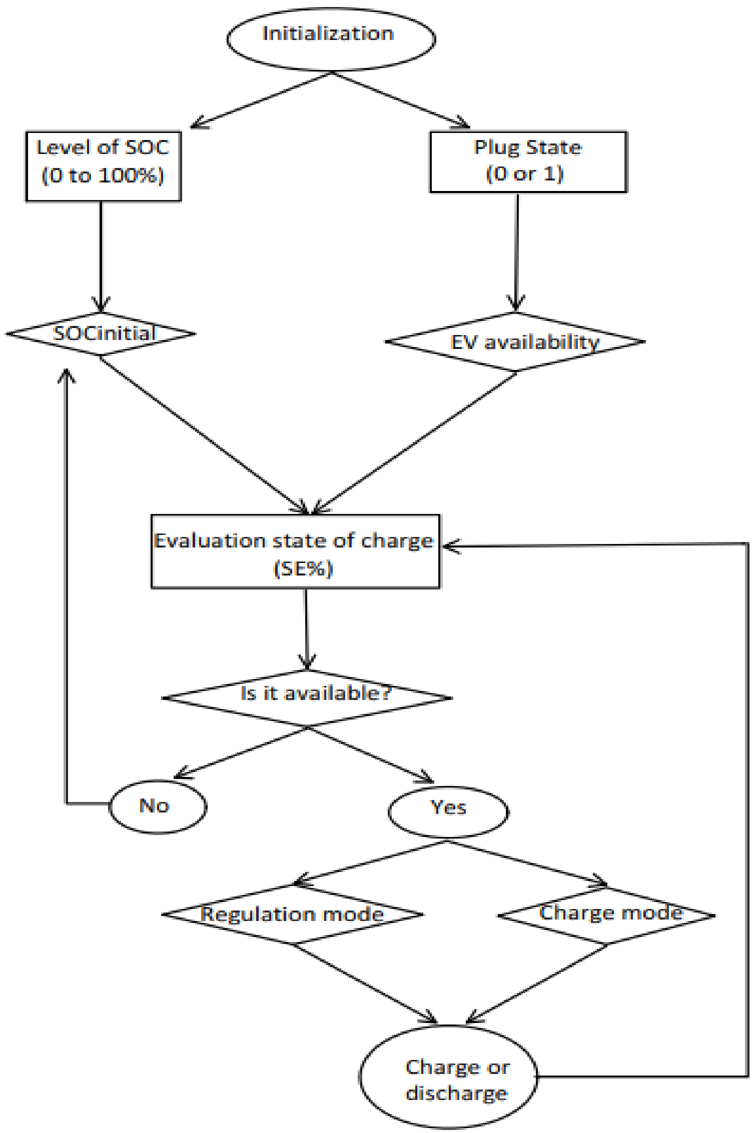


Figure 23: Evaluation state of charge during the simulation

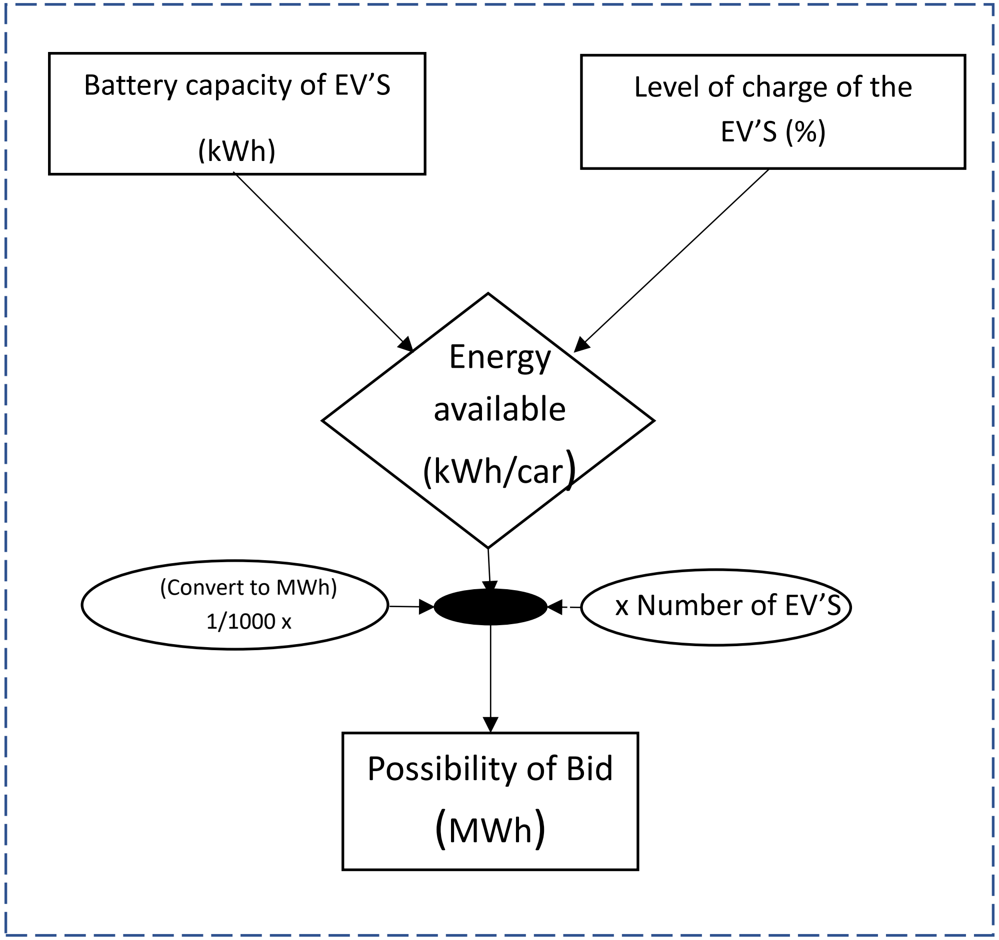


Figure 24: Possibility of Bid depending on the battery capacity and SOC

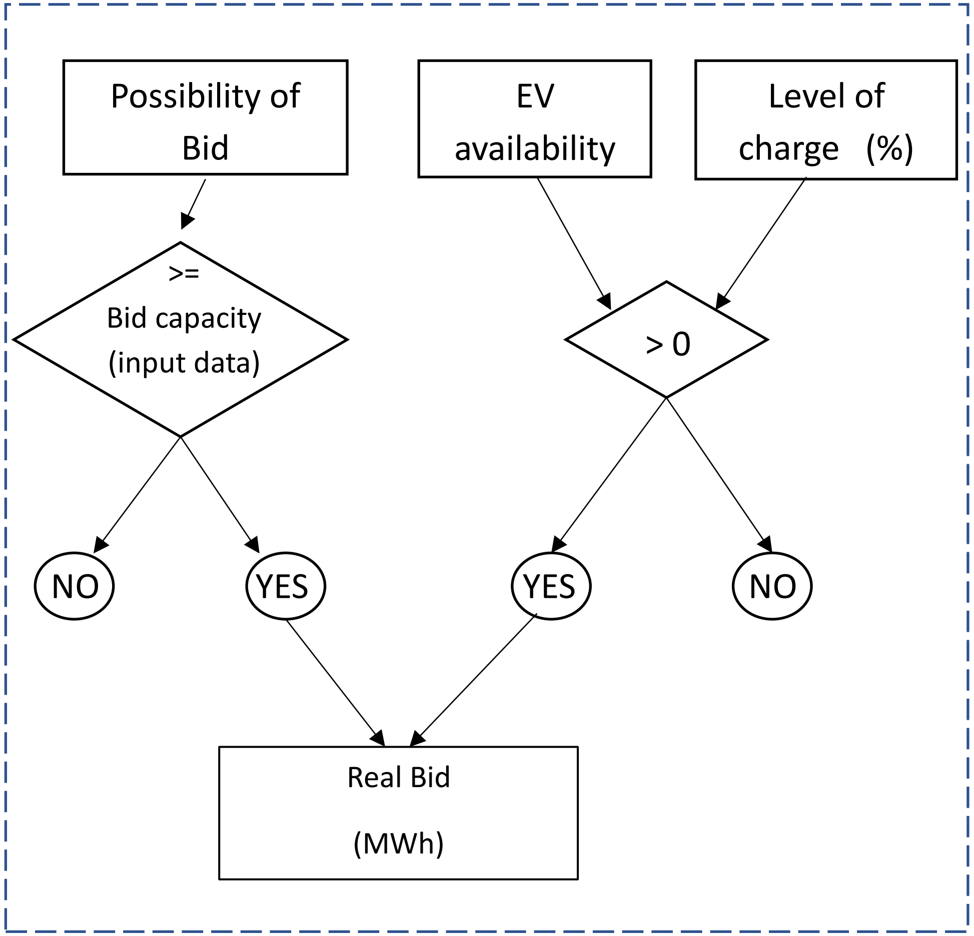


Figure 25: Comparison between Possibility of Bid and the Bid capacity (input)

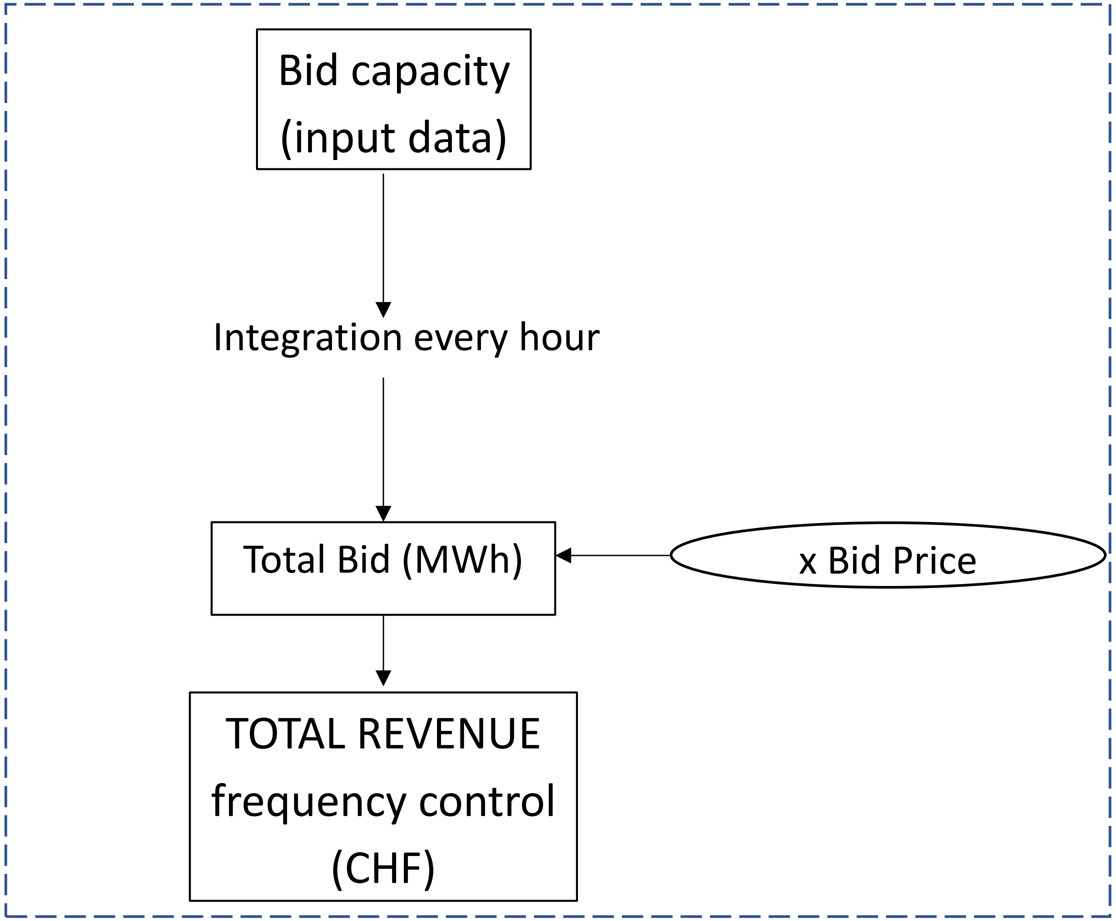


Figure 26: Calculation of the Total revenue frequency control

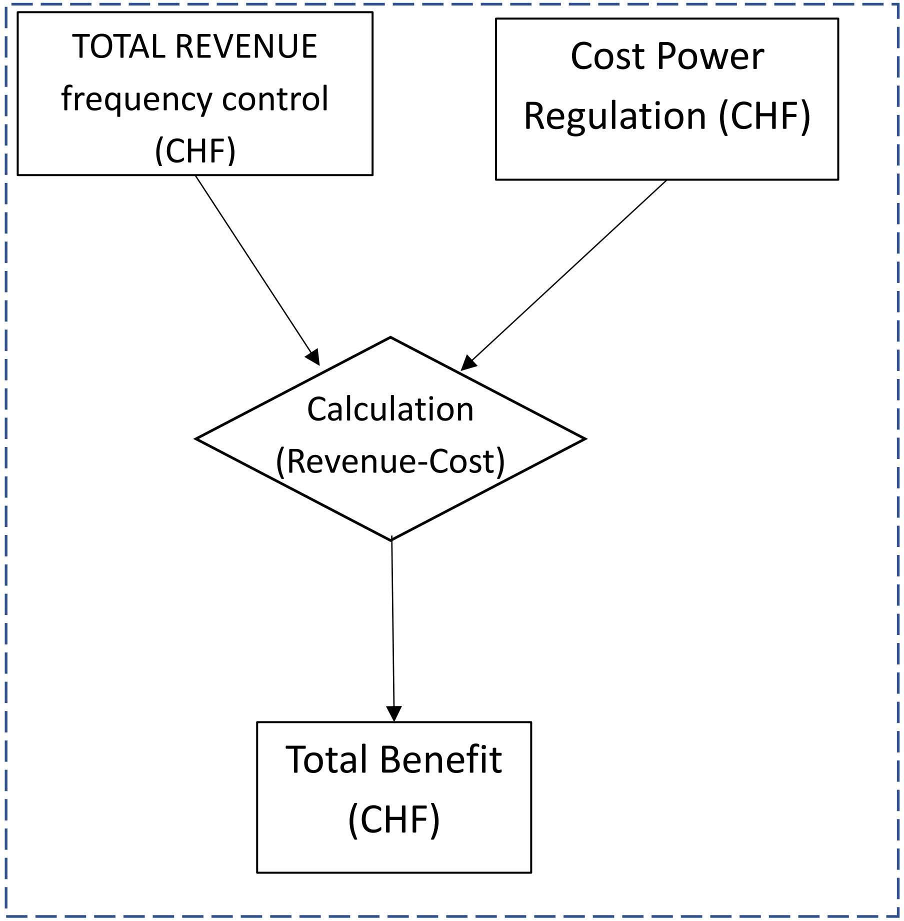


Figure 27: Total benefit of frequency control

As we can see in Figure 22, considering whether there is frequency deviation or not, it is possible to calculate the power to be regulated, taking into account the Offer offered and the maximum frequency deviation.

If the power is positive, the battery of the EV's will be charged, assuming an additional cost for taking energy from the grid; however, if the power is negative, the battery of the EV's will be discharged, assuming an additional income for feeding energy into the grid. The most crucial point to consider is whether the EV's are available for the periods when it is necessary to regulate the power. If they are not available, we will not be able to regulate that power.

If we have cars in discharging mode, it means that we will have the possibility to offer the services and discharge the batteries because the frequency variation is negative. On the other hand, if we have cars in charging mode, we can take energy from the grid to regulate the power because the frequency variation is positive. After filtering the availability of regulating the power of the grid, we can obtain the energy in kWh by applying an integration every 10 seconds, due to the data used are frequency variations every 10 seconds.

Once depending on whether the energy is supplied to the or taken from the grid, it is multiplied by the corresponding tariff, which can be found in the data specification and finally will be obtained the total cost of power regulation.

In the Figure 23, we find the diagram that considers the variation of the state of charge of the battery during the simulation of the model, as discharging or charging the battery must be taken into account for the simulation.

As I have defined before, we introduce the parameters defined as the level of charge (SOC) and if the EV's are connected or not to the recharge point; these parameters I have defined before will be a vector of 24 values corresponding to each hour of the day. Once we start the simulation, the model obtains the initial SOC and availability as a starting point. The first state of charge is obtained, with which, evaluating whether it is available or not, it will follow two different paths: discharging mode or charging mode.

- Discharging mode: in this mode, the EV's are responsible for supplying energy to the grid in order to regulate the frequency at 50 Hz, thereby reducing the charge level and discharging the batteries. This implies additional revenue due to the energy supply to the grid.
- Charging mode: in this mode, the EV's are responsible for drawing power from the grid in order to regulate the frequency to 50 Hz, thereby increasing the charge level and charging the batteries. This implies additional cost due to the energy taken from the grid.

One of the main points to take into account in the simulation is the availability of EV's, since if they are disconnected from the charging point, the program loses the information about the state of charge.

In case that EV’s are not plugged into the charge station or are not available, and the program loses the data about the level of Charge, the program will take the value introduced as an input data in the script of Matlab to initialize the program in case of connection of the EV’s at any time during the simulation in order to reassess its state of charge and variation.

As we can see in the Figure 24 as I mentioned before, to be able to evaluate the Bid possibility, it will depend on the number of EV cars, together with the charge level and the battery capacity; in this way, it is possible to obtain a value during the simulation with which to compare with respect to the Bid we are trying to offer for the frequency control. This value is calculated in order to be able to compare the bid capacity we want to offer, because if we do not ensure the bidding capacity that we are offering together with the available capacity, we may not be able to regulate the frequency and thus receive fines or penalties.

Figure 25, finally the comparison between the Bid possibility we have and Bid capacity (input data), making sure that the total power available is greater or equal to the power what I offer, in addition, the car load value and the availability must be greater than 0, in this way, we will obtain the Bid that really will be provided for frequency control.

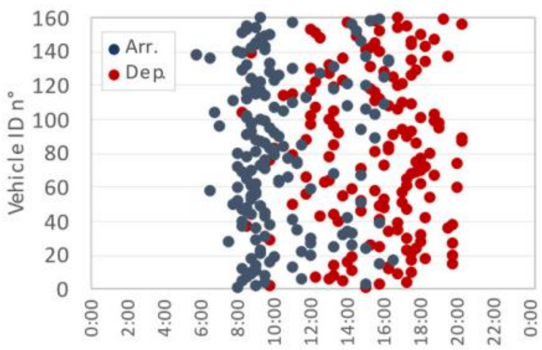
Figure 26, once we have the variable Bid possibility during the simulation, As I mentioned before, if it is greater than or equal to the bid capacity which we are bidding, it will be possible to offer the services. Considering this requirement, we are ensuring that we have more or the same power reserve capacity as we are offering; in addition, in all this, the electric car's load level and availability must be greater than 0. Fulfilling the two requirements that we can see in the Figure 27 a real Bid will be taken by the program.

Finally, in Figure 27 the program calculates the total revenue of the frequency control considering the corresponding average between the historical data of bids that I mentioned in **4.1 DATA SPECIFICATION**. Considering the cost of power regulation, the total benefit during the simulation is obtained.

4.3 Simulation case 1

The first simulation case consists of a single fleet of electric cars that all have the same characteristics, i.e., they all have the same battery characteristics and same availability schedule.

To define the timetable in which EVs will be connected to the charging station, the article [21] has been used to establish a realistic schedule.



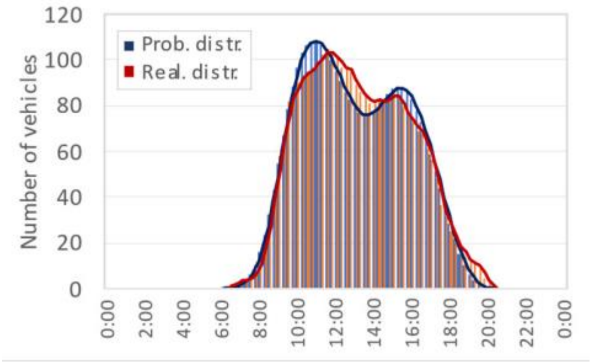
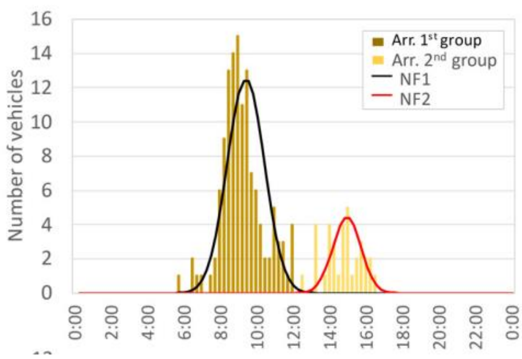


Figure 28: (a)

Figure 29: (b)



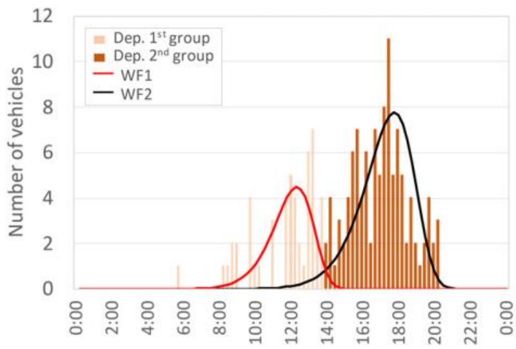


Figure 30: (c)

Figure 31:(d)

Figure 28 (a) Arrival and departure times for each vehicle

Figure 29 (b) Number of total parked vehicles (presences) in each 15 min time intervals

Figure 30 (c) Top-frame, number of departures versus time and its probabilistic function

Figure 31 (d) Top-frame, number of departures versus time and its probabilistic function

These graphs obtained from the article [21] show from a historical series of data, the number of vehicles with respect to the time of day that arrives or leaves a work zone car park; This visually demonstrates the hours of the day when the EV's might be connected to a charging point because it is in the car park.

Therefore, in this scenario, EV's will be available and connected only when they are in the parking zone of work. Considering that the EV's are available in these hours, we are considering that the charger points of the different working parking are available to use technology for bidirectional batteries, as we must consider that it may be the case that cars will have to supply energy. The charge and discharge energy are limited to 5 kW so, we can assume that EV'S are going to have capacity after the services offered.

Finally, as we can see in the graphs the schedule considered is [08:00 to 19:00] that is reasonable taking into account the timetable of work during a normal day. In relation to the level of charge I am going to assume 80% due to the trip for arrive to the parking.

SIMULATION CASE 1			
In the first simulation case I considered a single fleet of EV'S. All the EV's that form part of the fleet are equal and have the same characteristics. Same battery capacity, level of charge and Bid capacity. It is considered that EV's are available only when they are not in the parking place.			
FLEET INFORMATION:		**MODEL: HONDA E**	
Number of EV's	500		
Battery Size (KWh)	35.5		
Maximum charging/discharging (kW)	10		
Charge factor	0.5		
Availability of the fleet (%)	100		
Hours (h)	**LEVEL OF CHARGE**	**PLUG STATE**	**BIDING CAPACITY**
00:00-1:00	0	0	0
1:00-2:00	0	0	0
2:00-3:00	0	0	0
3:00-4:00	0	0	0
4:00-5:00	0	0	0
5:00-6:00	0	0	0
6:00-7:00	0	0	0
7:00-8:00	0	0	0
8:00-9:00	0.8	1	6
9:00-10:00	0.8	1	6
10:00-11:00	0.8	1	6
11:00-12:00	0.8	1	6
12:00-13:00	0.8	1	6
13:00-14:00	0.8	1	6
14:00-15:00	0.8	1	6
15:00-16:00	0.8	1	6
16:00-17:00	0.8	1	6* (0)
17:00-18:00	0.8	1	6* (0)
18:00-19:00	0.8	1	6* (0)
19:00-20:00	0	0	0* (0)
20:00-21:00	0	0	0
21:00-22:00	0	0	0
22:00-23:00	0	0	0
23:00-00:00	0	0	0

Table 8: Definition of Scenario 1

The bid capacity is considered the requirements explained in ***2.2.4 Technical specification for the participation of Ancillary services*** for the participation of Ancillary services, where the power offered in the bid must be the same during blocks of 4 hours and not more than 25 MW. In the scenario 1 is a maximum of 24 every period (6 MW/h in 4 hours) so this makes real the simulation.

*Due to the period [16:00 to 20:00 h] that is not possible to assure the same power during the 4 hours, is not possible to obtain revenue despite of have EV'S available so the number assigned finally will be 0.

4.4 Simulation case 2

The second simulation case consists of a single fleet of electric cars that all have the same characteristics, i.e., they all have the same battery characteristics and same schedule but different from scenario 1

To define the timetable in which EVs will be connected to the charging station, the article [21] has been used to establish a realistic schedule.

Considering the schedule established for **4.3 Simulation case 1**, the schedule for **4.4 Simulation case 2** is the opposite; I am considering the EV's availability when the car is not in the working parking. The schedule when the EV's are going to be plug-in into the charging station available to provide the services are going to be [00:00 to 08:00 h] and [19:00 to 00:00h].

SIMULATION CASE 2
In the second simulation case I considered a single fleet of EV’S. All the EV’s that form part of the fleet are equal and have the same characteristics. Same battery capacity, level of charge and Bid capacity. The schedule is the opposite of the scenario 1

FLEET INFORMATION:		MODEL: HONDA E
Number of EV’s	500	
Battery Size (KWh)	35.5	
Maximum charging/discharging (kW)	10	
Charge factor	0.5	
Availability of the fleet (%)	100	

Hours (h)	LEVEL OF CHARGE	PLUG STATE	BIDING CAPACITY
00:00-1:00	0.8	1	6
1:00-2:00	0.8	1	6
2:00-3:00	0.8	1	6
3:00-4:00	0.8	1	6
4:00-5:00	0.8	1	6
5:00-6:00	0.8	1	6
6:00-7:00	0.8	1	6
7:00-8:00	0.8	1	6
8:00-9:00	0	0	0
9:00-10:00	0	0	0
10:00-11:00	0	0	0
11:00-12:00	0	0	0
12:00-13:00	0	0	0
13:00-14:00	0	0	0
14:00-15:00	0	0	0
15:00-16:00	0	0	0
16:00-17:00	0	0	0
17:00-18:00	0	0	0
18:00-19:00	0	0	0
19:00-20:00	0.8	1	0
20:00-21:00	0.8	1	6
21:00-22:00	0.8	1	6
22:00-23:00	0.8	1	6
23:00-00:00	0.8	1	6

Table 9: Definition of Scenario 2

The bid capacity was defined making the same assumptions than **4.3 Simulation case 1** following the **2.2.4 Technical specification for the participation of Ancillary services**. And with the resources founded in [21].

4.5 Simulation case 3

Once I defined the Simulation **case 1** and **Simulation case 2**, I defined another scenario by combining the different parameters in order to obtain the results according to the reality due to because if we have full availability, the result should be the possibility to provide services during each hour and the economic result should be approximately the sum of the two scenarios.

The third simulation case is the combination of simulation cases 1 and 2 in order to demonstrate with the results after the simulation that with the availability of EVs, it is possible to provide the frequency control all day and the simulation is correct.

To define the timetable in which EVs will be connected to the charging station, the article [21] has been used to establish a realistic schedule, as I mentioned, is a combination of both cases so the definition of the schedule was total availability of EVs and bid capacity.

SIMULATION CASE 3
In the third simulation case I considered a single fleet of EV's. All the EV's that form part of the fleet are equal and have the same characteristics. Same battery capacity, level of charge and Bid capacity. The schedule is the combination between scenario (1) and (2)

FLEET INFORMATION:		MODEL: HONDA E
Number of EV's	500	
Battery Size (KWh)	35.5	
Maximum charging/discharging (kW)	10	
Charge factor	0.5	
Availability of the fleet (%)	100	

Hours (h)	LEVEL OF CHARGE	PLUG STATE	BIDING CAPACITY
00:00-1:00	0.8	1	6
1:00-2:00	0.8	1	6
2:00-3:00	0.8	1	6
3:00-4:00	0.8	1	6
4:00-5:00	0.8	1	6
5:00-6:00	0.8	1	6
6:00-7:00	0.8	1	6
7:00-8:00	0.8	1	6
8:00-9:00	0.8	1	6
9:00-10:00	0.8	1	6
10:00-11:00	0.8	1	6
11:00-12:00	0.8	1	6
12:00-13:00	0.8	1	6
13:00-14:00	0.8	1	6
14:00-15:00	0.8	1	6
15:00-16:00	0.8	1	6
16:00-17:00	0.8	1	6
17:00-18:00	0.8	1	6
18:00-19:00	0.8	1	6
19:00-20:00	0.8	1	6
20:00-21:00	0.8	1	6
21:00-22:00	0.8	1	6
22:00-23:00	0.8	1	6
23:00-00:00	0.8	1	6

Table 10: Definition Scenario 3

5. RESULTS OF SIMULATION

In this part of the bachelor thesis, the results obtained in the different scenarios are presented. The results include graphs which show the behavior of the fleet of electric cars using the level of charge of the cars, the availability, and the power which fleet is regulating, as well as the final economic result of providing frequency control to the grid.

5.1 RESULTS SCENARIO 1

In order to demonstrate the results obtained, we can see the initialization values that I introduced into the program for defining the EVs fleet in **¡Error! No se encuentra el origen de la referencia.**:

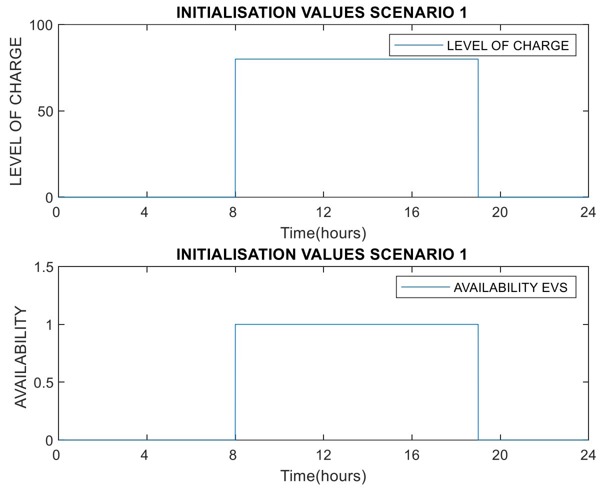


Figure 32: Initialisation values Scenario 1

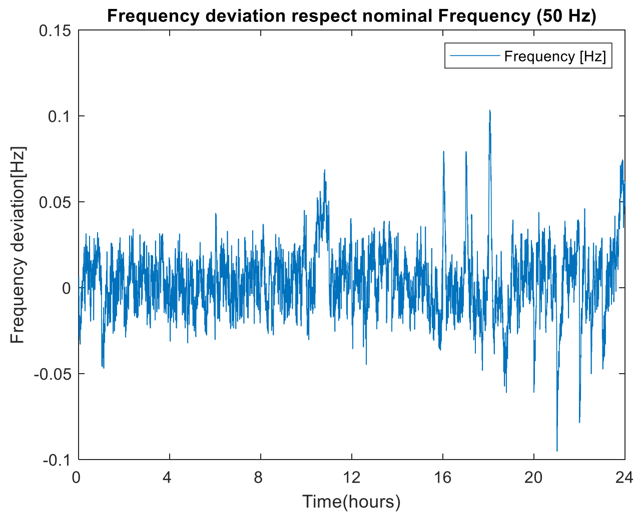


Figure 33:: Frequency deviation respect nominal Frequency (50 Hz)

In Figure 33 we observe the frequency deviation over one day, as shown above, which corresponds to the main input data, but taking into account the availability of the EVs defined in the **4.3 Simulation case 1**, the program differentiate in a graph the maximum hours in which it is possible to offer the frequency control, but without taking into account the factors which define the behavior of the batteries :

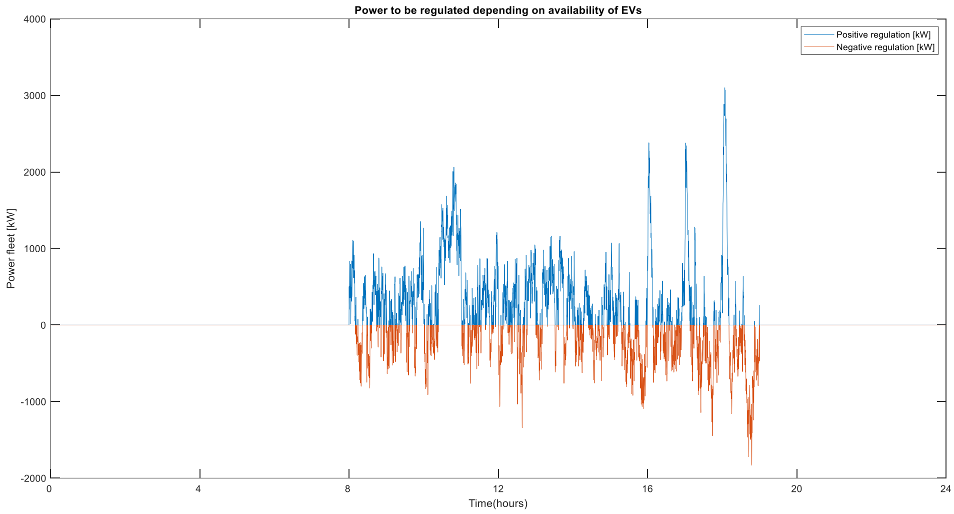


Figure 34:Power to regulate depending on available schedule EVS scenario 1

The data of Figure 34 when it is possible to control the frequency corresponds to the Schedule defined when the EVs are available [08:00 to 19:00].

Secondly, the program is acting as a filter; taking into account the availability mentioned before, the efficiency of charge, discharge, and the maximum energy of discharge and charge which are factors that characterize the performance of the batteries, I obtained the hours when it is possible to provide the frequency control:

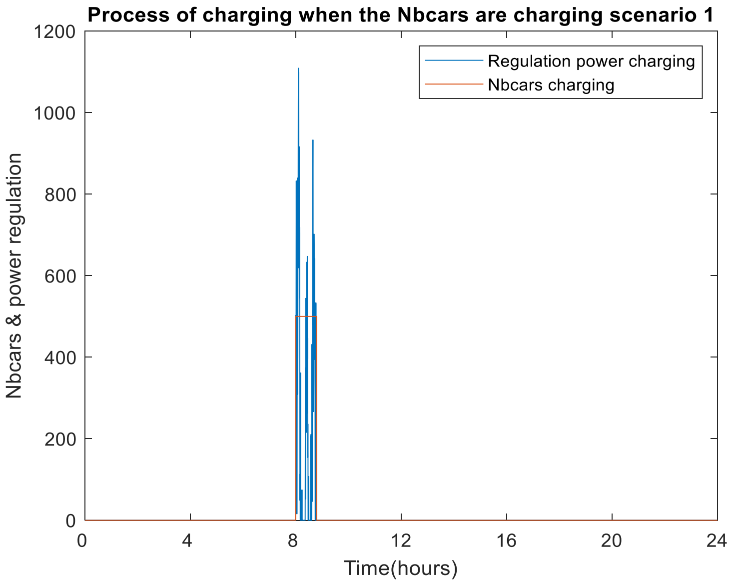


Figure 35:Comparison process charging (1)

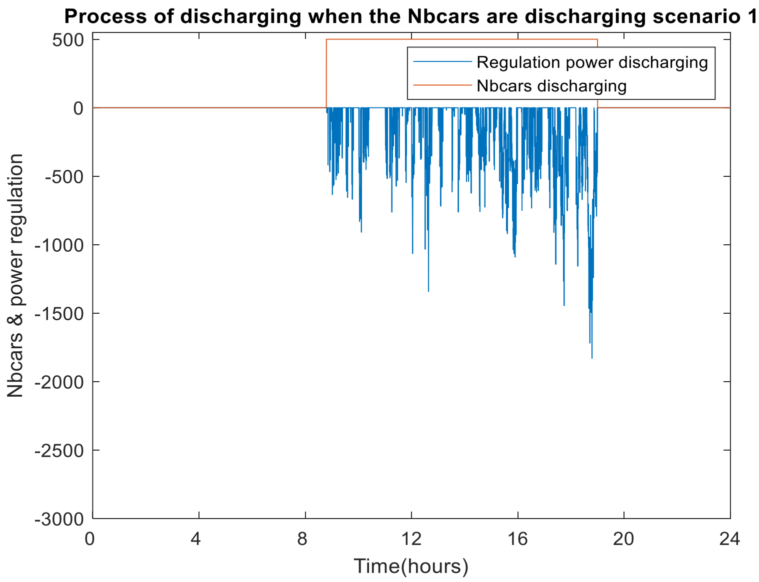


Figure 36:Comparison process discharging (1)

As we can see in Figure 35 and Figure 36 when EVs are available for charging taking into account all the variables, the program gets at this time the power that has to be regulated by the load from the whole data set of Figure 33 in which all the power that could be regulated was shown, but not really the power that is possible to regulate.

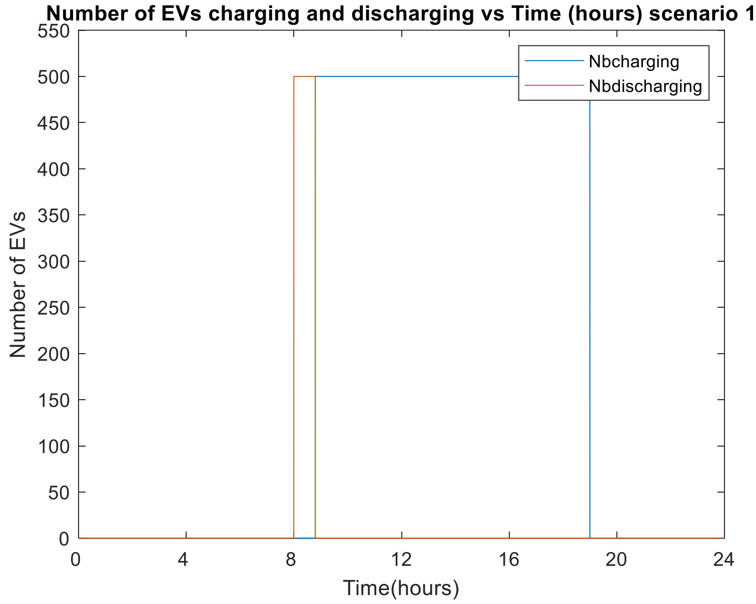


Figure 37:EVs charging and discharging during the simulation scenario 1

In this Figure 37 It is possible to understand the difference between EVs charging and discharging during the simulation, and It is possible to see that when there are EVs is due to the schedule defined which It is [08:00 to 19:00].

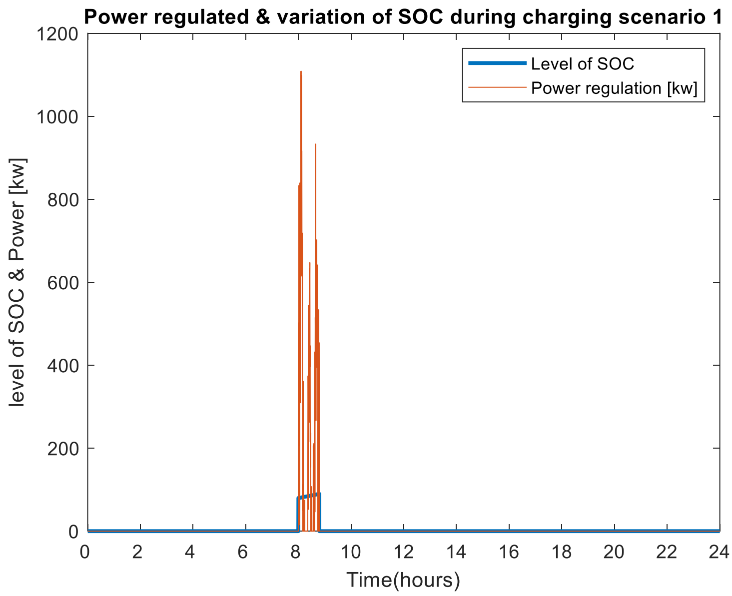


Figure 38:Power regulated & variation of SOC scenario 1

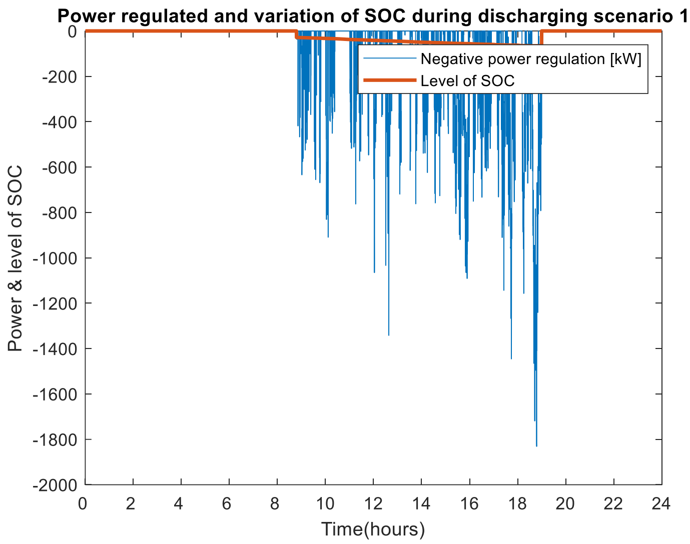


Figure 39:Power regulated and variation of SOC during discharging Scenario 1

Figure 38 and Figure 39 demonstrate the behavior of the battery during charging and discharging, as we can see, in the Figure 39 is negative the value of SOC due to the representation that I chose in the program. Finally, It is possible to appreciate how the level of charge is changing only during the hours of regulation.

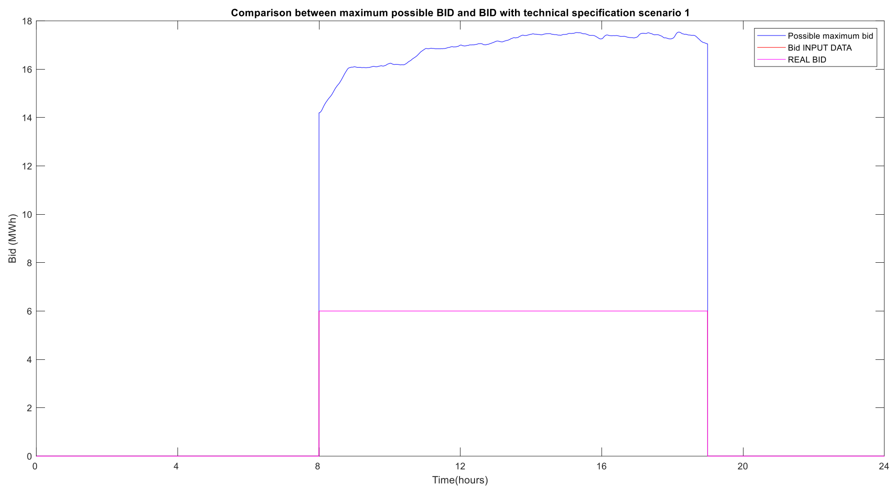


Figure 40:Comparison between máximum possible Bid and BID with technical requirements scenario 1

Finally, in the Figure 40 we can see the difference between the total power available during the simulation, considering all the technical aspects that define the battery capacity and the number of EVs, and the real Bid that we are offering in order to provide the services. As I have explained in **4.1 DATA SPECIFICATION**, it is obligatory to offer the same power during the 4 hours and not has to be more than 25 MW.

The real bid input data (red lane) and real bid (magenta) are the same values, is this the reason why it is not possible to see the bid input data in the Figure 40.

Using the block Scope into the tool Simulink, the program obtains and show the economic aspects of the simulation as we can see in Table 11

Total cost charging batteries	372,6 CHF (-)
Total revenue discharge batteries	1551 CHF (+)
Total revenue Bid capacity offered	1145 CHF (+)
TOTAL BENEFIT	**2324 CHF**

Table 11: Economic analysis scenario 1

At first glance, with the economic analysis taking into account the amount of power offered to the network, we could consider a wide range of benefits in the simulation; therefore, we could consider lower bid capacities to ensure the reliability considering the reduction of economic benefit

5.2 RESULTS SCENARIO 2

Figure 41 corresponds to the initial values Introduced in the Script of Matlab defining in Table 9.

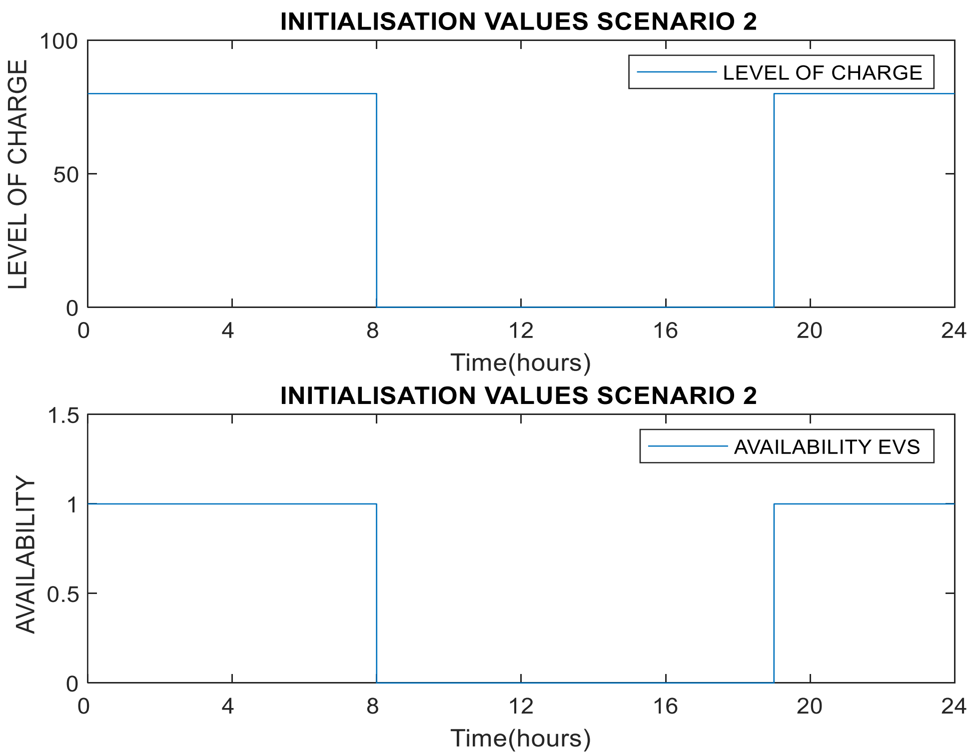


Figure 41:Initialisation values Scenario 2

In order to obtain the results of Scenario 2, the input data was the same as the simulation 1 although the main difference is the timetable of availability of the EVS. Considering the whole data of Figure 41, the graph must show the availability of provide the control of frequency in the opposite hours defined in Scenario 1:

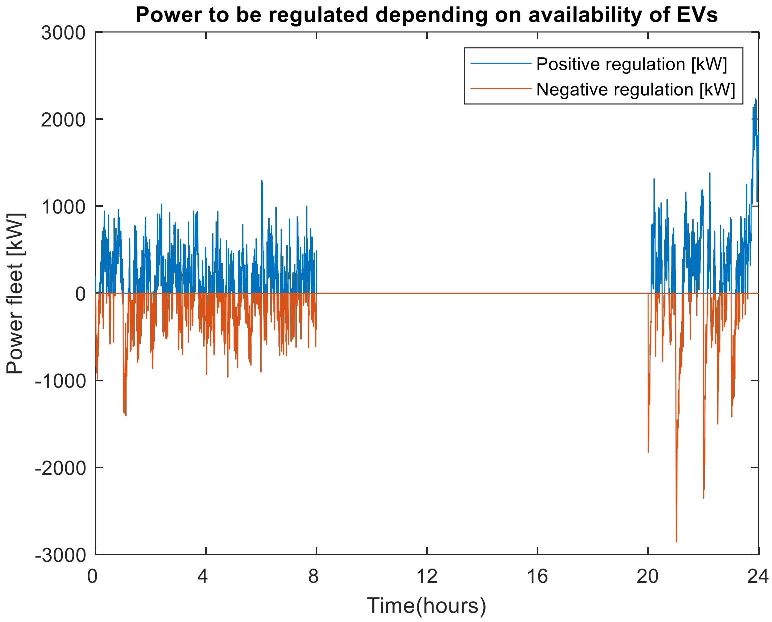


Figure 42:Power to regulate depending on available schedule EVS scenario 2

As I mentioned before in Figure 42, acting as a filter, it is possible to appreciate the hours when it is going to be able to provide the services depending only on the availability of EVs without considering the technical aspects.

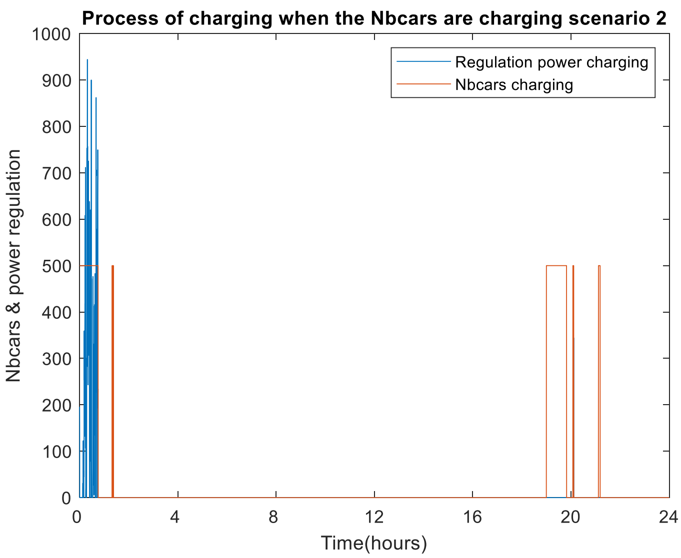


Figure 43:Hours of regulation with EVS charging Scenario (2)

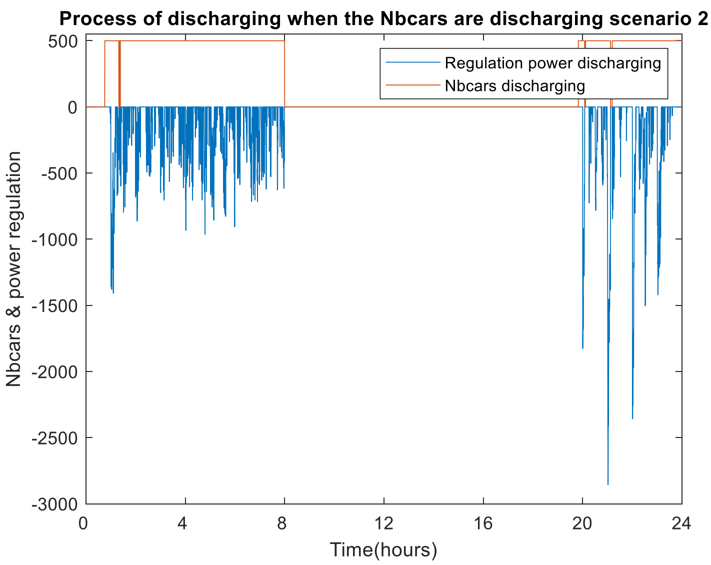


Figure 44:Hours of regulation with EVS scenario (2)

Figure 43:Hours of regulation with EVS charging Scenario (2) Figure 43 and Figure 44, are demonstrating when the EVs are available for providing frequency control and as we can see, in each period we have EVs discharging, appears power regulation.

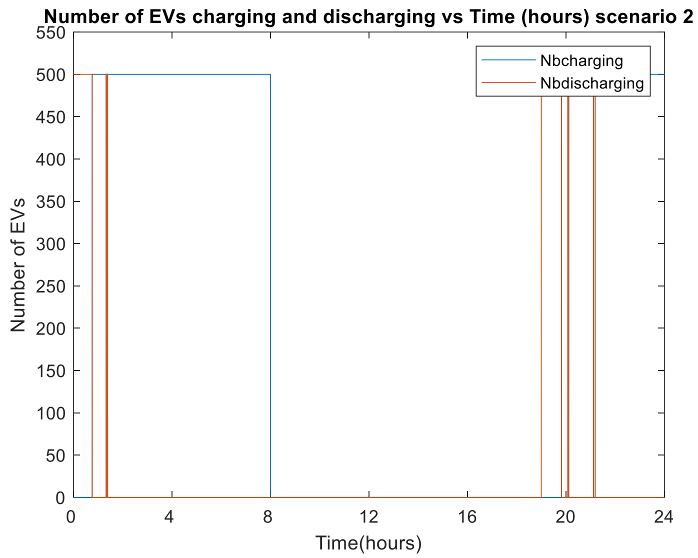


Figure 45:EVs charging and discharging during the simulation scenario 2

The EVS charging and discharging process is different from scenario 1 because the data is not symmetrical, and the frequency deviation is different throughout the different hours of the day.

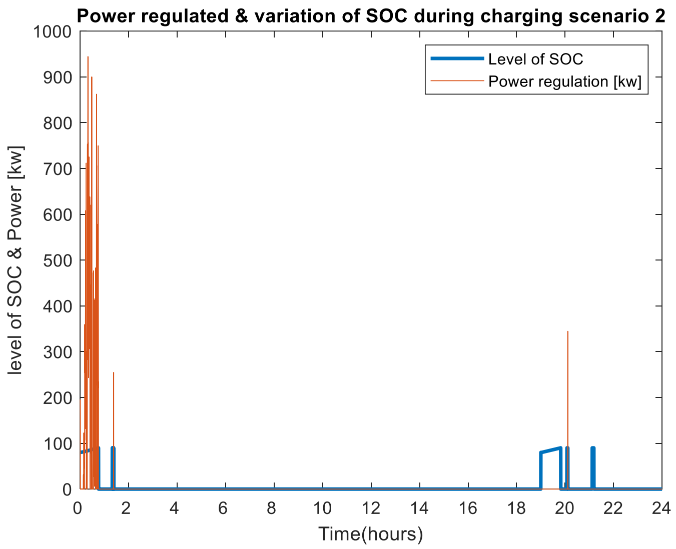


Figure 46:Comparison process charging (2)

In Figure 46 the variation of the load level is represented as in Scenario 1 and the regulated power; however, as I mentioned before, with the hours when EVs are available, it is technically possible to offer the services which correspond to the opposite hours of Scenario 1.

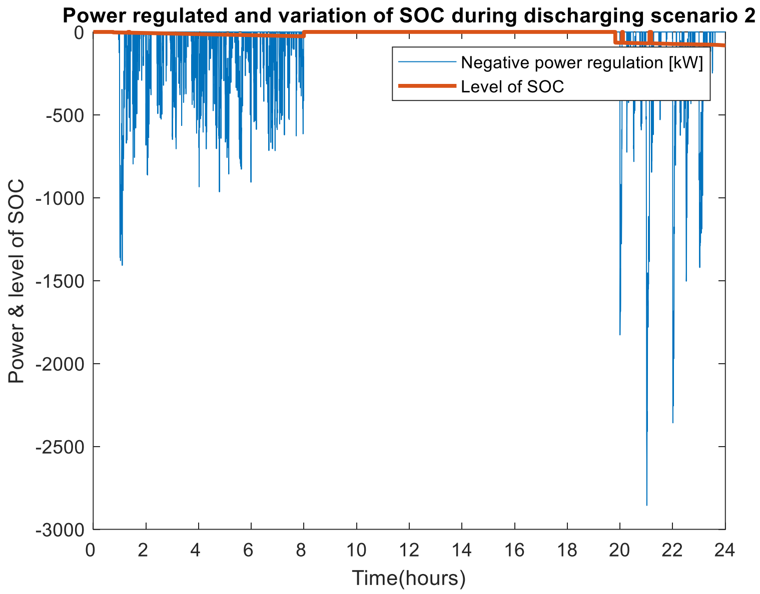


Figure 47:Comparison process discharging (2)

Following the same specification as Scenario 1, the bid capacity considered is the same, so, the hours where it is possible to bid, are the hours of availability, moreover, the technical requirements specified the real bid capacity between the maximum possible bid, which is impossible to offer due to the aspects mentioned before.

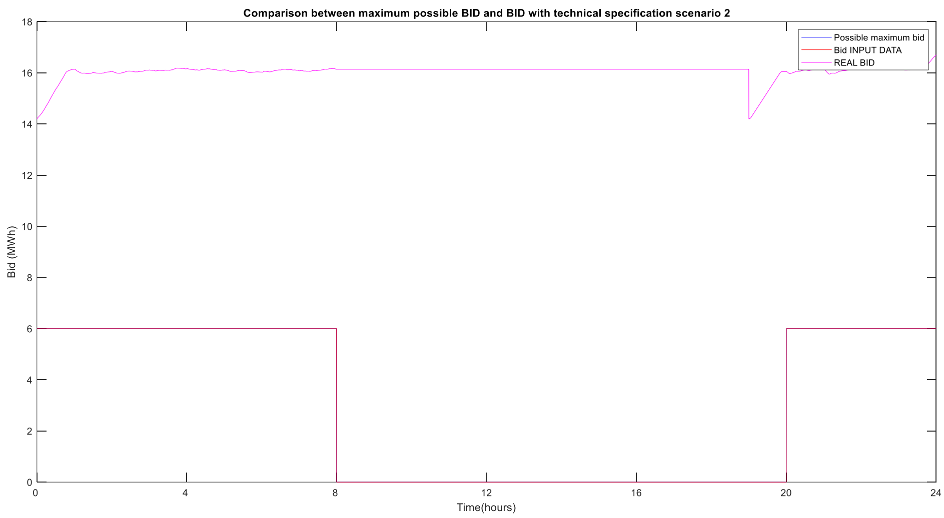


Figure 48:Comparison between maximum possible Bid and BID with technical requirements scenario 2

Total cost charging batteries	323.9 CHF (-)
Total revenue discharge batteries	1704 CHF (+)
Total revenue Bid capacity offered	1249 CHF (+)
TOTAL BENEFIT	**2629 CHF**

Table 12: Economic analysis scenario 2

The benefit is more than scenario 1 due to the amount of energy feed-in into the grid which is more amount than the **5.1 RESULTS SCENARIO 1**

5.3 RESULTS SCENARIO 3

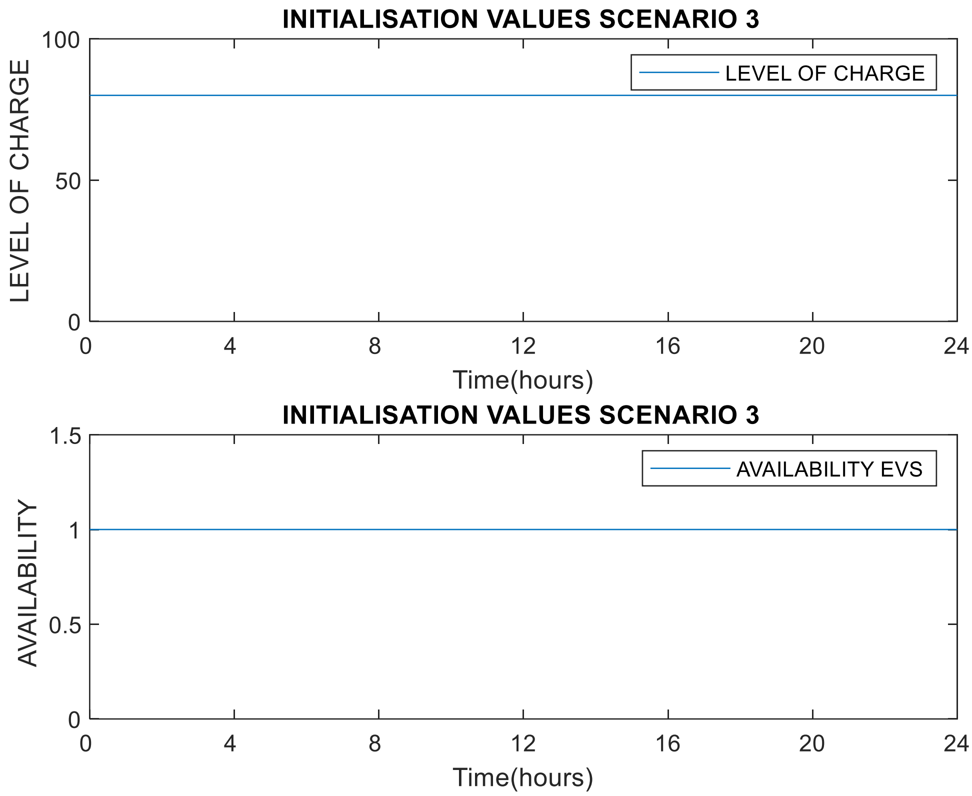


Figure 49:Initialisation values Scenario 3

Firstly, due to the availability of the electric cars, which corresponds to the whole simulation, we can observe in Figure 49 how two straight lines appear, which correspond to the input values since we consider in this scenario that they are always connected and therefore always have the same charge level.

Secondly, considering the **5.1 RESULTS SCENARIO 1** and **5.2 RESULTS SCENARIO 2**, the graph of the power to be regulated depending on the availability of EVS has to be the same as Figure 37, the availability of EVs fleet, which is available during the entire simulation, is the combination scenario 1 and scenario 2.

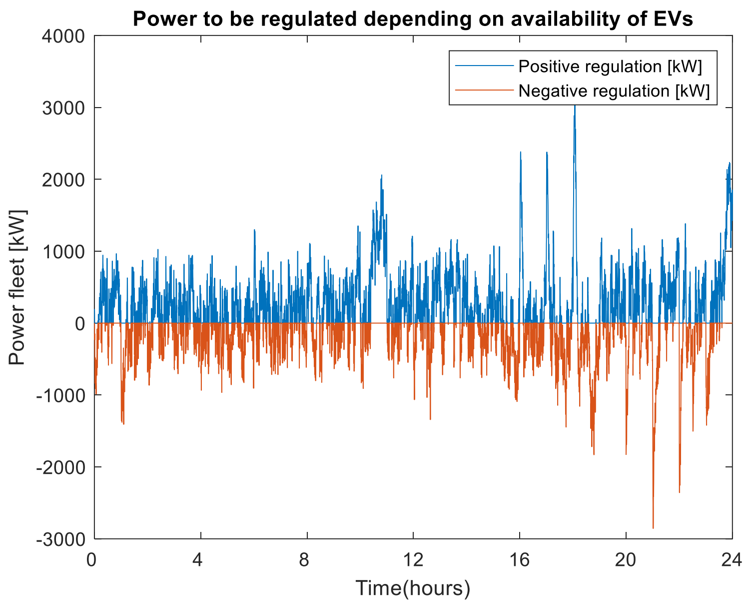


Figure 50:Power to be regulated depending on availability of EVs scenario 3

Figure 50, as I mentioned, is the whole power regulation available during the simulation only considering the schedule of the EVs; due to the definition of the timetable, EVs are available the whole day:

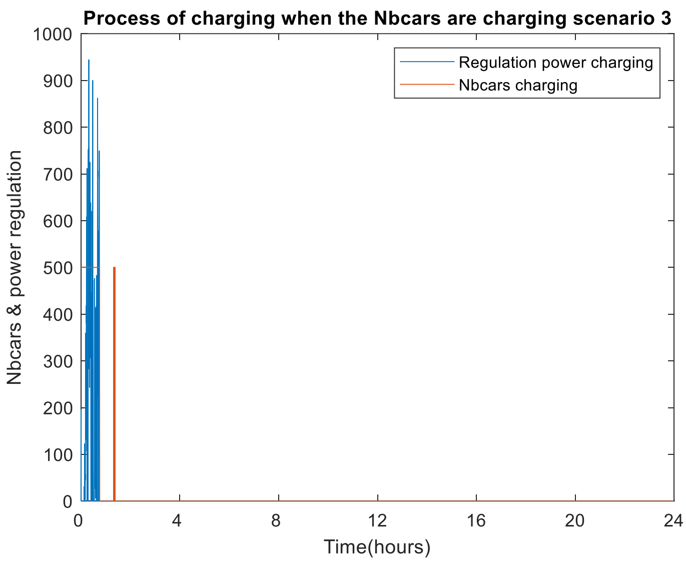


Figure 51:Comparison process charging (3)

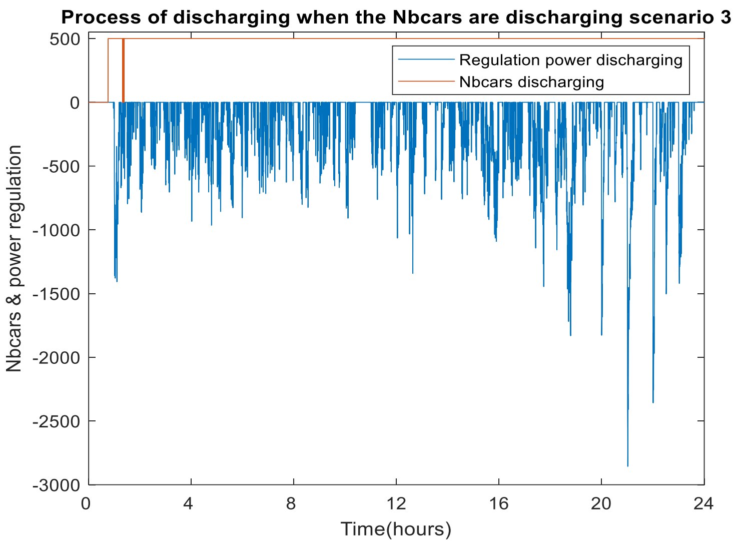


Figure 52:Comparison process discharging (3)

Figure 51 and Figure 52 are demonstrating when it is possible to regulate taking into account the Number of EVs depending on be in the mode charging or discharging, we can appreciate that considering the historical frequency data and the technical specification, the amount of power feed-in into the grid in comparison with the power charging is minimum.

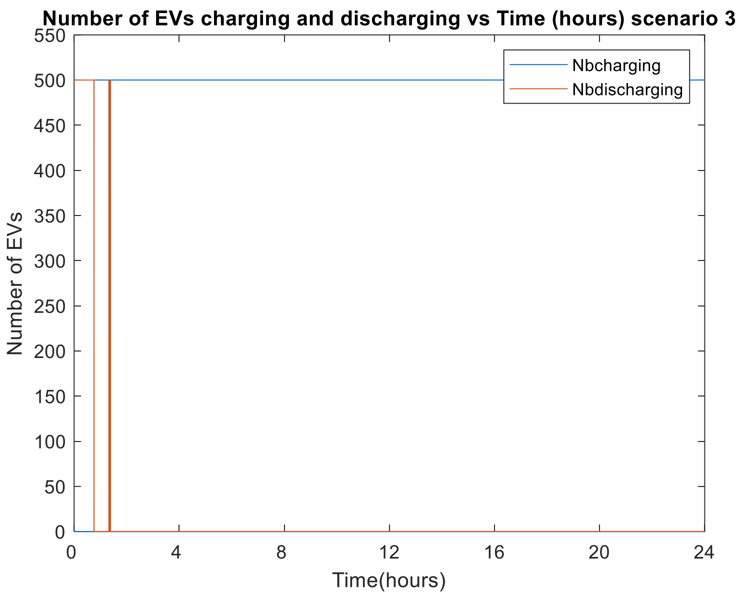


Figure 53:EVs charging and discharging during the simulation scenario 3

Unlike the other graphs, in this one we can see when the EVs are charging and discharging and during the whole simulation.

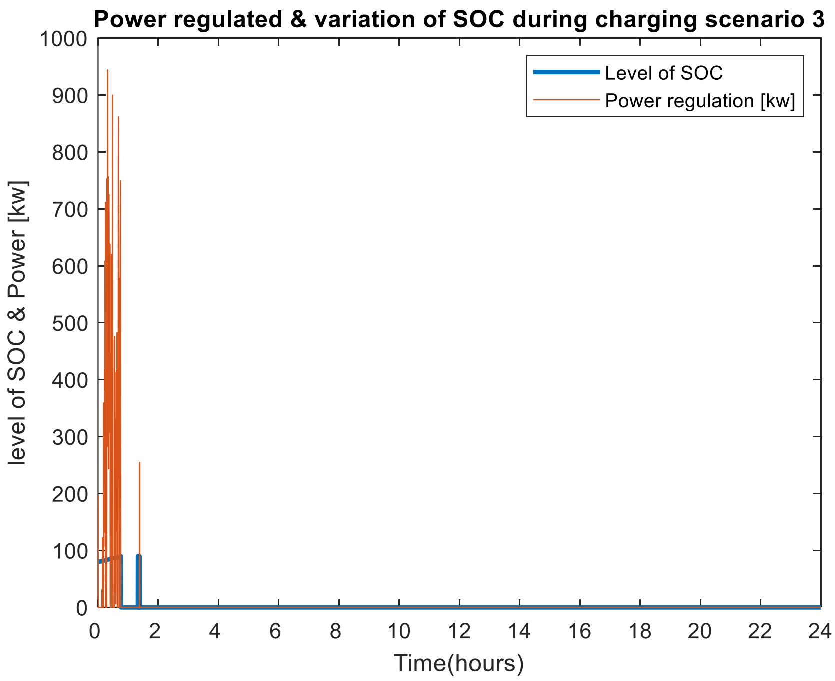


Figure 54:Comparison process charging (3)

we can appreciate as in the graphs shown above the variation of the load level with respect to the power regulation which appears when the cars are available.

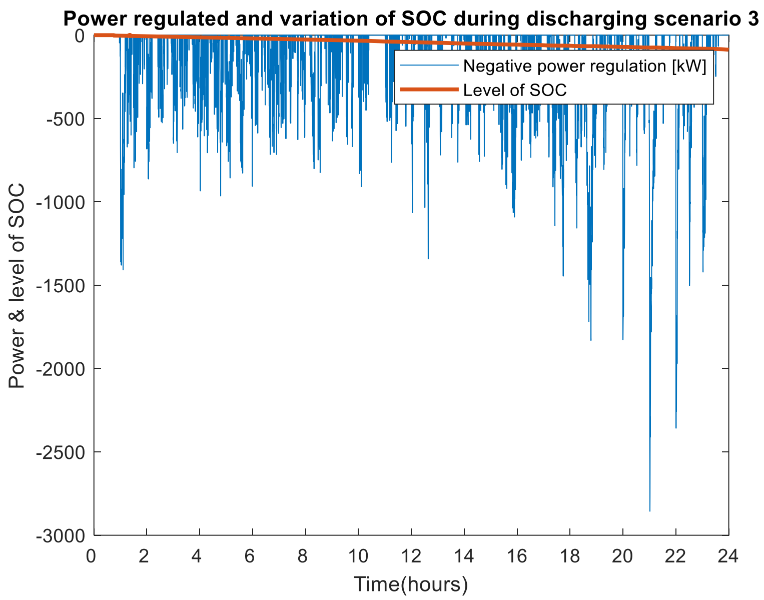


Figure 55:Comparison process discharging (3)

Figure 55 the bid capacity is 6 MW during every hour due to the availability of EVs which is better in order to obtain more revenue.

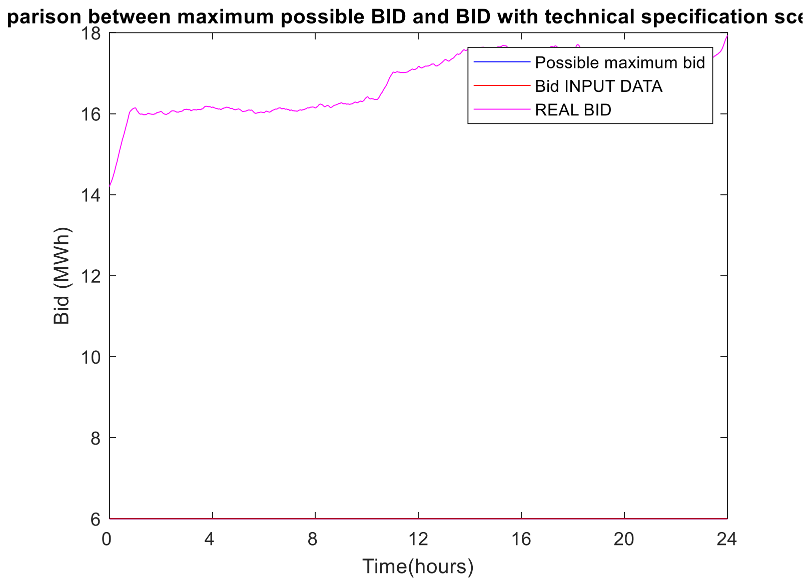


Figure 56:Comparison between maximum possible Bid and BID with technical requirements scenario 2

Finally, since the EV fleet is available during the whole simulation, the economic result should be more favorable as we can see in the Figure 14: Frequency deviation of one day

Total cost charging batteries	322.2 CHF (-)
Total revenue discharge batteries	3477 CHF (+)
Total revenue Bid capacity offered	2498 CHF (+)
TOTAL BENEFIT	**5653 CHF**

Table 13: Economic analysis scenario 2

6.CONCLUSION

This bachelor thesis analyses the situation of the Swiss electricity system and the different ancillary services that could be provided with the V2G concept, focusing on frequency control, and explaining the different technical requirements to provide them.

Three different scenarios were defined to demonstrate the feasibility of integrating EVs to provide these services. These three scenarios were defined based on the review of different research studies on the connection schedule of EVs to charging points and considering the requirements.

Following the different diagrams which were defined before the realization of the model, in Simulink, I obtained the final results by observing the behavior of the EV's batteries depending on the historical frequency data.

As we could observe with the difference between **4.3 Simulation case 1** and **4.4 Simulation case 2**, We can obtain economic benefit with the conditions defined and demonstrate that the combination of both cases **4.5 Simulation case 3**, is the availability of the whole simulation and increase the benefits of providing the services.

Considering the results obtained in Table 11 ,Table 12 and Table 13 It is possible to consider the integration of the EVs as a good chance in order to improve the quality of the grid and improve the feasibility, and there are some financial benefits for fleet operators to participate in frequency regulation, in order to obtain results as real as possible, It is necessary to define the factors and timetable about the behavior of EV's connecting to the recharger points otherwise the simulation would not be real because the most important part of the analysis of this project is when the EVs will be available for use.

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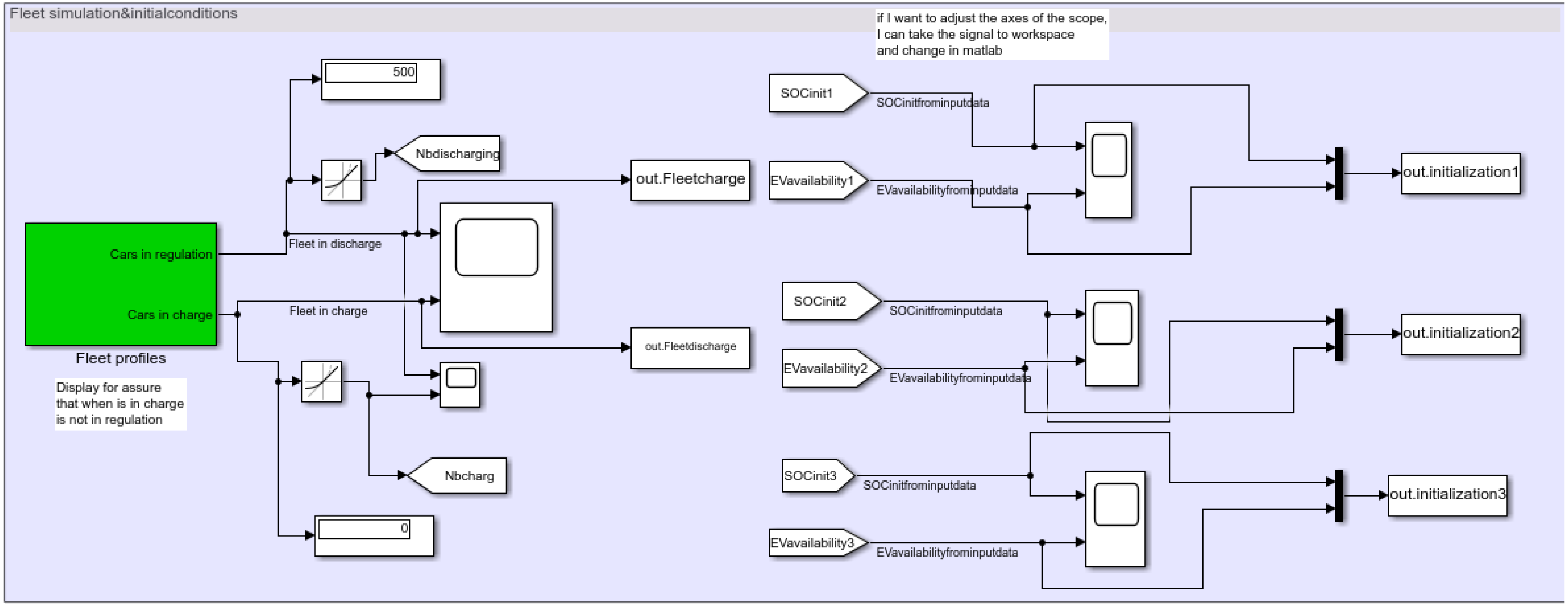
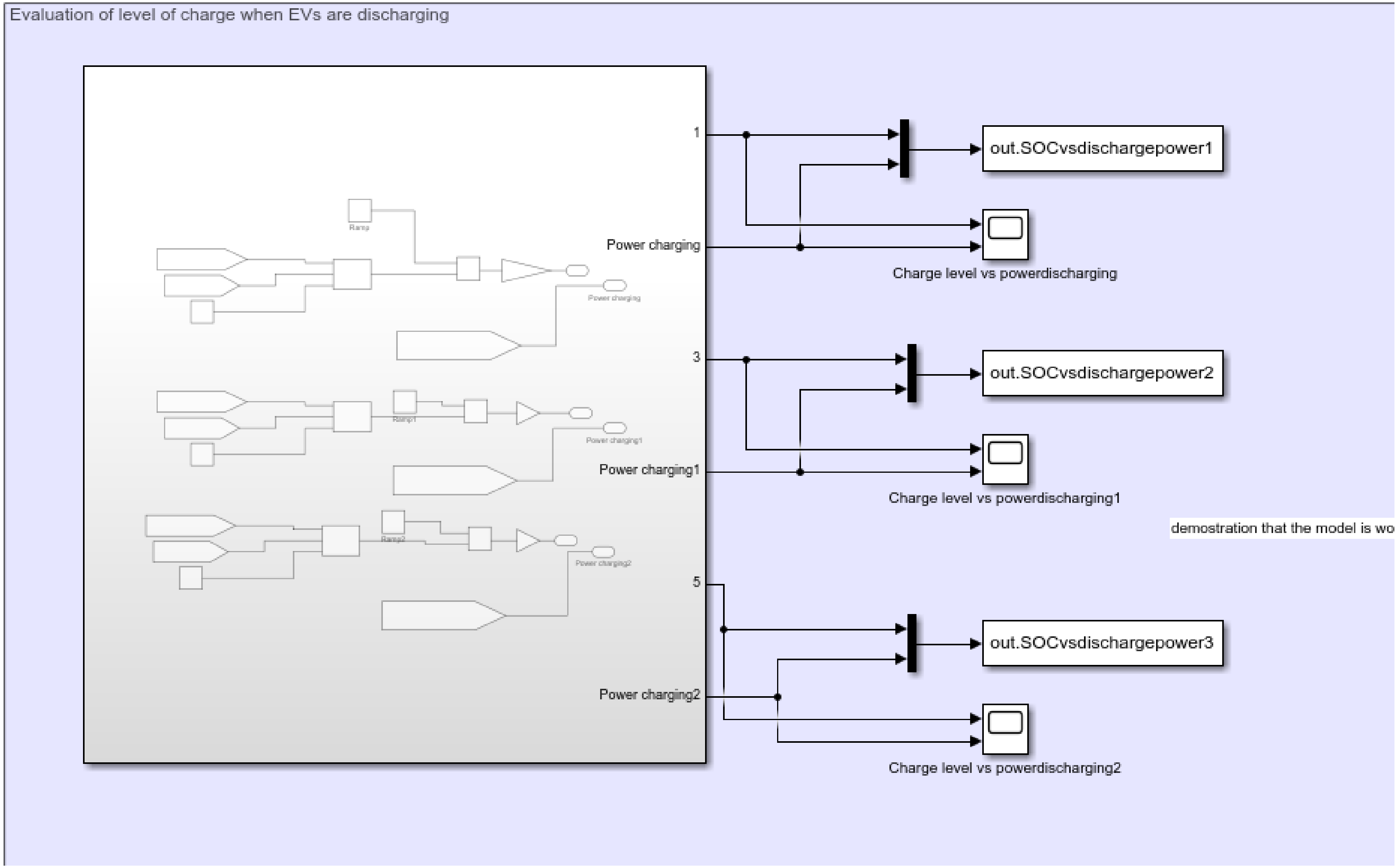
Appendix A

SIMULINK MODEL

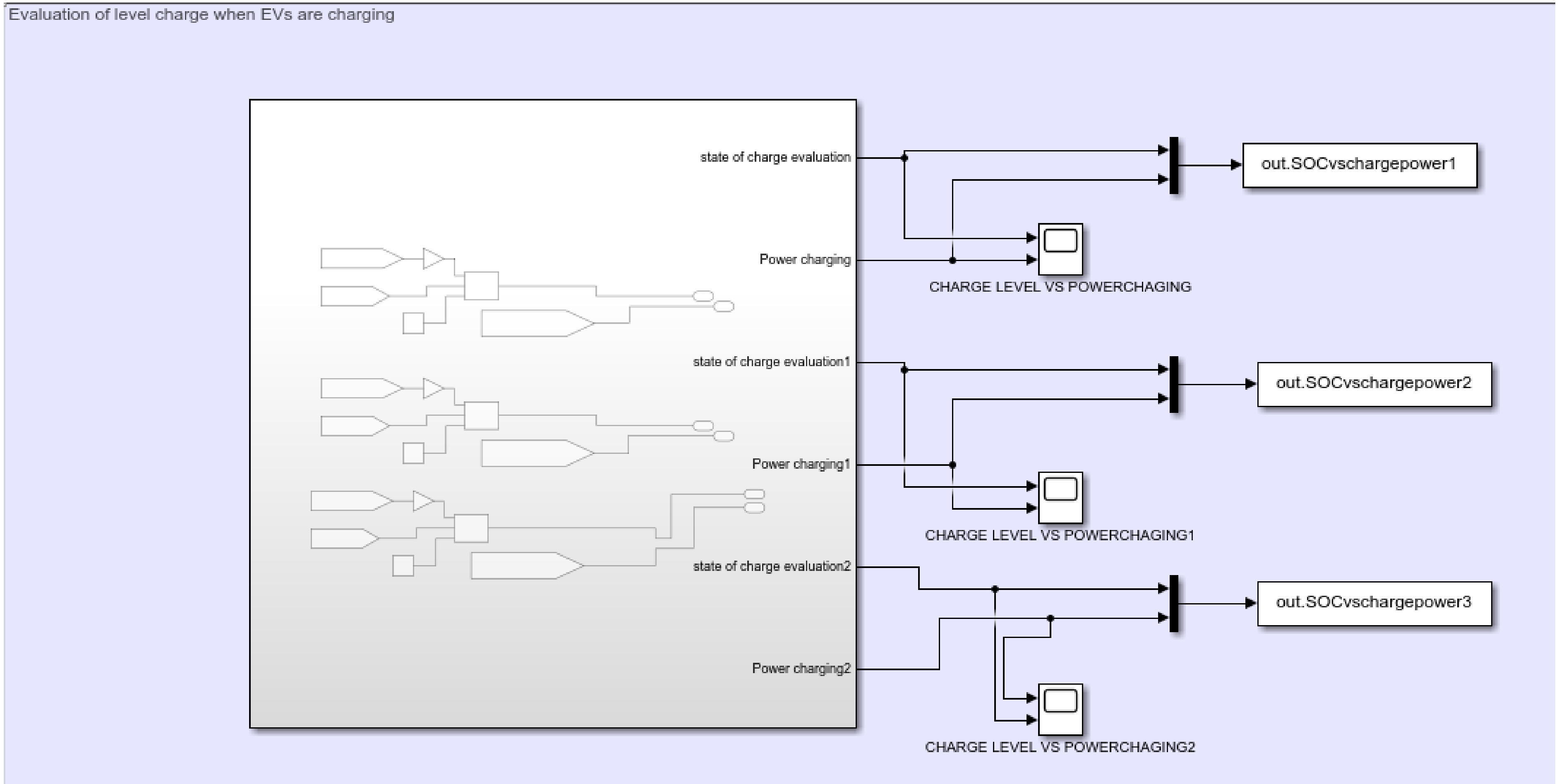
- INITIALIZATION PART and FLEET PROFILES (Nbcharging & Nbdischarging)



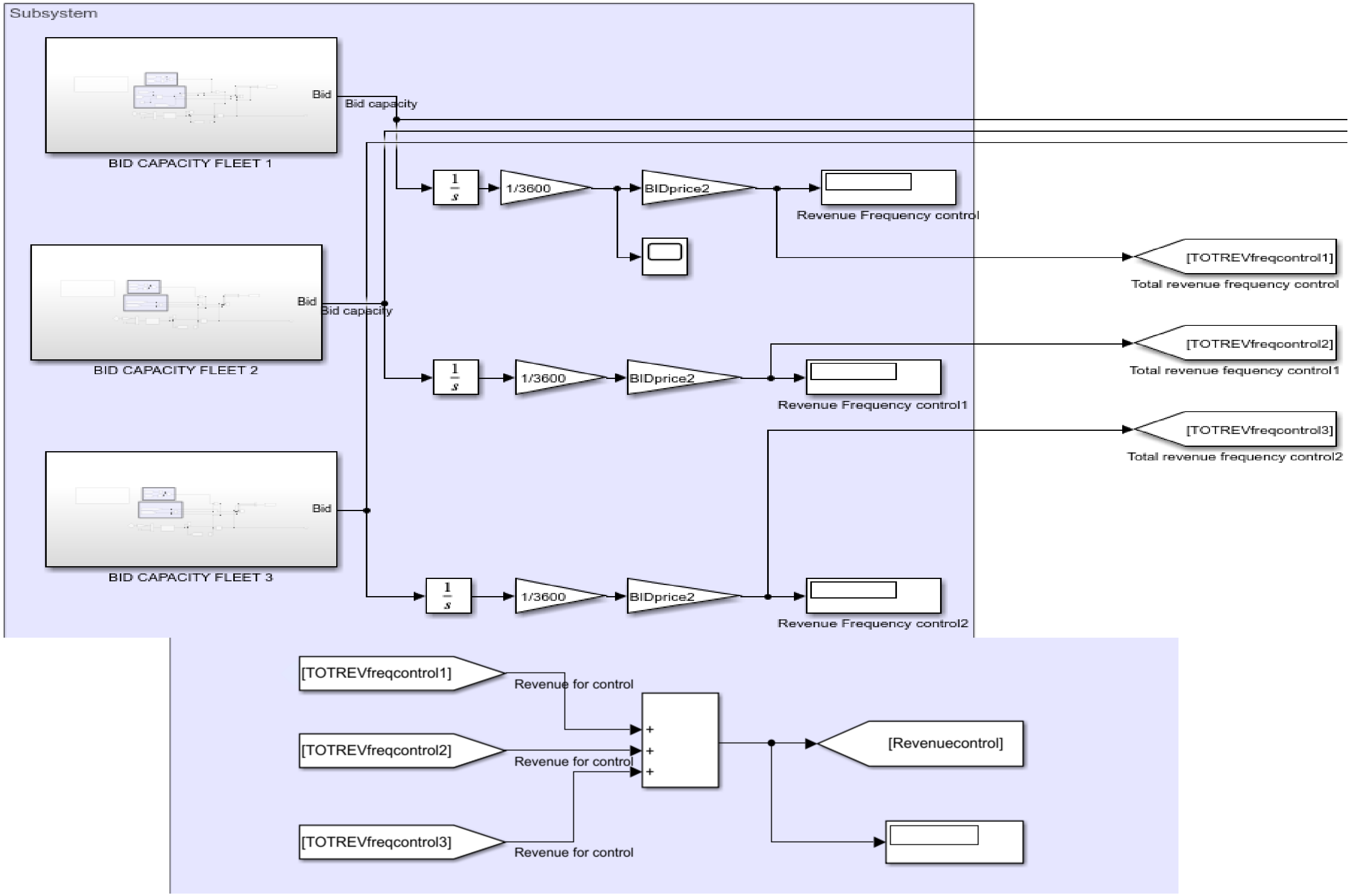
- EVALUATION OF LEVEL OF CHARGE WHEN EVs ARE DISCHARGING



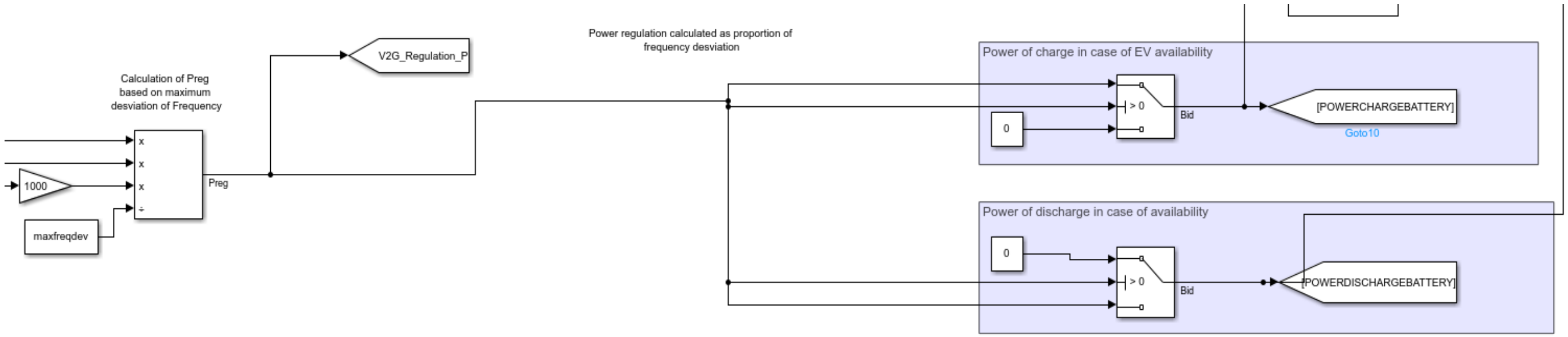
- EVALUATION OF LEVEL OF CHARGE WHEN EVs ARE CHARGING

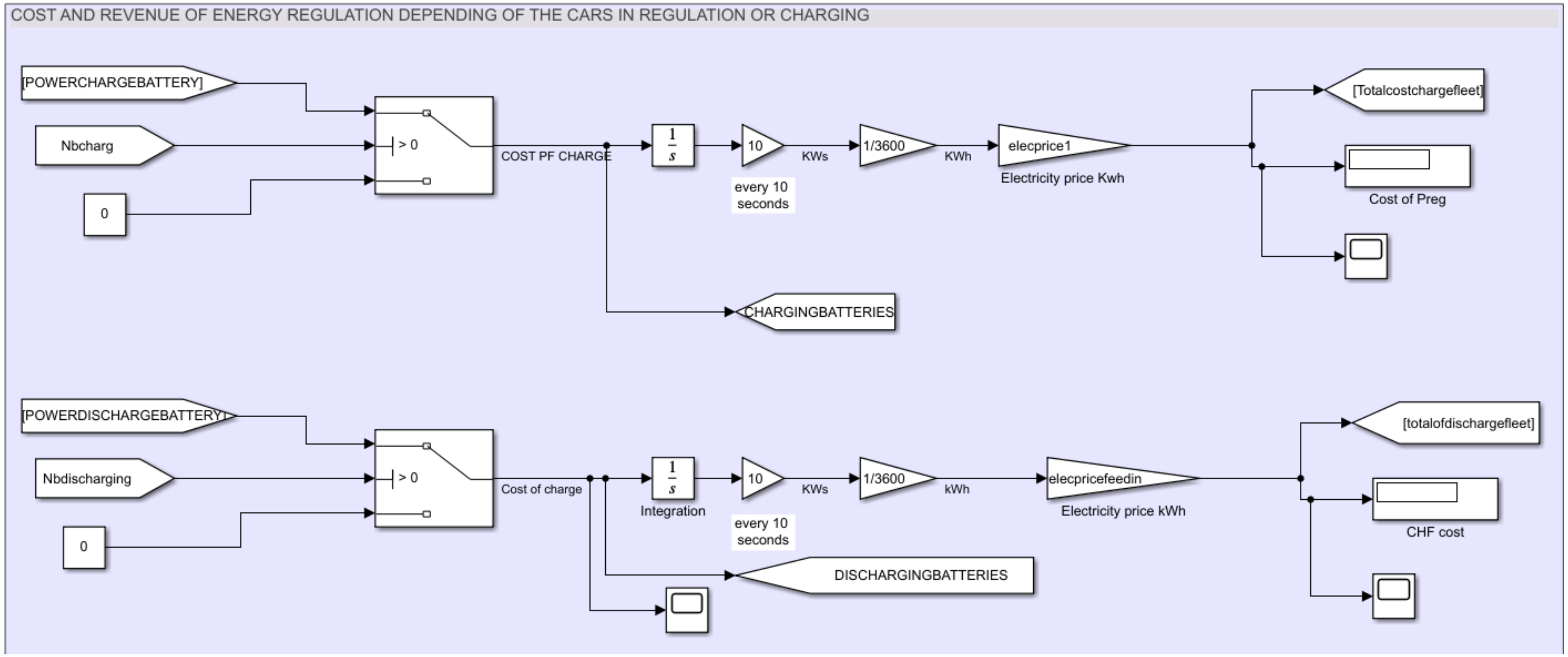


- BIDING CAPACITY AND CALCULATION



- COST AND REVENUE OF ENERGY REGULATION DEPENDING ON THE CARS IN REGULATION OR CHARGING





Appendix B

RECOPILATION FIGURES OF RESULT SCENARIO 1,2 & 3