UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE ELECTRIC POWER INDUSTRY

Master's Thesis

Implementation of lithium-ion batteries in the distribution network

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Madrid, July 2022

Official Master's Degree in the Electric Power Industry (MEPI)

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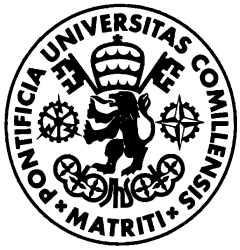

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1. Summary

Firstly, the legislative vision of batteries in the distribution grid is still in its early stages, as there is still a lot of legislation to be drafted in this field. Currently, the distribution grid cannot use these resources for economic benefit, i.e., to reduce consumption peaks. The batteries can be used to solve local problems of overloads, overvoltages, undervoltages, reactive power control and to improve the quality of supply (QoS). More and more regulatory measures are being taken in this regard and, in the not-too-distant future, the distribution grid will certainly make more efficient use of these batteries.

In this document is presented a study that has been carried out to find the optimal solution to improve the QoS in a line, located in the mountains of Castilla - La Mancha. Since the construction of new lines is unfeasible due to the geographical complexity of the area and the crossing of protected areas, a battery is the optimal solution. For the analysis, 4 locations for properly dimensioned batteries resulting in 5 different cases have been considered and compared. These cases are:

Case 1. A small battery for the branch of the line with the highest demand (number of customers and contracted power), which has been named branch 1.

Case 2. The battery of case 1 plus a small battery for branch 2, which is the one with the second largest number of customers.

Case 3. The battery of case 1 plus a small battery for branch 3, which is the one with the second highest contracted power.

Case 4. The 3 previous small batteries, one on each end of the line

Case 5. A large battery capable of supplying the entire line.

The above-mentioned branches can be seen in Figure 1. The hourly power distribution and the energy delivered by the line and each one of its branches in 2021 has been analyzed to size the 4 batteries, followed by the decision as to which case produces the most improvement in the grid.

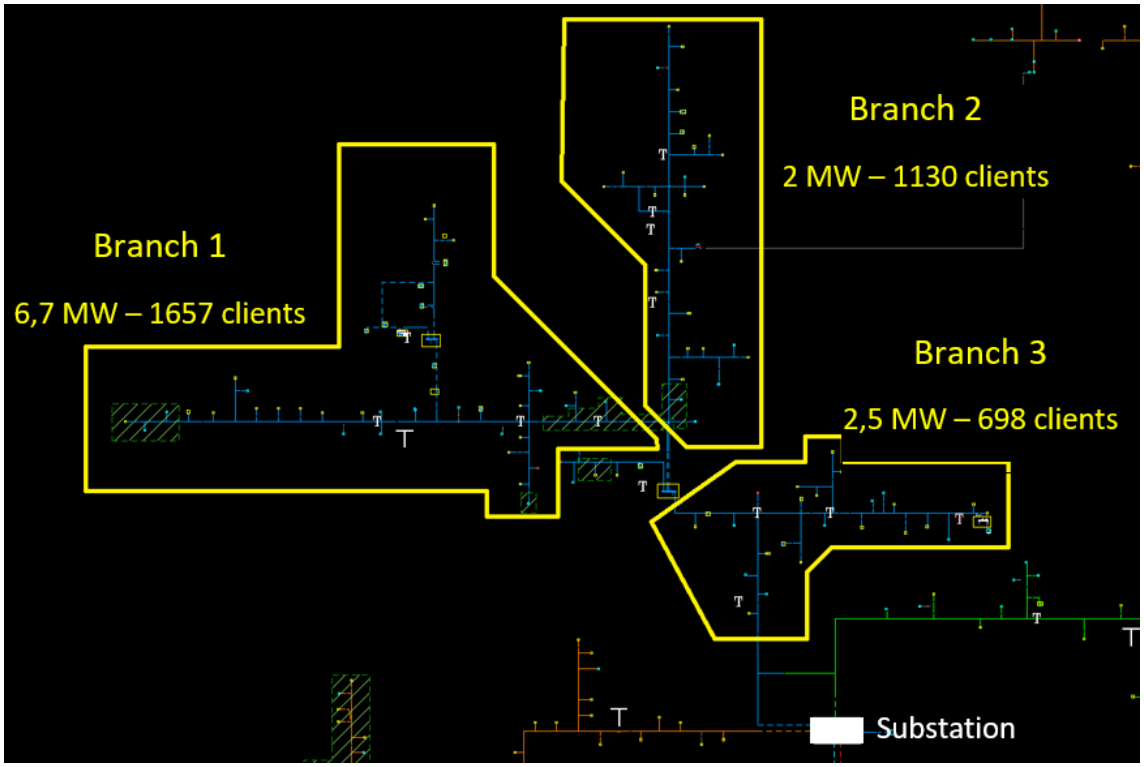

Figure 1. Schematic network configuration.

Finally, the investment cost of these 5 cases has been calculated in order to develop an economic evaluation of each scenario. This section begins with a study of the current battery market so that the cost of each battery and, consequently, the cost of each case study can be determined. Once the investment cost was obtained, a comparison was made with the improvement of the TIEPI index and the monetization of the benefit to society. After all the data were available, the most efficient investment was selected, with an associated justification.

I would like to thank i-DE for providing all the necessary information, together with real demand data, which has helped me to carry out my study.

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4. Introduction and motivation

The transition to climate neutrality implies a profound transformation of the energy system, which will be powered primarily by renewable resources. The variable and stochastic nature of some of these energy sources entails that a variety of tools are needed to provide flexibility to the system, including energy storage. The National Integrated Energy and Climate Plan 2021-2030 (PNIEC) foresees the development of storage as one of the key tools to provide flexibility to the electricity system to support the significant growth of renewable generation, as well as contributing to the management of electricity grids, the participation of the public in the transition of the energy paradigm, and greater integration and competition in the energy market. [1]

To meet these objectives in the foreseeable future, it is expected that the grid will migrate from a centralized or traditional structure to a more flexible and distributed one, whose diagrams can be seen in Figure 2. This means that the electricity generated does not only come from the main power plants, such as coal or nuclear plants, but also from self-consumption solar panels or batteries.

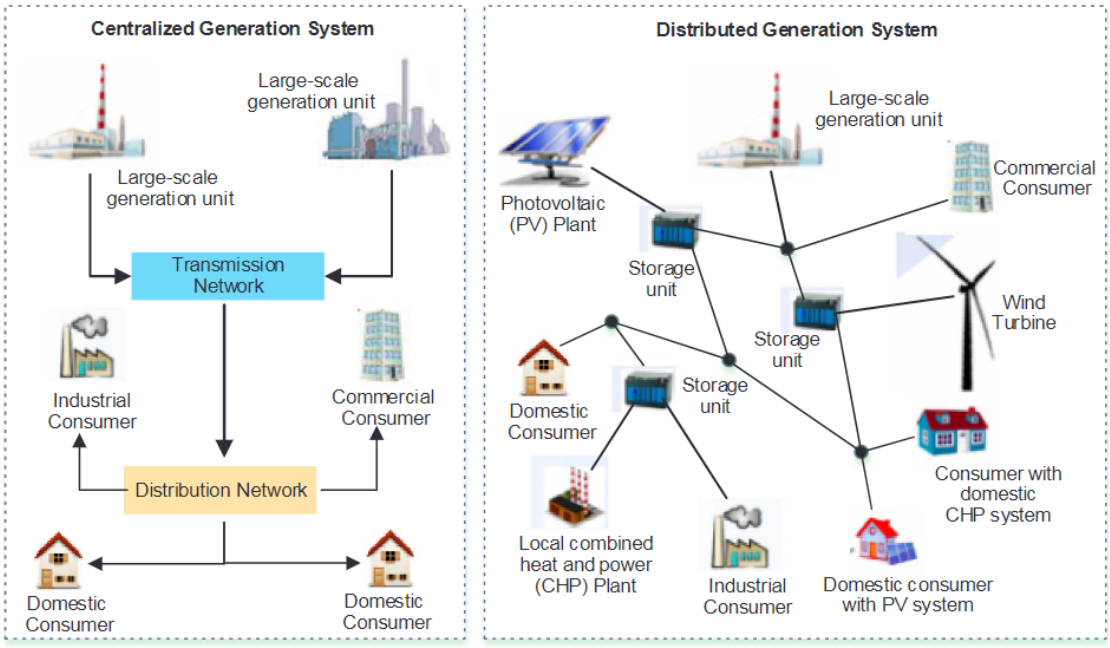

Figure 2. Centralized vs. distributed electric system. [2]

Focusing on the Battery Energy Storage System (BESS), great improvements in this technology have been made, which bring us closer to the global change in the energy sector. Massive amounts of money introduced in battery manufacturing and a decreasing

investment cost in this technology, have set a turnover point in how 1st world countries will organize energy systems in the close future, such as 2030. [3]

The minimum storage needs for Spain, derived from the objectives of the PNIEC and the Long-Term Decarbonization Strategy (ELP) 2050, have been quantified in The Energy Storage Strategy document. The total storage power available will move from the 8.3 GW available in 2020, to a value around 20 GW in 2030 and 30 GW in 2050. This quantification includes large-scale daily and weekly storage, behind-the-meter storage and seasonal storage, based on the current deployment of technologies. [4]

During the drafting of the ELP, the first steps have already been taken to transform, in line with European directives, the regulatory framework. The regulation will need to be reorganized to integrate energy storage, both on a large scale, in electricity grids and even behind the meter. However, for the development of this new agent in the energy sector, it will still be necessary to adapt regulation to the new characteristics implicit in these technologies. The Energy Storage Strategy lays the foundations to respond to these needs, acting as a tool to promote the deployment of energy storage in Spain, and being aligned with and complementing the Recovery, Transformation and Resilience Plan (PRTR) [5]. The latter was approved by the Government on 7th October 2020, as the guide document for the implementation of funds from the European Next Generation EU instrument.

4.1. Objectives and structure of the thesis

The main objective of this thesis is to find the optimal deployment of an energy storage system based on batteries in a mountainous area of Castilla – La Mancha, Spain.

First of all, an analysis of lithium-ion batteries: advantages, disadvantages, and a degradation study is developed. Then, an analysis of the current legislation will be done since there are many limitations on the use of BESS by distribution companies. Before beginning the calculations, there is a chapter for analyzing the location of the battery and an explanation of the reasons to implement this battery: unfeasibility of traditional solutions and continuity of supply (CoS). Consequently, the calculation of the battery optimal design is developed: technical design and improvement of CoS. Followed by an economic analysis: market research, investment cost, TIEPI vs. cost analysis and benefit for society vs. cost. Finally, there is a chapter with the justification of the results and another with the conclusions of the whole thesis.

5. Lithium-ion batteries

A lithium-ion battery or Li-Ion battery is a type of rechargeable battery that uses lithium compounds as one of the electrodes. In 1985, Akira Yoshino developed the first prototype based on earlier research by John Goodenough and other experts during the 1970s, winning the Nobel Prize in Chemistry in 2019. Subsequently, a team at Sony developed the first commercial lithium-ion battery in 1991 [7]. Over the years, further advances were incorporated, notably in the use of nickel-manganese-cobalt oxide (NMC) cathodes, which improved charge density, performance, and safety. Lithium-ion batteries are composed of the following parts: a negative electrode or anode from which electrons are released and a positive electrode or cathode that receives them. When the battery is connected, lithium ions move from the anode to the cathode through an electrolyte, resulting in the potential difference that produces the current flow. When the battery is charged, the lithium ions return to the anode. In Figure 3 it can be observed the charging and discharging process.

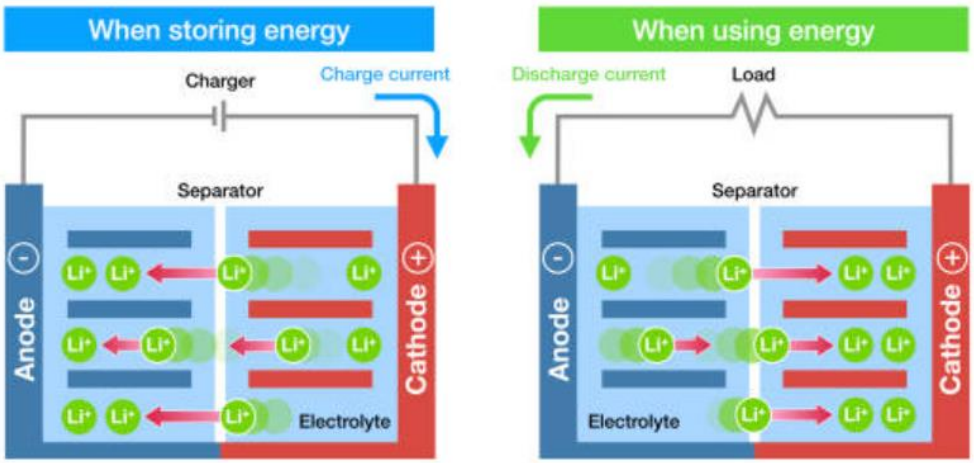

Figure 3. Working principle of a lithium-ion battery. [8]

Batteries, in turn, are made up of one or more cells and, depending on their end use, there are different types: cylindrical cells, used in most electric vehicles, consist of sheets of different components that are rolled into a cylinder, while flat cells, such as those found in mobile phones and laptops, use lithium-ion polymer in the form of stacked sheets.

In addition, lithium-ion batteries incorporate other elements that enhance their performance and safety: a temperature sensor, a voltage regulator circuit, and a state-of-charge monitor. These components track the charge and current flow, record the last capacity reached at full charge and monitor temperature, which can adversely affect the life of the battery.

5.1. Advantages

The best properties of these batteries and the reason why their use is so widespread are listed below: [9]

High energy density: Lithium-ion batteries can last much longer between charges while maintaining a high current output, which is the chief advantage of this technology. This makes it the perfect battery for most modern needs.

Low self-discharge: Not only while in use, but lithium-ion batteries have a distinct advantage when not in use as well. When kept at rest, the rate of self-discharge (a common phenomenon in batteries) is extremely low. This is particularly interesting for distribution network batteries, since there might be long times between two incidents.

No memory effect: The memory effect is a phenomenon that reduces the capacity of incompletely charged batteries. This phenomenon occurs when a battery is charged without being fully discharged beforehand: crystals are created inside these batteries, due to a chemical reaction when the battery is heated, either by use or by bad charges. A great characteristic since the duration of the incident might provoke that the battery is not fully discharged.

Low or minimal maintenance: Lithium-ion batteries are also popular because of their low maintenance, which is also a plus for the distribution companies.

5.2. Disadvantages

On the other hand, the major drawbacks of this technology are: [9]

Flammable: Lithium-ion batteries can easily catch fire at extreme temperatures. Therefore, they need good protection against high temperatures.

Cost: Although they are a technological marvel, they come at a cost. Lithium-ion batteries tend to be considerably more expensive than their counterparts. However, their cost is decreasing extremely fast, as it is explained in Chapter 10.

In addition, it is recommended that they remain in a cool place (15° C) and avoid excessive heat. However, in the next section the effects of temperatures in the capacity degradation will be deeply explained.

5.3. Capacity degradation

It is very important to talk about the degradation of lithium-ion batteries since they do not retain their initial capacity throughout their useful life. There are several degradation modes, and each of them can cause power or energy loss, as shown in Figure 4.

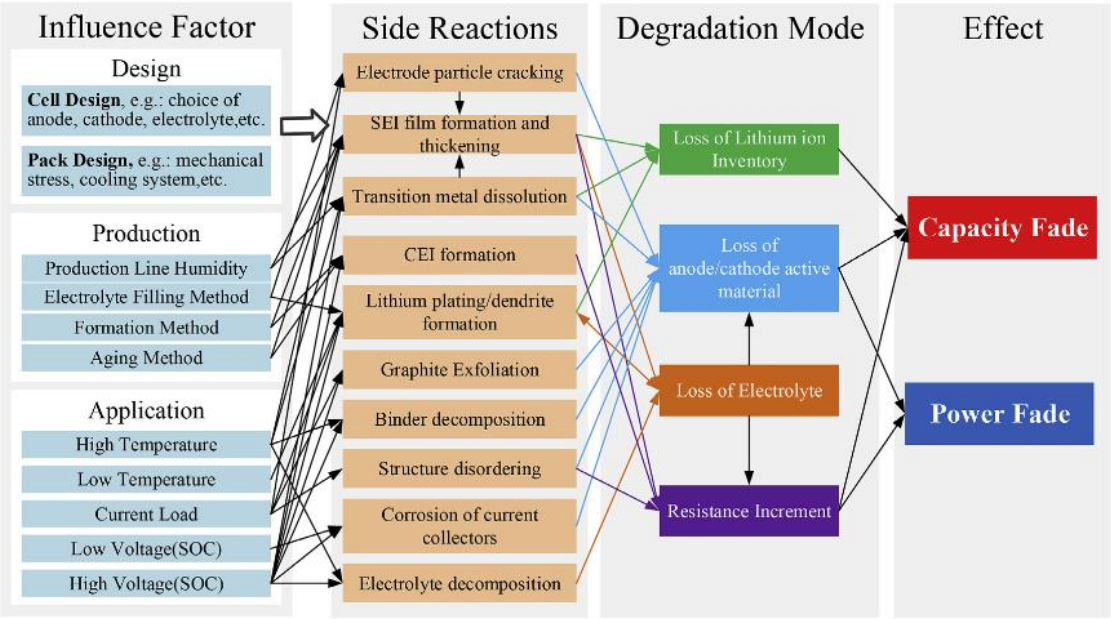

Figure 4. Causes and effects of battery degradation. [10]

To determine the total cost of the project's batteries, it is important to know which is the necessary capacity at the beginning of its life. The reason is, to assure this technology continues to be useful at the end of its life. The degradation of the battery, among other parameters, depends greatly on the temperature at which it operates, with extreme temperatures being more detrimental. Since the battery will be installed in Castilla - La Mancha, Spain, the most worrying aspect is the extremely hot temperatures. However, being located in the mountains, temperatures will not exceed 25-30 degrees Celsius every day of the year. The degradation of the battery according to the temperature can be analyzed in Figure 5 and 6.

Figure 5 shows the State of Health (SOH) of the battery through the years, depending on the temperature and the State of Charge (SOC). Since in most cases the battery will not discharge all of its capacity, and the temperatures in a mountain area are not very aggressive, it can be concluded that the annually capacity degradation is around 2.5%. In addition, the degradation of the battery follows a straight-line trajectory over the years, so in 12 years, the degradation will be approximately 30%.

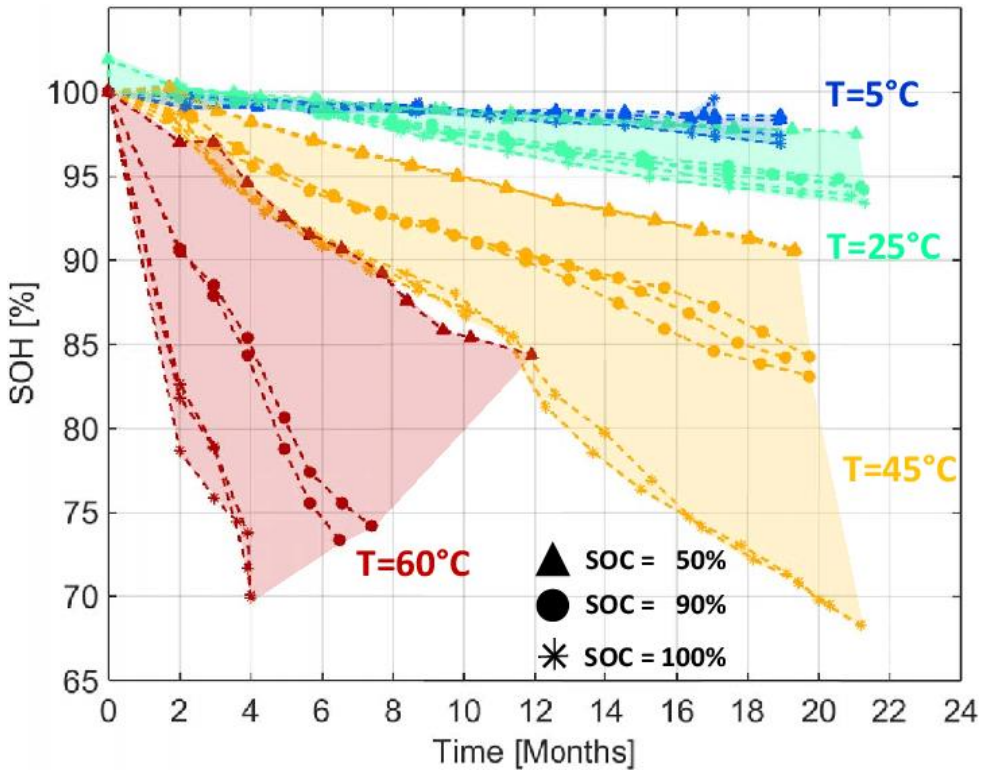

Figure 5. Evolution of the SOH of a lithium-ion battery. [11]

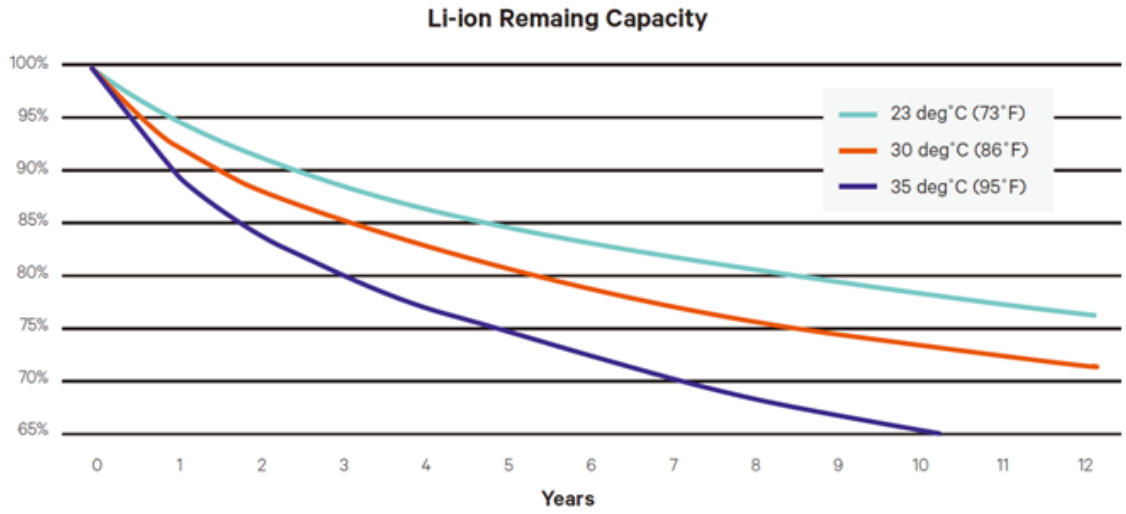

Figure 6. Lithium-ion battery life chart. [12]

The graph in Figure 6 shows that, being very pessimistic, the degradation of the battery in 12 years is 30% of initial capacity, which corroborates the result of the previous graph. Twelve years is set since this is the payback period for this technology, which is explained in detail in section 7.4. A pessimistic scenario is used since there are other factors, such as the charging and discharging speed, maintenance, or the number of discharge cycles per year, which also deteriorate the capacity of lithium-ion batteries.

6. Batteries legislation

In the following chapter, the current legislation regarding the use on batteries in Spain and Europe will be analyzed to understand the great dilemma that arises when using batteries, which could be seen as a source of generation (liberalized business) by electricity distribution companies, which carry out a fully regulated business.

6.1. European Directive 2019/944

Directive 2019/944 on common rules for the internal market in electricity is of great interest, as it places limits on the activity of the distribution network in terms of uses in the operation of batteries.

Firstly, one of the main objectives of the European Directive is to move towards a fully decarbonized, i.e., totally emission-free electricity sector to become the first carbon-neutral continent by 2050. To achieve its goal, Europe needs progress to be made in cyclic energy storage. Such energy storage is one element that could be used as a tool for electricity system management, and to cope with the variability of electricity production from renewable sources and associated contingencies over long horizons.

It has a key point in relation to electricity distribution companies, or Distribution System Operators (DSOs), whose main functions are described below:

- Ensuring that the grid has the long-term ability to cope with the demand for electricity distribution, taking into account the cost-effective implementation of new electricity generation facilities and, especially, those producing electricity from renewable resources.
- Provide customers with the necessary information to use and access the grid efficiently.
- They should publish grid development plans analyzing the planned investments for the next 5 to 10 years.
- If they are part of a vertically integrated undertaking, they must be independent of the other non-distribution activities, at least in terms of organization, decision-making and legal personality.
- They are **not** allowed to manage, own, develop or operate storage technologies **except** when specific requirements are met.

The Directive emphasizes that network operators should not manage, own, develop or operate energy storage facilities. In the new electricity market architecture, all energy storage services must achieve to be competitive and market-based, with as minimal involvement by regulatory agents as practicable. Consequently, it should be avoided the cross-subsidization between transmission and distribution operations (regulated activities), and energy storage. These ownership restrictions on energy storage facilities are intended to avoid market distortion, eliminate the risk of discrimination, ensure for all market participants a fair access to all kind of storage resources, and promote efficient and effective use of energy storage facilities, beyond transmission and distribution network management. That requirement should be applied and interpreted in accordance with the principles and rights written down in the Charter of Fundamental Rights of the European Union, specifically the freedom to conduct a business and the right to property guaranteed by Articles 16 and 17 of the Charter. [13]

Energy storage facilities can be developed, owned, operated, or managed by DSOs if they are fully integrated network components that are not used for congestion or balancing management. Always under the consideration and permission of the regulatory authority. This fully integrated grid components may include energy storage resources, for example lithium-ion batteries or capacitors, which provide relevant services for the reliability and security of the network and help to enable synchronization between different areas of the system.

In summary, the European Directive 2019/944 on common rules for the internal market in electricity (Article 36) only allows distribution system operators to own, develop, manage, or operate energy storage facilities, where they are fully integrated network components and only used to ensure safe and reliable operation of the network (and not for the purpose of buying and selling energy).

6.2. Royal Decree 29/2021

Directive 2019/944 of the European Parliament and of the Council of 5 June 2019 concerning common rules for the internal market in electricity and amending Directive 2012/27/EU has introduced the concept of "fully integrated network components", entering into force from 1st January 2021.

Following the entry into force of this European regulation, Spain passed Royal Decree Law 20/2021, of 21st December, adopting urgent measures in the field of energy to promote electric mobility, self-consumption, and the deployment of renewable energies. One of the most relevant points for the electricity grid is that fully integrated distribution

grid components are accepted as constituent elements of the distribution grid, including storage facilities, which will be those used to ensure the safe and reliable operation of the transmission grid and not for balancing or congestion management purposes [14]. Modifying the Electricity Sector Act 24/2013.

6.3. Battery application

Batteries have a wide variety of contributions to the system, although not all agents can take advantage of each of them. There is a big difference between the regulated and liberalized business, and the distributor can only work in a regulated framework (as defined in the ED 2019/944, explained in the previous chapter). Therefore, the applications of the battery in the distribution network are highly supervised by the regulators. The most relevant applications are shown in Figure 7, image obtained from the Rocky Mountain Institute (RMI).

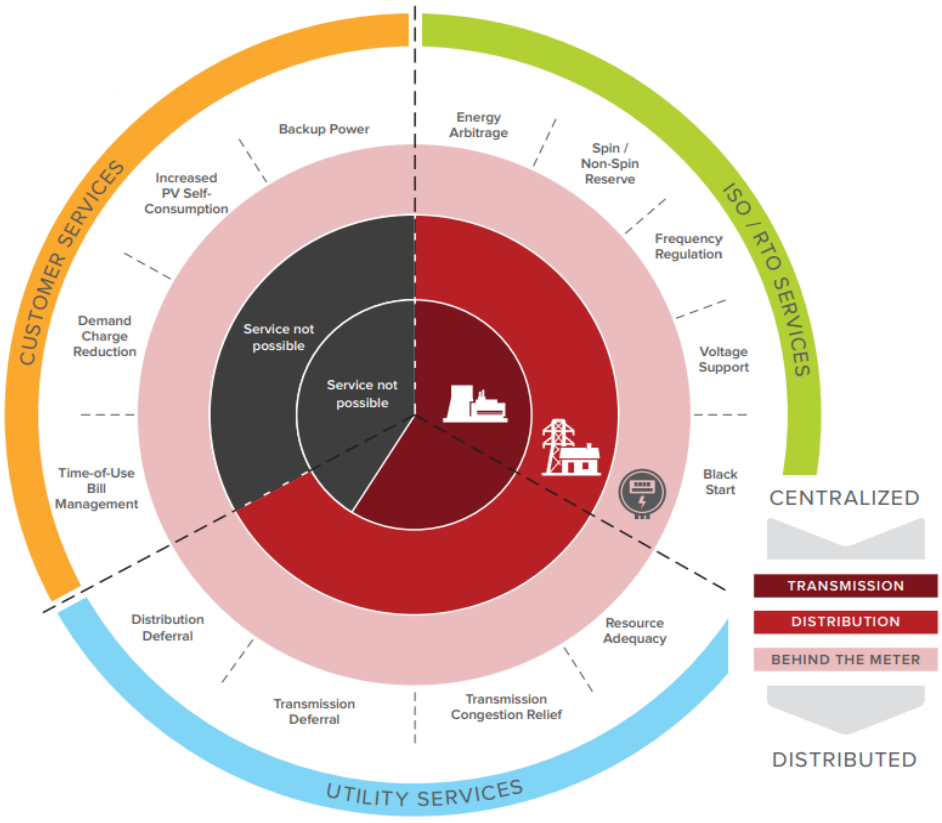

Figure 7. Different applications of lithium-ion batteries. [3]

In terms of the services provided by batteries in the distribution grid, the most important are those that provide support to the grid to ensure its reliability. Although there are several applications in this sense, the most common are voltage and frequency

regulation, autonomous grid start-up, energy arbitration and various types of reserves. Given the fast response time of battery systems, they are particularly suitable for primary frequency regulation, which requires the shortest response time, generally less than 30 seconds (they can also be used for secondary and tertiary regulation, which are less demanding in time response).

The location of battery storage has more advantages placed at the distribution network level, compared to the transmission network, since in the event of a grid outage, batteries installed in the distribution grid are a superior choice for reducing unmet demand. They provide non-served energy reduction, approximately two times greater than if they had been in the transmission level. In addition, annual energy losses have a greater reduction, and a superior voltage profile is achieved. [15]

Furthermore, it is important to make a comparison between distribution and behind the meter levels, although behind the meter nowadays is not economically viable, since batteries have a massive unitary cost. Also, telecommunications for the management of numerous LV batteries would be more costly and unreliable. It is important to know that the availability of the energy stored in the batteries is determined by the customer´s interest, so it cannot be fully guaranteed during distribution network outages. Finally, a LV consumer's average disconnection time in minutes due to HV or MV failures is longer than LV faults, which indicates that the quality of service would not be much improved by switching from MV to LV batteries. [15]

6.3.1. ROLE OF DISTRIBUTION COMPANIES

Investments in transmission and distribution networks are "lumpy" [16] and take advantage of the economies of scale as they initially require large capital commitments. The resulting works have a long lifetime and amortization period (from 20 to 40 years). Furthermore, grid planning has to identify vital investments with the mission of meeting the demand in a reliably future scenario and in a cost-effectively manner, while maximizing the utilization of all assets. At the distribution level, companies are often economically constrained, and networks are more congested than in transmission grids.

Storage, distributed generation, and demand response had never been considered by distribution companies in their long-term grid planning, which nowadays is changing because of the paradigm shift in the energy industry and the recent legislative changes that entitle them to do so and be paid for it. Moreover, it is remarkable that electricity grids are dimensioned to be able to meet the peak demand, during the hours with the highest consumption in the system, this is to ensure the reliability of the system. This provokes that, at most times of the year, they are over-dimensioned. Consequently, due to the size of the discrepancy in peak demand projections under various scenarios and

assumptions, the application of probabilistic forecasting and flexible planning are very relevant.

In addition, when demand begins to grow, traditional work is required, which consists of creating new facilities or upgrading the existing ones. This solution can take decades or even be unfeasible due to environmental problems (protected areas, green zones, areas of cultural interest, etc.). Thanks to batteries, placed in strategic areas, the cancellation or postponement of traditional works can be achieved. This fact is especially significant when distribution utilities consider using distributed energy resources (DER) as a grid expansion alternative. DER deployment is driven by the modularity of this resources and their fast installation. Diesel generators, which are typically located near major consumptions, have been the most frequently deployed DER technology in European countries until recently [16].

However, the decreasing costs of lithium-ion battery resources make it a more attractive option. Moreover, battery storage has the great advantage of not polluting the local air, an essential ecologic and environmental condition in most locations. In addition, the impact on the carbon footprint varies significantly depending on the energy source used to recharge the battery, being the latter option the one with the lowest impact.

6.4. Amortization period

Batteries must be designed to be able to operate under the appropriate conditions throughout their useful life. The National Commission for Markets and Competition (CNMC) defines the regulatory life of several grid elements, whose amortization period is different from 40 years, and is shown in Table 1. BESSs are considered intelligent systems, so their life is set at 12 years, the period in which this asset is amortized for distribution companies.

Table 1. Useful lifetimes of electric assets. [17]

Concept	Useful life (years)
Construction and buildings	50
Communications systems, technical management systems and computer applications and equipment for information processes	5
Tools	5
Transportation elements (including electric vehicles)	6
Furniture	10
Machinery	10
Intelligent systems	12
Remote management	15
Measuring equipment not located at customer's borders	15

7. Location of the battery

A major reason for the investment in a BESS is the area that must be crossed in order to feed the different loads.

7.1. Description of the area

This work will be carried out in the Autonomous Community of Castilla-La Mancha, in the province of Albacete, in an area that will not be determined in the document because it is confidential information (Location X and Line X). The installation of one or more batteries on the medium voltage (MV) network, in 20 kV, begins in a Substation whose name will also be concealed in the document. At this location, the consumptions are fed from a single MV overhead line, whose route has an elevation of over 100 meters above sea level in some sections. This fact exposes this line to adverse weather conditions, with frequent snowfalls and, in recent years, occasional phenomena of the formation of an ice cap on the conductors. The installation of this battery will improve the resilience of the network and will guarantee supply to towns in a mountain area of Albacete where the development of new electricity lines is very complex due to environmental requirementsly. The line can be observed in Figure 8, in color blue.

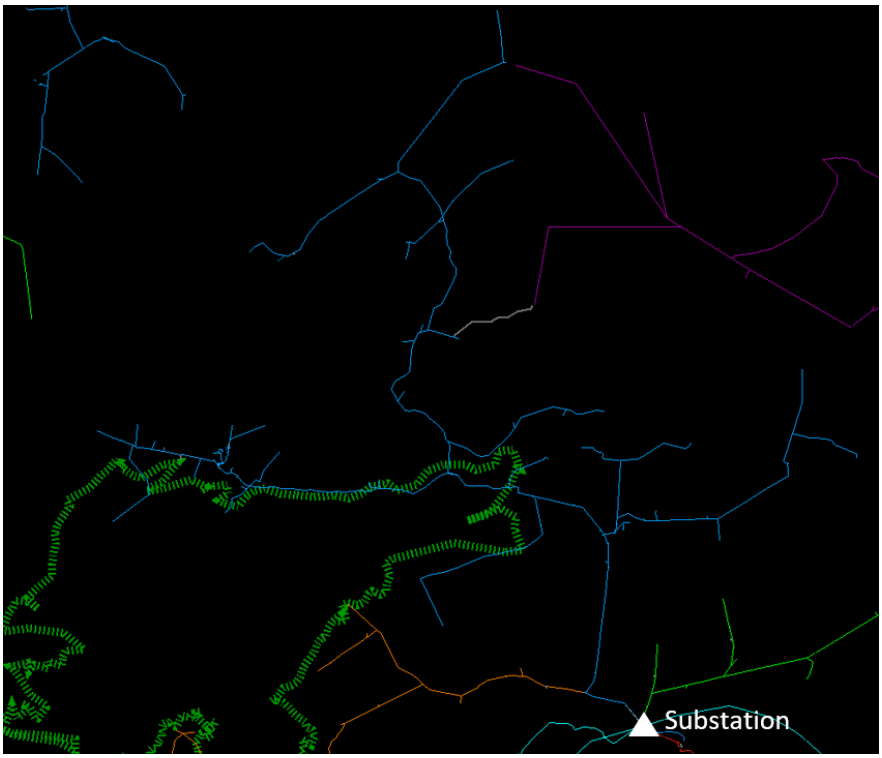

Figure 8. Geographic MV network scheme.

This line crosses natural parks and protected areas, represented in Figure 8 with shorts green stripes. In addition, the line is formed by three main antennas, the largest in terms of contracted power and number of customers is the one to the left, called branch 1. Branch 2 is the one with the second largest number of customers and the smallest contracted power, and branch 3 is the one with the second largest contracted power and the smallest number of customers. The specific data can be seen in Figure 9.

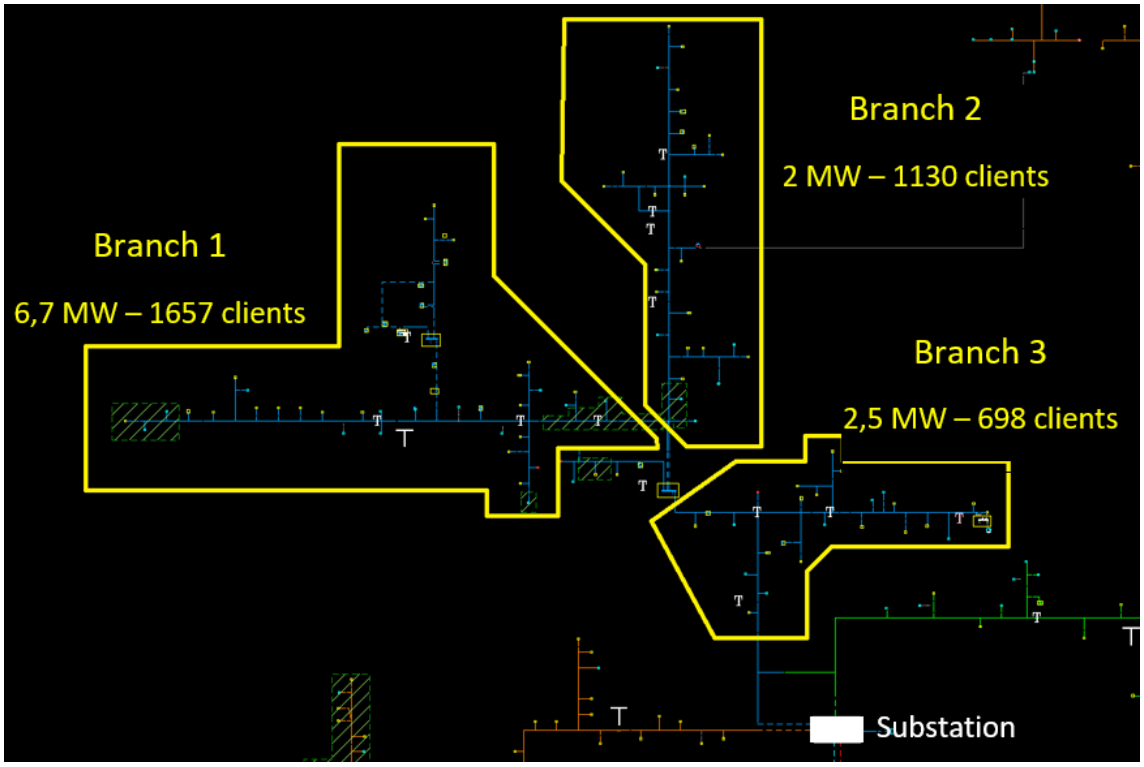

Figure 9. Schematic network configuration.

8. Battery justification

An in-depth study will be carried out for the optimal design of the batteries in this Location X. As detailed in the legislation chapter (chapter 7), these batteries cannot be used to exploit them economically, but will contain functional improvements aimed at:

- Increase their versatility and robustness in adverse conditions (grid incidents, fault localization, resistance to grid maneuvers, etc.).
- Develop the system for parallel operation of batteries and automatic island mode operation.
- Automate the islanding functionality in the event of grid failure.
- Include the generation of synthetic inertia and damping of oscillations.

First of all, it is necessary to justify the installation of a battery in the medium-voltage grid, due to the large investment involved. The basic prerequisite for the installation of batteries in an area is that they solve a problem in it. In order to decide on the exact point where it is advantageous to install a battery, the following factors must be analyzed: feasibility of traditional solutions and continuity of supply.

8.1. Feasibility of traditional solutions

In this section it is explained the technical feasibility of traditional solutions (new transformers, lines, etc.). At present, it is a fundamental condition for considering the installation of a battery to know whether or not the traditional solutions are viable to solve the problem presented by the grid, since if they are, it is very unlikely that the installation of batteries at current prices, would be more efficient than the traditional solution. Furthermore, the justification of the impediments to the development of the traditional solution will be the major argument for the need for a battery solution.

One traditional solution is building an overhead line linking the end of branch one back to the substation, to reinforce the supply of this area, which is the one with the highest contracted power and number of customers. To implement this solution, it is needed an investment of approximately 50-60 k€ / km for medium-voltage lines. The length of the line that would have to be built is 20 km, so the investment is 1.1 M€, which is less than any investment in lithium-ion batteries at present. The problem is that, in this specific area, there are many constraints from birdlife, green areas and protected zones that

make it very challenging to build long overhead lines to bring power to such scattered consumptions. This solution is almost impossible to be approved by the authorities.

Another traditional solution that avoids conflicts for environmental reasons, is the construction of the same line, but instead of being overhead, developed it under the ground. The cost of this solution is much more expensive, around 150 k€ / km, which position the total investment cost at 3 M€, which is approximately the cost of batteries nowadays. In addition, this line must be developed following the path of roads that, due to the narrowness of these in the mountain area is very difficult that the solution is feasible.

8.2. Continuity of Supply

The main use of the battery in the distribution network will be to ensure continuity of supply (CoS) a main factor that provides quality of supply (QoS) to the end-consumers. This produces benefits for both network users and the distribution company itself. Continuity of supply is determined by the number and duration of interruptions, with two key factors: TIEPI and NIEPI.

8. 2. 1. TIEPI

TIEPI is the equivalent interruption time of the installed power at medium voltage (1 kV < V ≤ 36 kV). This index is defined by the following expression: [18]

$$TIEPI\ (hours) = \frac{\sum_{i=1}^{K}(PI_i \cdot H_i)}{\sum PI}$$

$\sum PI$ = sum of the installed power in MV/LV distribution CTs plus the contracted power in MV (in kVA).

PI_i = installed power in the MV/LV distribution CTs plus the contracted power in MV, affected by the interruption "i" (in kVA).

H_i = interrupted hours of the supply that affects to the PIi power.

K = total number of interruptions during the considered period.

The interruptions to be considered in the TIEPI calculation will be those lasting more than three minutes. It should be noted that an elimination of 100% TIEPI is not realistic because, being a live network, it is impossible for no incidents to occur, so it is more typical

to work with the concept of the 80 percentile of the TIEPI. This is the TIEPI value that is not exceeded by 80% of the municipalities in the defined provincial scope.

8. 2. 2. NIEPI

On the other hand, the NIEPI is an index that has not been important when assessing incidents but is gaining more and more weight. This index measures the equivalent number of interruptions of the installed power at medium voltage. This index is defined by the following expression: [18]

$$NIEPI\ (hours) = \frac{\sum_{i=1}^{K} PI_i}{\sum PI}$$

$\sum PI$ = sum of the installed power in MV/LV distribution CTs plus the contracted power in MV (in kVA).

PI_i = installed power in the MV/LV distribution CTs plus the contracted power in MV, affected by the interruption "i" (in kVA).

K = total number of interruptions during the considered period.

As with the TIEPI, the interruptions that will be considered in the calculation of the NIEPI will be those lasting more than three minutes.

These indexes are very important and closely monitored by the distribution companies, as they can lead to significant benefits or penalties. This remuneration is known as a supply quality incentive and can be found in Circular 6/2019, of 5 December, of the CNMC [17]. Specifically, article 26 establishes the methodology for calculating the remuneration of the electricity distribution activity, an incentive for improving the quality of supply in the distribution networks in relation to TIEPI. The installation of a battery must lead to an improvement in the quality of supply, so that, in the study area, the TIEPI must be at least higher than the average TIEPI in i-DE (approx. 50 mins). The TIEPI in this area is approximately 4 hours, a significantly high value. This time varies depending on the area, since as a reference, we take the history of incidents in the area, how long it has taken to resolve them, and the normal travel time of the brigades to the area. With the implementation of the battery, we will try to cover a large part of the incidents, bearing in mind that the price of the batteries depends a lot on this factor. The desired time for the supply to be guaranteed in the affected area is at least half of the current time, 2 hours.

9. Battery design

In this chapter it will be determined the optimal dimensions of the 4 batteries for 5 different scenarios. The batteries will be:

1. A small battery for the branch of the line with the highest demand (number of customers and contracted power), this being the one that is placed furthest to the left.

2. A small battery for the central branch, which is the branch with the second largest number of customers.

3. A small battery for the right-hand branch, which is the branch with the second highest contracted power.

4. A large battery capable of supplying the entire line.

Regarding the scenarios:

1. The first one consists of placing a battery in the line branch with the highest consumption and customers, which is an option to reduce the duration of incidents (TIEPI) in a section of the line (battery 1).

2. The second case will have two small batteries to supply power in the two larger customer branches, a better option from a technical point of view, but more expensive than case 1 (batteries 1 and 2).

3. The third case will have two small batteries to supply energy in the two branches with the highest contracted power (batteries 1 and 3).

4. As for case four, 3 small batteries will be introduced, one in each branch (batteries 1, 2 and 3).

5. Finally, in case five, the option of placing a large battery (battery 4), located in the branch with the highest power, as in case 1, but sized to supply to the whole line.

All four batteries start with the same procedure. Firstly, the consumptions to be supplied by each battery in the event of a grid failure is selected. Researching on i-DE's internal database applications, the maximum hourly current is extracted from the relevant

electronic relay (OCR), which stores current information even every 5 minutes. This current in amperes is multiplied by the nominal voltage, which is 20 kV in the study area, and by the square root of 3, in order to obtain the maximum hourly three-phase power, in kW. The information to be analyzed is from the year 2021 (last year), since it is the most updated record that best resembles the state of the network nowadays. Therefore, there will be 8,760 registers for each case. The case of study is located in a mountainous area with higher consumption in the summer season.

9.1. Battery 1

As explained above, this section consists of the analysis of the implementation of a battery in the largest branch in contacted power and number of clients, 6.7 MW contracted and 1,657 customers. The resulting calculations are shown in Annex I. After obtaining the 8,760 records, it is necessary to filter by hours, in order to be able to work with all the information.

9. 1. 1. SIZING

First, the mean power, maximum power, and various percentiles, shown in Figure 10, are analyzed.

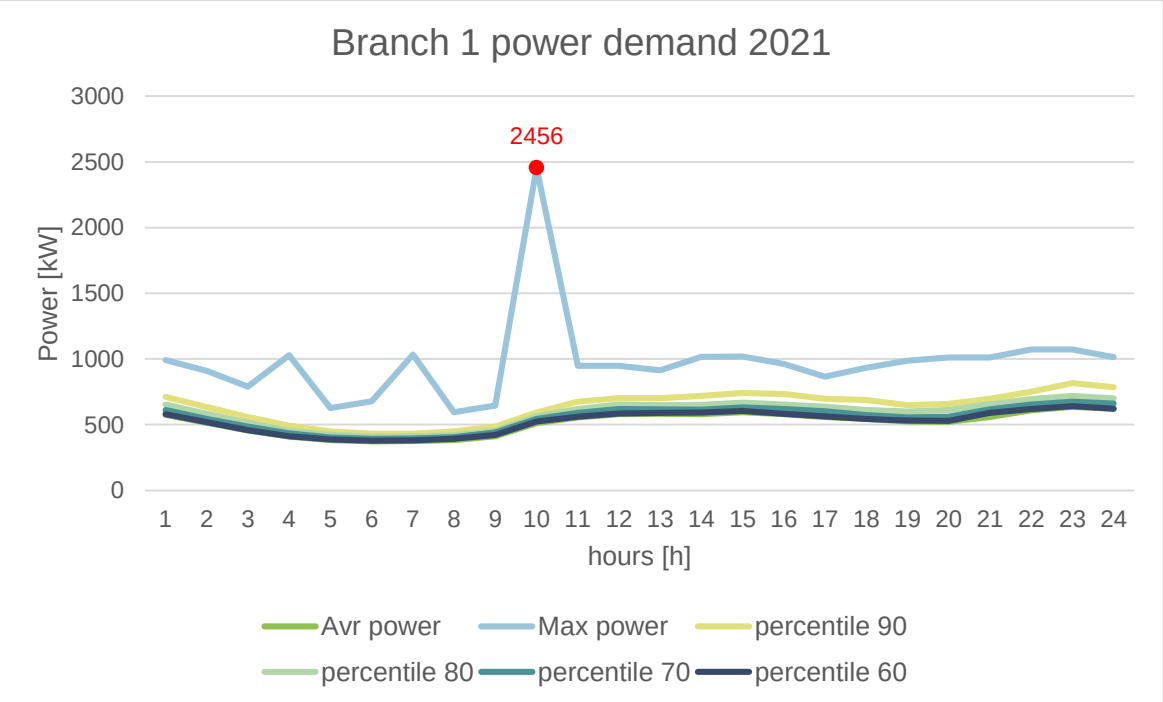

Figure 10. Branch 1 power demand with an outlier.

Figure 10 has a large outlier of maximum power recorded between 9 - 10 a.m., being the second highest record at this time of approximately 800 kW. It is eliminated, as it is a measurement error and is not representative for the study. Therefore, it is decided to replace this value with the second maximum power measurement at this time period.

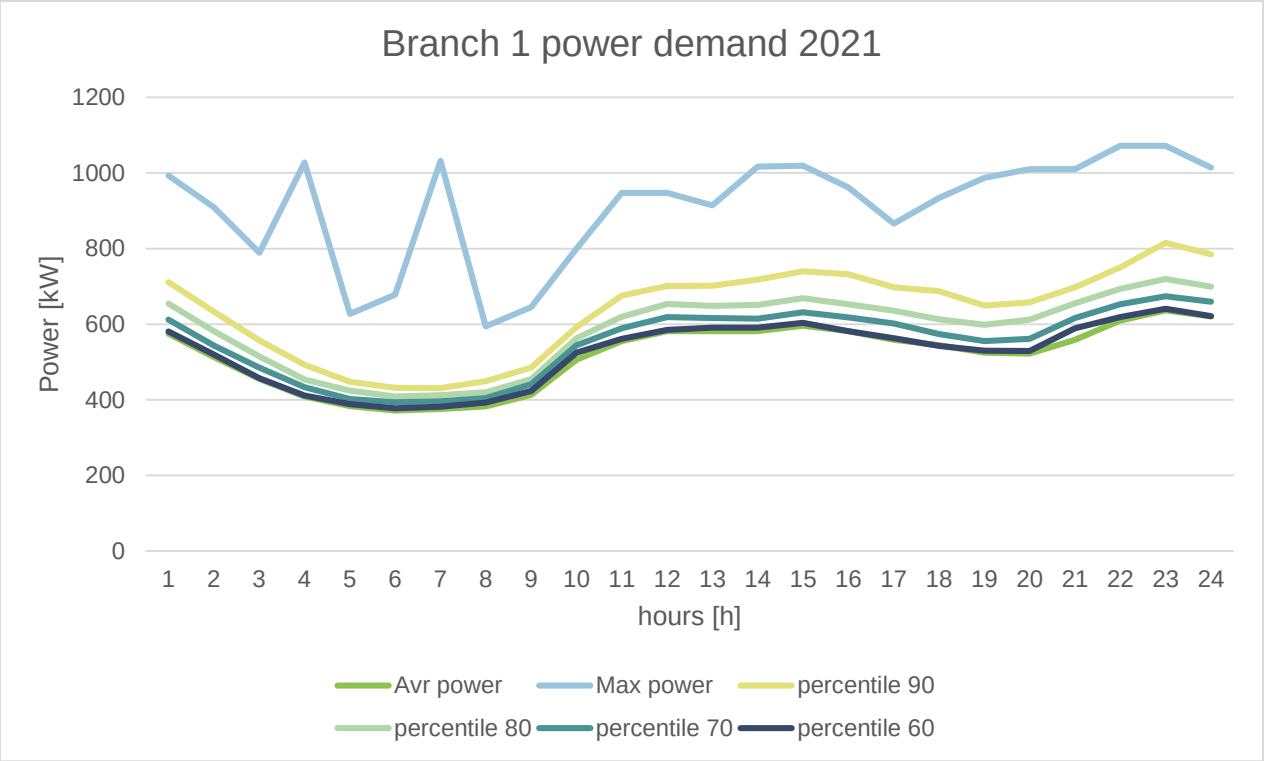

Figure 11. Branch 1 corrected power demand.

From Figure 11 important conclusions can be drawn. It is worth noting that the peak power is around 1 MW, specifically 1.07 MW. However, looking at percentiles, the power does not usually exceed 800 kW, not even at the 90 percentile (90% of the measurements analyzed).

Next, it is studied the power to be supplied by the battery, considering that the average duration of incidents in rural areas is 4 to 6 hours. The Figures 12 to 14 present, for each hour of the day, the energy supplied by the branch 1 in the following 4, 5 or 6 hours respectively. This information is helpful to establish the energy storage requirements for the battery.

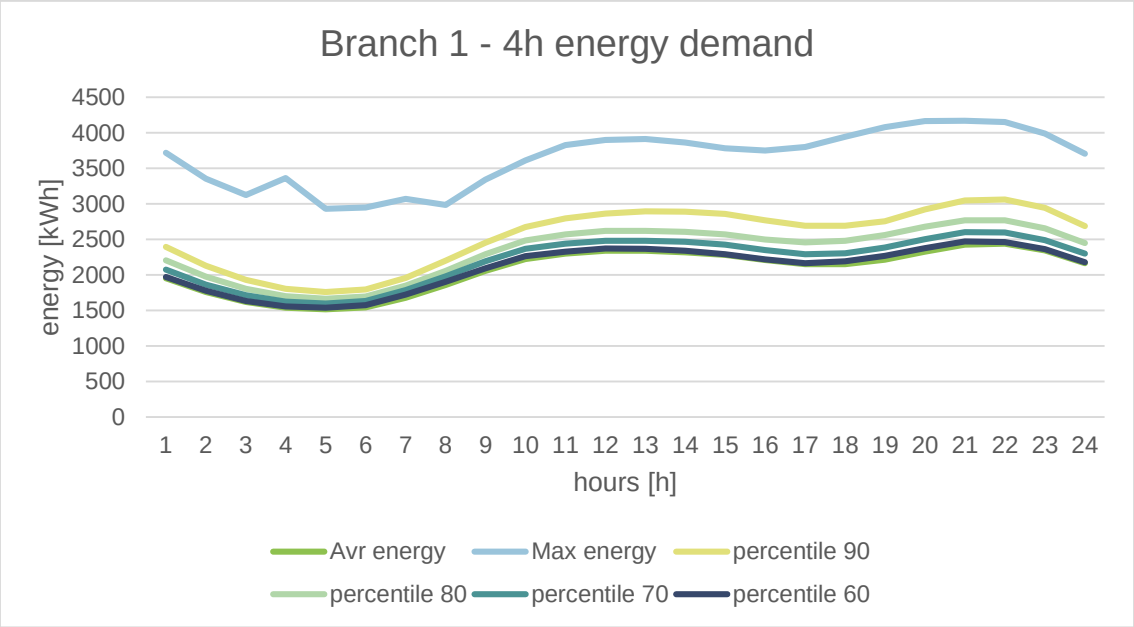

Figure 12. Branch 1 – 4 hour energy demand.

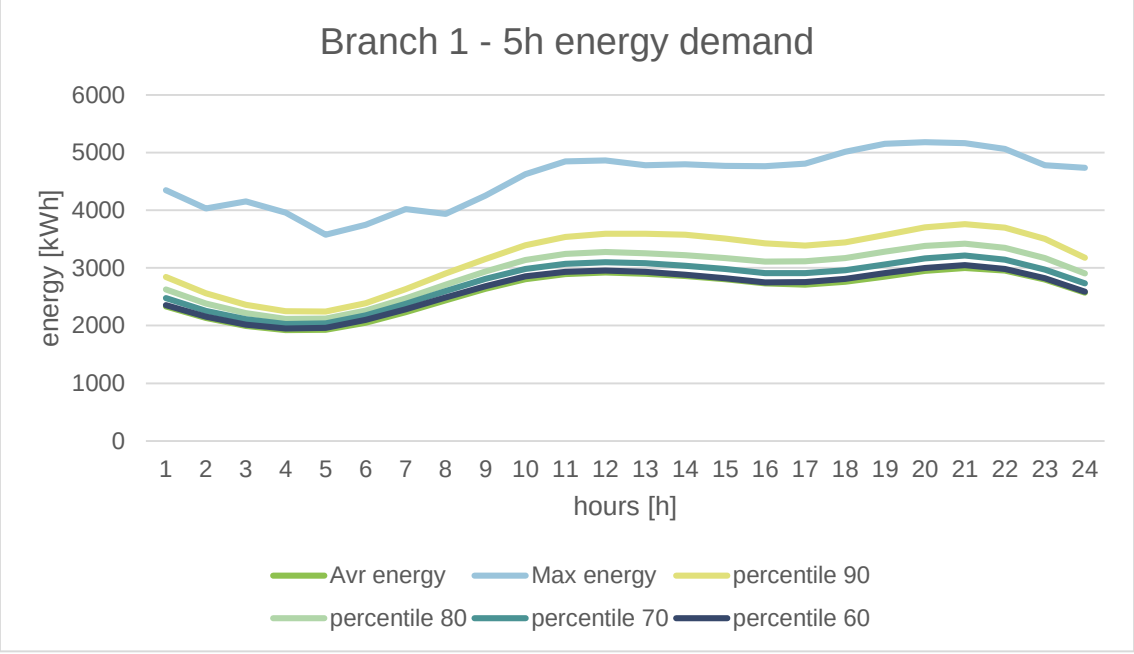

Figure 13. Branch 1 – 5 hour energy demand.

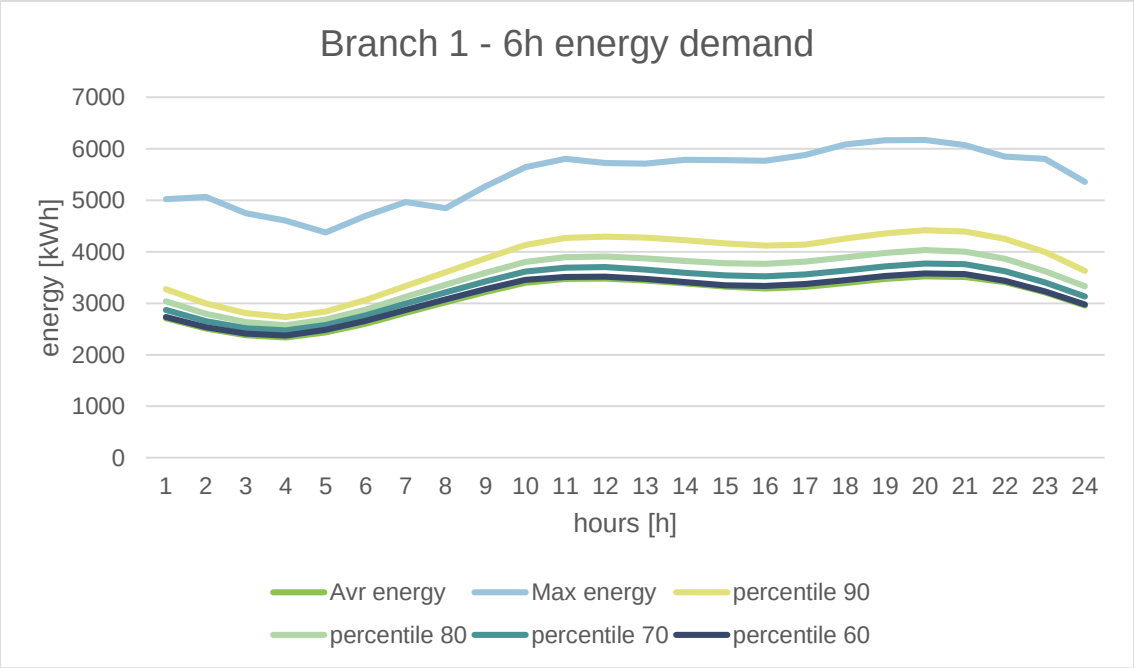

Figure 14. Branch 1 – 6 hour energy demand.

The battery is going to be sized for an average duration of the fault of 5 hours. Given that the normal values are 4-6 hours, if the battery is designed for 4 hours, in the event of a 6-hour incident it would not be able to supply the full demand, and if it is sized for 6 hours, it would be considerably oversized in the event of short incidents, making it economically inefficient. Therefore, it is decided that the optimum is a 5 hour period. Furthermore, Figures 12, 13 and 14 show the large spread between the maximum power and the 90 percentile, which is the reason why sizing for the maximum power is not efficient, since these are isolated instances throughout the year. Looking at the 90 percentile in Figure 13, with incidences of 5 hours, it is concluded that the optimal value is 4 MWh, as it is always a bit lower. In fact, looking at Figure 14, with incidences of 6 hours, it can be stated that the battery would be able to completely supply the demand in most cases.

In addition, vegetative growth must be considered since a battery is estimated to have a lifetime of 12 years. Therefore, the estimated vegetative growth of the area in the following 12 years is 3%, a very low percentage as this area is mainly rural and growth is slow. Then, the power and energy with growth is analyzed with the help of a Macro-enabled Excel, indicating that the maximums are 1.1 MW and 5.33 MWh. For all of the above, the most interesting option is to dimension the battery so that it has a maximum peak power of 1 MW, but to dimension its energy considering that the most common situation is to supply 800 kW for 5 hours. In addition, to ensure that the annual operating hours are close to 100% without oversizing the capacity, and to be as economical as possible, a capacity of 4 MWh seems to be the most appropriate option.

9. 1. 2. VERIFICATION

It is necessary to check that the battery size is the optimum for the particular load area, and to do this, an analysis is made of how much demand this technology is capable of supplying throughout the year.

Firstly, the number of hours in a year in which the power demanded, taking into account the vegetative growth, is higher than the battery power is 20 hours, and as a result of that the battery will not be able to attend the demand in those hours. Consequently, the Energy Not Supplied (ENS) in a year could be estimated as 0.903 MWh. The 20 hours above 1 MW can be observed in Figure 15.

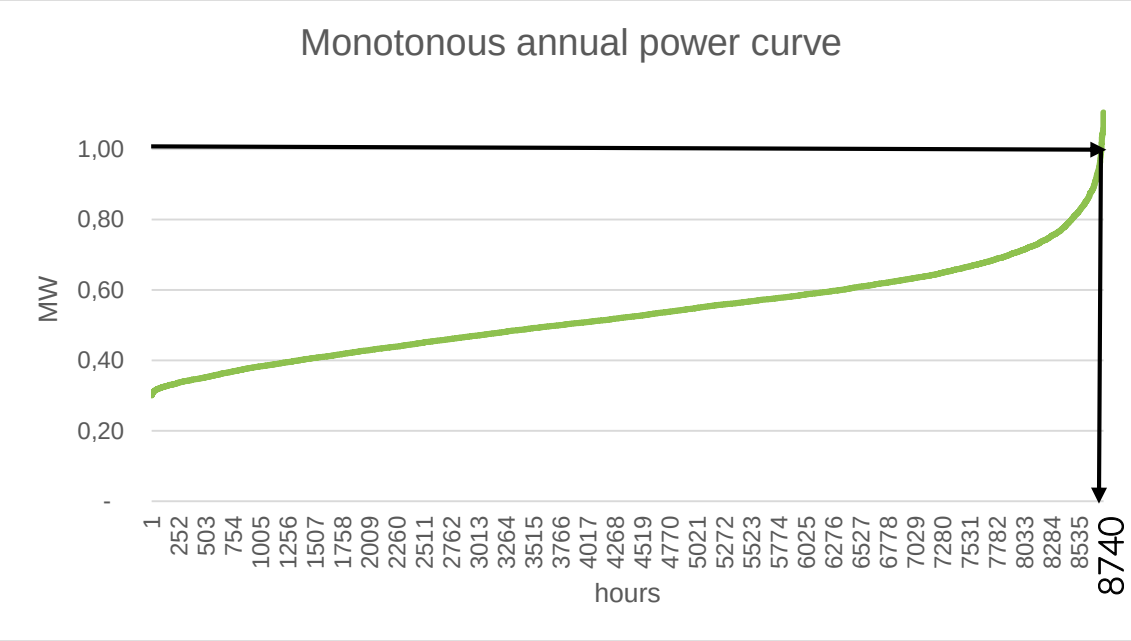

Figure 15. Monotonous annual power curve of branch 1.

Secondly, the number of hours in a year in which the energy demanded in the following 5 hours exceeds the battery storage capacity (4 MWh) is 235 hours, so that the total ENS in a year would be 66.28 MWh. The energy above 4 MWh can be observed in Figure 16.

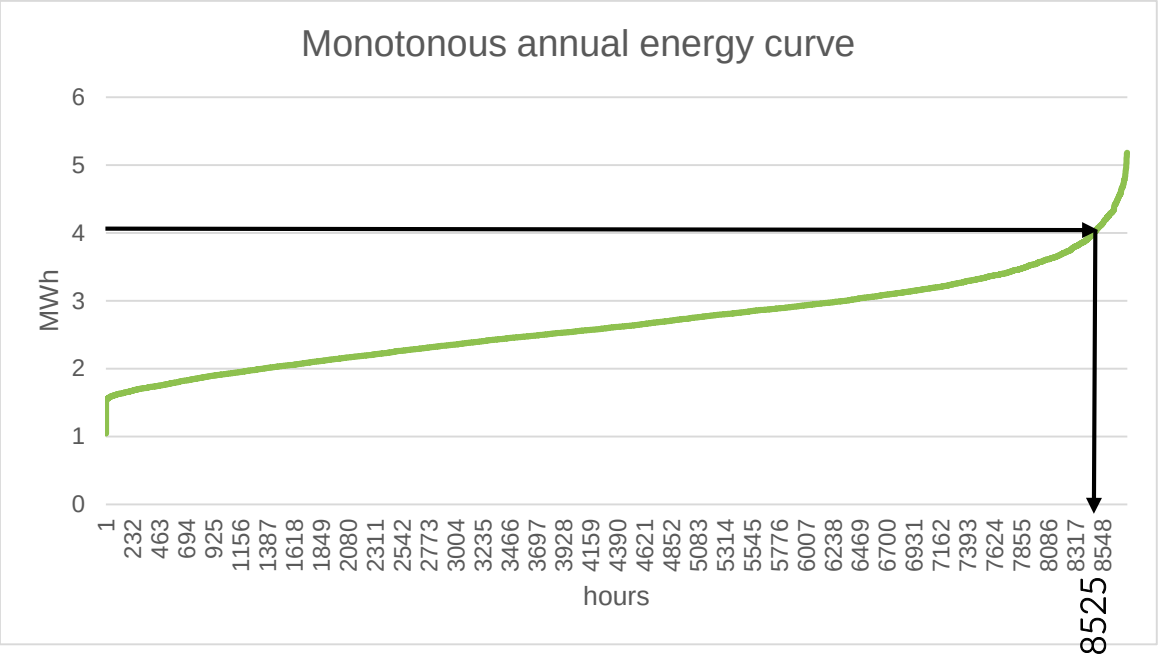

Figure 16. Monotonous annual energy curve of branch 1.

Finally, the number of cases in which, in the event of a contingency, the battery would not be able to supply the entire demand during the defined hours of contingency replacement is 235 hours, in 20 of them because neither the power nor the energy are sufficient. In other words, the battery will be able to supply the total demand in case of a contingency 5 hours long occurred in 97.32% of the 8,760 hours in a year, which can be seen in Figure 17.

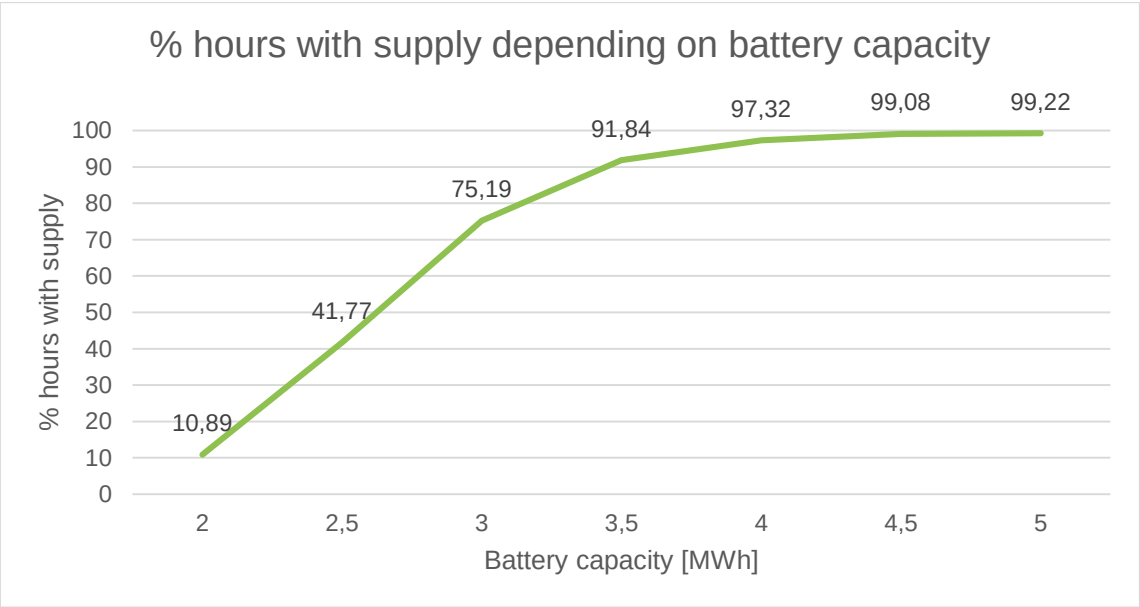

Figure 17. Trade-off between ENS and Battery 1 capacity.

In the remaining 235 hours the battery will not be able to supply all the demand during 5 hours, but it will supply its 4 MWh covering the 92.95% of the energy demanded in that period. This is an optimal result between the technical compromise of supplying the greatest amount of demand, and the economic compromise of not oversizing the tool.

9. 1. 3. RESULT

It is concluded that the ideal battery dimensions are 1 MW and 4 MWh capacity.

9.2. Battery 2

It has been previously explained that case 2 consists of the analysis of the implementation of two batteries. One of them in the largest branch, which has already been sized in case 1, and another small battery will be added in the second branch with the largest number of customers, branch 2, with 2 MW contracted and 1,130 customers. The latter will be dimension in this section, and the resulting calculations are shown in Annex I. After obtaining the 8,760 records, it is necessary to filter by hours, in order to be able to work with all the information.

9. 2. 1. SIZING

Firstly, the maximum mean power and several percentiles are analyzed, shown in Figure 18.

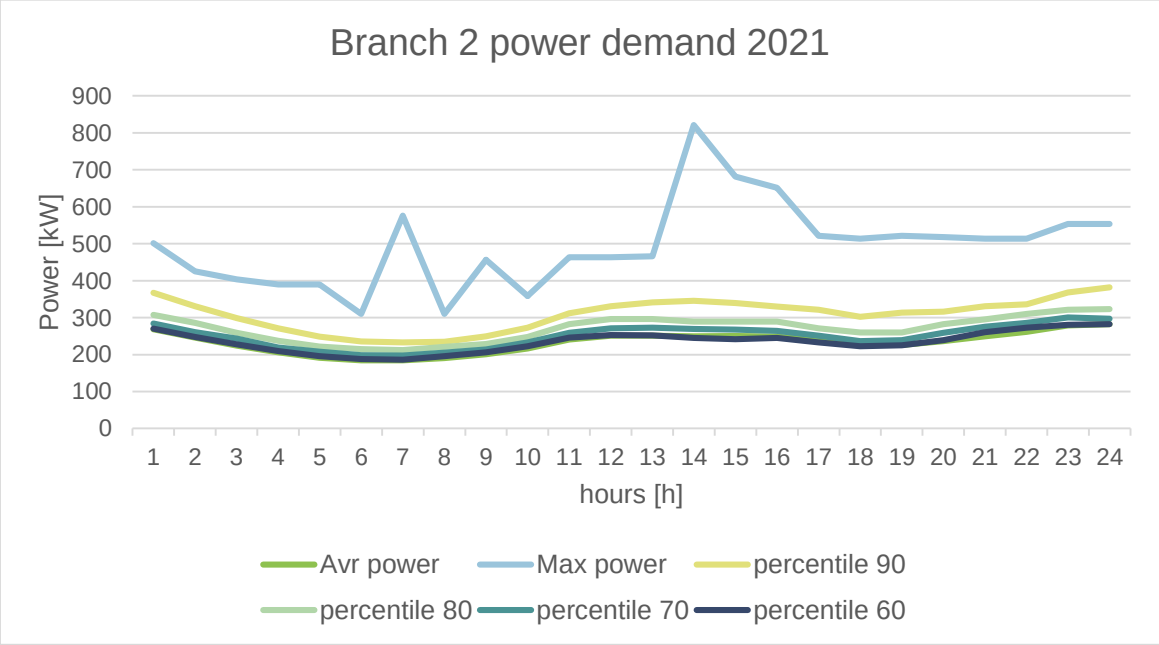

Figure 18. Branch 1 power demand.

From Figure 18 it can be noted that the peak power is around 800 kW, specifically 821 kW. However, looking at percentiles, the power does not usually exceed 400 kW, not even at the 90 percentile.

Let's study now the storage capacity requirements for the battery. Although the common considered values are 4 to 6 hours, looking at the geographical map in Figure 8, it can be seen that the branch is very long even though it does not have as many customers and contracted power as branch 1, so an incident will be more difficult to locate and will take longer on average. As a result of that, we will consider that the average fault duration in this branch is 6 hours, The Figure 19 present, for each hour of the day, the energy supplied by the branch 1 in the following 6 hours.

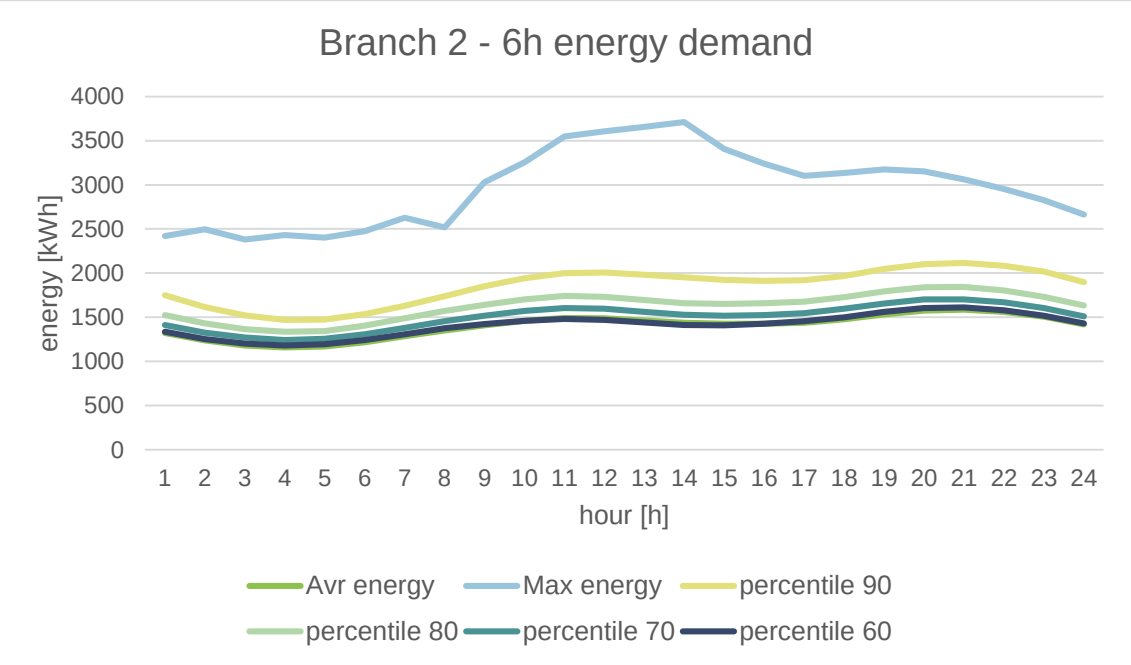

Figure 19. Branch 2 – 6h energy demand.

The Figure 19 shows the large difference between the maximum power and the 90 percentile, so that sizing for the maximum power is not efficient, since the latter takes into account very isolated cases throughout the year. Looking at the 90 percentile in Figure 19, with 6-hour occurrences, it is concluded that the optimal value is 2.5 MWh, as it is always a little below.

In addition, as mentioned in the previous case, vegetative growth must be considered, since a battery is estimated to have a useful life of 12 years. Power and energy have been analyzed with the 3% growth, and it is observed that the maximums are 0.85 MW and 3.15 MWh. In view of the above, the most interesting option is to size the battery to have

a maximum peak power of 600 kW, but to size its energy taking into account that, the most common scenario will normally be, to supply 400 kW for 6 hours. In addition, in order to ensure that the annual operating hours are close to 100% without oversizing the capacity, and to be as economical as possible, a capacity of 2.5 MWh seems to be the most appropriate option.

9. 2. 2. VERIFICATION

It must be verified that the battery is optimal for the area, to do this, it is analyzed how much demand this technology is capable of supplying throughout the year if it has those dimensions.

In the first place, the number of hours in a year in which the power demanded, taking into account the vegetative growth, is higher than the battery power is **4 hours**, and as a result of that the battery will not be able to attend the demand in those hours. Consequently, the Energy Not Supplied (ENS) in a year could be estimated as 0.77 MWh. The 4 hours above 0.6 MW can be observed in Figure 20.

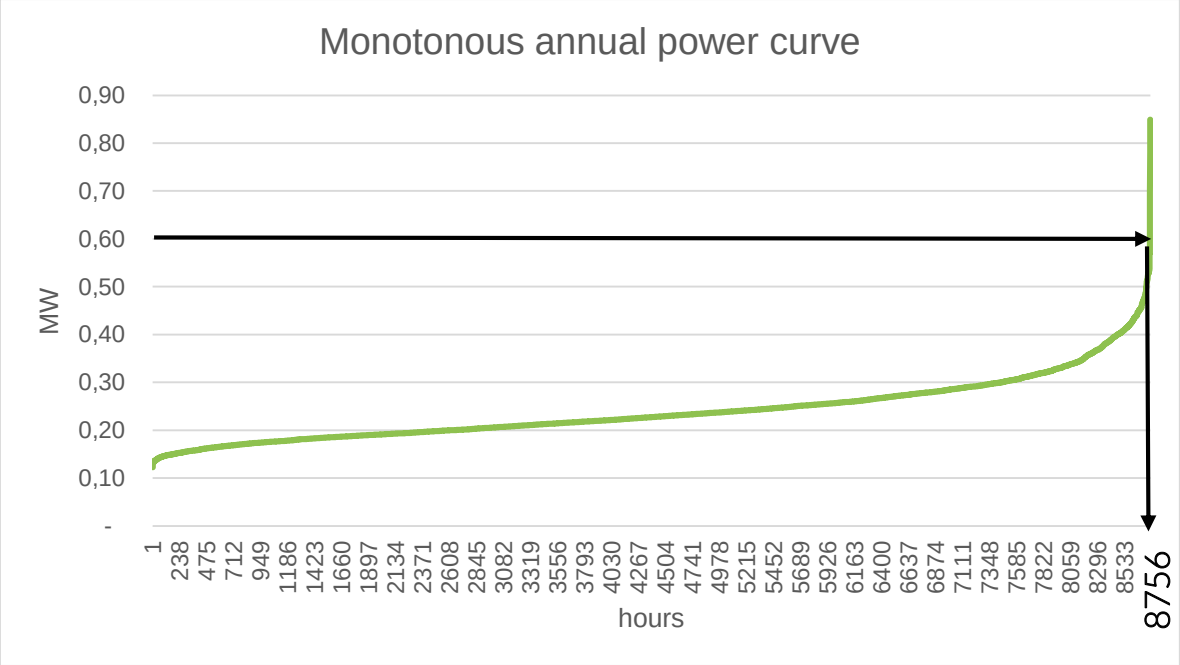

Figure 20. Monotonous annual power curve of branch 2.

Secondly, the number of hours in a year in which the energy demanded in the following 6 hours exceeds the battery storage capacity (2.5 MWh) is **177 hours**, so that the total ENS in a year would be 28.65 MWh. The energy above 2.5 MWh can be observed in Figure 21.

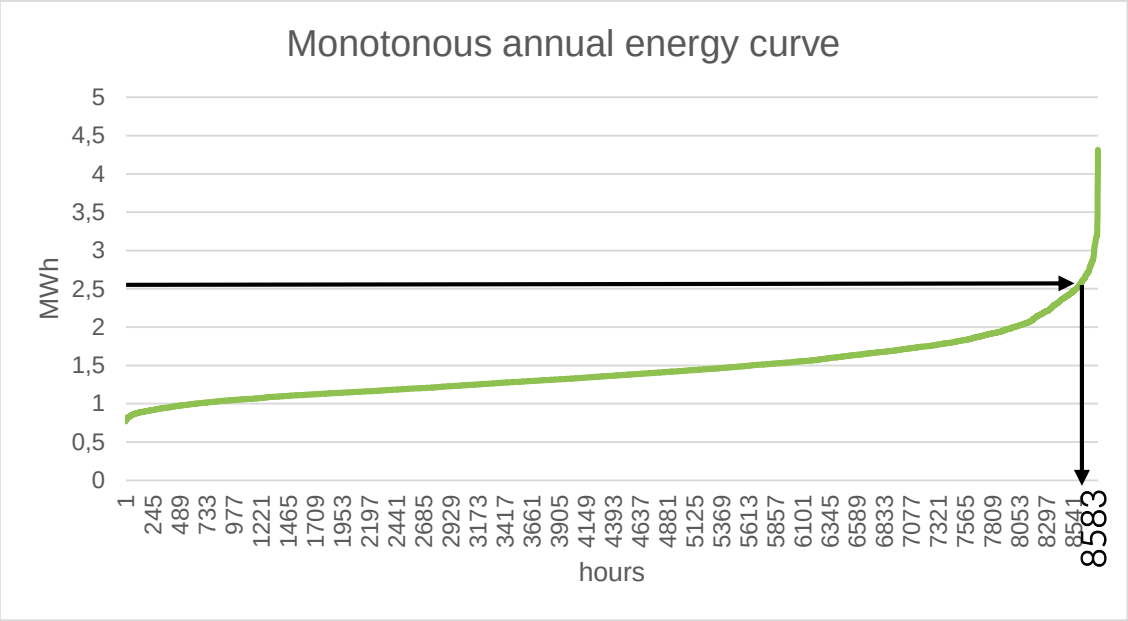

Figure 21. Monotonous annual energy curve of branch 2.

Finally, the number of cases in which, in the event of a contingency, the battery would not be able to supply the entire demand during the defined hours of contingency replacement is 177 hours, in 4 of them because neither the power nor the energy are sufficient. In other words, the battery will be able to supply the total demand in case of a contingency 5 hours long occurred in 97.98% of the 8,760 hours in a year, which can be seen in Figure 22.

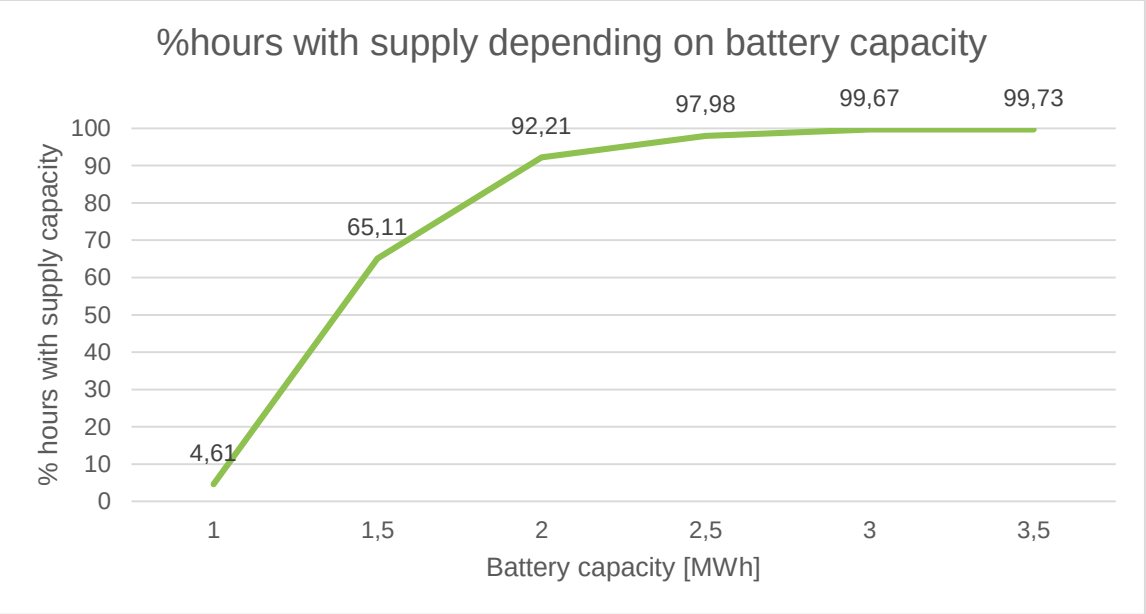

Figure 22. Trade-off between ENS and Battery 2 capacity.

In the remaining 177 hours the battery will not be able to supply all the demand during 6 hours, but it will supply its 2.5 MWh covering the 93.52% of the energy demanded in that period. This is an optimal result between the technical compromise of supplying the greatest amount of demand, and the economic compromise of not oversizing the tool.

9. 2. 3. RESULT

It is concluded that the ideal battery dimensions are 0.6 MW and 2.5 MWh capacity.

9.3. Battery 3

It has been previously explained that case 3 consists of the analysis of the implementation of two batteries. One of them in the largest bag, which has already been dimensioned in section 10.1 and, in addition, another small battery will be dimensioned in the right branch of the line, branch 3, with 2.5 MW contracted and 698 clients. The latter is the battery to be sized next, battery 3, and the resulting calculations are shown in Annex I. After obtaining the 8,760 records, it is necessary to filter by hours, in order to work with all the information.

9. 3. 1. SIZING

Firstly, the maximum mean power and several percentiles are analyzed, shown in Figure 23.

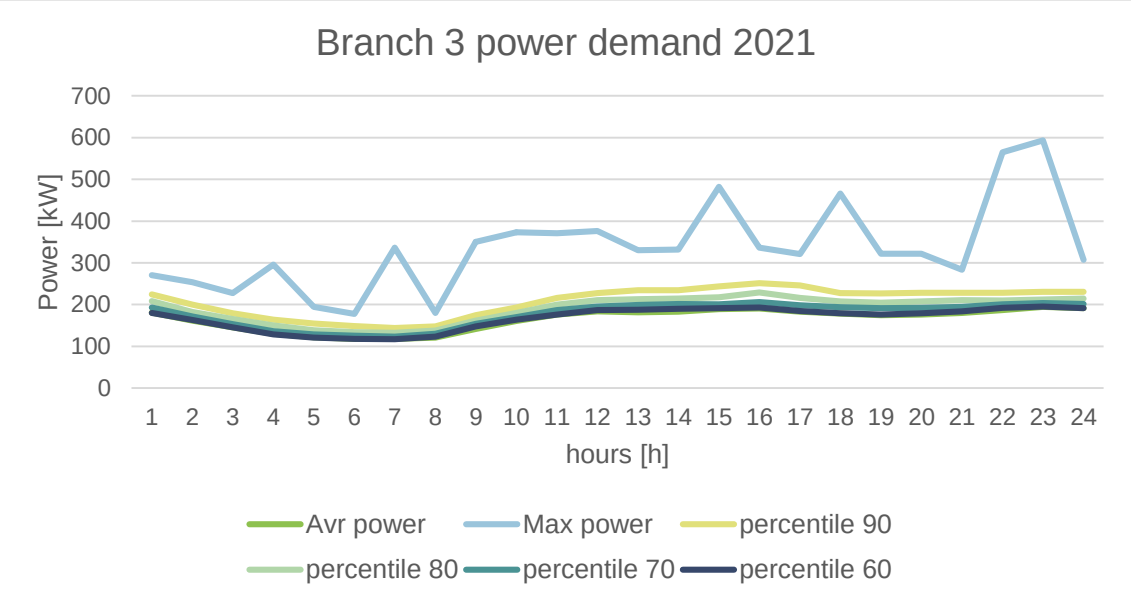

Figure 23. Branch 3 power demand.

Important conclusions can be drawn from Figure 23. It should be noted that the peak power is around 600 kW, specifically 593 kW. However, looking at percentiles, the power does not usually exceed 300 kW, not even at the 90 percentile. Next, the energy that the battery must supply is studied.

Next Figures 24 an 25 present, for each hour of the day, the energy supplied by the branch 1 in the following 5 or 6 hours respectively. This information is helpful to establish the energy storage requirements for the battery. The battery is going to be dimensioned for an average duration of the contingency of 5 hours. This is because, looking at Figure 8, it can be seen that consumption is not as dispersed as it is in branch 2. For this reason, it is decided that an average value of 5 hours is optimal. Observing the 90 percentile of Figure 24, it is concluded that the optimal value is 1.5 MWh, since it is always a little lower. In fact, looking at Figure 25, it can be stated that the battery would be able to fully supply the demand in most cases.

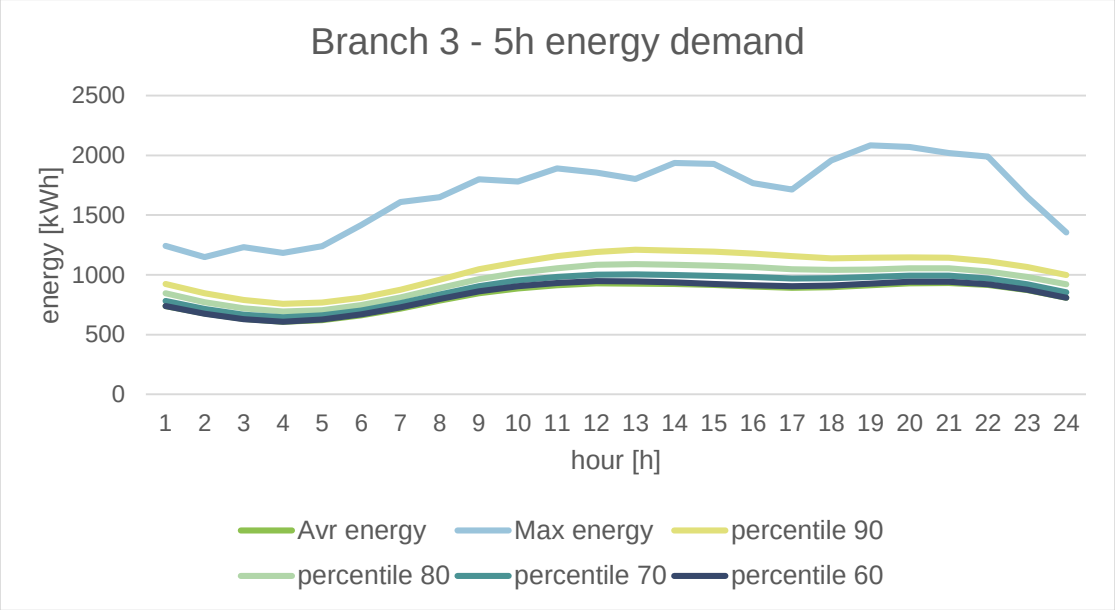

Figure 24. Branch 3 – 5h energy demand.

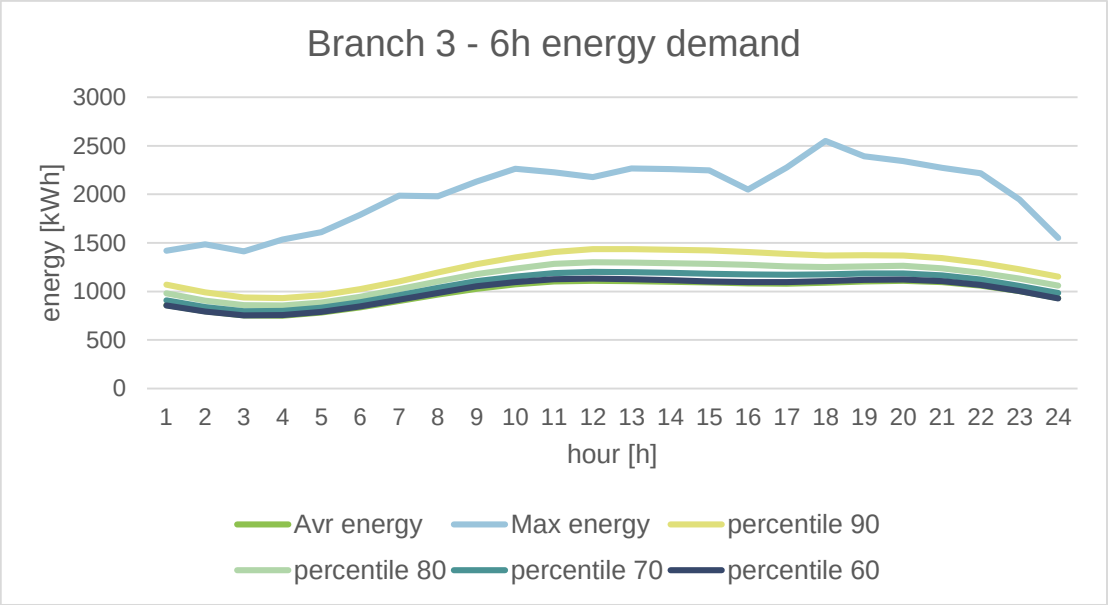

Figure 25. Branch 3 – 6h energy demand.

Taking into account the vegetative growth of 3% in the area, the maximum power and energy is 0.61 MW and 1.91 MWh. For all of the above, the most interesting option is to size the battery so that it has a maximum peak power of 400 kW, so that it can supply certain demands that are higher than usual, but dimensioning its energy taking into account that, in the most common scenario is, that the battery needs to supply 250 kW for 5 hours. In addition, so that the annual hours with service are close to 100% without oversizing the capacity, and it is also as economical as possible, a capacity of 1.5 MWh seems to be the most appropriate option.

9. 3. 2. VERIFICATION

It must be verified that the battery is optimal for the area, to do this, it is analyzed how much demand this technology is capable of supplying throughout the year if it has those dimensions.

In the first place, the number of hours in a year in which the power demanded, taking into account the vegetative growth, is higher than the battery power is 5 hours, and as a result of that the battery will not be able to attend the demand in those hours. Consequently, the Energy Not Supplied (ENS) in a year could be estimated as 0.68 MWh. The 5 hours above 0.4 MW can be observed in Figure 26.

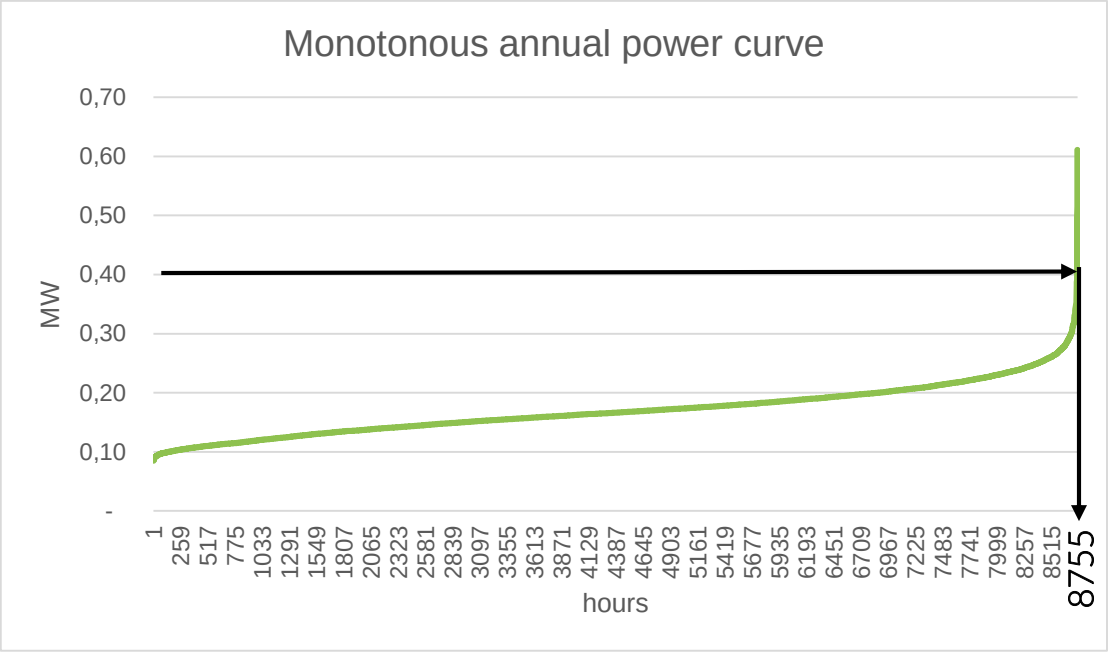

Figure 26. Monotonous annual power curve of branch 3.

Secondly, the number of hours in a year in which the energy demanded in the following 5 hours exceeds the battery storage capacity (1.5 MWh) is 278 hours, so that the total ENS in a year would be 29.72 MWh. The energy above 1.5 MWh can be observed in Figure 27.

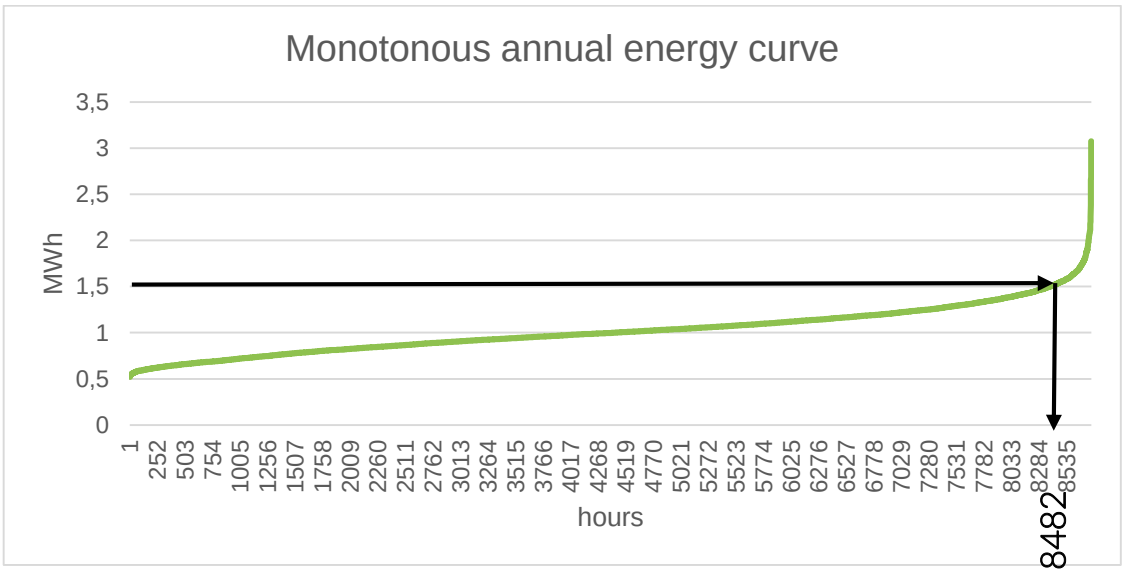

Figure 27. Monotonous annual energy curve of branch 3.

Finally, the number of cases in which, in the event of a contingency, the battery would not be able to supply the entire demand during the defined hours of contingency replacement is 278 hours, in 5 of them because neither the power nor the energy are

sufficient. In other words, the battery will be able to supply the total demand in case of a contingency 5 hours long occurred in 96.83% of the 8,760 hours in a year, which can be seen in Figure 28.

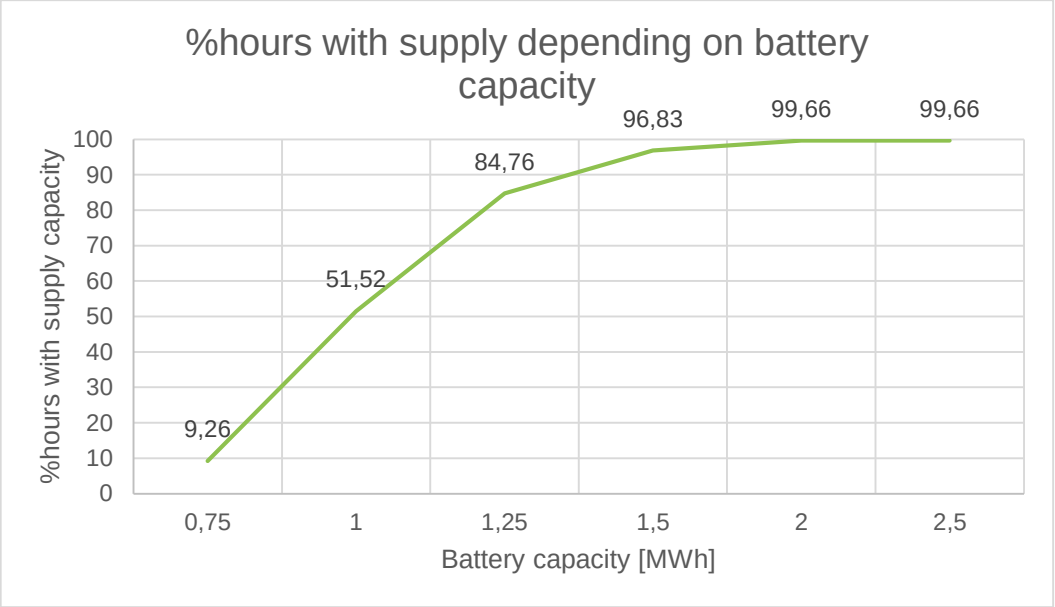

Figure 28. Trade-off between ENS and Battery 3 capacity.

In the remaining 278 hours the battery will not be able to supply all the demand during 5 hours, but it will supply its 1.5 MWh covering the 92.87% of the energy demanded in that period. This is an optimal result between the technical compromise of supplying the greatest amount of demand, and the economic compromise of not oversizing the tool.

9. 3. 3. RESULT

It is concluded that the ideal battery dimensions are 0.4 MW and 1.5 MWh capacity.

9.4. Battery 4

This case consists of the analysis of the implementation of a large battery that takes over the powers of the entire line, of 11.2 MW contracted and 3,485 clients. The resulting calculations are shown in Annex I. As in the previous cases, after obtaining the 8,760 records, it is necessary to filter by hours, in order to work with all the information.

9. 4. 1. SIZING

Firstly, the maximum mean power and several percentiles are analyzed, shown in Figure 29.

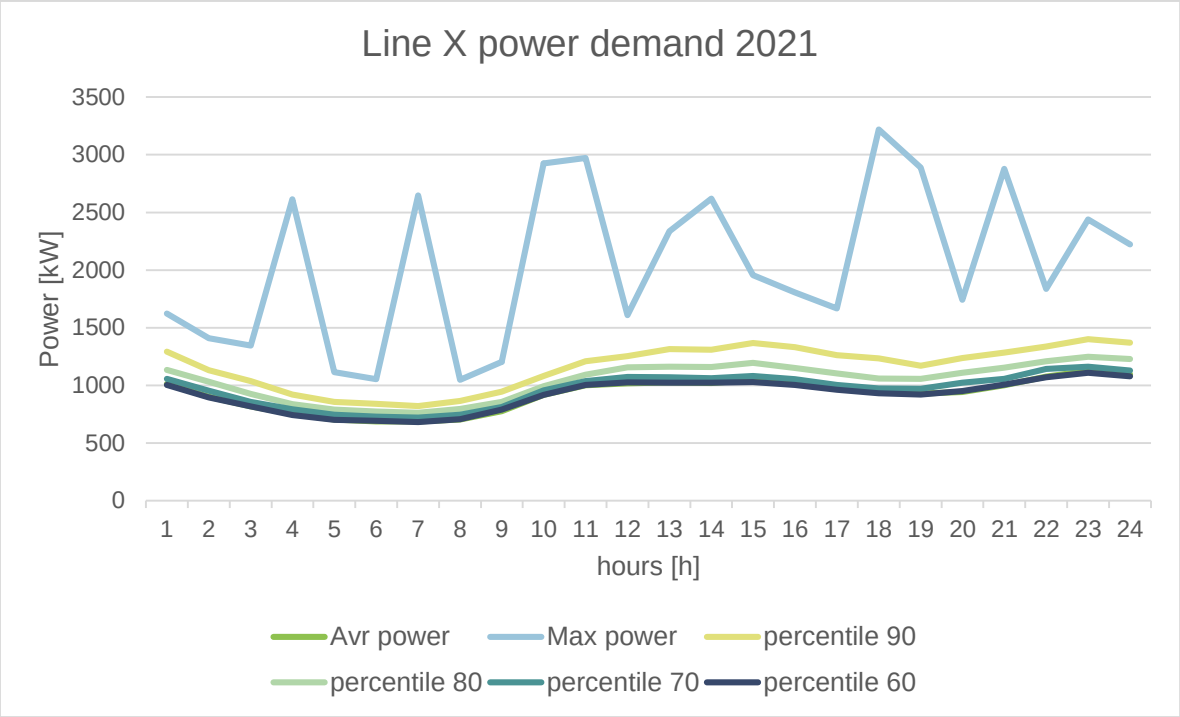

Figure 29. Line X power demand.

From the graph it should be noted that the peak power is around 3.5 MW, specifically 3.22 MW. However, looking at percentiles, the power does not usually exceed 1.5 MW, not even at the 90 percentile.

Next figures 30 and 31 present, for each hour of the day, the energy supplied by the branch 1 in the following 5 or 6 hours respectively. This information is helpful to establish the energy storage requirements for the battery.

This case includes the 3 branches analyzed previously, therefore, the average time of the incidents is 5 hours, since there are more dispersed areas such as branch 2 and more localized consumption such as branch 1 or 3. It is decided that 5-6 hours is optimal, this is because, although in branches 1 and 3 the reposition time has been assumed to be 5 hours, it is going to be taken into account that the line is very scattered and, on some occasions, incident resolution times can exceed 5 hours.

Observing the 90 percentile in Figure 30, with incidences of 5 hours, it is concluded that the optimum value is 7 MWh, since it is always a little lower. In contrast to the rest of the

cases, observing Figure 31, with incidents of 6 hours, it can be seen that the battery would not be able to fully supply the demand in most cases, since the 90 percentile is around of the 8 MWh. Therefore, it is necessary to analyze which option is better, 7 or 8 MWh.

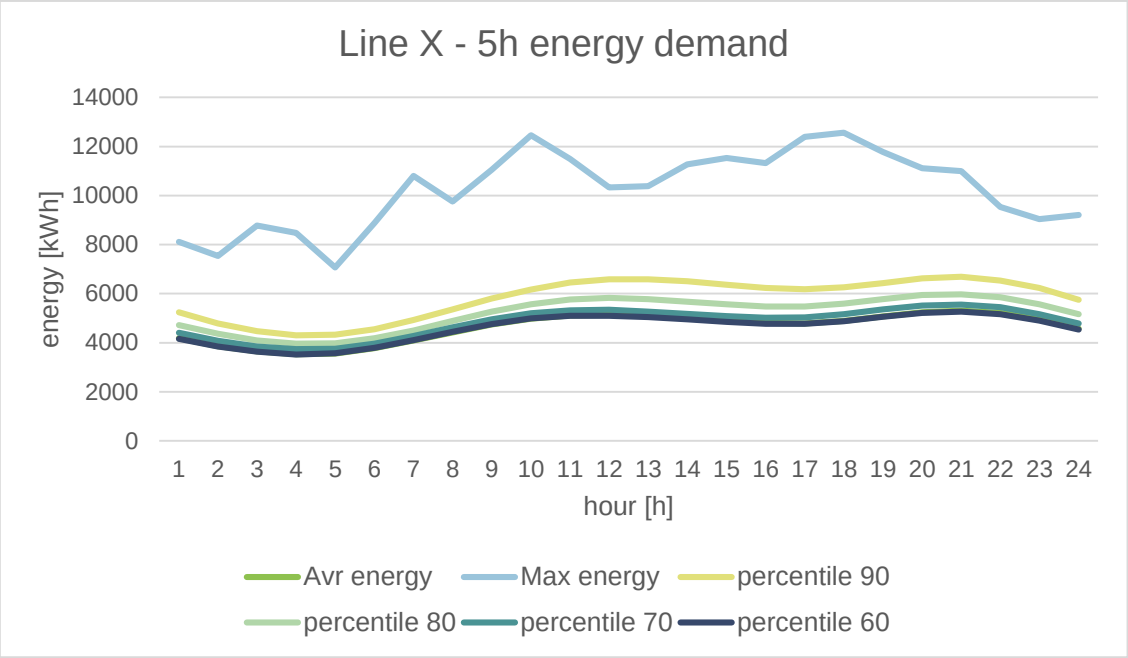

Figure 30. Line X – 5 hour energy demand.

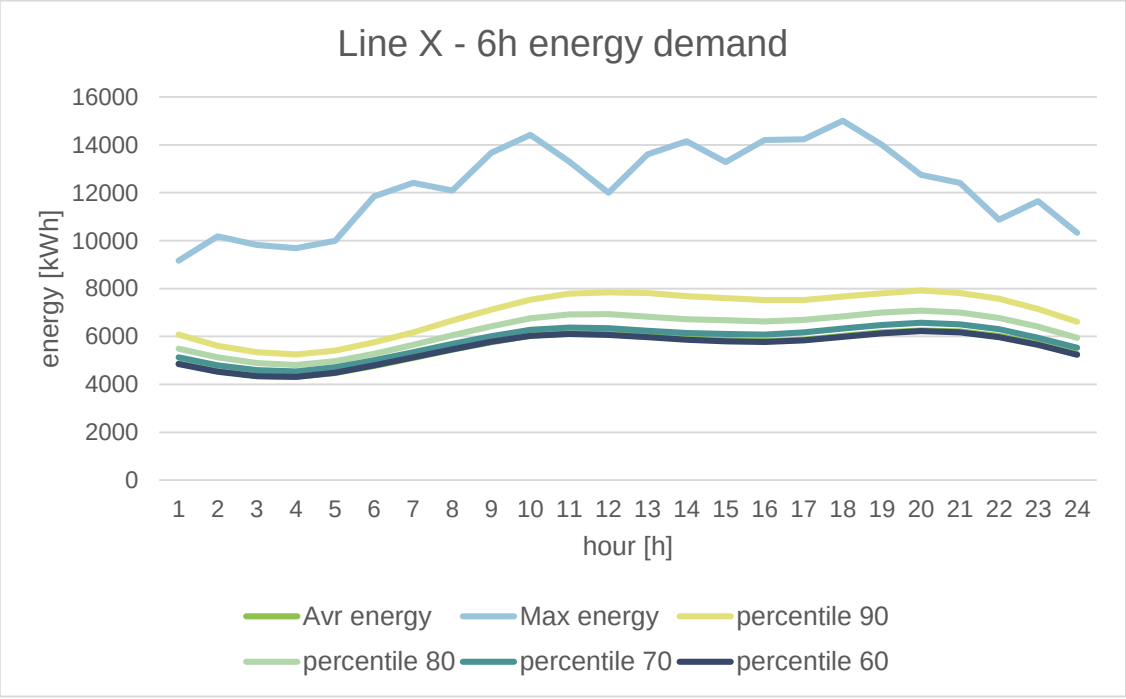

Figure 31. Line X – 6 hour energy demand.

9. 4. 2. VERIFICATION

It must be verified that the battery is optimal for the area, to do this, it is analyzed how much demand this technology is capable of supplying throughout the year if it has those dimensions.

In the first place, the number of hours in a year in which the power demanded, taking into account the vegetative growth, is higher than the battery power is 14 hours, and as a result of that the battery will not be able to attend the demand in those hours. Consequently, the Energy Not Supplied (ENS) in a year could be estimated as 9.73 MWh. The 14 hours above 2 MW can be observed in Figure 32.

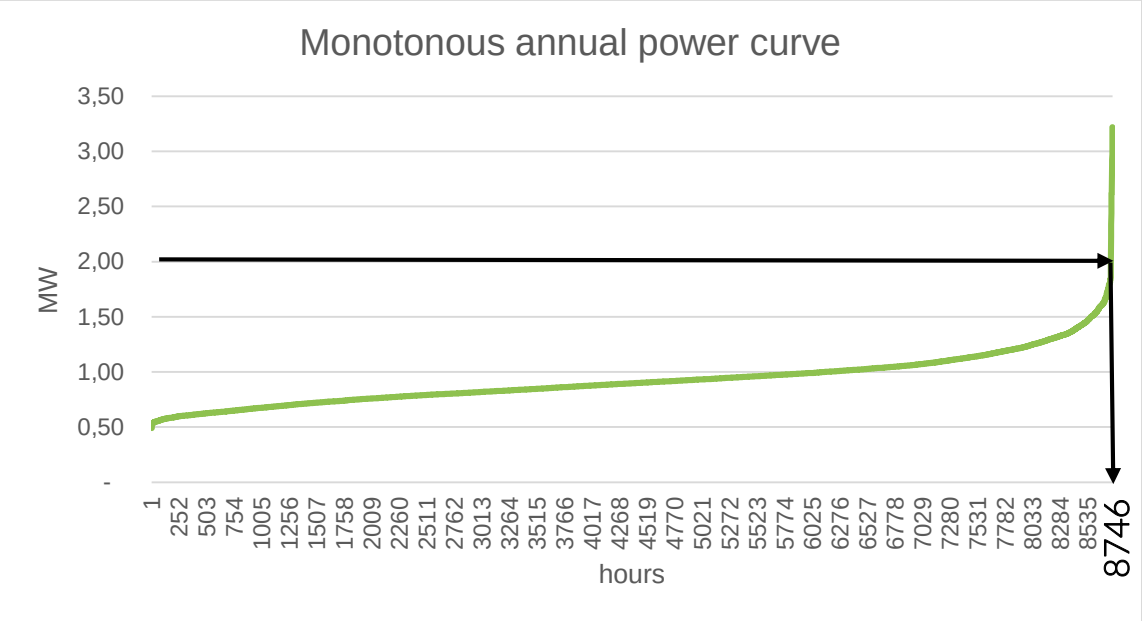

Figure 32. Monotonous annual power curve of Line-X.

Secondly, the number of hours in a year in which the energy demanded in the following 5 hours exceeds the battery storage capacity (8 MWh) is 136 hours, so that the total ENS in a year would be 132.01 MWh. The energy above 8 MWh can be observed in Figure 33.

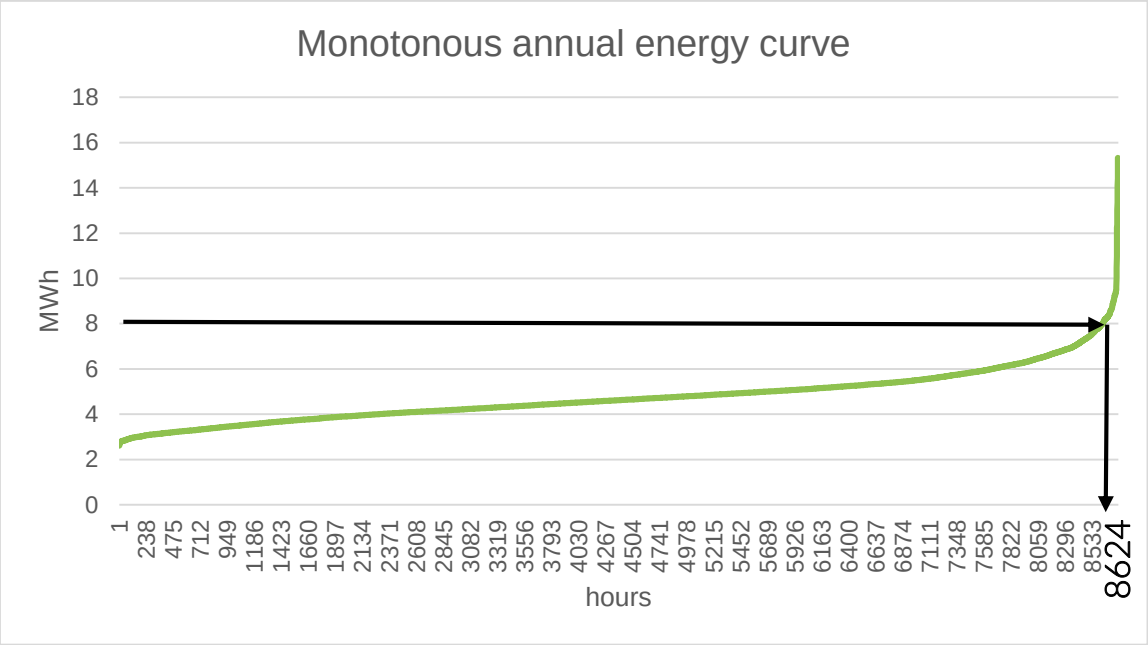

Figure 33. Monotonous annual energy curve of Line-X.

Finally, the number of cases in which, in the event of a contingency, the battery would not be able to supply the entire demand during the defined hours of contingency replacement is 136 hours, in 14 of them because neither the power nor the energy are sufficient. In other words, the battery will be able to supply the total demand in case of a contingency 5 hours long occurred in 98.45% of the 8,760 hours in a year, which can be seen in Figure 34.

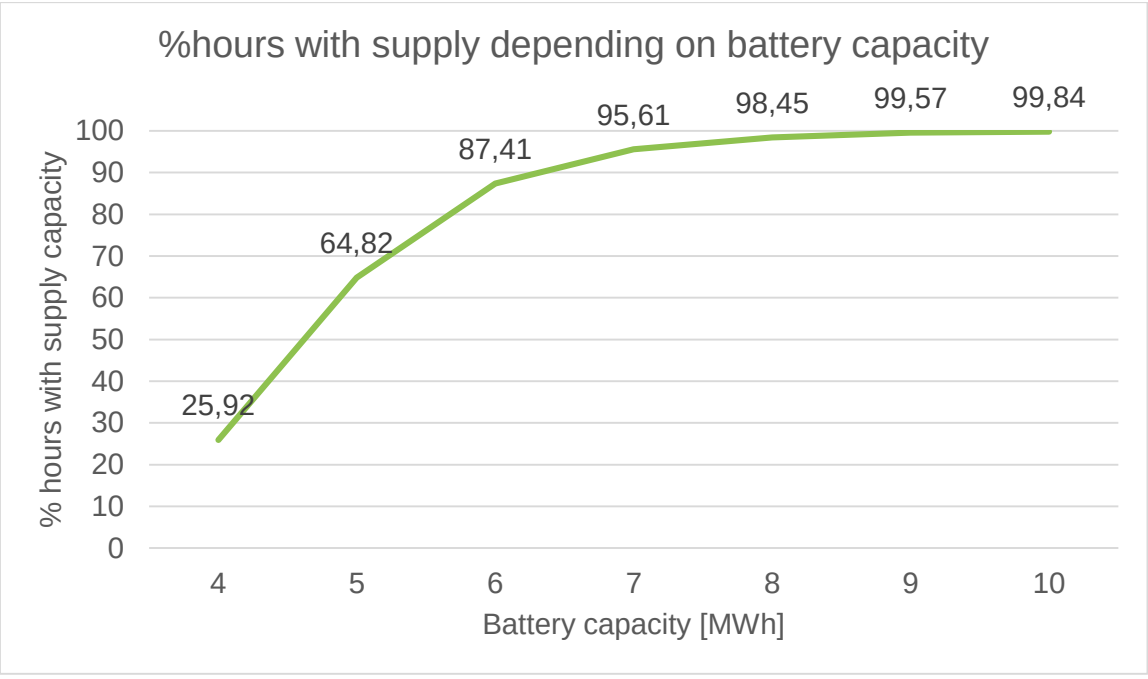

Figure 34. Trade-off between ENS and Battery 4 capacity.

In the remaining 136 hours the battery will not be able to supply all the demand during 5 hours, but it will supply its 8 MWh covering the 87.87% of the energy demanded in that period. This is an optimal result between the technical compromise of supplying the greatest amount of demand, and the economic compromise of not oversizing the tool

9. 4. 3. RESULT

It is concluded that the ideal battery dimensions are 2 MW and 8 MWh capacity.

9.5. TIEPI analysis

This section analyzes the impact of the batteries on the TIEPI (in hours) in the area. Each of the previously mentioned cases has been studied with the corresponding batteries sized in the previous sections. The procedure and calculations have been developed in Annex II and the results obtained are shown in Table 2.

Table 2. TIEPI results.

Case	Description	TIEPI [h]
Base	Initial situation of the line, without batteries	3.897
1	Battery in the largest branch of the line: clients and connected power	1.716
2	Two batteries in the two largest branches of the line in number of clients	1.465
3	Two batteries in the two largest branches of the line in connected power	1.305
4	Three batteries, one in each branch of the line: clients and contected power	1.15
5	One battery to meet all the demand of the line: clients and contected power	1.432

9.6. Results

Finally, this section compiles the results of each of the cases, with the dimensions of their batteries and the resulting TIEPI, in Table 3.

Table 3. Summary of results.

	Description	Battery	Power [MW]	Energy [MWh]	TIEPI [h]
Case 1	Battery in the largest branch of the line: clients and connected power	1	1	4	1.716
Case 2	Two batteries in the two largest branches of the line in number of clients	1	1	4	1.465
		2	0.6	2.5	
Case 3	Two batteries in the two largest branches of the line in connected power	1	1	4	1.305
		3	0.4	1.5	
Case 4	Three batteries, one in each branch of the line: clients and contected power	1	1	4	1.15
		2	0.6	2.5	
		3	0.4	1.5	
Case 5	One battery to meet all the demand of the line: clients and contected power	4	2	8	1.432

10. Economic analysis

The above study responds to a purely technical perspective. However, it is very important to make an economic assessment in order to decide the most efficient solution. This section first examines the current battery market situation (December 2021) and then establishes the initial investment required to install the BESS sized in the previous chapter. To draw conclusions, an analysis is made of the investment cost versus the improvement in the QoS to the grid and the cost versus the benefit to end-consumers, a concept that is explained in section 11.4.

As developed in chapter 7, on legislation of batteries operated by energy distribution companies, this technology cannot be used in peak periods to reduce the price paid by consumers in their tariffs, since distribution companies belong to a regulated business and this type of operation is deregulated, as if it were a generator. Because it is a regulated business, the only use they can make of the BESS is to improve the conditions of the network, and nothing related to reducing the price of peak periods or similar. That is why, in this chapter, an analysis of investment cost versus supply quality improvement will be made, using the TIEPI index [hours] to draw conclusions on the most efficient investment that can be carried out.

To conclude the economic analysis, it is necessary to evaluate the benefit to society of the battery, as a factor to assess which is the optimal case of those studied. The benefit to society has a monetized value, with a formula that is developed in section 10.4, and it is a constraint already used by i-DE to value and prioritize investments.

To recapitulate, the investments in each case study are as follows:

- Case 1: 1 BESS of 1 MW and 4 MWh.
- Case 2: 1 BESS of 1 MW and 4 MWh and 1 BESS of 0.6 MW and 2.5 MWh.
- Case 3: 1 BESS of 1 MW and 4 MWh and 1 BESS of 0.4 MW and 1.5 MWh.
- Case 4: 1 BESS of 1 MW and 4 MWh, 1 BESS of 0.6 MW and 2.5 MWh and 1 BESS of 0.4 MW and 1.5 MWh.
- Case 5: 1 BESS of 2 MW and 8 MWh.

10.1. Market study

The price of batteries has decreased a lot in the last 30 years, specifically by 97% since the first time this technology was commercialized in 1991 [19]. In the last 5 years' prices have decreased by 54%, as can be seen in Figure 35. The accelerated cost reduction year by year is the factor that has made batteries an increasingly competitive and growing technology.

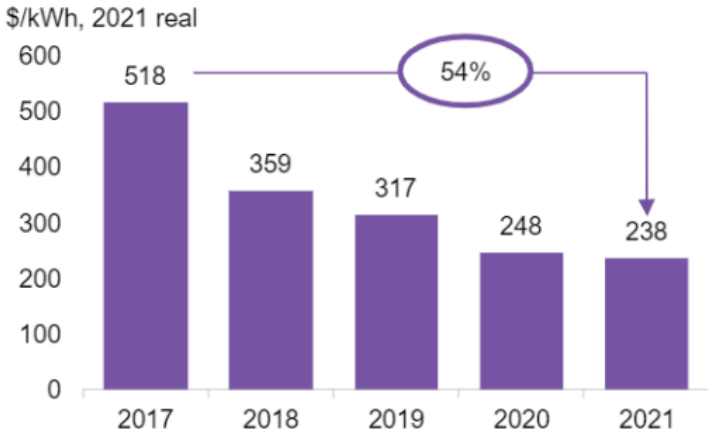

Figure 35. 5-year price reduction for four-hour energy storage systems. [20]

It should be noted that the price of batteries depends on their duration, and the higher the capacity, the lower the unitary cost. As can be seen in Figure 36, with information as of December 21, 2021, the costs of 4-hour batteries are more efficient than smaller batteries. In addition, in this paper the prices used are those of Europe since the project is done in Spain, a price which is higher than the average.

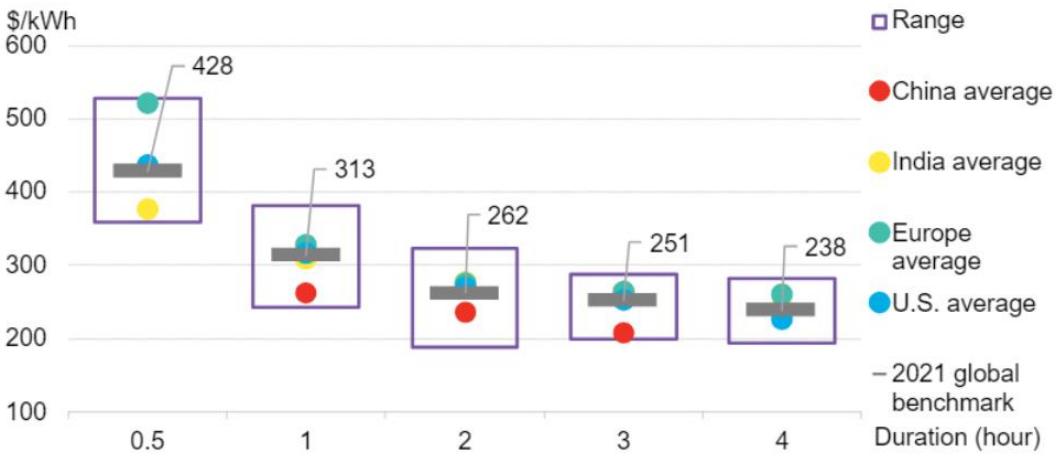

Figure 36. Unitary cost of batteries in 2021. [20]

Moreover, it is important to note that these prices are a function of the usable capacity of the battery. Therefore, they are the $/kWh ratios that it will be used in the batteries at the end of life, but multiplying by the kWh at the beginning of life, an investment that must be incurred to ensure that the battery is useful for 12 years, until it is amortized. In addition, it must be considered that 4 MWh batteries account for 66% of the cost of the energy storage project, but the lower the battery capacity, the lower the percentage corresponding to the investment in the battery itself. To this cost the Power Conditioning System (PCS) must be added, which has more quota the lower the battery capacity is, since batteries with lower capacity are designed to cope with power, above all. In addition, there is the cost of the balance of system, the Energy Management System (EMS), the transformer and the cost margin. All this information can be seen in Figure 37.

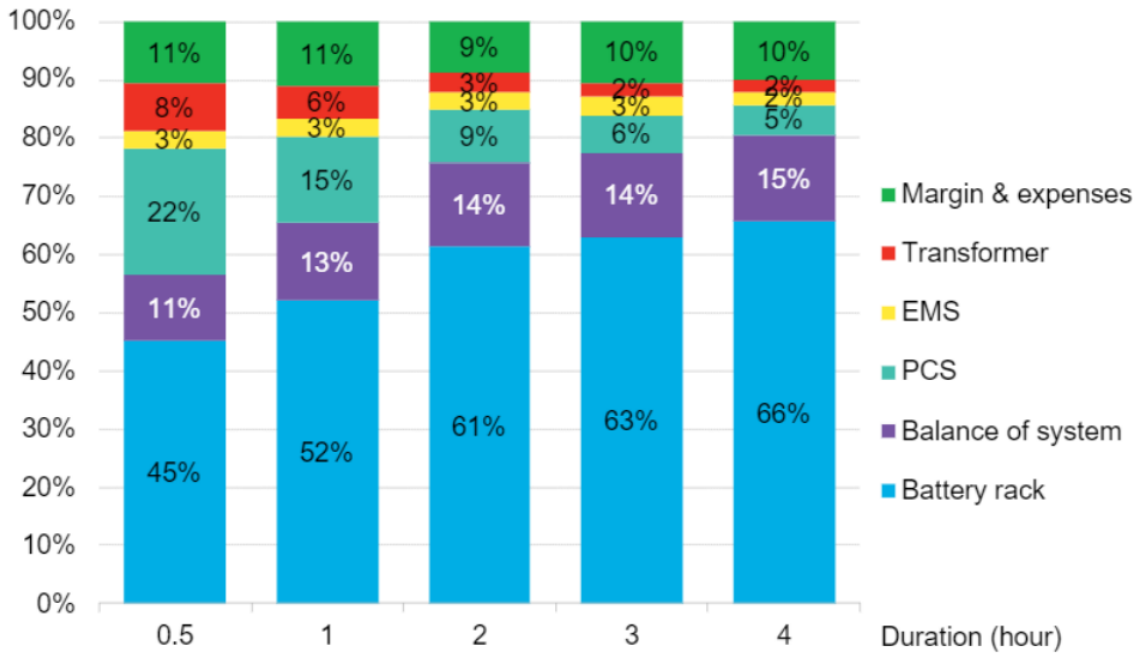

Figure 37. Allocation of costs for BSSE projects. [20]

10.2. Battery CAPEX

As explained in Section 5.3 and 6.4, lithium-ion batteries are intended to have a regulatory life of 12 years being the capacity degradation over this period of 30%. The values of the capacities of the study batteries at the beginning of their useful life are shown in Table 4.

Table 4. Initial capacity of each battery.

	End of Life capacity [MWh]	Initial capacity (+ 30%) [MWh]
Battery 1	4	5.2
Battery 2	2.5	3.25
Battery 3	1.5	1.95
Battery 4	8	10.4

Battery costs are therefore calculated according to the following equation, the values of which vary according to the capacity of the individual batteries.

$$Cost[M€] = \frac{\$}{\boldsymbol{kWh}} * INITIAL\ capacity\ (kWh)\ * \frac{\mathbf{1}}{\%\boldsymbol{total\ work}} * \frac{1\ \mathrm{M\$}}{1000000\ \$} * 0.90\ \frac{\mathrm{M€}}{\mathrm{M\$}}$$

Being the figures of $/kWh those of Figure 9, and the values of %total work those of Figure 10. The cost of each of the four BESS projects are shown in Table 5.

Table 5. Cost of each BESS.

	Cost [M€]
Battery 1	1.938
Battery 2	1.402
Battery 3	1.028
Battery 4	3.754

With the previous information, the cost of each case of study is shown in Table 6.

Table 6. Cost of each case of study.

	Cost [M€]
Case 1	1.938
Case 2	3.340
Case 3	2.966
Case 4	4.368
Case 5	3.754

10.3. Cost vs. TIEPI analysis

With the data obtained in section 11.2, we will proceed to compare which case produces more benefits to the network, i.e., which one provides more quality of supply in terms of the investment cost to be incurred. The TIEPI improvement results have been obtained by subtracting the TIEPI of the base case, 3.897 hours, from the resulting TIEPI in each case. Table 7 shows the result in each case of study.

Table 7. Improvement in TIEPI and Cost of each case of study.

	Improvement in TIEPI [h]	Cost [M€]
Case 1	2.181	1.938
Case 2	2.432	3.340
Case 3	2.592	2.966
Case 4	2.747	4.368
Case 5	2.465	3.754

With this table it is decided to plot the results in a graph (Figure 38) in order to better observe the results, since case 4 is the best in terms of improvement in TIEPI but the most expensive and case 1 is the opposite.

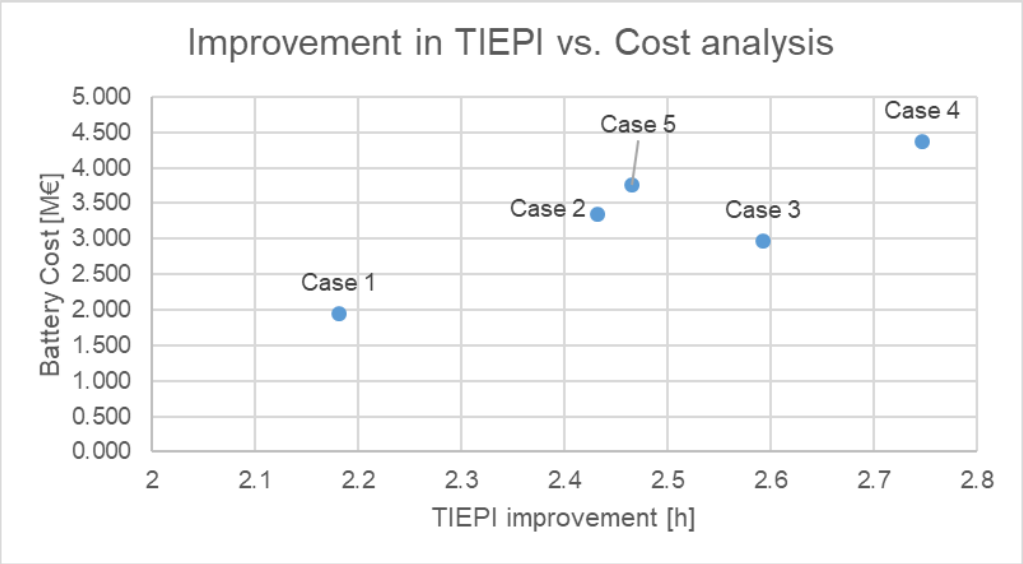

Figure 38. Scatter chart of Improvement in TIEPI vs. Cost.

It can be deduced that the worst ratio, in terms of continuity of supply improvement versus cost, belongs to case 5. This is due to the fact that the battery is very large but does not reduce the incident time too much, because its placement is very limiting against this fact. Even if placed in the branch with the highest number of incidents and the highest TIEPI improvement, this is not an economically efficient option, since, by being placed in a certain branch, the incidents of the other branch cannot be saved. It would be the best option if the highest number of incidents were on the line before splitting into the 3 main branches, but this is not the case. Cases 2 and 4 are not the most efficient either, this is because the battery located in branch 2 does not manage to improve the TIEPI too much. It is the line with the lowest number of installed power, a very relevant factor when calculating the TIEPI. It is a branch that, despite its large extension, does not produce major complications; it does not have many incidents and those that do occur do not increase the TIEPI very much due to its low contracted power.

To view the results more clearly, the ratios are plotted in Table 8 and another scatter plot is drawn in Figure 39.

Table 8. Ratio of improvement in TIEPI vs. Cost.

	Improvement TIEPI/Cost [h/M€]
Ratio case 1	1.125
Ratio case 2	0.728
Ratio case 3	0.874
Ratio case 4	0.629
Ratio case 5	0.657

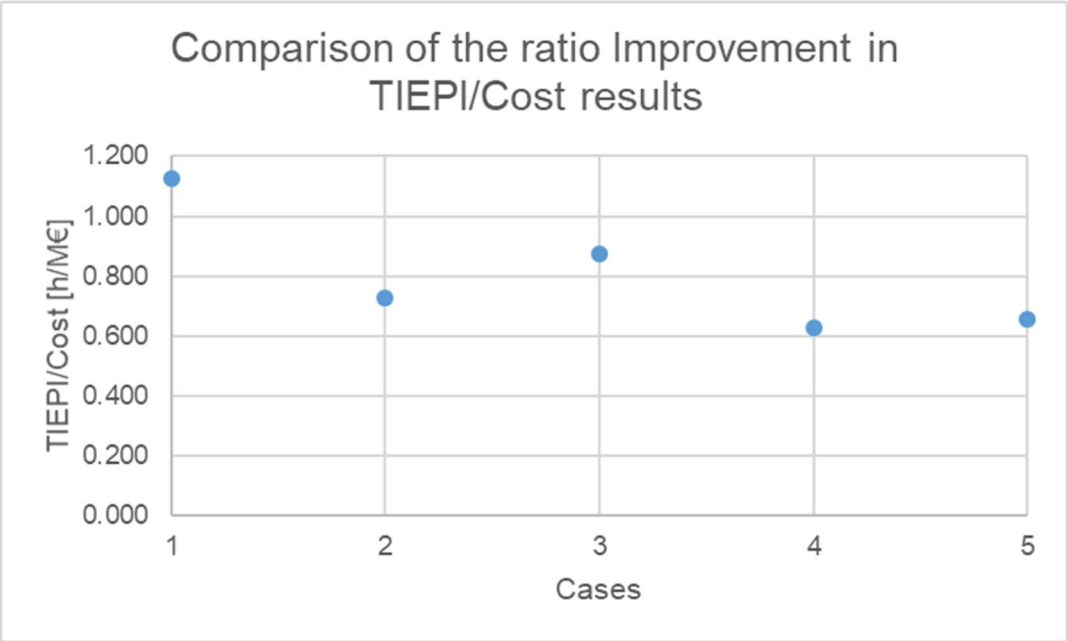

Figure 39. Ratio of improvement in TIEPI vs. Cost.

It is concluded that the best solution corresponds to case 1, a BESS of 1 MW and 4 MWh. This battery is the one that offers the most opportunities for improving the grid, reducing the hours without supply of the line more than the rest of the options, comparing the investments that the distribution company must face. This is maily due to the large amount of money involved.

However, since case 3 (1 BESS on branch 1 and another on branch 3) also produces large QoS improvements although its cost is higher, it is necessary to analyze the benefit it produces to network users, in order to see if the monetized benefit between the investment cost is higher in case 1 or 3, and thus have a parameter to decide which investment to carry out.

10.4.Monetized benefits for society

In i-DE there is a parameter for weighting investments known as monetization of the QoS, which consists of assigning an economic value to the quality of supply, based on the benefits to society of improving the quality of their supply. This monetization counts as another parameter to evaluate which investments have the highest priority. The formula is:

$$Monetized\ QoS\ [€] = Installed\ Power\ [MW] \cdot Time\ without\ service[h]\ \cdot \mathbf{7880}\left[\frac{€}{\boldsymbol{MWh}}\right]$$

The installed power of the equation is the installed power of each branch, as it can be seen in Figure 9 , and the time without service is the average time of the interruption, between 5 – 6 hours. The data can be seen in Table 9.

Table 9. Data of each branch.

	Installed power [MW]	Time without service [h]
Branch 1	6.7	5
Branch 2	2	6
Branch 3	2.5	5

The Value of Lost Load (VoLL) in Spain is estimated in 7.88 €/kWh which has been obtained from the study on the estimation of the VoLL of electricity supply in Europe. This study is from the Agency for the Cooperation of Energy Regulators (ACER), prepared by Cambridge Economic Policy Associates (CEPA) [21].

With all these information, the monetized benefit for each branch is calculated in Table 10.

Table 10. Monetized benefit for society of each branch.

	Monetized benefit for society [M€]
Branch 1	0.264
Branch 2	0.095
Branch 3	0.099

For each case the total values are the addition of the calculation of each corresponding branch:

Case 1: Branch 1

Case 2: Branch 1 + 2

Case 3: Branch 1 + 3

Case 4: Branch 1 + 2 + 3

Case 5: Branch 1 + 2 + 3

The final results are shown in the Table 11 and in the scatter plot of Figure 40.

Table 11. Monetized benefits for society of each case.

	Monetized benefit for society [M€]	Monetized benefit / Cost
Case 1	0.264	0.136
Case 2	0.359	0.107
Case 3	0.362	0.122
Case 4	0.457	0.105
Case 5	0.457	0.122

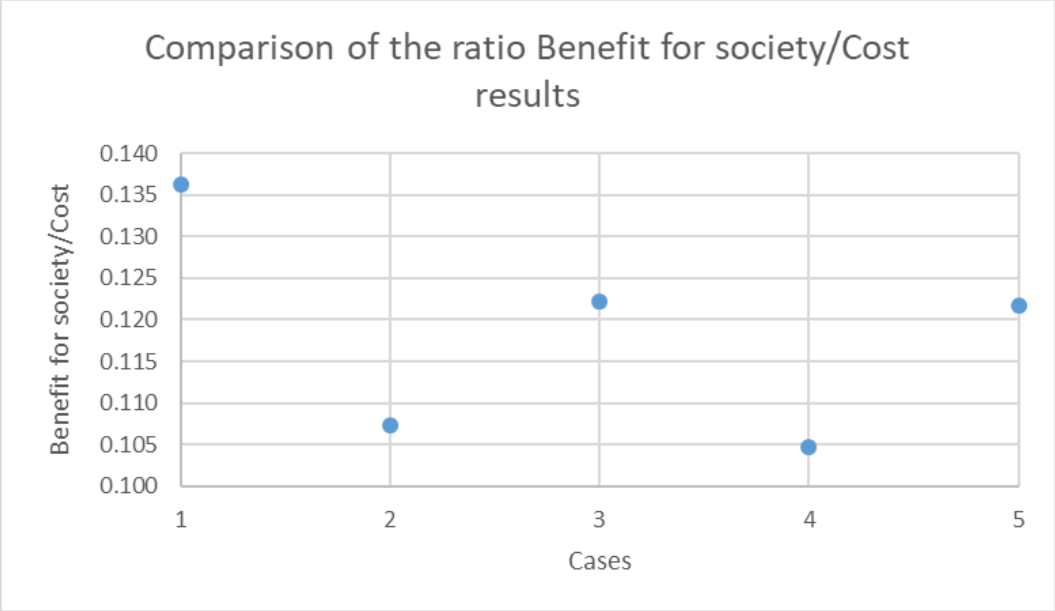

Figure 40. Benefit for society vs. Cost.

It can be concluded that the case of study that brings the greatest benefits to end-consumers with the lowest investment cost, i.e., the most efficient investment, is case 1, a 1 MW and 4 MWh battery. This is the optimal solution both in the QoS improvement scenario, and in the scenario with the greatest benefit to consumers.

11. Analysis of the results

Firstly, regarding the sizing of the batteries, it is important to highlight the importance of the analysis of the power and energy percentiles in order not to oversize the batteries. In this case study, it has been decided to extract the maximum hourly current, thus obtaining the maximum annual hourly power. Having already used the worst case, it is convenient to analyze the hourly demand curve, not only obtaining the most damaging cases, such as the maximum power, but also the different percentiles. Especially the 90 percentile, which covers 90% of the extracted data, avoiding sizing this technology for special occasions.

The first conclusion that can be drawn after analyzing the sizing of the batteries is that in all cases the quality of supply improves, meaning that there is a reduction in the TIEPI index with respect to the base case (without batteries). In some cases, the improvement is much more significant, as in case 4, where the reduction in TIEPI is almost four times lower than in the base case. However, the estimated cost of the case is 4.4 million euros, the highest of all those analyzed, as it consists of 3 batteries distributed along the line. The improvement of the TIEPI with respect to the cost of these batteries is 0.629, that is, for each million euros invested, the TIEPI is reduced by 0.629 hours. This reduction is the smallest of all the cases studied, so this option is discarded due to being the least efficient.

Case 5 is not the best option either, as the improvement of the TIEPI is very limited to the location of the larger battery. It would be a great option if most of the incidents were located on the line before it diverges into the 3 branches, since in that case, it could supply each of them. However, although it is placed on branch 1, which is the one that produces the greatest reduction in TIEPI, the ratio in function of cost is 0.657, a result very similar to that obtained in case 3. It is not a profitable investment as, in this case, it is better to place batteries at the end of the lines, since it is along the branches where the greatest number of incidents occur. Case 5 is not efficient and is discarded as a possible investment.

Case 2 presents a reduction in TIEPI of 0.728 hours per million euros invested, which is not the most efficient option either. Even though branch 2 has a higher number of customers, the TIEPI considers the installed power, which is higher in branch 3. In case of placing two small batteries, it is more efficient to place the second one in branch 3 and not in branch 2, therefore, case 2 is discarded.

When comparing case 1 and case 3, which are the most efficient, the dilemma arises that, although case 1 reduces the TIEPI more per million euros invested, it still results in a high

value (in hours). For this reason, in order to select the most efficient investment, the monetized value of the benefit to society has been used, a parameter that assigns an economic value to the benefit that the improvement in the quality of supply produces in society. The result obtained from this analysis is that the small battery in branch 1 is the most efficient scenario in terms of increasing the benefit to society in relation to the investment cost, in a ratio of 0.132 vs. the 0.12 ratio of case 3.

To conclude, the optimal investment in terms of highest efficiency per million euros invested is case 1, with the small battery in branch 1, being valid the size of 1 MW and 4 MWh.

12. Conclusions

The transition to climate neutrality implies a profound transformation of the energy system. The variable and stochastic nature of the renewable energy resources entails that a variety of tools are needed to provide flexibility to the system, including energy storage. Also, in many locations with large number of incidents, batteries will replace current diesel motor engines, which emit large quantities of carbon and toxic substances into the air and thus, damaging both the environment and the health of residents living nearby.

In addition, it is important that to ensure the reliability of the system, the electricity grids are dimensioned in such a way that they can satisfy the maximum demand during the hours of peak consumption. Consequently, this means that during most of the year the grids are over-dimensioned. As a result, due to the magnitude of the discrepancy in peak demand projections under various scenarios and assumptions, the application of probabilistic forecasting and flexible planning is highly relevant. Batteries are flexible resources that will help and accelerate the transition from a centralized to a distributed electricity system.

Moreover, when demand begins to grow, traditional work is required, which consists of creating new lines or upgrading existing ones. This solution can take decades or even be unfeasible due to environmental problems (protected areas, green zones, areas of cultural interest, etc.). Batteries are temporary solutions to the need for large, long-term works and, in the early future, will become real substitutes for traditional reinforcement works, as prices for this technology are likely to continue to fall in the face of increased performance and capacity.

It is essential that distributors know the limits to the use they can make of this technology, since, as it is a regulated business, they cannot use it for the economic benefit of the company itself (ED 2019/944). For example, they cannot use them to sell energy during peak hours. This type of management must be used by liberalized businesses, both generation batteries, which store surplus renewable energy, and behind-the-meter batteries that allow end-users to manage their own demand. Furthermore, since this is a very recent issue, more regulation and flexibility will be provided to distributors, which is necessary in the new paradigm of the electricity sector. As it has been mentioned above, batteries belonging to the distribution network have several benefits that do not seek to enrich the company but instead, look for the improvement of the operation of the whole electricity system.

Even so, and due to the paradigm shift, that is taking place in the energy sector, various alternatives should be studied to take advantage of energy storage for electricity distribution services, and that are not as restrictive as they are today. As explained in chapter 7, a change in the regulation of distribution network services is needed and will eventually arrive in the near future, as many of the benefits that these batteries could bring to all consumers are being missed.

Nowadays, batteries can only be financed if traditional solutions are not viable and the QoS is very low, and which can be significantly improved with a BESS. In this work, due to the high costs of these batteries at present, several cases for the implementation of a battery have been studied in order to decide the most efficient investment. The optimal solution is explained in the previous chapter, and is the best solution based on QoS and benefit to society versus the investment cost. In the end, the end-consumers in that area, when the battery is implemented, will improve their quality of supply from 4 hours of TIEPI to 1.7 hours, which will also have a significant impact on their quality of life.

From all the above, it can be concluded that batteries are the future, at least in the distribution network, where the benefits are quite remarkable. These benefits are not just for the distribution companies, but for the whole society. BESS are a key resource for achieving the carbon neutrality desired by Europe. All this, together with the price reduction in lithium-ion electrochemical battery technology, makes them a great solution near areas of consumption. All Member States should invest in them to improve their services and move towards a decarbonized and flexible future.

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14. Annex I – Hourly power data

14.1. Branch 1 data

Date/Hour	0:00:00	1:00:00	2:00:00	3:00:00	4:00:00	5:00:00	6:00:00	7:00:00	8:00:00	9:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
01/01/2021	705,147	675,849	656,010	587,482	545,585	494,552	489,396	346,966	341,282	330,887	453,379	584,845	592,331	546,387	679,415	552,011	592,518	718,544	704,414	498,883	530,009	641,171	808,438	608,338
02/01/2021	780,699	692,891	591,146	521,108	491,030	491,030	502,032	380,060	362,293	475,631	541,358	397,084	554,439	571,487	581,289	575,724	756,803	706,923	713,419	654,524	633,347	577,517	793,022	786,975
03/01/2021	786,648	719,742	593,969	526,208	486,969	476,235	455,932	366,086	366,680	388,630	493,712	561,353	592,085	583,945	672,316	572,316	756,803	682,353	683,812	617,426	633,782	614,104	724,104	724,104
04/01/2021	707,010	655,027	594,654	553,733	525,794	493,348	477,059	365,803	351,385	400,376	378,084	336,546	342,530	513,659	580,120	579,677	733,855	684,191	694,921	479,281	464,946	421,514	496,831	560,737
05/01/2021	670,970	620,583	565,534	493,640	458,034	438,046	428,837	329,844	355,004	353,041	625,706	622,763	668,236	625,245	699,243	719,992	719,992	688,964	644,901	644,901	596,936	593,669	497,750	514,780
06/01/2021	659,959	613,811	547,482	485,047	462,487	436,459	436,459	361,780	367,432	344,805	561,358	602,129	702,026	676,825	649,676	646,780	640,472	693,971	589,871	579,843	744,743	795,435	801,574	727,249
07/01/2021	886,881	724,555	592,150	496,420	444,505	441,582	424,551	342,806	355,020	360,537	425,171	524,031	565,664	565,664	685,032	640,448	590,449	615,750	615,750	601,705	560,540	637,284	701,032	701,032
08/01/2021	880,924	614,786	550,671	505,049	465,358	444,445	429,241	381,282	371,817	371,817	396,440	472,482	569,062	662,611	689,612	710,246	744,138	704,002	619,713	683,975	618,088	586,341	673,364	673,364
09/01/2021	641,612	558,952	496,160	484,698	452,825	402,853	403,671	451,777	485,982	526,947	563,547	523,537	525,062	595,269	685,032	650,491	654,917	641,528	611,580	618,524	601,568	588,404	543,533	547,640
10/01/2021	631,713	545,309	490,550	434,478	426,829	408,191	412,298	473,925	482,193	532,342	545,371	670,342	639,812	633,263	633,263	639,397	657,286	657,207	617,022	589,615	552,023	644,643	644,643	644,643
11/01/2021	616,704	573,659	480,916	449,540	429,692	411,260	427,442	463,795	550,201	566,464	629,000	603,537	629,000	636,061	636,061	629,029	648,263	617,991	598,995	595,660	579,959	593,278	691,756	691,756
12/01/2021	593,191	534,741	489,550	423,594	425,067	408,641	437,955	559,545	588,458	512,538	512,538	593,363	593,363	593,363	593,363	624,375	610,319	582,790	582,790	591,756	591,756	591,756	591,756	591,756
13/01/2021	618,463	573,804	503,144	438,341	447,355	423,943	503,134	542,395	541,372	670,342	629,814	639,812	639,812	639,812	639,812	639,812	639,812	639,812	639,812	639,812	639,812	639,812	639,812	639,812
14/01/2021	616,704	573,659	480,916	449,540	429,692	411,260	427,442	463,795	550,201	566,464	629,000	636,061	629,000	636,061	636,061	629,029	648,263	617,991	598,995	595,660	579,959	593,278	691,756	691,756
15/01/2021	593,191	534,741	489,550	423,594	425,067	408,641	437,955	559,545	588,458	512,538	512,538	593,363	593,363	593,363	593,363	624,375	610,319	582,790	582,790	591,756	591,756	591,756	591,756	591,756
16/01/2021	618,463	573,804	503,144	438,341	447,355	423,943	503,134	542,395	541,372	670,342	629,814	639,812	639,812	639,812	639,812	639,812	639,812	639,812	639,812	639,812	639,812	639,812	639,812	639,812
17/01/2021	616,704	573,659	480,916	449,540	429,692	411,260	427,442	463,795	550,201	566,464	629,000	636,061	629,000	636,061	636,061	629,029	648,263	617,991	598,995	595,660	579,959	593,278	691,756	691,756
18/01/2021	593,191	534,741	489,550	423,594	425,067	408,641	437,955	559,545	588,458	512,538	512,538	593,363	593,363	593,363	593,363	624,375	610,319	582,790	582,790	591,756	591,756	591,756	591,756	591,756
19/01/2021	618,463	573,804	503,144	438,341	447,355	423,943	503,134	542,395	541,372	670,342	629,814	639,812	639,812	639,812	639,812	639,812	639,812	639,812	639,812	639,812	639,812	639,812	639,812	639,812
20/01/2021	573,664	535,952	488,876	418,590	384,240	375,005	378,370	420,486	480,178	526,262	534,491	572,579	611,755	639,907	639,907	699,777	829,433	712,950	601,705	560,543	634,357	721,661	833,603	742,799
21/01/2021	592,751	527,119	473,448	415,391	381,749	381,310	384,266	420,089	490,542	515,125	534,491	569,564	603,048	659,213	665,025	619,399	698,633	615,750	601,705	560,543	634,357	721,661	833,603	742,799
22/01/2021	599,752	524,130	447,143	407,968	379,929	374,777	384,266	405,751	478,101	514,235	549,391	601,791	639,907	699,777	829,433	712,950	601,705	560,543	634,357	721,661	833,603	742,799	833,603	742,799
23/01/2021	580,474	564,001	447,143	417,111	395,471	373,808	392,040	392,040	399,104	534,852	532,852	583,235	583,235	583,235	583,235	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852
24/01/2021	587,113	527,898	483,432	413,952	383,895	386,218	386,218	387,921	380,329	409,648	665,573	665,573	566,136	603,782	604,852	583,237	604,852	583,237	614,325	614,325	511,607	626,922	626,922	626,922
25/01/2021	581,710	510,748	457,440	419,294	388,688	374,456	387,342	442,542	577,754	529,682	548,686	583,327	583,327	583,327	583,327	630,584	528,905	506,271	568,774	568,774	568,774	568,774	568,774	568,774
26/01/2021	508,158	469,236	424,612	376,327	367,538	360,283	369,123	414,241	483,503	500,237	534,547	540,245	556,320	561,940	561,940	561,940	490,872	469,902	469,902	469,902	503,858	571,095	587,585	570,555
27/01/2021	572,075	555,168	469,236	378,631	356,743	353,713	353,626	420,804	487,638	487,638	499,759	514,062	514,062	537,544	537,544	481,248	423,983	421,491	413,719	413,719	573,413	573,413	573,413	573,413
28/01/2021	588,015	520,092	468,344	407,968	382,596	374,778	383,366	397,491	373,165	411,255	511,255	503,218	503,878	503,878	503,878	440,875	440,875	486,496	486,496	486,496	486,496	486,496	486,496	486,496
29/01/2021	549,641	511,985	463,432	407,968	379,929	374,777	384,266	405,751	478,101	514,235	549,391	601,791	639,907	699,777	829,433	712,950	601,705	560,543	634,357	721,661	833,603	742,799	833,603	742,799
30/01/2021	580,474	564,001	447,143	417,111	395,471	373,808	392,040	392,040	399,104	534,852	532,852	583,235	583,235	583,235	583,235	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852
31/01/2021	587,113	527,898	483,432	413,952	383,895	386,218	386,218	387,921	380,329	409,648	665,573	665,573	566,136	603,782	604,852	583,237	604,852	583,237	614,325	614,325	511,607	626,922	626,922	626,922
01/02/2021	581,710	510,748	457,440	419,294	388,688	374,456	387,342	442,542	577,754	529,682	548,686	583,327	583,327	583,327	583,327	630,584	528,905	506,271	568,774	568,774	568,774	568,774	568,774	568,774
02/02/2021	508,158	469,236	424,612	376,327	367,538	360,283	369,123	414,241	483,503	500,237	534,547	540,245	556,320	561,940	561,940	561,940	490,872	469,902	469,902	469,902	503,858	571,095	587,585	570,555
03/02/2021	572,075	555,168	469,236	378,631	356,743	353,713	353,626	420,804	487,638	487,638	499,759	514,062	514,062	537,544	537,544	481,248	423,983	421,491	413,719	413,719	573,413	573,413	573,413	573,413
04/02/2021	588,015	520,092	468,344	407,968	382,596	374,778	383,366	397,491	373,165	411,255	511,255	503,218	503,878	503,878	503,878	440,875	440,875	486,496	486,496	486,496	486,496	486,496	486,496	486,496
05/02/2021	549,641	511,985	463,432	407,968	379,929	374,777	384,266	405,751	478,101	514,235	549,391	601,791	639,907	699,777	829,433	712,950	601,705	560,543	634,357	721,661	833,603	742,799	833,603	742,799
06/02/2021	580,474	564,001	447,143	417,111	395,471	373,808	392,040	392,040	399,104	534,852	532,852	583,235	583,235	583,235	583,235	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852
07/02/2021	587,113	527,898	483,432	413,952	383,895	386,218	386,218	387,921	380,329	409,648	665,573	665,573	566,136	603,782	604,852	583,237	604,852	583,237	614,325	614,325	511,607	626,922	626,922	626,922
08/02/2021	508,158	469,236	424,612	376,327	367,538	360,283	369,123	414,241	483,503	500,237	534,547	540,245	556,320	561,940	561,940	561,940	490,872	469,902	469,902	469,902	503,858	571,095	587,585	570,555
09/02/2021	572,075	555,168	469,236	378,631	356,743	353,713	353,626	420,804	487,638	487,638	499,759	514,062	514,062	537,544	537,544	481,248	423,983	421,491	413,719	413,719	573,413	573,413	573,413	573,413
10/02/2021	588,015	520,092	468,344	407,968	382,596	374,778	383,366	397,491	373,165	411,255	511,255	503,218	503,878	503,878	503,878	440,875	440,875	486,496	486,496	486,496	486,496	486,496	486,496	486,496
11/02/2021	549,641	511,985	463,432	407,968	379,929	374,777	384,266	405,751	478,101	514,235	549,391	601,791	639,907	699,777	829,433	712,950	601,705	560,543	634,357	721,661	833,603	742,799	833,603	742,799
12/02/2021	580,474	564,001	447,143	417,111	395,471	373,808	392,040	392,040	399,104	534,852	532,852	583,235	583,235	583,235	583,235	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852
13/02/2021	587,113	527,898	483,432	413,952	383,895	386,218	386,218	387,921	380,329	409,648	665,573	665,573	566,136	603,782	604,852	583,237	604,852	583,237	614,325	614,325	511,607	626,922	626,922	626,922
14/02/2021	508,158	469,236	424,612	376,327	367,538	360,283	369,123	414,241	483,503	500,237	534,547	540,245	556,320	561,940	561,940	561,940	490,872	469,902	469,902	469,902	503,858	571,095	587,585	570,555
15/02/2021	572,075	555,168	469,236	378,631	356,743	353,713	353,626	420,804	487,638	487,638	499,759	514,062	514,062	537,544	537,544	481,248	423,983	421,491	413,719	413,719	573,413	573,413	573,413	573,413
16/02/2021	588,015	520,092	468,344	407,968	382,596	374,778	383,366	397,491	373,165	411,255	511,255	503,218	503,878	503,878	503,878	440,875	440,875	486,496	486,496	486,496	486,496	486,496	486,496	486,496
17/02/2021	549,641	511,985	463,432	407,968	379,929	374,777	384,266	405,751	478,101	514,235	549,391	601,791	639,907	699,777	829,433	712,950	601,705	560,543	634,357	721,661	833,603	742,799	833,603	742,799
18/02/2021	580,474	564,001	447,143	417,111	395,471	373,808	392,040	392,040	399,104	534,852	532,852	583,235	583,235	583,235	583,235	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852
19/02/2021	587,113	527,898	483,432	413,952	383,895	386,218	386,218	387,921	380,329	409,648	665,573	665,573	566,136	603,782	604,852	583,237	604,852	583,237	614,325	614,325	511,607	626,922	626,922	626,922
20/02/2021	508,158	469,236	424,612	376,327	367,538	360,283	369,123	414,241	483,503	500,237	534,547	540,245	556,320	561,940	561,940	561,940	490,872	469,902	469,902	469,902	503,858	571,095	587,585	570,555
21/02/2021	572,075	555,168	469,236	378,631	356,743	353,713	353,626	420,804	487,638	487,638	499,759	514,062	514,062	537,544	537,544	481,248	423,983	421,491	413,719	413,719	573,413	573,413	573,413	573,413
22/02/2021	588,015	520,092	468,344	407,968	382,596	374,778	383,366	397,491	373,165	411,255	511,255	503,218	503,878	503,878	503,878	440,875	440,875	486,496	486,496	486,496	486,496	486,496	486,496	486,496
23/02/2021	549,641	511,985	463,432	407,968	379,929	374,777	384,266	405,751	478,101	514,235	549,391	601,791	639,907	699,777	829,433	712,950	601,705	560,543	634,357	721,661	833,603	742,799	833,603	742,799
24/02/2021	580,474	564,001	447,143	417,111	395,471	373,808	392,040	392,040	399,104	534,852	532,852	583,235	583,235	583,235	583,235	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852
25/02/2021	587,113	527,898	483,432	413,952	383,895	386,218	386,218	387,921	380,329	409,648	665,573	665,573	566,136	603,782	604,852	583,237	604,852	583,237	614,325	614,325	511,607	626,922	626,922	626,922
26/02/2021	508,158	469,236	424,612	376,327	367,538	360,283	369,123	414,241	483,503	500,237	534,547	540,245	556,320	561,940	561,940	561,940	490,872	469,902	469,902	469,902	503,858	571,095	587,585	570,555
27/02/2021	572,075	555,168	469,236	378,631	356,743	353,713	353,626	420,804	487,638	487,638	499,759	514,062	514,062	537,544	537,544	481,248	423,983	421,491	413,719	413,719	573,413	573,413	573,413	573,413
28/02/2021	588,015	520,092	468,344	407,968	382,596	374,778	383,366	397,491	373,165	411,255	511,255	503,218	503,878	503,878	503,878	440,875	440,875	486,496	486,496	486,496	486,496	486,496	486,496	486,496
01/03/2021	549,641	511,985	463,432	407,968	379,929	374,777	384,266	405,751	478,101	514,235	549,391	601,791	639,907	699,777	829,433	712,950	601,705	560,543	634,357	721,661	833,603	742,799	833,603	742,799
02/03/2021	580,474	564,001	447,143	417,111	395,471	373,808	392,040	392,040	399,104	534,852	532,852	583,235	583,235	583,235	583,235	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852
03/03/2021	587,113	527,898	483,432	413,952	383,895	386,218	386,218	387,921	380,329	409,648	665,573	665,573	566,136	603,782	604,852	583,237	604,852	583,237	614,325	614,325	511,607	626,922	626,922	626,922
04/03/2021	508,158	469,236	424,612	376,327	367,538	360,283	369,123	414,241	483,503	500,237	534,547	540,245	556,320	561,940	561,940	561,940	490,872	469,902	469,902	469,902	503,858	571,095	587,585	570,555
05/03/2021	572,075	555,168	469,236	378,631	356,743	353,713	353,626	420,804	487,638	487,638	499,759	514,062	514,062	537,544	537,544	481,248	423,983	421,491	413,719	413,719	573,413	573,413	573,413	573,413
06/03/2021	588,015	520,092	468,344	407,968	382,596	374,778	383,366	397,491	373,165	411,255	511,255	503,218	503,878	503,878	503,878	440,875	440,875	486,496	486,496	486,496	486,496	486,496	486,496	486,496
07/03/2021	549,641	511,985	463,432	407,968	379,929	374,777	384,266	405,751	478,101	514,235	549,391	601,791	639,907	699,777	829,433	712,950	601,705	560,543	634,357	721,661	833,603	742,799	833,603	742,799
08/03/2021	580,474	564,001	447,143	417,111	395,471	373,808	392,040	392,040	399,104	534,852	532,852	583,235	583,235	583,235	583,235	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852
09/03/2021	587,113	527,898	483,432	413,952	383,895	386,218	386,218	387,921	380,329	409,648	665,573	665,573	566,136	603,782	604,852	583,237	604,852	583,237	614,325	614,325	511,607	626,922	626,922	626,922
10/03/2021	508,158	469,236	424,612	376,327	367,538	360,283	369,123	414,241	483,503	500,237	534,547	540,245	556,320	561,940	561,940	561,940	490,872	469,902	469,902	469,902	503,858	571,095	587,585	570,555
11/03/2021	572,075	555,168	469,236	378,631	356,743	353,713	353,626	420,804	487,638	487,638	499,759	514,062	514,062	537,544	537,544	481,248	423,983	421,491	413,719	413,719	573,413	573,413	573,413	573,413
12/03/2021	588,015	520,092	468,344	407,968	382,596	374,778	383,366	397,491	373,165	411,255	511,255	503,218	503,878	503,878	503,878	440,875	440,875	486,496	486,496	486,496	486,496	486,496	486,496	486,496
13/03/2021	549,641	511,985	463,432	407,968	379,929	374,777	384,266	405,751	478,101	514,235	549,391	601,791	639,907	699,777	829,433	712,950	601,705	560,543	634,357	721,661	833,603	742,799	833,603	742,799
14/03/2021	580,474	564,001	447,143	417,111	395,471	373,808	392,040	392,040	399,104	534,852	532,852	583,235	583,235	583,235	583,235	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852
15/03/2021	587,113	527,898	483,432	413,952	383,895	386,218	386,218	387,921	380,329	409,648	665,573	665,573	566,136	603,782	604,852	583,237	604,852	583,237	614,325	614,325	511,607	626,922	626,922	626,922
16/03/2021	508,158	469,236	424,612	376,327	367,538	360,283	369,123	414,241	483,503	500,237	534,547	540,245	556,320	561,940	561,940	561,940	490,872	469,902	469,902	469,902	503,858	571,095	587,585	570,555
17/03/2021	572,075	555,168	469,236	378,631	356,743	353,713	353,626	420,804	487,638	487,638	499,759	514,062	514,062	537,544	537,544	481,248	423,983	421,491	413,719	413,719	573,413	573,413	573,413	573,413
18/03/2021	588,015	520,092	468,344	407,968	382,596	374,778	383,366	397,491	373,165	411,255	511,255	503,218	503,878	503,878	503,878	440,875	440,875	486,496	486,496	486,496	486,496	486,496	486,496	486,496
19/03/2021	549,641	511,985	463,432	407,968	379,929	374,777	384,266	405,751	478,101	514,235	549,391	601,791	639,907	699,777	829,433	712,950	601,705	560,543	634,357	721,661	833,603	742,799	833,603	742,799
20/03/2021	580,474	564,001	447,143	417,111	395,471	373,808	392,040	392,040	399,104	534,852	532,852	583,235	583,235	583,235	583,235	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852
21/03/2021	587,113	527,898	483,432	413,952	383,895	386,218	386,218	387,921	380,329	409,648	665,573	665,573	566,136	603,782	604,852	583,237	604,852	583,237	614,325	614,325	511,607	626,922	626,922	626,922
22/03/2021	508,158	469,236	424,612	376,327	367,538	360,283	369,123	414,241	483,503	500,237	534,547	540,245	556,320	561,940	561,940	561,940	490,872	469,902	469,902	469,902	503,858	571,095	587,585	570,555
23/03/2021	572,075	555,168	469,236	378,631	356,743	353,713	353,626	420,804	487,638	487,638	499,759	514,062	514,062	537,544	537,544	481,248	423,983	421,491	413,719	413,719	573,413	573,413	573,413	573,413
24/03/2021	588,015	520,092	468,344	407,968	382,596	374,778	383,366	397,491	373,165	411,255	511,255	503,218	503,878	503,878	503,878	440,875	440,875	486,496	486,496	486,496	486,496	486,496	486,496	486,496
25/03/2021	549,641	511,985	463,432	407,968	379,929	374,777	384,266	405,751	478,101	514,235	549,391	601,791	639,907	699,777	829,433	712,950	601,705	560,543	634,357	721,661	833,603	742,799	833,603	742,799
26/03/2021	580,474	564,001	447,143	417,111	395,471	373,808	392,040	392,040	399,104	534,852	532,852	583,235	583,235	583,235	583,235	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852
27/03/2021	587,113	527,898	483,432	413,952	383,895	386,218	386,218	387,921	380,329	409,648	665,573	665,573	566,136	603,782	604,852	583,237	604,852	583,237	614,325	614,325	511,607	626,922	626,922	626,922
28/03/2021	508,158	469,236	424,612	376,327	367,538	360,283	369,123	414,241	483,503	500,237	534,547	540,245	556,320	561,940	561,940	561,940	490,872	469,902	469,902	469,902	503,858	571,095	587,585	570,555
29/03/2021	572,075	555,168	469,236	378,631	356,743	353,713	353,626	420,804	487,638	487,638	499,759	514,062	514,062	537,544	537,544	481,248	423,983	421,491	413,719	413,719	573,413	573,413	573,413	573,413
30/03/2021	588,015	520,092	468,344	407,968	382,596	374,778	383,366	397,491	373,165	411,255	511,255	503,218	503,878	503,878	503,878	440,875	440,875	486,496	486,496	486,496	486,496	486,496	486,496	486,496
31/03/2021	549,641	511,985	463,432	407,968	379,929	374,777	384,266	405,751	478,101	514,235	549,391	601,791	639,907	699,777	829,433	712,950	601,705	560,543	634,357	721,661	833,603	742,799	833,603	742,799
01/04/2021	580,474	564,001	447,143	417,111	395,471	373,808	392,040	392,040	399,104	534,852	532,852	583,235	583,235	583,235	583,235	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852
02/04/2021	587,113	527,898	483,432	413,952	383,895	386,218	386,218	387,921	380,329	409,648	665,573	665,573	566,136	603,782	604,852	583,237	604,852	583,237	614,325	614,325	511,607	626,922	626,922	626,922
03/04/2021	508,158	469,236	424,612	376,327	367,538	360,283	369,123	414,241	483,503	500,237	534,547	540,245	556,320	561,940	561,940	561,940	490,872	469,902	469,902	469,902	503,858	571,095	587,585	570,555
04/04/2021	572,075	555,168	469,236	378,631	356,743	353,713	353,626	420,804	487,638	487,638	499,759	514,062	514,062	537,544	537,544	481,248	423,983	421,491	413,719	413,719	573,413	573,413	573,413	573,413
05/04/2021	588,015	520,092	468,344	407,968	382,596	374,778	383,366	397,491	373,165	411,255	511,255	503,218	503,878	503,878	503,878	440,875	440,875	486,496	486,496	486,496	486,496	486,496	486,496	486,496
06/04/2021	549,641	511,985	463,432	407,968	379,929	374,777	384,266	405,751	478,101	514,235	549,391	601,791	639,907	699,777	829,433	712,950	601,705	560,543	634,357	721,661	833,603	742,799	833,603	742,799
07/04/2021	580,474	564,001	447,143	417,111	395,471	373,808	392,040	392,040	399,104	534,852	532,852	583,235	583,235	583,235	583,235	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852	604,852
08/04/2021	587,113	527,898	483,432	413,952	383,895	386,218	386,218	387,921	380,329	409,648	665,573	665,573	566,136	603,782	604,852	583,237	604,852	583,237	614,325	614,325	511,607	626,922	626,922	626,922
09/04/2021	508,158	469,236	424,612	376,327	367,538	360,283	369,123	414,241	483,503	500,237	534,547	540,245	556,320	561,940	561,940	561,940	490,872	469,902	469,902	469,902	503,858	571,095	587,585	570,555
10/04/2021	572,075	555,168	469,236	378,631	356,743	353,713	353,626	420,804	487,638	487,638	499,759	514,062	514,062	537,544	537,544	481,248	423,983	421,491	413,719	413,719	573,413	573,413	573,413	573,413
11/04/2021	588,015	520,092	468,344	407,968	382,596	374,778	383,366	397,491	373,165	411,255	511,255	503,218	503,878	503,878	503,878	440,875	440,875	486,496	486,496	486,496	486,496	486,496	486,496	486,496
12/04/2021	549,641	511,985	463,432	407,968	379,929	374,777	384,266	405,751	478,101	514,235	549,391	601,791	639,907	699,777

514,999 443,842 471,244 367,660 359,571 339,058 342,471 373,904 543,143 623,814 448,758 453,516 317,187 319,722 322,321 314,108 366,445 524,820 486,523 424,533 439,355

14.2. Branch 2 data

Date/Hour	00:00:00	01:00:00	02:00:00	03:00:00	04:00:00	05:00:00	06:00:00	07:00:00	08:00:00	09:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
01/02/2021	241.57	241.47	201.73	184.71	167.59	158.07	154.91	178.69	183.71	213.09	193.03	217.63	229.33	229.02	226.75	208.98	209.88	219.53	229.45	226.53	225.71	228.36	248.77	246.82
02/02/2021	248.17	222.3	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
03/02/2021	248.16	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
04/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
05/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
06/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
07/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
08/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
09/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
10/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
11/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
12/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
13/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
14/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
15/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
16/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
17/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
18/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
19/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
20/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
21/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
22/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
23/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
24/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
25/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
26/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
27/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
28/02/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
01/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
02/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
03/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
04/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
05/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
06/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
07/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
08/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
09/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
10/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
11/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
12/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
13/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
14/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
15/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
16/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
17/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
18/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
19/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
20/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
21/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
22/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63
23/03/2021	248.14	241.42	223.31	193.21	173.61	161.53	150.59	192.31	178.86	216.62	193.32	216.91	226.02	229.03	240.61	260.91	260.16	260.97	268.93	256.56	246.11	241.75	242.17	242.63

| | | |

14.3. Branch 3 data

Date/Hour	0:00:00	1:00:00	2:00:00	3:00:00	4:00:00	5:00:00	6:00:00	7:00:00	8:00:00	9:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
01/02/2021	224.46	212.26	212.76	198.02	165.02	158.04	158.46	164.94	170.41	198.26	199.26	205.51	228.76	228.46	240.41	253.14	248.98	240.72	170.01	164.94	158.46	164.77	154.77	180.35
02/02/2021	182.78	182.17	151.48	138.48	146.01	131.52	116.62	121.78	118.78	116.09	115.52	117.43	118.27	116.09	118.14	118.27	116.62	120.74	118.64	118.27	116.09	115.52	117.43	122.75
03/02/2021	252.94	227.17	174.81	168.27	173.41	165.73	163.79	169.88	183.50	183.76	182.76	183.58	183.76	179.64	179.42	179.64	183.88	179.42	179.64	183.88	183.76	179.64	183.88	183.76
04/02/2021	210.07	182.63	179.60	174.06	173.41	169.42	165.55	163.45	168.34	169.79	169.42	168.34	169.79	169.42	168.34	169.79	169.42	168.34	169.79	169.42	168.34	169.79	169.42	168.34
05/02/2021	204.78	182.54	179.60	174.06	173.41	169.42	165.55	163.45	168.34	169.79	169.42	168.34	169.79	169.42	168.34	169.79	169.42	168.34	169.79	169.42	168.34	169.79	169.42	168.34
06/02/2021	185.44	184.64	185.76	179.06	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65
07/02/2021	174.92	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32
08/02/2021	151.92	143.22	151.76	151.07	151.76	151.07	151.76	151.07	151.76	151.07	151.76	151.07	151.76	151.07	151.76	151.07	151.76	151.07	151.76	151.07	151.76	151.07	151.76	151.07
09/02/2021	174.19	153.76	172.44	172.44	174.06	172.44	172.44	172.44	172.44	172.44	172.44	172.44	172.44	172.44	172.44	172.44	172.44	172.44	172.44	172.44	172.44	172.44	172.44	172.44
10/02/2021	184.66	184.69	187.47	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64
11/02/2021	156.94	147.24	144.02	144.02	144.02	144.02	144.02	144.02	144.02	144.02	144.02	144.02	144.02	144.02	144.02	144.02	144.02	144.02	144.02	144.02	144.02	144.02	144.02	144.02
12/02/2021	174.46	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32
13/02/2021	184.71	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64	184.64
14/02/2021	174.46	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32	174.32
15/02/2021	182.17	182.17	182.17	182.17	182.17	182.17	182.17	182.17	182.17	182.17	182.17	182.17	182.17	182.17	182.17	182.17	182.17	182.17	182.17	182.17	182.17	182.17	182.17	182.17
16/02/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
17/02/2021	230.76	230.76	230.76	230.76	230.76	230.76	230.76	230.76	230.76	230.76	230.76	230.76	230.76	230.76	230.76	230.76	230.76	230.76	230.76	230.76	230.76	230.76	230.76	230.76
18/02/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
19/02/2021	174.92	174.92	174.92	174.92	174.92	174.92	174.92	174.92	174.92	174.92	174.92	174.92	174.92	174.92	174.92	174.92	174.92	174.92	174.92	174.92	174.92	174.92	174.92	174.92
20/02/2021	193.10	172.73	174.59	183.63	183.63	168.65	174.59	172.73	172.73	172.73	172.73	172.73	172.73	172.73	172.73	172.73	172.73	172.73	172.73	172.73	172.73	172.73	172.73	172.73
21/02/2021	167.91	161.24	161.24	161.24	161.24	161.24	161.24	161.24	161.24	161.24	161.24	161.24	161.24	161.24	161.24	161.24	161.24	161.24	161.24	161.24	161.24	161.24	161.24	161.24
22/02/2021	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54
23/02/2021	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54
24/02/2021	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54	176.54
25/02/2021	177.78	174.98	176.47	174.98	174.98	174.98	174.98	174.98	174.98	174.98	174.98	174.98	174.98	174.98	174.98	174.98	174.98	174.98	174.98	174.98	174.98	174.98	174.98	174.98
26/02/2021	185.44	184.64	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65	185.65
27/02/2021	174.07	174.67	174.67	174.67	174.67	174.67	174.67	174.67	174.67	174.67	174.67	174.67	174.67	174.67	174.67	174.67	174.67	174.67	174.67	174.67	174.67	174.67	174.67	174.67
28/02/2021	178.60	184.37	184.37	184.37	184.37	184.37	184.37	184.37	184.37	184.37	184.37	184.37	184.37	184.37	184.37	184.37	184.37	184.37	184.37	184.37	184.37	184.37	184.37	184.37
01/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
02/03/2021	167.30	167.65	168.29	201.74	201.74	201.74	201.74	201.74	201.74	201.74	201.74	201.74	201.74	201.74	201.74	201.74	201.74	201.74	201.74	201.74	201.74	201.74	201.74	201.74
03/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
04/03/2021	178.60	178.37	178.37	178.37	178.37	178.37	178.37	178.37	178.37	178.37	178.37	178.37	178.37	178.37	178.37	178.37	178.37	178.37	178.37	178.37	178.37	178.37	178.37	178.37
05/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
06/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
07/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
08/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
09/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
10/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
11/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
12/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
13/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
14/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
15/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
16/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
17/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
18/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
19/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
20/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
21/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
22/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
23/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
24/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
25/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
26/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
27/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
28/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
29/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
30/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
31/03/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
01/04/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
02/04/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
03/04/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
04/04/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
05/04/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
06/04/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70
07/04/2021	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70	182.70

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14.4. Line-X data

Date/Hour	0:00:00	1:00:00	2:00:00	3:00:00	4:00:00	5:00:00	6:00:00	7:00:00	8:00:00	9:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00
01/01/2021	1348.95	1283.67	1173.23	1159.11	1143.58	1134.83	1188.32	1188.02	1139.26	1136.78	1218.37	1146.78	1202.71	1183.37	1139.06	1147.06	1190.41	1184.18	1174.02	1153.84	1148.29	1148.29	1148.29	1148.29
02/01/2021	1494.54	1242.22	1108.49	1042.67	1023.74	1042.71	1141.07	1162.27	1238.41	1234.84	1233.27	1423.71	1464.47	1281.41	1366.38	1339.38	1402.83	1224.58	1217.55	1146.06	1153.43	1139.74	1139.74	1139.74
03/01/2021	1418.37	1109.53	977.61	913.89	843.30	900.05	1080.17	1228.11	1141.07	1141.07	1141.07	1141.07	1141.07	1141.07	1141.07	1141.07	1141.07	1141.07	1141.07	1141.07	1141.07	1141.07	1141.07	1141.07
04/01/2021	1230.14	1042.57	968.69	839.05	774.47	802.25	877.48	940.04	1088.68	1214.42	1232.47	1284.45	1201.74	1162.77	1238.47	1290.74	1232.78	1284.68	1255.96	1278.29	1278.29	1278.29	1278.29	1278.29
05/01/2021	955.55	930.48	906.16	837.48	794.42	766.34	939.61	969.74	1035.90	1035.90	1035.90	1035.90	1035.90	1035.90	1035.90	1035.90	1035.90	1035.90	1035.90	1035.90	1035.90	1035.90	1035.90	1035.90
06/01/2021	1545.67	1482.64	1409.27	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
07/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
08/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
09/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
10/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
11/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
12/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
13/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
14/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
15/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
16/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
17/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
18/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
19/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
20/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
21/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
22/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
23/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
24/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
25/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
26/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
27/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
28/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
29/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
30/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
31/01/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
01/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
02/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
03/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
04/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
05/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
06/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
07/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
08/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
09/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
10/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
11/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
12/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
13/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
14/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
15/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
16/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
17/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
18/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
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20/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
21/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
22/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
23/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
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25/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
26/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
27/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
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29/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
30/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
31/02/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
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03/03/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
04/03/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
05/03/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
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10/03/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
11/03/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
12/03/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
13/03/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
14/03/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
15/03/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
16/03/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
17/03/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
18/03/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
19/03/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
20/03/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
21/03/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
22/03/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60
23/03/2021	1484.36	1445.74	1389.98	1353.67	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60	1284.60

| | | |

15. Annex II – TIEPI analysis

In this section TIEPI calculations, in hours, are going to be developed using the PSS/E software. First of all, a model of the network in a compatible format has been downloaded from the PSE database, from where the .sav and .sld files are obtained. It has been decided to extract the network that forms the entire substation under study, and then delete all the information that do not belong to the corresponding line. The result in PSS/E is shown in Figure 41, with the line of the study in a black color and the deleted information in pink.

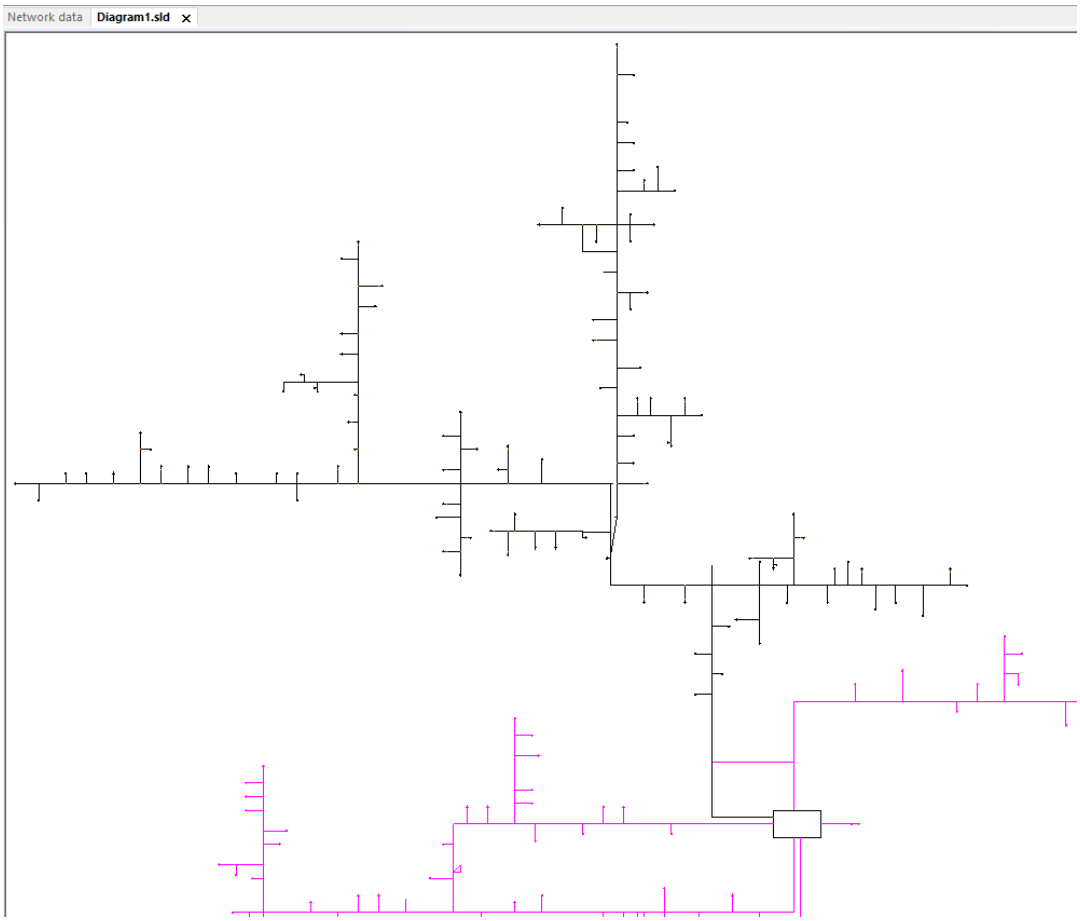

Figure 41. Network scheme in PSS/E.

The TIEPI is going to be calculated with the Python scripting tool used by i-DE to calculate this index. A drop-down of the TIEPI program can be seen in Figure 42, where the failure rate of underground lines, overhead lines, and transformer stations (CTs) are corresponding to the Castilla-La Mancha area of the project and collected from the i-DE database.

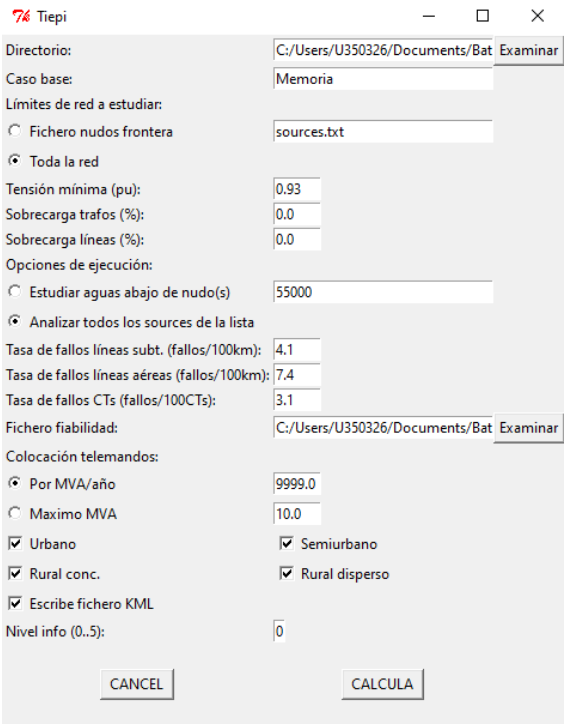

Figure 42. TIEPI script.

Once the optimum capacity of the battery has been sized due to the technical conditions of the line, the TIEPI calculation and analysis will be carried out. The cases to be analyzed have already been described previously and are as follows:

1. A battery in the branch of the line with the highest demand (number of customers and contracted power), which is the one oriented to the left.

2. Two batteries, the same as in case 1 with the addition of another one in the central branch, which is the second one with the largest number of customers.

3. Two batteries, the same as in case 1, adding another one in the right branch, which is the second one with the highest contracted power.

4. A large battery capable of supplying the whole line.

15.1. Base case

In this case, the TIEPI of the line will be calculated in the current conditions, before introducing any type of battery. The result is shown in Figure 43.

```
MVAh:59.27 MVA:15.21   TIEPI:3.897
TIEPI semiurbano:3.57
TIEPI rural concentrado:3.88
TIEPI rural disperso:7.09
Generado archivo tiepi.kml

 RED DE PSSE_3_0 (1.7.1.0)
 MODELO DE FECHA: 15/08/2021 13:00:00 - VERSION RAW DATA VRAW
```

Figure 43. TIEPI result of the base case.

15.2. Case 1

In this case a battery is placed in the most loaded branch, as shown in Figures 44 and 45. In Figure 44 it can be seen that the type of node is 3, which corresponds to a swing node, which serves to balance the power flows. Figure 45 shows the network scheme with the battery. It should be noted that the battery can solve more incidents if it is placed at the ends of the line, since the idea of the battery is to solve the incidents and supply energy to the consumption downstream of the incident. Even so, there must be space for its implementation, i.e., i-DE must have a large transformation center and space in that location to be able to implement a battery. Therefore, as in the case of other batteries, positions are chosen as far away as possible from the substation.

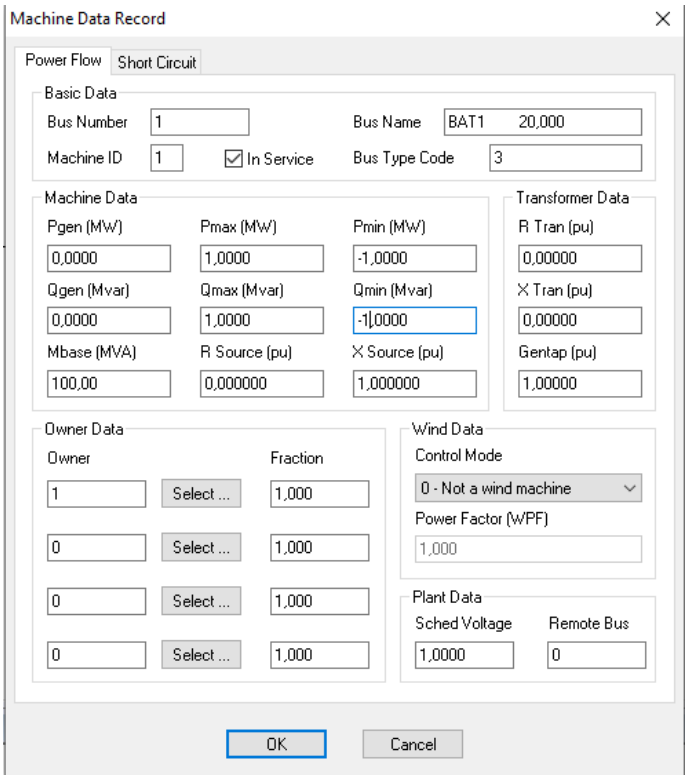

Figure 44. Battery 1 data.

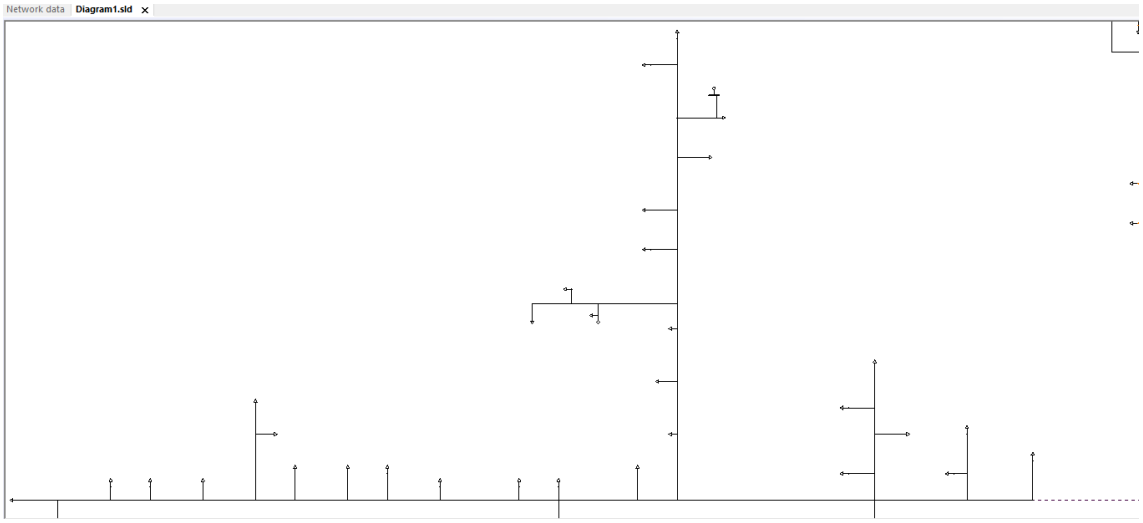

Figure 45. PSS/E scheme with battery 1.

The result obtained is shown in Figure 46, with TIEPI reductions of more than the half compared to the base case.

```
MVAh:26.10 MVA:15.21   TIEPI:1.716
TIEPI semiurbano:3.55
TIEPI rural concentrado:1.68
TIEPI rural disperso:3.37
Generado archivo tiepi.kml

 RED DE PSSE_3_0 (1.7.1.0)
 MODELO DE FECHA: 15/08/2021 13:00:00 - VERSION RAW DATA VRAW
```

Figure 46. TIEPI results case 1.

15.3. Case 2

Two batteries are placed, one identical to the one in case 1 and the other one in the central branch, which have been previously dimensioned (BESS 1 and 2). Figures 47 and 48 show the configuration of the central branch battery, which follows the same conditions as in case 1 as far as its placement is concerned.

The result is shown in Figure 49, being slightly more favorable than in the case with a battery.

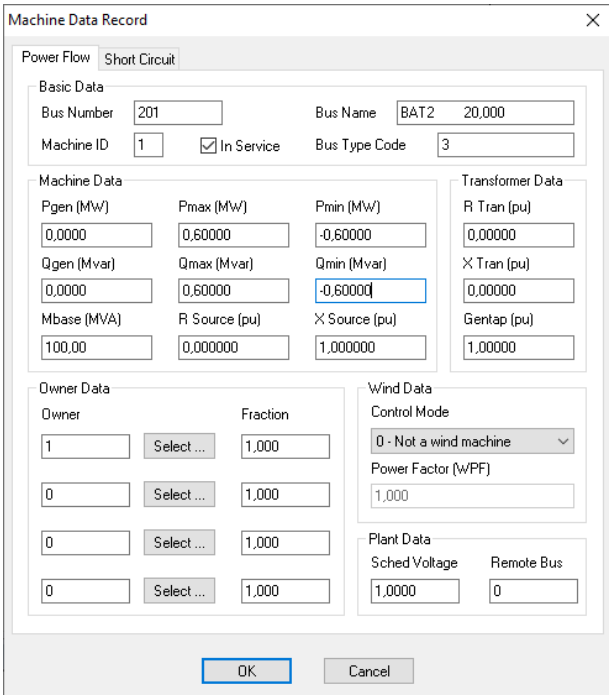

Figure 47. Battery 2 data.

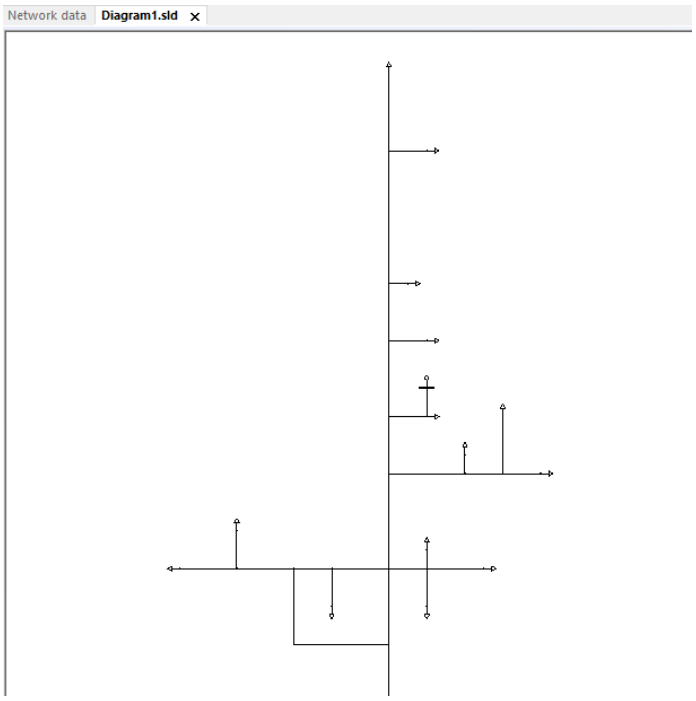

Figure 48. PSS/E scheme with battery 2.

```
MVAh:22.28 MVA:15.21   TIEPI:1.465
TIEPI semiurbano:3.55
TIEPI rural concentrado:1.42
TIEPI rural disperso:3.37
Generado archivo tiepi.kml

 RED DE PSSE_3_0 (1.7.1.0)
 MODELO DE FECHA: 15/08/2021 13:00:00 - VERSION RAW DATA VRAW
```

Figure 49. TIEPI results case 2.

15.4. Case 3

Two batteries are placed, one identical to the one in case 1 and the other one in the right branch, which have been previously dimensioned (batteries 1 and 3). Figures 50 and 51 show the configuration of the battery on the right branch, which follows the same conditions as in case 1 in terms of its placement.

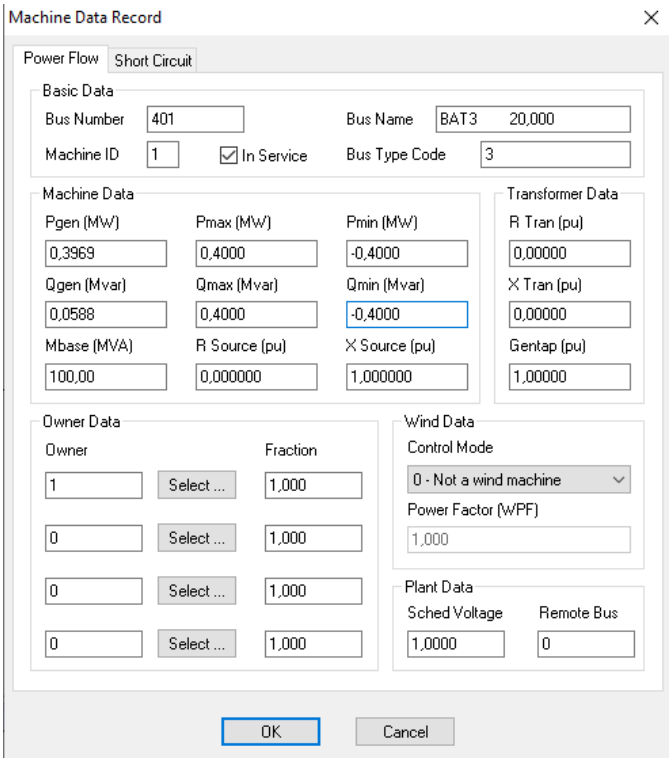

Figure 50. Battery 3 data.

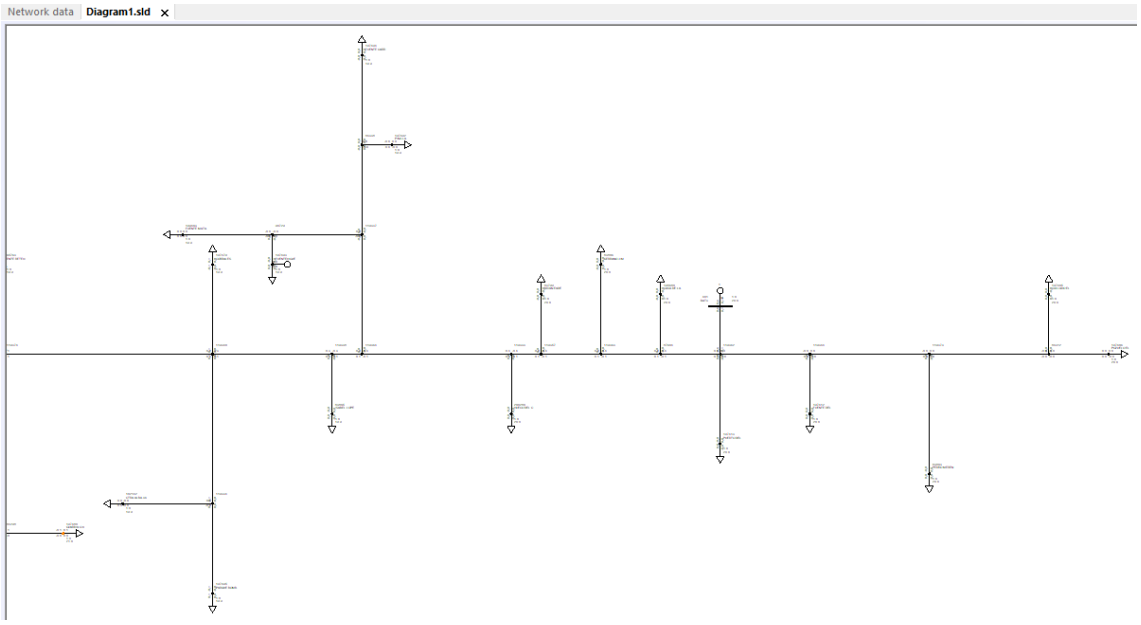

Figure 51. PSS/E scheme with battery 3.

The result obtained is shown in Figure 52, being more beneficial than case 2, so it can be concluded that a battery in the right branch is more effective than in the center. This may be due to the fact that the right branch, although it has fewer customers, has a higher contracted power, which is what the TIEPI index, as already explained in this document, uses as a denominator. It should be taken into account that, if the SAIDI, which takes into account the number of customers, were analyzed, the results could be different. Since in Spain the quality incentives of the distributors are governed by the TIEPI [17], this index is chosen rather than the SAIDI.

```
MVAh:19.86 MVA:15.21   TIEPI:1.305
TIEPI semiurbano:1.18
TIEPI rural concentrado:1.29
TIEPI rural disperso:3.37
Generado archivo tiepi.kml

 RED DE PSSE_3_0 (1.7.1.0)
 MODELO DE FECHA: 15/08/2021 13:00:00 - VERSION RAW DATA VRAW
```

Figure 52. TIEPI results case 3.

15.5. Case 4

Next, we study the case in which the three batteries described above (BESS 1, 2 and 3) are placed, each one at the ends of its branch. The result obtained is shown in Figure 53.

```
MVAh:17.50 MVA:15.21   TIEPI:1.150
TIEPI semiurbano:1.18
TIEPI rural concentrado:1.13
TIEPI rural disperso:3.37
Generado archivo tiepi.kml

 RED DE PSSE_3_0 (1.7.1.0)
 MODELO DE FECHA: 15/08/2021 13:00:00 - VERSION RAW DATA VRAW
```

Figure 53. TIEPI results case 4.

15.6. Case 5

In this case we are going to represent the possibility of introducing a battery in the network, capable by itself of generating power for the entire line (battery 4). The problem with this case is its placement, since if it is placed at the end of a branch, it will not be able to solve the problems at the ends of the other branches. Therefore, it is concluded that the optimal location of this battery is on the left branch, the one with the highest demand, placed at the end of it, as in case 1. In this way it will improve the TIEPI in greater quantity than in case 1, since during incidents near the substation, where the whole line is out of supply, this battery will be able to recover it, reducing the TIEPI a lot. The battery configuration is shown in Figures 54 and 55.

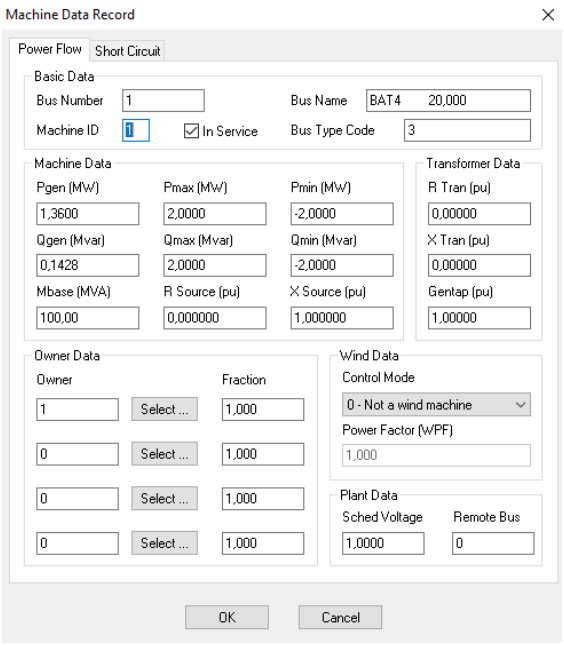

Figure 54. Battery 4 data.

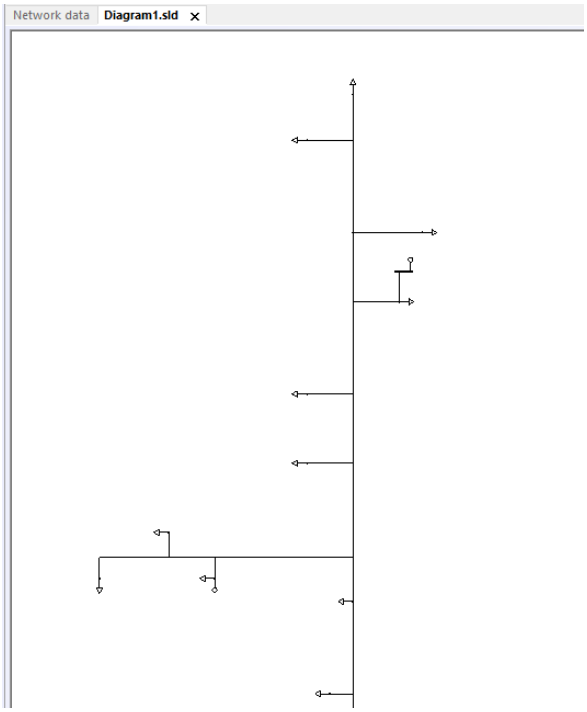

Figure 55. PSS/E scheme with battery 4.

The results obtained are shown in Figure 56, being much more favorable than the base case but not as optimal as in case 4, with 3 small batteries, each placed at one end.

```
MVAh:21.78 MVA:15.21   TIEPI:1.432
TIEPI semiurbano:3.04
TIEPI rural concentrado:1.39
TIEPI rural disperso:3.37
Generado archivo tiepi.kml

 RED DE PSSE_3_0 (1.7.1.0)
 MODELO DE FECHA: 15/08/2021 13:00:00 - VERSION RAW DATA VRAW
```

Figure 56. TIEPI results case 5.

The battery could be placed in another branch, but this would not be optimal since the largest incidences and those that most affect the TIEPI are in the left branch. This is demonstrated by moving the battery to the central branch, as shown in Figure 57.

The results obtained are shown in Figure 58, and are considerably less favorable than those in Figure 56.

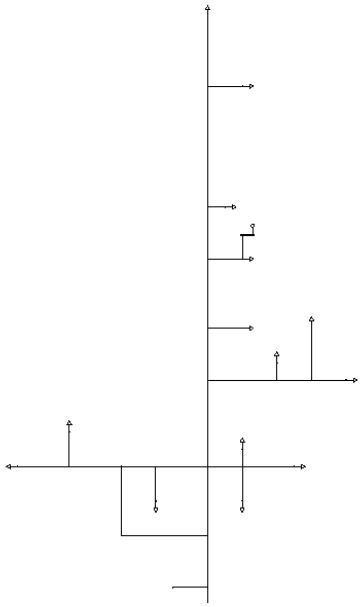

Figure 57. Change of the battery node in case 5.

```
MVAh:34.28 MVA:15.21   TIEPI:2.254
TIEPI semiurbano:3.04
TIEPI rural concentrado:2.22
TIEPI rural disperso:5.15
Generado archivo tiepi.kml

 RED DE PSSE_3_0 (1.7.1.0)
 MODELO DE FECHA: 15/08/2021 13:00:00 - VERSION RAW DATA VRAW
```

Figure 58. TIEPI results case 5 with change in battery location.

15.7. Summary

The results obtained from the TIEPI study are compiled in Table 12.

Table 12. Summary of TIEPI results.

Case	Description	TIEPI [h]
Base	Initial situation of the line, without batteries	3.897
1	Battery in the largest branch of the line: clients and connected power	1.716
2	Two batteries in the two largest branches of the line in number of clients	1.465
3	Two batteries in the two largest branches of the line in connected power	1.305
4	Three batteries, one in each branch of the line: clients and contected power	1.15
5	One battery to meet all the demand of the line: clients and contected power	1.432

16. Annex III – SDG reflection

The Sustainable Development Goals (SDGs), or also called Global Goals were conceived at the United Nations Conference on Sustainable Development held in Rio de Janeiro in 2012 [22] and represent the basic principles to end poverty, protect the planet and ensure that all people enjoy peace and prosperity. These Goals replace the Millennium Development Goals (MDGs, 2000) to create a set of global goals related to the environmental, political, and economic challenges facing our world. They were adopted by Member States in 2015 as a universal call and will guide the policies and funding of the United Nations Development Agenda for the next 15 years. This program has 17 SDGs in an integrated manner, such that interventions in one area will affect the outcomes of others and their development and implementation must balance environmental, economic, and social sustainability. Within the SDGs there are 3 that are key to energy development:

7- Affordable and clean energy: ensure access to affordable, secure, sustainable and modern energy for all.

11- Sustainable cities and communities: Making cities and human settlements inclusive, safe, resilient and sustainable.

13- Climate action: Adopt urgent measures to combat climate change and its effects.

This document focuses especially on goals 7 and 13, which are the main focus for i-DE, part of the Iberdrola group. Figure 59 shows the Iberdrola group's contributions to these objectives.

SDG 7: *Affordable and clean energy*.

It is imperative to obtain non-polluting alternatives to supply the distribution network. As will be explained in this document, there are many locations that suffer numerous incidents and have diesel engines to back them up. These engines are highly polluting and are also located close to population centers, which is detrimental to the health and well-being of their citizens. The battery is an affordable energy resource for areas far away from large consumption and in need of a backup, due to a large number of incidents.

SDG 13: *Climate action.*

Following the same ideas as the previous objective, it is vital to move towards a decarbonized future, with a sustainable exploitation of resources that ensures a future for the next generations. Moving towards the implementation of batteries in the grid is fully aligned with this objective and is a small step towards a distributed electricity system with an abundance of renewable generation and smart consumption.

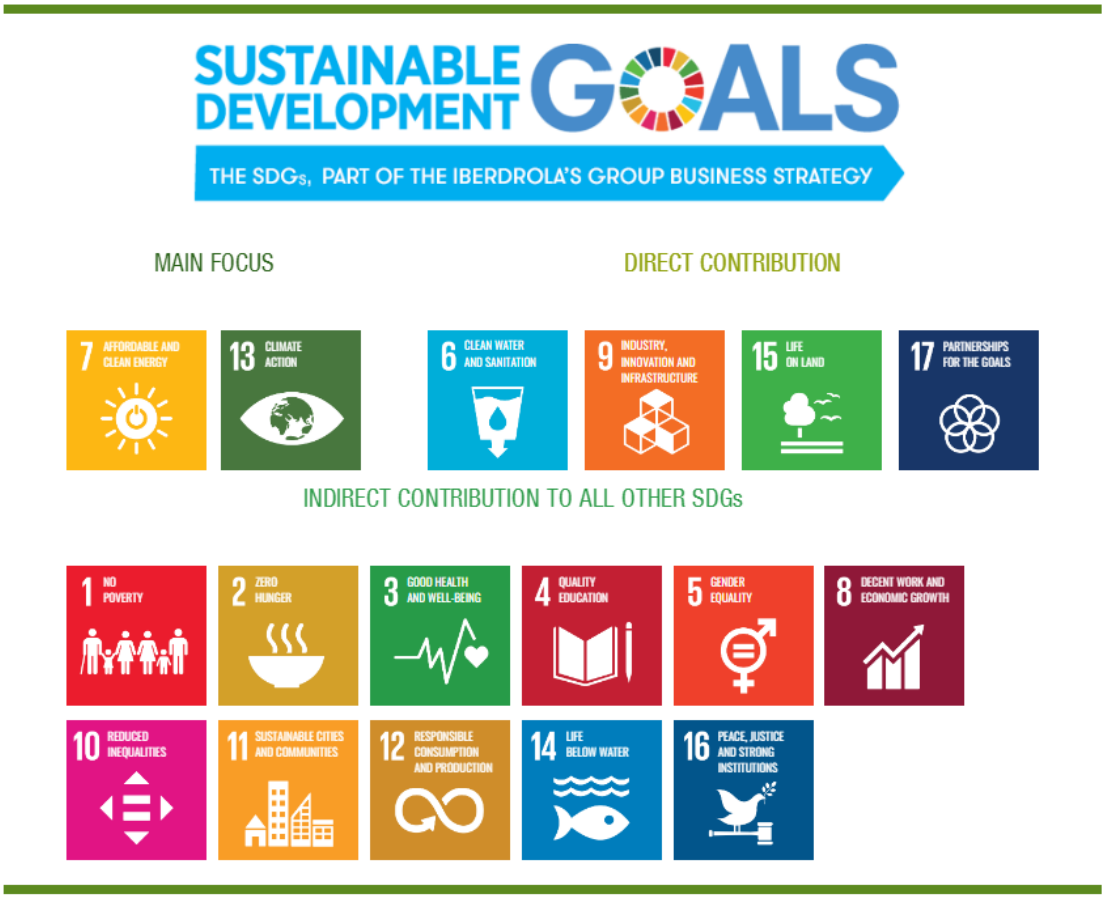

Figure 59. The SDGs as part of Iberdrola Group's business strategy. [23]