Flexibility services and investments in distribution networks

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Abstract

This study focuses on the economic question of how to invest in the electricity grid. When a Distribution System Operator (DSO) currently must deal with grid problems such as congestion or overvoltage, the idea is usually to reinforce the grid, such as changing lines or transformers, although there is the possibility to opt for so-called utility services to help in these situations and avoid reinforcing the grid. Although this is an option, there are still not the right incentives from the regulatory authorities for the DSO to actually opt for the use of such services. This work aims to make an economic study of how much it would cost annually to opt for one of these services, in this case the type of service was a Battery Energy Storage System (BESS), and compare it with how much compensation would be received, in Spain, if it opted for the reinforcement of the network, more expediently the exchange of electrical cables

Keywords: Electric grids, Distribution Network, Flexibility services, Overloading, Economic Analysis, Battery, Cost Comparison, Annual Cost

1 Introduction

With the increase of renewable energy resources (RES) and electrical vehicles (EVs), in distributed generation and increased network use [1], congestion issues occur much more often in distribution networks, such issues are often handled by the distribution system operator (DSO), that opts for grid expansion with the objective of giving back to the grid an equilibrium for the long term. Another way to prevent such congestion is the addition of flexibility services. Flexibility services can be defined as the ability of a power system to utilise resources to respond to changes in net load [2], more on that is explained in section 2. So comes the role of the DERs (Distributed Energy Resources), which can play a substantial role, because they can offer their flexibility services to the DSO in order to help with the good performance of the grid and prevent grid expansion. The DSO, when faced with a congestion or overloading problem in his grid, should be able to have the option of procuring flexibility service preventing grid reinforcement. For this to happen, the market as to be structured for such operations to occur, to have the better exploitation of DERs flexibility or even other identities that can offer such service, on [3] the authors focus on this matter, where it is stated the fact that in a lot of Europeans countries such interactions between the DSO and other identities, such as DERs, that offer flexibility services are not allowed, and they analyse the European regulation to identify the most important ways to enable such interaction.

If the changes in the markets occur and in the regulation mechanisms, giving the DSO the actual power on having the option to go for a flexibility service it is important to see if in fact such options are profitable for the DSO and that is where the motivation sets place, is to give a view of comparison between the annual cost of investing, in flexibility service, in the case of this study a Battery energy storage system (BESS), and the remuneration given by the regulation of Spain that is built to only support the DSO into grid expansion [1].

The remain of this paper is structured as follows. In the next section is developed a review of the relevant literature to the study of DSO role in the sector, flexibility services and DERs. In the third section the benchmarking and modelling of the select grids is presented. The fourth section discusses the developed methodology, main objective of the present study. The fifth section presents the economic analysis. And finally, section six summarises the conclusions of the study and indicates further research needs.

2 Literature Review

2.1Distribution System Operators

A Distribution System Operator (DSO) is an active manager or owner of one electricity distribution network, and it is responsible for its operation and maintenance, aiming at a good performance. A good performance consists on meeting the demands of all the end-users of the distribution network. Examples of DSOs around Europe are EDP Distribuição from Portugal, EREDES and E-Distribución from Spain.

Due to the high demand of electricity DSO face today the challenge of guaranteeing flexibility. This can be achieved through the usage of flexibility services that can be obtained from different sources as is the case of DER. To explore this in adequate form the need of appropriated regulation is needed. These aspects are analysed below.

2.2 Flexibility Services and DERs

With the growth of renewable energy sources (RES) the need for flexibility will always increase. The interaction between DSOs and DERs through the aggregator in electricity markets is assumed by several research papers. But in a lot of European countries such interaction is not allowed. DERs are raising challenges due the introduction of reverse flow, congestion problems, and voltage limit violations, but can also help in a lot of technical problems for the DSOs if they are properly aggregated, such aggregation is defended by the local flexibility markets (LFM), allowing markets access to DERs that is studied in [2].

With regulatory changes in the Europe Union, the aggregator will be able to offer its flexibility from the distribution level up to short-term markets. This will enable DSOs to become their own active manager, and so to search for flexibility in their geographical area. In this context DERs will then become the main flexibility source for DSOs to handle technical problems giving them an alternative to avoid grid reinforcement [3].

This type of changes will change the DSO markets, and these markets will be correlated into the LFM, but this type of markets are still under research or at pilot-stage in Europe.

Once again, the flexibility services provided by DERs help the distribution network problems such as overloading of the lines due to the current passing being higher from the maximum current that the lines can sustain, and are alternatives to grid reinforcement, but in some way the DSOs have to see if, in fact, makes sense to invest in this type of flexibility services. In [4] a method is introduced where for each flexibility service exists a value of flexibility that is what the DSO is ready to pay for the corresponded flexibility. If the cost of using the flexibility service exceeds its value of flexibility, contracting that service will not be economically viable for the DSO. Several types of flexibility services exist, such as demand response, BESS, reconfiguration (RE) exist.

But these types of investments, in flexibility services, demand an adequate regulation, as it will be discussed in the next section.

2.3 DSO Flexibility and Regulation

In 2014 the article [5], the authors focused on the missing aspect of the current regulation, recognising DSOs as regulated monopolies but also key players along the electricity supply chain. DERs appear as a key player and can help the DSOs, with the right market and regulation, and a more efficient and cleaner electricity system could be achieved.
With the rapid growth of DERs and electrification mobility, and the challenges they imposed on the DSOs, the necessity for upgrading to a more intelligent and communicative electricity network was inevitable, the so-called Smart Grids (SG).
The deployment of a SG imposes a change in a distribution network that is operated by DSOs. A good correlation between the regulating identities and the DSOs is important since the regulation directly affects DSO budgets and in turn their ability raise capital for the implementation of innovative SG project [6], [7].
In [8] the author defended in fact that regulation can have an important role in setting up a good framework for grid investment.
The regulatory mechanisms can be divided in the way they induce cost efficiency or productivity by providing relevant incentives to DSOs. In [9] the study identifies three broad categories of models:(1) incentive-based models, (2) cost-based models, (3) hybrid-based models.
An Innovation-stimulus mechanism is also a way the regulators have used to stimulate innovation within the distribution system; this type of mechanism is designed to support innovative ideas that DSOs are unlikely to undertake without incentives.

2.4 The Problem

With base on all the matters that were addressed before, the main goal of this study is to when in a situation where a better function of the grid is needed, should the DSO invest in grid reinforcements or should he invest in flexibility services by either contracting a type of service or doing it by themself. Cases of grid stressing will be created, and then budgets will be calculated, one for the grid reinforcement and other for the flexibility service and compared in order to see which one is more plausible for the DSO to invest on.

3. Benchmarking Distribution Networks & Modelling

3.1 Building the benchmark

Due to lack of information in a real Distribution Network, in order to use it for testing and evaluation, a real grid was not used. Going for a testing grid gives the advantage of the availability of data and the certainty of working properly. The study aims the DSOs, so the medium voltage distribution grid allows for a better interpretation of the problem, because it has the benefit of introducing distributed generation units and assessing its impact. Two testing grids were assembled and modelled, GRID1 and GRID2, the benchmarking and modelling of both grids will be discussed in this section.

3.1.1 GRID1

This grid was taken out of the article [10], where the authors have chosen replicating the case IEEE 37 bus test system from the article [11], and adapted it to 25 kV and all necessary elements (Figure 3.1). From analysing the grid, all the elements were extracted and organised into support data (better detailed in the thesis) the grid has 35 nodes and 35 lines, has transformers of 160, 250, 400 and 630 kVA connecting the LV side to the MV side, and each station has a different structure regarding the transformers, some stations have only one transformer, others have 2 or 3. Exists two types of cables, that are referred in Table (3.1).

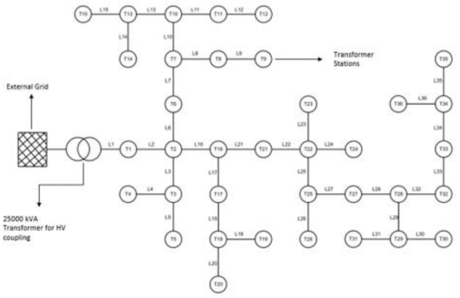
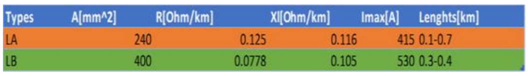


Figure 3 .1 - Grid 1layout (source: [10]*)*

Table 3. 1 - Features of the Lines/Cables



Types	A[mm^2]	R[Ohm/km]	Xl[Ohm/km]	Imax[A]	Lenghts[km]
LA	240	0.125	0.116	415	0.1-0.7
LB	400	0.0778	0.105	530	0.3-0.4

3.1.2 GRID2

Grid selected from the study [12]. For this study, the interest was only taken into the MV grid topology where the LV grids are connected, with 9 nodes. The rated line to line voltage is 11kV, and the distance between each node is 600m. This type of topology is a realistic urban MV feeder topology [13] (Figure 3.2). The grid is constituted by transformers of 250, 400 and 630 kVA connecting the LV side to the MV side, and the cable is referred in Table (3.2) [14] (the rest of the elements are refereed on the thesis).

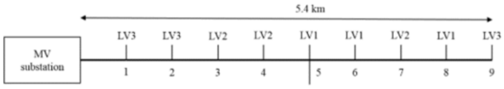
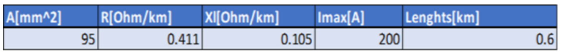


Figure 3. 2 - Grid 2 layout (source: [35])

Table 3. 2 - Features on the Lines/Cables



A[mm^2]	R[Ohm/km]	Xl[Ohm/km]	Imax[A]	Lenghts[km]
95	0.411	0.105	200	0.6

3.1.3 Tool "PandaPower"

"PandaPower" is a Python based power system analysis tool aimed to the automation of analysis and optimisation of balanced power systems. It provides the possibility of doing power flow and optimal power flow tests, also topology graph searches and short-circuit calculations. The network model is modelled on electric elements such as lines, transformers and switches, and all of these elements exist in variety in the format of libraries and are validated against industry-standard software tools according to article [15].

3.2 Demand and PV generation values in Spain

One of the challenges faced during this phase, of gathering values for demand and PV generation, was to find an accurate efficient way to demonstrate a consumption curve as well as a PV generation curve, this due to lack of information given from the utilities, realistic measures of consumption or PV generation never was obtained. This being said, the approach was:

1. Using the Red Eléctrica website, taking out the aggregated consumption curves and measured PV generation curves, hourly, from January and June.
2. Doing an average of consumption and PV generation for each day.
3. A scaling approach was done in order to remove the values of consumption and PV generation from their scale, MWh, and just have curves of "per se" behaviour type, either from consumption or PV generation.
4. To then pass the unit values again to MWh, a power factor was created for consumption and PV generation, and a mathematical calculation was made, for each load, the unit value is multiplied by the power factor and by the value of the transformer that is making the MV/LV connection in that load, that comes in MVA, in order to obtain a value in the dimension to MW (Eq.(1)). For PV generation (Eq.(2)) the power factor, comes in 0.5 and 0.7, representing the percentage of PV that is used.

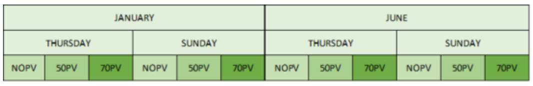
$$Load(MW) = Unit\ Value \times Power\ Factor \times Power\ of\ the\ Tranformer(MVA) \qquad (1)$$

$$PV_{GEN(MW)} = Unit\ Value \times Generation\ Factor \times Power\ of\ the\ Transformer(MVA) \qquad (2)$$

3.3 Scenarios Definition

In order to build good cases for testing, the grids were exposed to a scenario during winter, the month of January was chosen, and in the summer, the month of June was chosen because of the PV generation behaviour that differs from one to the other. So the data collected, that was referred to in the section before, was from the month of January in 2019 in Spain and from the month June in 2019 in Spain, after the data was all extracted, was gathered into weekdays and weekends and an average, of the consumption and PV generation, for each day was made, with the objective of obtaining a curve that demonstrated an average behaviour of consumption and an average of PV generation for weekdays and weekends, after this Thursday and Sunday were the days selected from weekends and weekdays to build cases on. At this point this we have the following scenarios, a Thursday and Sunday from January and a Thursday and Sunday from June. To finalise for each day of each month four scenarios of PV generation used were created; for each scenario, a different generation factor that is used on Eq.(2), expressed in percentage, was used, so a scenario of non-PV (NoPV) a 50% of PV (50PV), 70% of PV (70PV) and. That 50% and 70% refers to the generation factor in Eq.(2) (Table 3.3).

Table 3. 3 – Scenarios layout



JANUARY						JUNE					
THURSDAY			SUNDAY			THURSDAY			SUNDAY		
NOPV	50PV	70PV	NOPV	50PV	70PV	NOPV	50PV	70PV	NOPV	50PV	70PV

4 Stressing the Grid & Flexibility Analysis

4.1 Running Scenarios

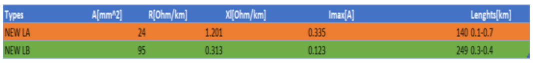
The two chosen grids, GRID1 and GRID2, were then structured in excel files in order that they are accessible to “PandaPower” and be able to run a power flow analysis using, as stated before, the demand values from the aggregation consumption curves and the generation values from the measured PV generation curves. The main objective is now to obtain a stressed grid, meaning that the lines should be overloading. In “PandaPower”, the loading of the line is presented in percentage and the threshold for overloading was considered to be 85%. Running the different scenarios through the two grids in “PandaPower” both grids did not present stressed situations. With this information, the loading of the lines for both grids, is the highest in a situation of NoPV, in comparison with 50PV and 70PV, because on those cases there is the generation of PV, so some of the demand is compensated by the power generated. The approach implemented was to change lines by weaker ones: for this study, the main parameters when selecting a line were the maximum current that the line can sustain, its reactance and resistance to know the impedance, the cross-section area is not considered in the inputs of creating a line in “PandaPower” [16], therefore was not an important parameter, although thinner lines present weaker behaviour.

The objective of obtaining a stressed grid was to have three or more lines going over the percentage of voltage that was referred at the beginning of this chapter, 85% for GRID1 and GRID2, and it is also important to point out that the threshold for the loading was 120%, that meaning that although the objective was to stress the grids, some limits were created in order not to have the lines overloading too much.

4.2 Changes in GRID1 & Results

For GRID1, the original lines, were changed, the type LB that is the one filled in green on Table (3.1) was substituted by a line with a section area of 95 mm², an impedance of 0.313+0.123i and a maximum current of 0.249 kA, and LA by a line with a section area of 24 mm², an impedance of 1.201+0.335i Ω/km and maximum current of 0.140 kA (Table 4.1). In comparison with the original lines, it is notable the decrease in the section area and in the maximum current that the lines can sustain, this was implemented to achieve a worst-case scenario of a stressing grid (more than two lines overloading), the length of lines were untouched.

Table 4. 1 - Features on the new Lines/Cables GRID1



Types	A[mm^2]	R[Ohm/km]	Xl[Ohm/km]	Imax[A]	Lenghts[km]
NEW LA	24	1.201	0.335	140	0.1-0.7
NEW LB	95	0.313	0.123	249	0.3-0.4

The selection was due to the fact, that the results with these types of lines gave a stressed grid, as stated before more than 2 lines were stressed over the day; the stressed lines (going over 85% of line loading), were the L1, L2, L16, L21 and L22, these lines are the ones where more power and current flow through before the grid starts to ramify into other transformer stations (Figure 3.1). L1 and L2 and L16 in all the cases presented in the section 3.3 on Table(3.3). For L21 and L22, without PV generation overload in all the cases and when exists PV generation both lines overload in the January Sunday case, but in January Thursday and June Sunday cases only L21 overloads, and on the June Thursday case neither one overloads, Figure (4.1) gives has the values for January Sunday case.

4.3 Changes in GRID2 & Results

In GRID2, the original Lines (Table 3.5), were changed, and the grid ended up with two different types of lines because the first line had to be stronger to not overload too much, not to go over 120%. The distribution of the transformers was also changed in this grid, once again to achieve the goal of a stressed grid without going over 120%. The gird has now two types of lines, LC that is the first one and then the rest of the grid is built with the line LD (Table 4.2). On the transformers side the one with 250 kVA were substituted by 400 kVA transformers.

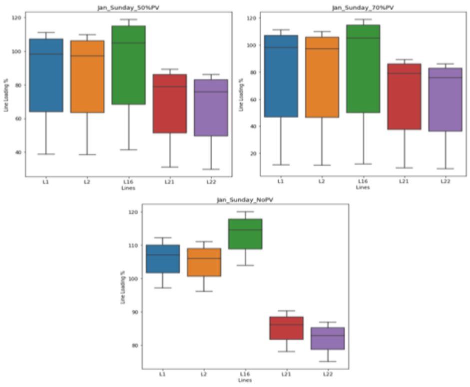


Figure 4. 1 - GRID1 Box Plot of the Line Loading (L1, L2, L16, L21 and L22) in January Sunday

The lines that presented overloading status were L1, L2 and L3. These three were stressed with PV and without PV in a Sunday of January. For a Thursday of January L2 presented overloading with PV and without PV, but L1 and L3 only for the case with no PV generation, in the month of June, L1 did not overload, L2 overloaded with PV and without PV, L3 only on the case with no PV generation (Figures 4.2 for January Sunday).

Table 4. 2 - Features on the new Lines/Cables GRID2

Types	A[mm^2]	R[Ohm/km]	Xl[Ohm/km]	Imax[A]	Lenghts[km]
LC	48	0.5939	0.35	210	0.6
LD	36	0.8342	0.36	170	0.6

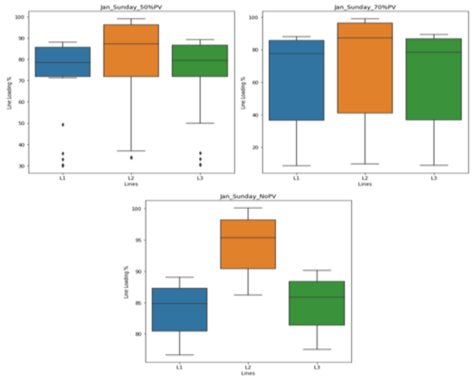


Figure 4. 2 - GRID2 Box Plot of the Line Loading (L1, L2 and L3) in January Sunday

4.4 Adding Flexibility

Flexibility services are conventional alternatives to grid reinforcement [4], as it was stated in section 2, one of the types of flexibility is BESS (Battery energy storage system) that can play a vital role in avoiding excessive power generation capacity to meet short-term peak electricity need, reduce the investment in power grid conduction, and ensure an efficient and safe operation of the power grid system [17]. In this study, the objective is to add a BESS to help with the overvoltage of lines by implementing a BESS in the end bus of the line that is overloading; by doing such implementation when needed, the BESS would discharge the amount of energy needed so that the line does not have to sustain a big amount of power and current, this would lead to a result where the line is not overloading

4.4.1 BESS

When applying a BESS, the first step was to see if it would be possible to apply a battery energy storage system by seeing how many hours each line was overloading during the days in the study for each grid, because a battery has always a charge/discharge cycle.

The second step, if in a scenario is possible to apply a BESS meaning that exists a set of hours, *number_hours,* where the line is overloading and where is possible to charge and discharge the BESS*,* and calculate the amount of power and energy that would be needed for the BESS to discharge, the approach followed was:

1) Identify at which hour in the scenario considered the lines are overloading the most.
2) Identify the amount of power that is flowing through the line, line*_power_h,* and the corresponding loading percentage, *loading_percentage.*
3) Define a threshold of loading percentage that would indicate that the line is not overloading anymore, 85% corresponding with statement made in section 4.1, *loading_thresold*
4) Calculate the difference between the loading of the line and the reference value for the threshold, this difference, in percentage, represents the amount of power that will be needed from the battery at that hour in order for the line to achieve threshold.
5) Apply this percentage difference to the peak power that is flowing through the line (*line_power_h*) and calculate the power needed for the battery system, *BESS_peakpower,* Eq.(3) and Eq.(4), using *BESS_peakpower* calculate the energy needed, *BESS_energy.* In the calculations, the values for *BESS_peakpower* were rounded to two decimal houses.

$$\left((loading_{percentage}) - (loading_{thresold})\right) \times line_{power_{h(MW)}} = BESS_{peakpower(MW)} \tag{3}$$

$$BESS_{peakpower(MW)} \times number_{hours(h)} = BESS_{energy(MWh)} \tag{4}$$

4.5 BESS in GRID1 & GRID2

Following the steps of the chapter before, the first step is to calculate whether if it is possible to apply a BESS in each end bus corresponding to the line that is overloading. In section 4.2, for GRID1 the results were that L1, L2, L16, L21 and L22 are overloading. L1, L2 and L16 present overload status in all the scenarios and L21 and L22 have some exceptions. By grouping all scenarios, to remember we have JAN_THURS, JAN_SUNDAY, JUN_THURS and

JUN_SUNDAY (the days in January to represent winter case and the days in June to represent a summer case), the conclusions are that in the situation of L21 and L22 it is possible to apply a BESS for the cases with PV generation (more detailed in the thesis). For GRID2 the lines that presented overload were L1, L2 and L3. Once again, by grouping all the days scenarios to see if it is possible or not to use a BESS. The conclusions are that it is possible to apply a BESS in the end bus of L1 and L3 only when exists PV generation (more detailed in the thesis).In GRID1 the scenarios were shortened to L21 and L22 on 50PV, 70PV and for GRID2 L1 and L3 on 50PV and 70PV.

The focus now is to calculate the peak power, and the energy needed from the BESS. To simplify the process, the approach was to identify which day has the highest demand, meaning highest load, it us Sunday of January (JAN_SUNDAY), and inside the set of hours that the lines were overloading at this day, identify the hour with the bigger load that represents the hour in which the lines are under more stress. For both grids was 19h, and so applying Eq.(3) and Eq.(4) the peak power and energy needed from the BESS in both grids are obtained (Table 4.3 & 4.4).

Table 4. 3 - Peak Power & Energy Needed from BESS for GRID1

JAN_SUNDAY_19h	Line_power_h (MW)	Loading_percent (%)	Difference beetwen loading_percent and 85%	Peak Power (MW)	Enegy Needed (MWh)
L21	5.5	89.2	4.2	0.23	1.38
L22	5.3	85.9	0.9	0.05	0.25

Table 4. 4 - Peak Power & Energy Needed from BESS for GRID2

JAN_SUNDAY_19h	line_power_h (MW)	loading_percent (%)	Difference beetwen loadinf_percent and 85%	Peak Power (MW)	Enegy Needed (MWh)
L1	4.1	88.1	3.1	0.13	0.78
L3	3.2	89.2	4.2	0.14	0.84

4.5.1 Results

Using "PandaPower" function *create_storage* [16], it is possible to observe the results in the loading of the lines of both grids. In Figure (4.3), that represents the situation with 50% of PV, which translates the results for L21 and L22 of GRID1, it is notable that the loading of the lines does not go over the threshold of 85%. The same results are on the Figure (4.4), that represents the situation with 50% of PV, which corresponds for L1 and L3 of GRID2 (more detailed on this results in the thesis). For the case of 70% of PV generation, the lines also present stable loading values; a big reason is that if the application of storage makes the loading of the line decrease in a situation where exists 50% of PV generation, in cases with more PV generation the loading will be lower and never bigger because less power is being demand from the grid, so less power is flowing through the lines.

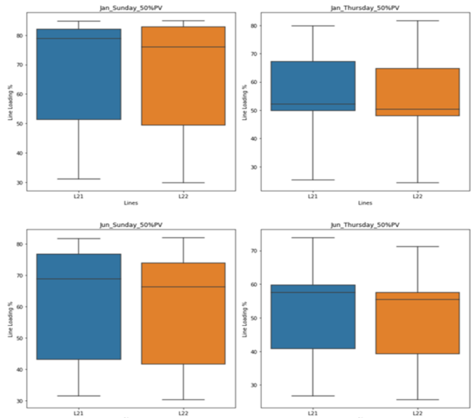


Figure 4. 3 - GRID1 Box Plot of the Line Loading (L21 and L22) with BESS for 50%PV

4.6 Type of Battery for BESS

The idea in this study is for the DSO to contract a flexibility service that would give him an alternative to changing the lines. As stated, before this flexibility service is a BESS, so for the methodology to be concluded, a cost of service must be implemented analysed and compared. Among the various types of electrical batteries technologies, lithium-ion (Li-ion) batteries have attracted significant interest because of their high energy density, high energy efficiency and long cycle life [18].

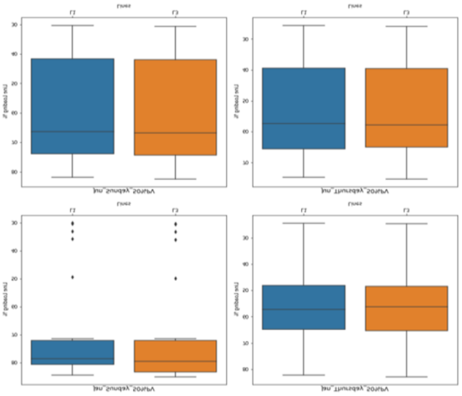


Figure 4. 4 - GRID2 Box Plot of the Line Loading (L1 and L3) with BESS for 50%PV

From section 4.5 it was concluded that both grids need BESS with a power of 0.23MW/1.38MWh, 0.05MW/0.25MWh, 0.13MW/0.78MWh and 0.14MW/0.84MWh; these four different amounts of power and energy are achievable using lithium-ion batteries, because for example, in the UK, the largest European lithium-ion energy storage pilot is in process, it as a power of 6MW/10MWh [19]. To access a credible cost of service tool for the batteries, IRENA (International Renewable Energy Agency) report for Cost and Markets to 2030 was used [20]. Inside the family of Lithium-ion batteries, NMC/LMO (nickel manganese cobalt/lithium manganese oxide) was the type selected, it carries many advantages, such as: can be fitted for high power or high energy, stable thermal profile, can operate at high voltages, and in terms of energy installation cost has a very low price.

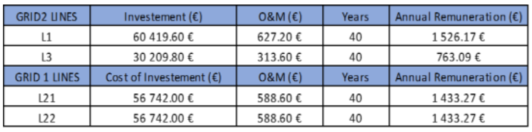
5 Cost Comparison

5.1 Spain Royal Decree IET/2660/2015

To end the process of this study, the goal is to obtain an annual cost relative to the flexibility service BESS compare it and conclude if the investment in this flexibility service is more viable than changing the line. The regulatory identity in Spain, approved a royal decree called IET/2660/2015 [1], in this article is stated that a remuneration methodology for distribution activities will be established by the regulation, considering the costs necessary to build, operate and maintain the facilities and carry out the good performance of the grid and at the lowest cost for the electricity system.

In the thesis the process is in more detail, but the approach here is if the DSO is, in fact, going for new lines, the targeted section areas for those lines are the ones that were in the original grids [10] [12] before they were stressed for this study (Table 3.1 and 3.2), and voltages are 25kV for GRID1 and 11kV for GRID2. Since the study focus on distribution networks, to be more precise for low voltage consumption, the lines in focus are of the underground type due to the fact that they are in the middle of a city per se, and do not have to carry high voltages levels. The conclusion is on Table (5.3), that represents the annual remuneration the DSO would get from the Spain regulation if opted on changing the lines, in [1] the Spain regulation defines the average life for an underground line to be 40 years, so the remuneration will be the total divided by 40, this also applies for the investment done by the DSO for BESS.

Table 5. 1 - Annual Remuneration for each line of GRID1 and GRID2



GRID2 LINES	Investement (€)	O&M (€)	Years	Annual Remuneration (€)
L1	60 419.60 €	627.20 €	40	1 526.17 €
L3	30 209.80 €	313.60 €	40	763.09 €
GRID 1 LINES	**Cost of Investement (€)**	**O&M (€)**	**Years**	**Annual Remuneration (€)**
L21	56 742.00 €	588.60 €	40	1 433.27 €
L22	56 742.00 €	588.60 €	40	1 433.27 €

5.2 BESS Cost Assessment

The methodology now is to define a cost assessment for the BESS. The idea here is that the DSO contracts a flexibility service, in this case, an identity that owns BESS, that will make to the DSO a cost assessment depending on his requirements for the BESS. The IRENA report [45] was the base structure for this due to the fact that it gives access to more complete and trusted values for NMC/LMO battery. Values of cost assessment for NMC/LMO for 2020 were extracted, the IRENA report is from 2015, so the values are divided into best values, reference values and worst values. In this methodology, the cost assessment is going to have capital expenditure (CAPEX) and operational expenditure (OPEX). The CAPEX is composed by:

1) Energy storage installation cost, the comes in €/kWh, which indicates how much it is going to cost to store the energy needed for each BESS.
2) Power conversion system cost, in €/kW, that represents the cost of the inverter and packing.

The OPEX, in [45] the authors assume that the operation and maintenance (O&M) is 1.5% of the total investment of the represented unit:

1) O&M of the storage system, it is 1.5% of the energy storage installation cost.
2) O&M of the power conversion system, 1.5% of the power conversion system cost.

The values obtained from section 4.5, are going to be used to calculate the energy capacity and power capacity for the BESS. The values for the points talked before, that are represented in the Table (5.2) were all extracted from the IRENA report.

Table 5. 2 - NMC/LMO values for cost assessment

Battery	Power Conversion Installation Cost (€/kW)	Energy Storage Installation Cost (€/kWh)	Round-trip efficiency	O&M storage system/ power conversion system (%)
Li-ion (NMC/LMO) Best	48.5	125.8	1	1.50%
Li-ion (NMC/LMO) Reference	69.9	264.8	0.95	1.50%
Li-ion (NMC/LMO) Worst	125.8	529.5	0.81	1.50%

This cost assessment is for the total cost of BESS, and usually for a DSO to integrate a BESS only in order to reduce grid reinforcement tend to be nonprofitable [21]. This being said, in this study, a factor defined as usage of BESS if going to be added, this factor represents how much the DSO is actually going to use the BESS in question for grid orientation, in this case, to help with the overloading of the lines, the factor comes in percentage, and it's the percentage of how much of the total cost of the BESS the DSO is going to pay, the first assumption for it was of 10% (a sensibility analysis is made on this factor in the thesis in order to make better conclusions of how much more could the DSO use a BESS for grid application and still be profitable comparing to the grid reinforcement but was excluded from this document).

5.3 Annual Cost Comparison

In section 4.5 the values for power and energy needed from the BESS for each grid were extracted, and then the energy capacity and power capacity were calculated, to account for the energy losses (this process is more detailed on the thesis). The next step now is to calculate how much is going to be the annual cost in investing in a BESS (all of these steps are well detailed on the thesis with the right equations):

1) Calculate the energy storage installation cost in euros and the power conversion installation cost power in Euros.
2) Calculate the total annual CAPEX, consists of the energy storage installation cost and power conversion system cost, divided by 40 years.
3) Calculate the total annual OPEX, that consist of applying the 1.5% of the annual energy installation cost and annual power cost.
4) Get the total annual cost by summing total annual CAPEX and total annual OPEX, and multiplying the use of BESS factor that comes in percentage.

5.3.1 Annual Cost Comparison for GRID1

As it was referred on section 5.3 the power capacity in kW and energy capacity in kWh of the BESS were calculated see Table (5.3), using the worst, best and reference values of Table (5.2). After this the steps referenced before were put into practice, thus obtaining the total annual cost of the BESS (with reference, best and worst values). With total annual costs for each BESS, and considering the best, reference and worst values, the comparison with the annual remuneration if the DSO would, in fact, go for grid expansion (changing the lines) it is made in Table (5.4), in the column of total annual, when the cost on adding flexibility service BESS its profitable for the DSO the cell is covered in green, and when is not its covered in red. The Table (5.4) show promising results, due to only not being profitable applying BESS on L21 with worst values, but a big factor in this result is the use of BESS that is only on 10%, meaning that the DSO would only pay for 10% of the total cost.

Table 5. 3 – Values for Power and Energy capacity of BESS for each line

Valaues NMC/LMP	BESS for L21 (kW)	BESS for L22(kW)
Best Values	230kW/1380kWh	50kW/250kWh
Refrence Values	242kW/1452kWh	53kW/265kWh
Worst Values	284kW/1704kWh	62kW/310kWh

Table 5. 4 – Comparison between annual costs

BESS	Valaues NMC/LMP	Total Annual	Annual Remunaration	Lines
BESS for L21	Best Values	468.73 €	1 526.17 €	Changing line L21
	Refrence Values	1 018.43 €		
	Worst Values	2 041.68 €		
BESS for L22	Best Values	85.94 €	763.09 €	Changing line L22
	Refrence Values	187.44 €		
	Worst Values	436.33 €		

As it was stated before, the factor of BESS use was considered to be 10%, to remember this factor represents the use of BESS for grid application, in this case helping with the stress of the grid lines, in turn, represents how much the DSO is going to pay from the total cost of the BESS. The sensitivity analysis is more detailed on the thesis document, but the basis is again the comparison between the annual cost of the BESS and the annual remuneration when changing the line, and to retrieve a breakeven point, basically when thus contracting a flexibility service that uses BESS starts to stop being profitable for the DSO, only the best and reference values were considered on the analysis. The conclusion regarding both lines, L21 and L22, is shown on Table (5.5), regarding L21 it is notable the difference in the breakeven point between the best values and reference values, for the reference values, the breakeven point is 14.99%, and for the best values is 32.56% (Table 5.5), so basically, on one end the DSO could purchase up to 14.99% of the BESS system for grid application and on the other end could go until 32.56% that is reasonably better. For L22 the conclusions are basically the same but the breakeven points are higher comparing to the sensitivity analysis done for the BESS of L21, the BESS for L22 requires a notable less amount of energy and power, so automatically the annual costs are going to be lower the lids to the possibility of the DSO using more of the BESS as flexibility service for grid applications, even almost going for the full use of it when the values are at the best levels, 88.79% (Table 5.5).

Table 5. 5 - Breakeven points for the use of BESS in L21 and L22

Breakeven Point	Use of BESS L21(%)	Use of BESS L22(&)
Best Values	32.56%	88.79%
Reference Values	14.99%	40.71%

5.3.2 Annual Cost Comparison for GRID2

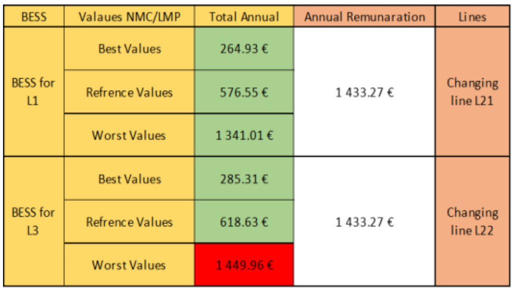
The steps for GRID2 are exactly the same, first the energy capacity and power capacity for each BESS were calculated, in this case in L1 and L3 (Table 5.6). After this, following the steps in section 5.3 the annual cost was obtained for the BESS, The Table (5.7) shows the comparisons between the annual costs of the acquisition of the BESS, considering the best, reference and worst values, and the annual remuneration of the DSO when the decision is changing the line that is overloading, in these case L1 and L2 (the green represents a profitable investment on BESS and the red the contrary). The results are quite like the ones one GRID1, only the worst values of the BESS for L3 do not present a profitable investment. Again, the big factor is the use of BESS being only 10% makes the annual cost of BESS decrease and gives a profitable investment for the DSO.

Like in GRID1 a sensitivity analysis on the factor of BESS use was done for GRID2, to remember that this analysis is more detailed on the thesis. The aim is the comparison between the annual remuneration when changing the line that is overloading, in this case, L1 and L3, and the annual cost of the BESS for the DSO, where the breakeven point is retrieved, as it was said in section 5.3.1, the breakeven point reflects when contracting a flexibility service stops being profitable over changing the line.

Table 5.6 - Values for Power and Energy capacity of BESS for each line

Valaues NMC/LMP	BESS for L1 (kW)	BESS for L3 (kW)
Best Values	130kW/780KWh	140kW/840kW
Refrence Values	137kW/822KWh	147kW/882kW
Worst Values	160kW/960KWh	173kW/1038kW

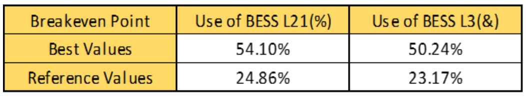
Table 5. 7 - Comparison between annual costs



BESS	Valaues NMC/LMP	Total Annual	Annual Remunaration	Lines
BESS for L1	Best Values	264.93 €	1 433.27 €	Changing line L21
	Refrence Values	576.55 €		
	Worst Values	1 341.01 €		
BESS for L3	Best Values	285.31 €	1 433.27 €	Changing line L22
	Refrence Values	618.63 €		
	Worst Values	1 449.96 €		

From the Table (5.6) where the power and energy capacities for each BESS are represented, it is notable that they do not diverge between lines, so basically, the results on the annual costs are really similar, and because the lines in the study, L1 and L3 have exactly the same characteristics. That being said, in Table (5.8) the breakeven points are listed, it is notable that the values are really similar, the breakeven points for the reference values on each line are around the 50% and diverge around 25% from the breakeven points for the best values.

Table 5. 8 - Breakeven points for the use of BESS in L1 and L3



Breakeven Point	Use of BESS L21(%)	Use of BESS L3(&)
Best Values	54.10%	50.24%
Reference Values	24.86%	23.17%

6 Conclusion

The purpose of this study was to get an annual cost of how much would it cost to purchase a flexibility service, more specific a BESS and compare to the annual remuneration that would be given to the DSO if he opted to go for grid expansion; basically, the idea was to build a tool that would give the ability to the DSO of comparing the cost in order to help him with the decision to achieve grid efficiency.

The results of the costs comparison are the strength of this thesis due to the fact they present promise results where it would be possible for the DSO to acquire a percentage of a BESS and use it for grid applications level and prevent grid expansion for both grids in the study. These results come from some assumptions and decisions made on the curse of this thesis, and that can be viewed as the limitations of this study:

1. The unavailability of real data consenting to the consumption curves and PV generation curves due to un access to information from utilities, and also the fact of using model grids and not a real grid scenario.
2. At the beginning of the study cases assuming that every type of load consumption in the grid would have PV generation were created, and only in those cases, it was possible to apply a BESS, when no PV generation existed, the need for changing the stressed lines was inevitable. In a real situation not every client of the DSO has a PV system installed, in the future, that could be achieved but by now, it is the reality.
3. The modelling of the battery was not done in this study because it was not the goal; the goal was to in an accurate way show that by applying a BESS the overloading of the lines would stop. It was not the optimisation of the battery but, yes, the results of applying it.
4. The *use of BESS* factor, presented in section 5, is the main feature that gives the DSO the opportunity of buying that type of flexibility service and still have a profitable investment. This factor, assumes that other parties are going to join the DSO into the purchase of BESS to then use it for their own necessities, this assumption is reasonable because using a BESS for only one purpose is not always a profitable investment, but never the less, it is an assumption that gives the results obtained on chapter 6.
5. The life span of the battery wasn't considered, because the DSO it is acquiring a service that provides a BESS so the all the concerns on changing the battery were of the identity that provides the BESS.

The main goal of the study was achieved, that consisted of giving a methodology to make a cost assessment on flexibility service so that the DSO could them use it to decide whether to go for the purchase of that flexibility service or to opting for grid expansion. Once again, the results are promising because they actually give an idea that prevention of grid expansion by using BESS is achievable, although all of the data used in this study is theoretical, and the results are theoretical.

This methodology should, in fact, be more studied open and reinforced by coordinate the project with some DSO utilities to then use real data, give more time to the modelling of the BESS so that the results could be more efficient, do a more accurate study of how could the BESS be distributed by different identities to each one use it for its own purpose and of course with all of this reinforcement on the methodology built an economic analysis more accurate and efficient that could then be used on the practical field by actual DSO companies. One more important point is the changes in the regulatory mechanisms; in the future, the incentive-based mechanisms and cost-based mechanism should also focus on the fact that the DSO is preventing grid reinforcement by investing in flexibility service and still achieving good performance of the grid, in this example considering the regulation of Spain no remuneration was predicted to this type of cases and only for grid reinforcement. The demand for electricity over the years will only increase, causing a more effective performance of the distribution networks; flexibility services are a very important tool on good grid performance and should be more focused on with the main goal of preventing grid expansion.

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