Feasibility Analysis of a Battery Energy Storage System combined with a Utility-Scale Solar PV Power Plant in the Atacama Desert

Federico Baldasso

federicobaldasso@gmail.com

Instituto Superior Técnico, Universidade de Lisboa, Portugal

October 2021

Abstract

Nowadays the trends are indicating that the world will face different problems related to the CO2 emissions if the use of conventional energy sources is kept as it was in the past years. Therefore, there is a global need for incorporating renewable energy sources into the grid.
The aim of this project thesis is to study the feasibility of a battery energy storage system combined with the photovoltaic power plant Campos del Sol in Chile, located in the Atacama Desert.
In order to study the economic feasibility, different configurations of battery energy storage systems have been analyzed with the software Matlab. The power of the BESS taken in consideration are 50MW, 100MW, 150MW, 200MW and for each power a capacity of 1, 2, 3, 4 hours has been studied.
A sensitivity analysis has been done by changing the Energy Prices (creating 3 different price scenarios where each scenario multiplies the real value of the energy price by a multiplicative coefficient that depends on the production of photovoltaic energy) and the Initial BESS cost (considering a decrease of 30% of the actual BESS cost).
With the actual battery costs and energy prices, the proposed solution is still not economically feasible (the configuration with the best results has a final NPV of -17.982.354 €).
The best results are reached with the configuration 200 MW 800 MWh Energy Prices scenario 3 (that is the scenario with the highest multiplicative coefficient) and the final NPV is of the order of +59 M€.
Keywords: Photovoltaic System, Energy Storage, Chile, Matlab, NPV

Introduction

The main objective of this thesis work is to analyze the economic feasibility of a battery energy storage system connected with the photovoltaic (PV) park Campos del Sol in Chile, located in the Atacama Desert. For the development of this work two softwares have been used in order to compute all the necessary data: System Advisor Model (SAM) to compute the photovoltaic power and energy production of the PV park Campos del Sol and the software MATLAB to study the technical and economic feasibility of a battery energy storage system (BESS) connected to the PV park. In the software an optimization problem was created in order to maximize the economic revenues from the battery energy storage system.
The optimization problem analyzes the photovoltaic energy production and the energy prices during the day and optimizes the Battery Energy Storage System Energy flows. In fact, based on the price values three different energy flows are controlled, the energy flow from the PV to the BESS, from the PV to the grid, from the grid to the BESS and from the BESS to the grid.
One of the main goals of the BESS coupling with a renewable energy power plant is the Energy shifting: that is the possibility to store energy for a long time before delivering it, this way the production would be separated in time from the utilization of the stored energy. This service is really useful especially for the power plant that are not programmable, where the energy production depends on the availability of an intermittent energy source, and it is not possible to modulate it. For example, in a photovoltaic power plant the production depends on the solar radiation that reaches the solar panel which is highly variable during the day and month.

Some of the beneficiaries of this service are the prosumers, that are at the same time consumer and producer of electric energy. [1]
Typically, the prosumers are private people or small companies with small power plant (usually

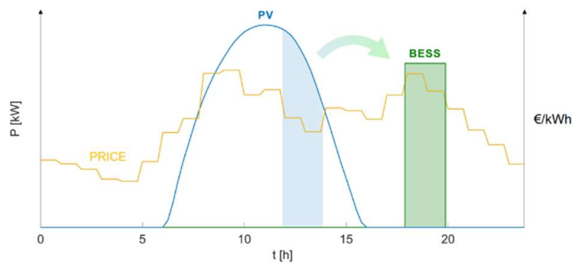

Figure 1 : Example of Energy Shifting

photovoltaic) finalized to the production of a part (or all) of their energy demand. In these systems, thanks to the energy shifting, it is possible to accumulate the surplus of energy when the production exceeds the consumptions, as it is possible to see in Figure 1. The surplus can then be used when the production of energy is zero or not enough to satisfy the request. This situation is typical for the night hours, when for a photovoltaic plant the production is zero, or when the meteorological conditions are adverse.
Another advantage in having the possibility of storing energy is that it is always disadvantageous from the economic point of view to sell the surplus energy to the electric grid and then buy the energy from it when there is the need, because the price for selling and buying the energy are always different [2].
Another fundamental function that is possible with the utilization of BESS is called the peak shaving. It consists of the possibility to accumulate part of the produced energy in the peak-production hours in order to level the production profile by deleting the energy peaks.

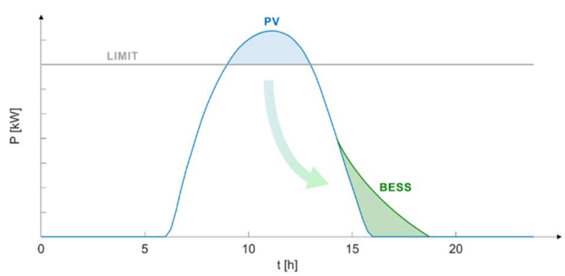

Figure 2: Example of Peak Shaving

This service allows to have an energy production curve more similar to the consumption curve and it allows to respect the power limit of the energy grid if any. As we can see in Figure 2 the energy production is respecting the limit and thanks to the BESS the power plant can satisfy more energy requests during the day.
Generally, the peak shaving operation is executed within a time period of 1 to 10 hours [2].

Problem Formulation

The main part of this thesis project is the study on the feasibility of a battery energy storage system for the 383MWp photovoltaic project Campos del Sol.
Due to the fact that the solar energy is not a predictable nor constant energy source throughout the whole day, the coupling with a battery system could be a solution in order to have constant energy delivery from the PV+BESS system.
With the use of a battery system, it could be possible to proceed with "peak shaving" and save energy during the day in order to deliver it to the grid during the night when the energy price is higher.
In order to understand the feasibility of a battery system, 16 different Li-Ion battery systems have been analyzed: the power of the BESS taken in consideration are 50MW, 100MW, 150MW, 200MW and for each power a capacity of 1, 2, 3, 4 hours has been studied.

Methods

The first step has been the calculation of the production of the PV park Campos del Sol. The data regarding the modules, inverter, system design have been taken from the company STE Energy Srl, where I work.
The 385 MWp Campos del Sol PV plant will generate around 920 GWh per year when fully up and running, savings more than 9000.000 tons of CO_2 emissions.
The project is located 60 km northeast of Copiapó, in the Atacama Desert.
This PV Power Plant is the largest solar plant currently under construction in Chile and it is facing south, and the tracking system is monoaxial (east to west). The modules are bifacial modules, a technology that maximizes energy generation by capturing solar radiation from both sides of the panel, generating on average 12% more electricity than conventional modules.

The data regarding the meteorological condition of the year 2020 were found in the SAM website Weather Page [3]The software SAM (System Advisor Model) has been used in order to compute the hourly energy production of PV park Campos del Sol. The results from the software SAM show the annual energy production of the PV park Campos del Sol for the first year of production. The production has the highest values (November to January) during the summer and the lowest values (May to July) during the winter. As we can see in Figure 3, the production follows a regular curve during the year, there are just some intermittencies probably due to cloudy days.

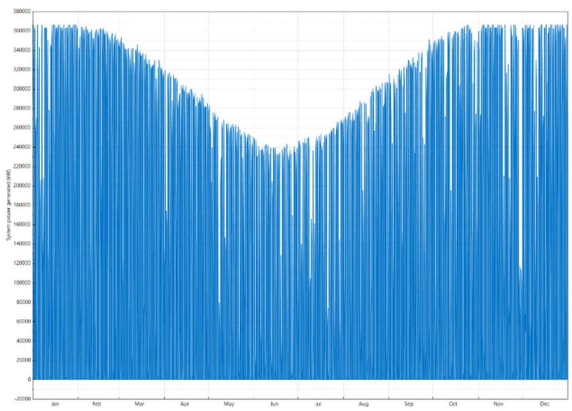

Figure 4 : Campos del Sol computed annual PV Power

The overall yearly production of the PV park is of the order of 920 GWh, as per the SAM results.
Once the PV production is computed, the results have been used for the main scope of the thesis: the BESS feasibility analysis. The analysis has been done with the software Matlab.
An optimization problem has been created in order to compute the best possible way to control the energy flows from the grid to the BESS, from the PV to the BESS, from the PV to the grid and from the BESS to the grid. With the use of a battery system, it could be possible to proceed with “energy shifting” saving energy during the day in order to deliver it to the grid in the late afternoon hours and evening hours when the energy price is higher.
As it is possible to see in Figure 4, the system taken into consideration is composed by three main components interconnected between them:

1. Photovoltaic Power Plant Campos del Sol
2. National Electric Grid
3. Battery Energy Storage System (BESS)

The electrical grid in the model created is considered as a component capable of absorbing or delivering power at any time with the only constraint of compliance with the maximum power limits supposed to be equal, both in input and output, to the photovoltaic peak power (385 MW).

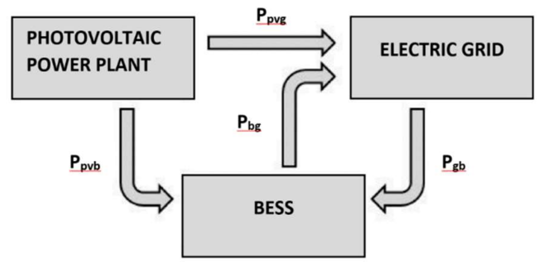

Figure 3 : Block Diagram of the Considered System

This means that, at any given instant, the sum of the power fed directly into the grid by the PV P_pvg and the power discharged from the P_bg battery cannot exceed this maximum value.
The flexibility of the tool allows to vary the maximum power that can be fed by extending the field of applicability even to scenarios in which the photovoltaic system is oversized compared to the power accepted as input from the grid, where therefore the storage system can be used to provide peak service shaving to enhance the energy profit.
The BESS is studied and analyzed with the software Matlab.
It is able to absorb power both from the PV and from the electricity grid during the charging process and to deliver power to the grid during the discharging process, respecting the limits on the state of charge. Specifically, the BESS can accumulate energy as long as its state of charge does not reach the maximum fixed value, while it can discharge the accumulated energy until the minimum fixed state of charge value is reached. This way, the storage system allows to delay the time in which the energy is produced by the photovoltaic park from its injection into the grid and, if convenient, to implement the sale of energy in order to maximize revenues based on the price trend.
It has been assumed that each BESS considered is constituted by the connection of identical electrochemical modules, characterized by the same characteristics which have been obtained from the LG Chem documentation [4]. The technology of the cells used is with a Lithium-Nickel-Cobalt-Manganese (NMC) cathode, with a negative electrode (anode) made of graphite.
It has been analyzed that the use of this technology has advantages both from an electrical and a structural point of view and the interest in its use in

stationary applications is growing after it has become commonly used in the automotive sector.
For these reasons and due to the availability of numerous data in this regard, this type of modules was considered the best candidate for the development of this project.

Degradation Model

In order to make the model as close as possible to reality, a specific function was created in Matlab, dedicated to the evaluation of the degradation of BESS considering every day . In fact, the storage system can reach the end of life more or less quickly depending on the operating conditions. In the tool created, given that the power profiles are evaluated by solving an optimization problem that will be detailed in the next paragraphs, the operating conditions vary day by day according to the trend of the PV production profile and the daily price profile and moreover, they are different according to the capacity and power of the BESS being analyzed. For this reason, for an accurate estimation of the life of the system it is necessary to evaluate every day the degradation rate for the evaluation of the lost capacity, studying the SOC profile that derives from the daily optimization itself. The rate of degradation and, therefore, the share of daily capacity lost are calculated starting from the evaluation of the stress parameters, using the semi-empirical equations referring to the study conducted by Bolun Xu et al., [5] which have been implemented in the Matlab model. In order to apply these equations, a preliminary study of the profile of daily SOC is necessary to identify the number of cycles performed and their characteristics.
Furthermore, it is necessary to know the internal temperature profile of the cells, for this reason a specific Simulink model has been created that simulates the heat exchange between the modules and the external environment.
This model reproduces the behavior of the cells by evaluating the amount of heat that is not dissipated through the convective exchange with the external environment, from which it processes the temperature trend. The heat generated in each instant is strictly correlated to the C-rate performed.
The model therefore considers that all the dissipated energy is transformed into heat inside the cell which causes an increase in the internal temperature, neglecting the effects of the enthalpy variation of the cells. However, this simplification has a limited impact, in fact the variation of enthalpy is a reversible phenomenon, which has an opposite effect on the temperature trend in the charging phase compared to the discharge, negligible in average terms.
With the ambient temperature, the useful heat exchange surface, the total weight of the storage system, the heat transfer coefficient and the specific heat at constant pressure, the model gives back the temperature profile which is supposed to be the same for all the cells that make up the BESS, from which the average daily temperature and the average temperature of each cycle identified by the Rainflow algorithm are subsequently calculated.
After identifying the number of daily cycles and the temperature profile of the cells that make up the BESS, it is possible to calculate the stress factors and the amount of capacity lost during the day.

Optimization Problem

DATA

The useful data for the optimization algorithm are the arrays containing the values of the power produced by the PV, called $P_{pv}(i)$, and the energy price values, called Price (i), at every i-instant of the day considered for optimization. All the efficiency values must also be provided in order to consider the power dissipated in the transfer between one system to another and the share of energy lost within the storage system during the charging and discharging processes. In the latter case, it is considered that the yield associated with these processes varies according to the C-rate used. Finally, the values of energy that can be stored in the initial conditions E_b and power E_b must be entered which define the nominal size of the BESS studied and the values within which the state of charge SOC_{MAX} and SOC_{min} must be maintained.

VARIABLES

The variables of the problem are all the values of the power exchanged between the systems and the value of SOC at every i-instant of the day.
The variables can be divided as:
$P_{pvb}(i)$, that represents the power produced by the PV system that is used to charge the BESS.
$P_{pvg}(i)$, that represents the power produced by the PV system that is directly delivered to the grid.
$P_{bg}(i)$, that represents the power delivered from the BESS to the grid.
$P_{gb}(i)$, that represents the power absorbed from the grid by the BESS during the charge.

$SOC(i)$, that represents the state of charge of the battery system. It is function of the input and output power of the BESS.

OBJECTIVE

The objective of this project is to maximize the daily revenues for the owner of the system.

The objective function is expressed as the sum of all the component of earnings and costs (these last ones are expressed with a negative sign), that characterize the trade of the daily energy production.

In the system the only expense is linked to the power that is bought in the early hours (when the energy prices are low) to charge the BESS, while the energy delivered from the PV system to the BESS does not count as a cost. This element can be expressed as:

$$C_{gb} = \sum_{i=1}^{N} P_{gb}(i)\Delta t Price(i)$$

Where N is the number of intervals that are considered during the day, $Price(i)$ is the Price of the Energy at instant i and Δt is the considered interval of time (one hour).

On the other side, the revenues come from the selling of the energy to the grid, both the energy from the PV system and the energy from the BESS. These revenues, supposing that there are not price variations between the purchase price and the selling price at the same considered time, can be expressed as:

$$R_{pvg} = \sum_{i=1}^{N} P_{pvg}(i)\eta_{pvg}\Delta t Price(i)$$

$$R_{bg} = \sum_{i=1}^{N} P_{bg}(i)\eta_{bg}\Delta t Price(i)$$

So, the objective function to be maximized is composed by the sum of the revenues minus the sum of the costs:

$$f = MAX(R_{pvb} + R_{bg} - C_{gb})$$

The solution of this problem gives as a result the time profiles of the exchanged power between the systems (PV park, battery and grid) that maximize the daily revenues and the SOC profile associated.

These results are then used to see if it is advantageous to incorporate the BESS with the PV system or not from an economic point of view.

EVALUATION OF EFFECTIVE REVENUE AND ECONOMIC PARAMETERS

The economic evaluations were used to understand if it is convenient to associate a BESS to a PV system and, in case of positive answer, which size of the system has to be considered in order to have the largest revenue. The net revenues correlated to the energy shifting and also the economic parameters as the Levelized Cost of Storage (LCOS) or the Internal Rate of Return (IRR) were studied.

In details, the daily revenues attributed to the BESS, R(d), in each day considered, are computed by diminishing the revenues linked to the power flux that is given from the BESS to the grid during the charging phase:

$$R(d) = \left(\sum_{i=1}^{N} P_{bg}(i)Price(i)\eta_{bg}\Delta t\right) - gbC_d - pvbC_d - omC_d$$

where the terms of the equation are the following:

- gbC_d represents the daily expense to absorb the energy from the grid to charge the battery.
- $pvbC_d$considers the lost revenues, that are linked to the absorption of the energy from the PV system in order to charge the BESS.
- The last term, called omC_d, considers the daily operative costs and the costs for the maintenance (O&M) of the BESS.

Starting from the daily revenues, evaluated for every day of the BESS lifetime, it is possible to obtain the Net Present Value, also called NPV, by discounting the deferred revenues in time and keeping in consideration the initial battery energy storage system's expenses bat_C:

$$NPV = \left[\sum_{y=1}^{Y}\left(\sum_{d=1}^{365} R(d)\right)\frac{1}{(1+r)^y}\right] - batC$$

where Y represents the lifetime of the BESS in years and r the actualization rate. The inflation rate used is the mean value of the Chilean inflation rates of the last 25 years.

Only if NPV is positive then the obtained revenues using the BESS, thanks to the energy shifting, allow to recover the initial expenses and to generate earnings for the owner of the system.

Considered Scenario

Using the current Chilean energy prices [6] it has been found that the use of a BESS is not economically feasible, mainly due to the high cost of the initial BESS investment.

Since currently the system would not be economically convenient few scenarios were designed to predict possible energy prices variations and battery costs variations that could happen in the future that could change the feasibility results.

Seven different scenarios have been considered:

- Scenario 1

- Scenario 2
- Scenario 3
- Energy Price = 90% Current Price
- Energy Price = 110% Current Price
- Initial BESS Cost = 70% Current Cost

The Scenarios 1, 2, 3 have been defined with different multiplicative coefficients following the PV energy production, as we can see in Figure 5.

These scenarios reflect the fact that in a near future, with more and more renewable energy power plant, the energy prices will be increasingly fluctuating reflecting the variability of renewable energy outputs. During the maximum production hours, the energy prices will be really low, and so it would be favorable to store the energy in a BESS in order to sell it to the grid during low production hours.
Two different scenarios were outlined considering respectively an increase and a decrease in the energy price with respect to the current values. Considering these new Price Scenarios the optimization problem was run again with Matlab to see if the new results of the different scenario simulations could be economically interesting or not.

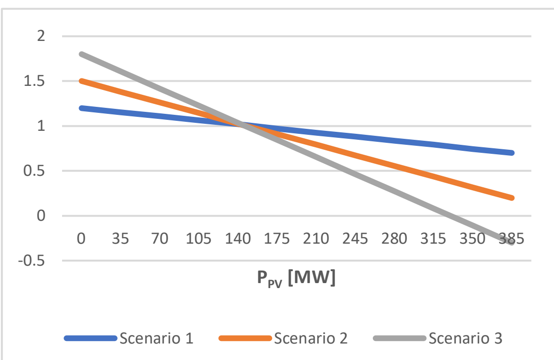

Figure 5 : Considered Price Scenario

The last scenario considered for the sensitivity analysis is the possibility that the cost of the BESS could decrease and so the initial investment could be lower than the current one. An initial BESS investment equal to 70% of the actual costs was considered.
With these new 7 scenarios, the results of the analysis are quite different from the analysis with the current BESS costs and Energy price.

Simulation Results

The results show that, considering all the scenarios, with the exception of the Energy Price Scenario 3, all the different BESS systems are not economically feasible, so the investment does not make sense. These results are consequences of the BESS initial investment, that is still too high to make the application economically feasible.
Considering the Energy Prices Scenario 3, the situation changes and there are some BESS systems that have a positive NPV value and are economically feasible. Specifically the configuration with the highest NPV is the 200 MW 800 MWh configuration that have a finale NPV (at the end of the PV park lifetime) of more than 56 M€.

		Precio 2020		Price = 90% of Precio 2020		Price = 110% of Precio 2020		Initial BESS Cost_70%	
MW	MWh	NPV BESS	IRR BESS	NPV BESS	IRR BESS	NPV BESS	IRR BESS	NPV BESS	IRR BESS
50	50	- 26,681,082 €	-11.83%	- 29,038,638 €	-13.38%	- 24,300,216 €	-10.42%	- 12,556,994 €	-6.83%
50	100	- 29,371,072 €	-7.76%	- 33,935,417 €	-9.34%	- 24,753,540 €	-6.31%	- 8,437,248 €	-2.75%
50	150	- 40,081,903 €	-9.11%	- 46,099,503 €	-11.01%	- 34,056,930 €	-7.40%	- 12,506,188 €	-3.37%
50	200	- 50,082,358 €	-10.02%	- 57,554,275 €	-12.17%	- 42,740,020 €	-8.12%	- 15,851,918 €	-3.66%
100	100	- 39,626,739 €	-9.45%	- 44,395,740 €	-10.99%	- 34,821,480 €	-8.05%	- 15,071,214 €	-4.44%
100	200	- 44,363,803 €	-6.68%	- 53,326,108 €	-8.38%	- 35,316,536 €	-5.12%	- 7,130,220 €	-1.31%
100	300	- 61,081,210 €	-7.32%	- 73,106,866 €	-9.22%	- 49,087,975 €	-5.63%	- 11,254,202 €	-1.61%
100	400	- 78,368,668 €	-8.19%	- 93,288,893 €	-10.33%	- 63,705,117 €	-6.32%	- 16,040,955 €	-1.94%
150	150	- 53,011,912 €	-8.65%	- 60,137,468 €	-10.17%	- 45,850,355 €	-7.26%	- 17,931,355 €	-3.62%
150	300	- 58,962,501 €	-6.06%	- 72,382,674 €	-7.76%	- 45,618,260 €	-4.52%	- 5,269,963 €	-0.66%
150	450	- 87,463,434 €	-7.88%	- 104,991,067 €	-10.01%	- 69,990,516 €	-5.99%	- 15,524,725 €	-1.63%
150	600	- 107,832,516 €	-7.64%	- 130,094,912 €	-9.77%	- 85,906,841 €	-5.77%	- 17,300,004 €	-1.42%
200	200	- 64,898,440 €	-7.98%	- 74,536,939 €	-9.53%	- 55,060,570 €	-6.54%	- 19,648,790 €	-2.98%
200	400	- 71,993,678 €	-5.65%	- 89,794,871 €	-7.35%	- 53,955,110 €	-4.07%	- 2,401,022 €	-0.23%
200	600	- 108,551,189 €	-7.43%	- 131,750,858 €	-9.54%	- 85,598,858 €	-5.57%	- 15,091,727 €	-1.20%
200	800	- 171,752,213 €	-11.28%	- 171,427,289 €	-11.28%	- 114,599,882 €	-6.63%	- 54,396,860 €	-3.95%

		Scenario 1		Scenario 2		Scenario 3	
MW	MWh	NPV BESS	IRR BESS	NPV BESS	IRR BESS	NPV BESS	IRR BESS
50	50	- 22,476,569 €	-9.11%	- 16,245,025 €	-6.11%	- 12,104,780 €	-4.50%
50	100	- 23,343,550 €	-6.19%	- 11,990,513 €	-2.93%	- 1,763,445 €	-0.41%
50	150	- 32,266,535 €	-7.54%	- 17,050,843 €	-3.56%	- 2,567,185 €	-0.49%
50	200	- 38,473,980 €	-7.11%	- 22,032,778 €	-3.13%	- 3,508,691 €	-0.58%
100	100	- 31,216,208 €	-6.88%	- 18,412,567 €	-3.77%	- 10,006,210 €	-2.02%
100	200	- 30,193,417 €	-4.28%	- 6,996,149 €	-0.92%	13,660,289 €	1.70%
100	300	- 45,094,303 €	-5.52%	- 14,292,969 €	-1.56%	14,872,298 €	1.51%
100	400	- 54,539,632 €	-5.25%	- 21,466,022 €	-2.04%	15,704,471 €	1.36%
150	150	- 40,475,955 €	-6.14%	- 21,059,124 €	-2.97%	- 8,029,104 €	-1.11%
150	300	- 37,457,338 €	-3.62%	- 2,401,190 €	-0.21%	28,891,117 €	2.45%
150	450	- 58,385,732 €	-4.83%	- 11,810,420 €	-0.88%	32,085,451 €	2.20%
150	600	- 71,223,164 €	-4.64%	- 21,297,732 €	-1.37%	34,555,215 €	2.02%
200	200	- 48,120,398 €	-5.58%	- 22,022,453 €	-2.37%	- 4,100,279 €	-0.43%
200	400	- 42,895,594 €	-3.16%	- 2,021,341 €	-0.15%	51,554,183 €	3.24%
200	600	- 68,983,032 €	-4.33%	- 6,738,023 €	-0.38%	52,151,417 €	2.72%
200	800	- 84,918,673 €	-4.20%	- 17,934,671 €	-0.87%	56,938,215 €	2.52%

Conclusions

In this thesis the feasibility of battery energy storage system for a 385 MWp photovoltaic power plant has been studied.

At this moment, considering real data (energy price from year 2020 and current battery costs) the investment of the battery energy system is not recovered during the PV park lifetime, so it is not economically feasible. This unfeasibility is due to the fact that at this moment the battery cost is still too high, and the initial investment for such big BESS (from the smallest configuration of 50 MW 50 MWh to the biggest configuration of 200 MW 800 MWh) is not recovered.

Different scenarios have been analyzed and the results have been particularly interesting in Energy Price Scenario 3, that is the scenario with the “biggest” multiplicative coefficient. This scenario reflects the fact that in a near future, with more and more renewable energy power plant, the energy prices will be influenced more and more from the photovoltaic energy production (in this specific case of the Campos del Sol project) and so during the maximum PV production hours the energy prices would be really low, and so it would be favorable to store the energy in a BESS. The possibility to combine a PV power plant with a BESS is a possibility to increase more and more the renewable energy production. The considered energy price scenario shows that the BESS could be really interesting in a near future, since in Chile there are building more and more photovoltaic power plant in the Atacama Desert.

Another aspect that has to be kept in mind is that the battery costs are decreasing year by year, and in a near future the BESS costs could become really interesting.

In this thesis work it has been considered one scenario where the BESS initial investment is decreasing of 30% of the actual cost, the initial cost is still too high to make the system economically feasible, however it could be possible that in the future a new type of battery or new material will be found, cheaper than the current one, further decreasing the initial investment.

The renewable energies are more and more important, and the future of the energy production is clearly related to the renewable energy production, so the development of the energy storage system is fundamental, in order to control the variability and unpredictability of the renewable energy sources.

It could be interesting to study different storage system combined with the photovoltaic power plant, considering that the technologies and the costs are rapidly changing.

Future studies on this field will show for sure more interesting results, also considering the fact that in Chile the photovoltaic power plants are increasing year by year and so the proposed energy price scenarios could become more and more realistic.

It would be interesting to scale the analysis also to smaller systems, considering residential solution and not only utility-scale photovoltaic power plant and showing if the BESS is an interesting solution for residential application, both from the technical and economic point of view.

References

[1] Besseghini et al., “I sistemi di accumulo elettrochimico: prospettive ed opportunità”, RSE & ANIE energia, 2017.
[2] Vazquez, S., Lukic, S. M., Galvan, E., Franquelo, L. G., & Carrasco, J. M. “Energy storage systems for transport and grid applications”, IEEE Transactions on Industrial Electronics, 2010, vol. 57(12), pp. 3881-3895.
[3] NREL online library: https://sam.nrel.gov/weather-data (visited on 05/2021)
[4] LG CHEM, Energy Solutions Company, ESS Battery Division, December 6th, 2018
[5] Xu, B., Oudalov, A., Ulbig, A., et al., “Modeling of Lithium-Ion Battery Degradation for Cell Life Assessment”, IEEE Transactions on Smart Grid, 2018, vol.9, pp.1131-1140
[6] Online Library: https://www.coordinador.cl/operacion/graficos/operacion-real/costo-marginal-real/ (visited on 05/2021)