A Model Proposal for the Electric Energy Valorization in a PV Power Plant equipped with CAES System

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Abstract

In this article, an analytical method is evaluated and implemented; to assess the possible electricity sales strategies produced by a 3 MW photovoltaic power plant, connected to a 250 kW CAES (Compressed Air Energy Storage) system, with a storage capacity of 750 kWh. The presented model combines a different numbers of parameters and variables, relevant for the system optimization. Several simulations of various system configurations have been carried out, to explore and evaluate the economic and technical feasibility of the plant, specifically it has been valued tow case of study: CASE 1 the system is not incentive; CASE 2 the system is incentive. In the end of paper it has been rated the Leveled Cost of Energy (LCOE) and specified how the investment could become affordable in the foreseeable future.

Keywords: CAES, Photovoltaic System, Energy Accumulation Systems, Energy Power Exchange, LCOE

1. Introduction

The renewable energy plays an important role for a sustainable progress, but by their nature, these sources do not allow, a continuous energy production. Sets of technologies are capable to accumulate the excess of energy to give it back when requested, commonly known like accumulation systems. These technologies are useful in the new configuration of the smart grid, that providing energy from renewable micro generation increasingly closer to the final consumer. Generally there are many storage systems, with different characteristics and specifications: hereinafter the ESA graphic determines the relations between their power rate range and their discharge time, for the different storage system.

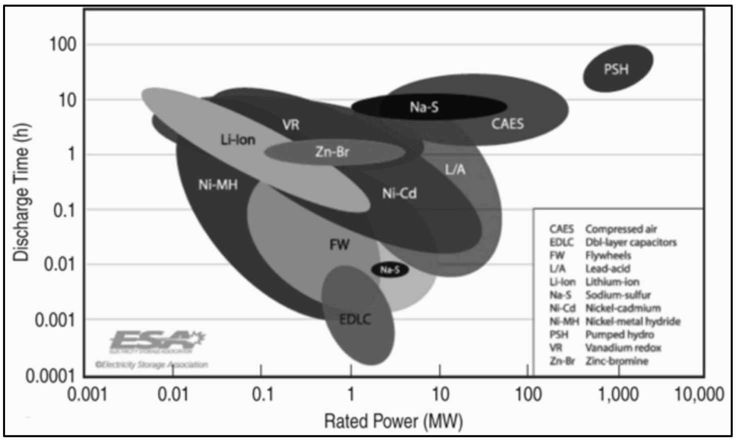


Figure 1. Characteristics of the different storage systems (Source: ESA)

1.1 Hydroelectric pumped storage

Principle of operation: a conventional hydroelectric power plant is used to generate a cyclical flow of water between two reservoirs at different elevations. The possible operating phases are two: the pumping phase (when the price of energy is lower) and the generation phase (when the price of energy is higher). Application areas and typical dimensions: the global pumping capacity amounts to approximately 200 GW. In addition, they represents around the 99% of the global stored capacity. The typical size occupies a range that varies from the order of MW to the order of GW. Strong points: high efficiency (70%), strengthened technology, reliability, very fast charge/discharge periods. Critical issues: need for placement in geo-morphologically favorable sites, relatively high investment costs.

1.2 Electrochemical storage (Na-S batteries)
Principle of operation: the sodium/sulfur battery belongs to the group of high temperature batteries in which the two electrodes are in the molten state, physically and electrically isolated from each other by a ceramic separator that allows the ion passage and performs the functions of electrolyte. Application areas and typical dimensions: large-scale electric network regulation (i.e. Grid Energy Storage), based on the MW scale (the figure shows a Japanese plant of approximately 30 MW); aerospace applications (e.g. Space Shuttle). Strong points: high energy density, high charge/discharge efficiency (89-92%), long life cycles, potential low cost in the application on a large scale, relatively mature technology, good environmental compatibility. Critical issues: the high temperatures do not allow the application to electric vehicles.

1.3 Mechanical storage (flywheels).
Principle of operation: the flywheels operate accelerating a rotor up to a very high speed and maintaining the energy in the system in the form of kinetic rotation energy. When energy is extracted from the system, for the principle of energy conservation, the flywheel speed decreases. Application areas and typical dimensions: network control service (i.e. Power Quality), the storage capacity of the order of tens of kWh, transfer power ranging between 10 and 20 kW.

1.4 Conventional CAES
CAES (Compressed Air Energy Storage), indicates a configuration which provides: a sequence of compressors with inter - and post - refrigeration stages (eventually aiming at reducing the compression work and maximizing the magnitude of the storage capacity). The storage can be a storage cave; a combustion chamber where the stored air is canalized and then attains the function of combustive agent of the natural gas; a turbine and a generator.
Application areas and typical dimensions: the only two applications in the world have been so far realized in Germany (1978, 290 MW) and USA (1991, 110 MW). Both of the plants use saline caverns as storage tanks. Currently in the world there are several plants of this type still in design phase or construction phase. Strong points: high reliability, sufficiently mature technology, compressor and turbine operate in two different instants. Critical issues: placement is needed in particularly rare sites (such as salt caverns or porous formations).

1.5 Comparisons between the different technologies
In the following diagram, a list of several technologies of storage systems is provided (for most electrochemical systems) classified according to the specific energy capacity as a function of the specific transfer power. The oblique lines represent the charge/discharge rate.

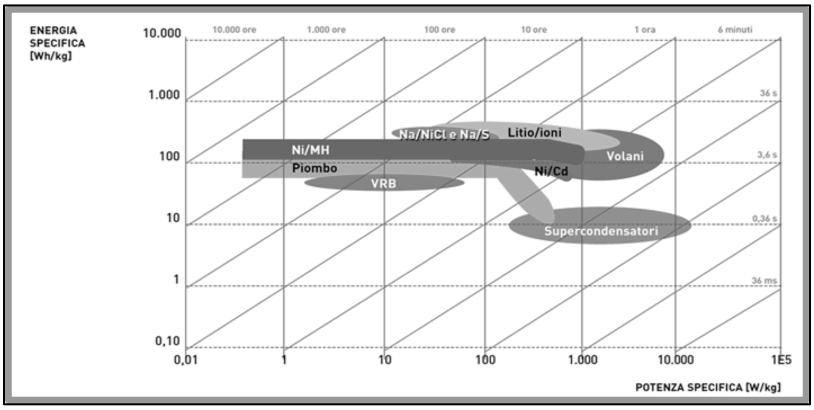


Figure 2. Diagram Power/Energy – charge/discharge rate

2. Innovative CAES system

LightSail Energy (LightSail) is in Berkeley, California. This company has developed a compressed air energy storage technology, which may be used for grid-scale storage. The main innovation is the injection of a mist of water spray into a compressed air system, so the spray rapidly absorbs the heat energy of compression and provides the energy during expansion. The system comprises a reversible mechanism to compress and expand air, one or more compressed air storage tanks, a control system, one or more heat exchangers and in certain embodiments of the invention, a motor-generator.

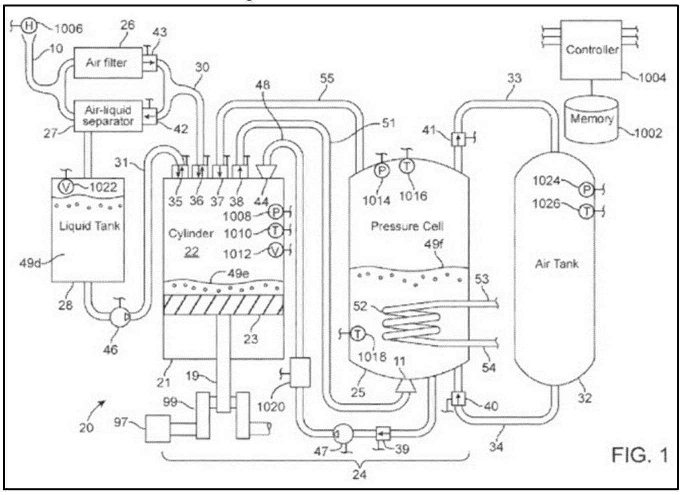


Figure 3. CAES plant layout [patent No: US 8,240,142 B2]

The reversible air compressor-expander uses mechanical power to compress air (when it is acting as a compressor) and converts the energy stored in compressed air to mechanical power (when it operates as an expander). The compressor-expander comprises one or more stages, each stage consisting of pressure vessel (the "pressure cell") partially filled with water or other liquid. In some embodiments, the pressure vessel communicates with one or more cylinder devices to exchange air and liquid with the cylinder chamber(s) thereof. Suitable valves allow air to enter and leave the pressure cell and cylinder device, if present, under electronic control. In a more detailed way, the system includes a cylinder device (21) defining a chamber (22), a piston device (23) in the chamber and a pressure cell (25). The cylinder (21) and pressure cell (25) together form a one-stage reversible pressure compression/expansion mechanism (24). Air enters the system (20) via pipe (10), passes through a filter (26) and enters the cylinder chamber (22) via pipe (30) where it is compressed by the action of the piston (23). Before compression begins, a liquid mist is introduced into the chamber (22) using an

atomizing nozzle (44). The volume of mist injected into the chamber (22) is predetermined to be the volume required to absorb all the heat generated during that piston stroke. As the mist condenses, it collects as a body of liquid (49e) in the cylinder chamber (22). The compressed air/liquid mixture is then transferred into the pressure cell (25) through outlet nozzle (11) via pipe (51). That is when the critical heat exchange occurs, followed by storage of the air: in the pressure cell 25, the transferred mixture exchanges the captured heat generated by compression to a body of liquid (49f) contained in the cell. The air bubbles up through the liquid and on to the top of the pressure cell, and then proceeds to the air storage tank 32, via pipe 33.
In conclusion, the LightSail's system is more efficient because it captures and stores both the mechanical energy and the thermal energy used in compressing air. Specifically, a water mist is infused into the compression chamber as the air is compressed. Water can hold 3,300 times as much heat as the same volume of air, and as such, it is able to capture the heat generated by the process more effectively. Both potential energy in the form of pressurized air and the heated (and therefore higher-energy) water can be stored. When the captured, pressurized air is released back through the system, the heated water is re-infused into it. That heated air can return more of the energy stored by the system than can other CAES processes.

2.1 Plant specifications

Application areas: electrical energy generation systems, both opened (connected to the grid) and closed (isolated from the grid). Typical dimensions: each module has a nominal transfer power (Power Unit, P.U.) of 250 kW and a nominal storage capacity (Storage Unit, S.U.) of 750 kWh. Advantages: high efficiency in comparison with the other CAES systems (the global transfer efficiency is 70% against 25÷30 % of traditional CAES). The system is modular: there is the possibility to adapt the system to the specific demands, varying the number of S.U. and P.U.. Innovative introduction of vaporized water injection for cooling purpose during the compression. Low cost of maintenance. Use of air as energy vector (with zero impact on operative costs). Low cost of decommissioning. Critical issues: high installation costs.

2.2 The Electrical Stock Market (Italian Power Exchange – IPEX)

The Electrical Stock Market is a telematic marketplace where electrical energy supply meets demand; it defines the amount and the price of the traded electrical energy. It represents an essential instrument for the creation of a competitive market. It has been created with the aim of facilitating the emerge of efficient balanced prices, which allows the producers and consumers to sell and buy energy when there is a greater economic profit. Some other functions are the stimulation of competition between the operators, the market's stabilization support, the incentive of new power plants and new electrical grids construction and the stimulus for new operators entrance in the Market. The IPEX was established on 1° April 2004 and it is now managed by the GME ("Energy Market Manager"). It is divided in two Markets: the MSD ("Market Services Dispatching") which is divided into the MI ("Intraday market") and the MGP ("Day-Ahead Market"), on which we will operate in this case study. The MGP is the location for the most of the electrical energy exchange transaction. There is the exchange of hourly energy stocks for the following day. The operators present their offers in which they establish the amounts of energy for sale and the minimal and maximum price at which they are willing to sell electrical energy. The session of MGP ends at 12.00 of the day before the electricity delivery. The results of MGP are communicated by 12.55 of the day before the electricity delivery. The offers are accepted after the end of the session, based on the economic subject and on the respect of the exchange limits between the zones. The MGP is an auction market and is not a continuous bargaining market. The accepted offers are referred to the PUN ("National Unique Price"), which is the medium of the prices of the geographical zones, weighted with amounts of energy purchased in those zones. The GME acts as a central counterparty.

3. Case study

The aim of this project is to realize a calculation code that operates as a simulator of sales strategies, to be applied to a PV system connected to the power grid and to the L.S.E. CAES plant. The purpose is to evaluate the economic convenience of the application of this system that, thanks to its innovative modularity, can be adapted to various power levels. In particular, it will be evaluated the application to a 3 MW photovoltaic system.

3.1 System hypothesis

HP 1. There is no possibility to sell at the same time the energy produced by the PV plant and the energy stored (CAES tank). The action number 1 of the flowchart guarantees the observance of this rule: the branches related to the respective sales have been separated.

HP 2. There is a price threshold at which the electricity sale is more advantageous than the electricity storage. This price threshold is called **δ** [€/MWh] and amounts to 57.14 €.

HP 3. This value has been calculated through the equation:

$$(1) \quad \boldsymbol{MGP} : \boldsymbol{\delta} = \eta : \mathbf{100\%}$$

Where:

- ✓ **MGP** is the Minimal Guaranteed Price: it's the marginal sale's price of electrical energy produced by renewable sources. This is an incentive condition for these types of technology. If the energy is sold to the grid in a moment in which the PUN is lower than 40 €/MWh, there is the guarantee to sell it anyway at this price.
- ✓ **η** is the global efficiency of the CAES plant (70%).

HP 4. The plant has a loss factor of 1.15. For the absorption of 250 kWh the CAES plant needs 250 kWh·1.15 = 287.5 kWh for each hour, so that after 3 hours it has absorbed 862.5 kWh accumulating only 750 kWh of electrical energy, losing 112.5 kWh. Similarly, during the emptying phase the plant sell to the grid 250 kWh of electrical energy. In this case the plant has to lose 250 kWh·0.15 = 37.5 kWh for each hour.

3.3 Calculation code

The purpose is to realize an iterative algorithm, able to automatically decide if it's more economically advantageous the sale of the energy produced by the PV plant or the storage of that energy for selling it in a second moment with a better price. During the structuring of the calculation code it was necessary to consider several parameters, from whose interaction is possible to obtain a simulation of the energy and economic operation of the system. In the following paragraph these parameters will be introduced and classified according to their nature and, for each of them, it will be given a short description.

Assessment's parameters:

PUN [€]: it's the average national price of the electrical energy; it has been obtained from the website of GME (Energy Market Manager).

SPREAD of the day before [€]: it's the difference between the value of the PUN related to the day before and the value of the MGP (Marginal Guaranteed Price). This parameter is an index of the profitability of the choice of selling energy. The arrows on the left of each value have the purpose of underline this profitability evaluation. Reclaiming the parameter δ, the following scheme is obtained:

- ✓ ↑: *SPREAD* > δ: the sale is very profitable.
- ✓ →: *0* < *SPREAD* < δ: the sale is moderately profitable.
- ✓ ↓: *SPREAD* < *0*: the sale isn't profitable (the price will be anyway 40 €/MWh).

Table 1. Assessment parameters

Date	Hour	PUN [€/MWh]		SPREAD of the day before [€/MWh]	G: Solar hourly radiation (2005) [Wh/m²]	E_{PV}: Hourly PV production [kWh]
03/01/2015	4	37,57	↓	**-4,72**	0	0
03/01/2015	5	37,15	↓	**-3,67**	0	0
03/01/2015	6	37,81	→	**0,60**	0	0
03/01/2015	7	49,60	→	**12,30**	5	14
03/01/2015	8	56,01	→	**16,77**	172	498
03/01/2015	9	60,41	↑	**24,24**	440	1.275
03/01/2015	10	60,51	↑	**24,25**	599	1.735
03/01/2015	11	55,22	↑	**24,84**	682	1.976
03/01/2015	12	53,75	↑	**22,92**	688	1.993
03/01/2015	13	52,00	↑	**18,45**	630	1.825
03/01/2015	14	51,91	↑	**18,45**	476	1.379

G: Solar hourly radiation (2005) [Wh/m^2]: it has been obtained through an estimate given by the website *"Solar Radiation Data (SoDa) – Solar Energy Services For Professionals"*.

E_{PV}: Hourly energy production of the PV plant [kWh]: it's been calculated with the following equation (in which $S_{TOT,PV}$ is the total surface of the PV plant, η_{PV} is the PV plant efficiency (14%):

(2) $E_{PV} = G * S_{TOT,PV} * \eta_{PV}$

System's variables:

It's possible to modify these three variables. Consequently the calculation code will produce different results.

$P_{P,PV}$: Peak PV Power [MW]: it's the design nominal power of the PV plant.
Number of Storage Units: number of tanks of the CAES plant.
Number of Power Units: number of units used for the energy transfer.

Other bound variables:
$C_{S.U.}$: Nominal capacity of a Storage Unit [MWh]
$P_{S.U.}$: Nominal Power of a Power Unit [kW]
C_{CAES}: Total capacity of the CAES plant [MWh]
P_{CAES}: Total transfer power of the CAES plant [kW]
$\eta_{G,CAES}$: CAES plant efficiency [%]
E_{CAES}: Stored energy [MWh]: it's the amount of energy stored as compressed air in the CAES tank.
Strategies:
SELL ENERGY PRODUCED BY PV PLANT: The energy instantly produced will be directly sold to the grid.
STORE : The energy instantly produced will be temporarily stored and released in a second moment.

SELL ENERGY STORED IN CAES: The energy earlier stored in the tank will be released and sold to the grid.

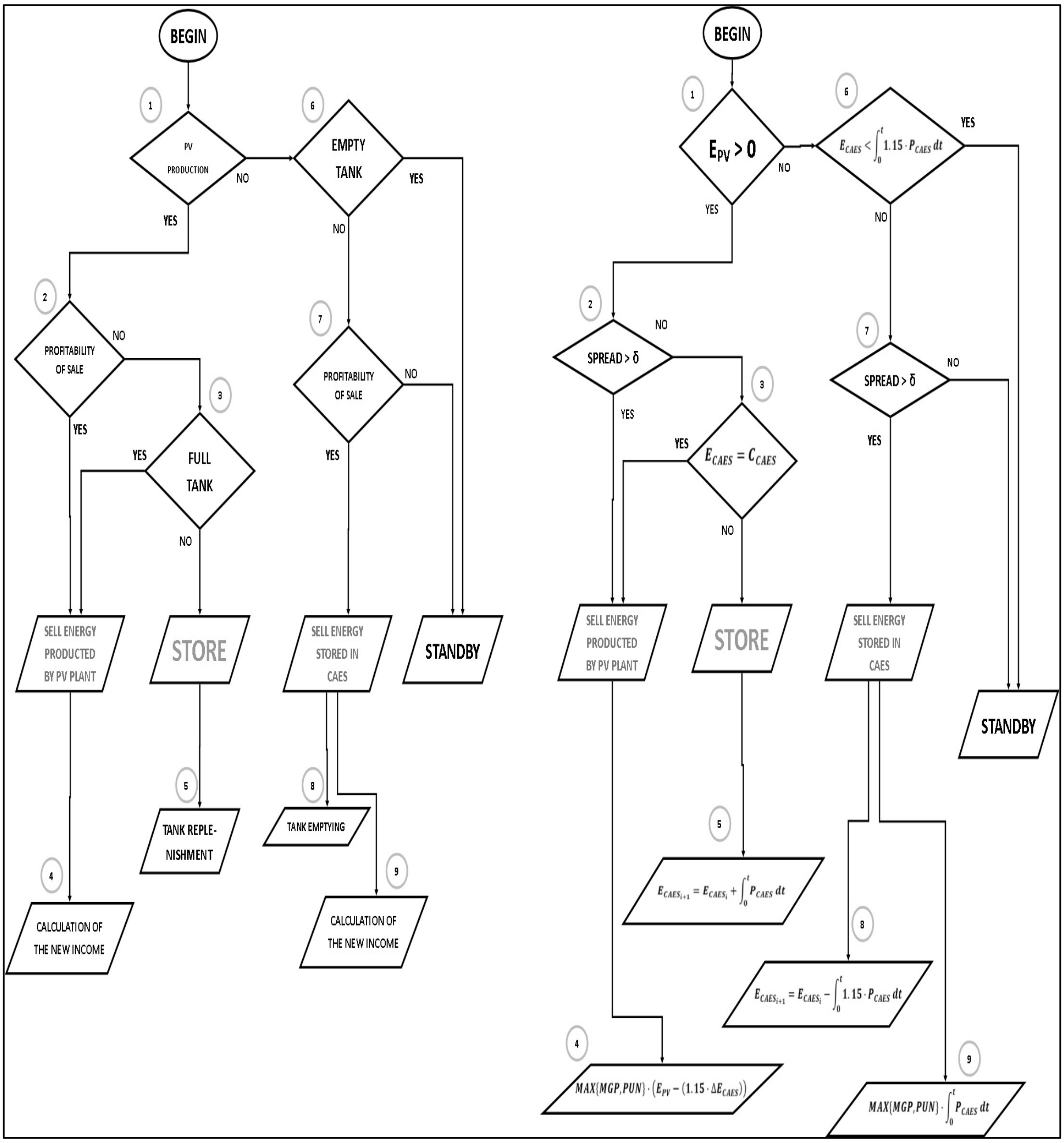


Figure 4. Flowchart of the calculation code

Table 2. Code operations

NUMBER OF CHOICE	TITLE	MEANING	FORMULA	NOTES
1	PV PRODUCTION	The PV plant is now producing electrical energy?	$E_{PV} > 0$	E_{PV} is the energy produced by PV plant.
2	PROFITABILITY OF SALE	The sale of electrical energy produced by PV plant is profitable at this moment or not?	$SPREAD > \delta$	The PV plant is now producing electrical energy [1]: we must decide what we should do with that electrical energy, if selling it or not.
3	FULL TANK	The CAES tank is totally full?	$E_{CAES} = C_{CAES}$	The energy sale is not profitable: so, we should insert in the tank the energy instantly produced [5]; but if

				the tank is full we must sell it anyway.
4	CALCULATION OF THE NEW INCOME	The new income comes from the sale of the electricity produced by PV plant.	$\boldsymbol{MAX\{MGP, PUN\} \cdot (E_{PV} - (1.15 \cdot \Delta E_{CAES}))}$	The amount $(\boldsymbol{1.15 \cdot \Delta E_{CAES}})$ is the electrical energy hourly stored (**HP 4**); the term $\boldsymbol{MAX\{MGP, PUN\}}$ is in consideration of **HP 2** and **HP 3.**
5	TANK REPLENISHMENT	The tank is replenished.	$\boldsymbol{E_{CAES_{i+1}} = E_{CAES_i} + \int_0^t P_{CAES}\, dt}$	The amount $\boldsymbol{\int_0^t P_{CAES}\, dt}$ in one hour is equal to 250 kWh (**HP 4**). The subscripts ***i*** and ***i + 1*** refer to the instants ***0*** and ***t*** respectively. When the tank is full the energy is sold to the grid.
6	EMPTY TANK	The tank is empty?	$\boldsymbol{E_{CAES} < \int_0^t 1.15 \cdot P_{CAES}\, dt}$	I this case we analyse the tank functioning. Considering the **HP 1** the energy sale from PV and CAES cannot be done simultaneously. If there is sufficiently energy in the tank, the sale (and the emptying [8]) can take place.
7	PROFITABILITY OF SALE	The sale of electrical energy earlier stored in the tank is profitable at this moment or not?	$\boldsymbol{SPREAD > \delta}$	The parameter $\boldsymbol{\delta}$ has been described in the **HP 2** and **HP 3**.
8	TANK EMPTYING	The tank is disburdened.	$\boldsymbol{E_{CAES_{i+1}} = E_{CAES_i} - \int_0^t 1.15 \cdot P_{CAES}\, dt}$	The term $\boldsymbol{\int_0^t 1.15 \cdot P_{CAES}\, dt}$ is the amount of energy that we can get from the tank in the period ***t***. If the period is one hour we can get 287.5 kWh.
9	CALCULATION OF THE NEW INCOME	The new income comes from the sale of the electricity earlier stored in the tank.	$\boldsymbol{MAX\{MGP, PUN\} \cdot \int_0^t P_{CAES}\, dt}$	The revenue from CAES energy sale is updating. This iterative algorithm evaluates the economic profit that we can obtain whit the combination PV + CAES plants, in the given specifications.

4. Economical view of project.

The economic feasibility of the project has been studied, performing the analysis of two specific cases: in the first case no market incentive is considered, in the second one market incentive is considered. For both cases, some simulations of different discount rates for evaluating the different NVP and IRR are shown. Finally, the Leveled Cost of Energy is evaluated, and, is defined when the PV + CAES technology become economically solid.

4.1 Generality of the simulation: hypothesis

Hereinafter the fixed and variables parameters of the case of study are defined:

Fixed parameters:

- PV and CAES System;
- Power of PV plants: 3,000 kW;
- Power of CAES System: 250 kW;
- Capacity of CAES System: 750 kWh;
- Year energy production by the Plants: 4,485,120 kWh;
- CAPEX 3,000,000 €;
- OPEX per year 17,940 €;
- Inflation rate 3%;
- Life plant: 21 year;
- Implementation time of the system: 2 years.

Variables Parameters

- Energy Price:
  - 0.06 €/kWh no incentive market;
  - 0.313 €/kWh incentive market.

4.1.1 Case 1

This case represents the current situation of the energy market in Italy, where the IPEx establishes the price to sell the energy, that now is 0.06 €/kWh. In the following table, is evaluating the trends of Net Present Value for different discount rates (15%, 12%, 10%, 8%, 6%, 4%) and Internal Rate of Return (IRR%).

Table 3. Economic analyses of the investment: CASE 1

CASE 1: no incentive market: 0,06 €/kWh	dn	dr	TAXED SYSTEM 41,3%	dn	dr
IRR%	8,73%	6,26%	IRR%	6,57%	3,46%
NPV@15%	-1.049.709,19 €	-1.049.709,19 €	NPV@15%	-1.457.538,39 €	-1.457.538,39 €
NPV@12%	-581.976,07 €	-581.976,07 €	NPV@12%	-1.122.136,29 €	-1.122.136,29 €
NPV@10%	-144.545,24 €	-144.545,24 €	NPV@10%	-808.838,74 €	-808.838,74 €
NPV@8%	441.531,97 €	441.531,97 €	NPV@8%	-389.735,96 €	-389.735,96 €
NPV@6%	1.240.358,36 €	1.240.358,36 €	NPV@6%	180.378,38 €	180.378,38 €
NPV@4%	2.348.849,28 €	2.348.849,28 €	NPV@4%	969.702,91 €	969.702,91 €

The dr is the Real Discount Rate, in which is considering the inflation; the equation is the following:

$$(3) \quad \boldsymbol{d_r} = \left[\frac{\mathbf{1}+\boldsymbol{d_n}}{\mathbf{1}+\boldsymbol{r}} - \mathbf{1}\right]$$

So there are the summary table of dn and dr:

Table 4. Nominal and Real Discount Rate

dn	dr
15,0%	11,7%
12,0%	8,7%
10,0%	6,8%
8,0%	4,9%
6,0%	2,9%
4,0%	1,0%

For all cases considered the investment is inconvenient, because the IRR% is low 8.73 % in case without inflation and 3.46% in the worse case, considering a 3.00 % of inflation and 41.3 % of taxes, as well as in the Italian marketplace. Therefore, the photovoltaic and CAES system considering, will be not-convenient.

4.1.2 Case 2

The Case 2 considering the energy selling price of 0.313 €/kWh (this is a case with government incentives like was in Italy some years ago); the business becomes highly affordable, the NVP and IRR are very convenience.

Table 5. Economic analyses of the investment: CASE 2

CASO 2: government incentivet: 0,313 €/kWh	dn	dr	TAXED SYSTEM 41,3%	dn	dr
IRR%	42,08%	37,97%	IRR%	31,80%	27,96%
NPV@15%	7.054.283,21 €	7.054.283,21 €	NPV@15%	3.675.449,36 €	3.675.449,36 €
NPV@12%	9.761.443,29 €	9.761.443,29 €	NPV@12%	5.345.804,69 €	5.345.804,69 €
NPV@10%	12.263.134,28 €	12.263.134,28 €	NPV@10%	6.885.366,85 €	6.885.366,85 €
NPV@8%	15.588.294,47 €	15.588.294,47 €	NPV@8%	8.927.670,69 €	8.927.670,69 €
NPV@6%	20.090.818,37 €	20.090.818,37 €	NPV@6%	11.688.092,38 €	11.688.092,38 €
NPV@4%	26.305.669,72 €	26.305.669,72 €	NPV@4%	15.492.033,12 €	15.492.033,12 €

The investment is economic, in the worst case where the market is inflated and taxed, the IRR is 27.96 % and the NPV 15% is 3,675,449.36 € after 21 years from the investment, more then 23% of initial capital. In the best case the IRR is 42.08% and the NVP 4% is 26,305,669.72 € more than 777% of initial capital.

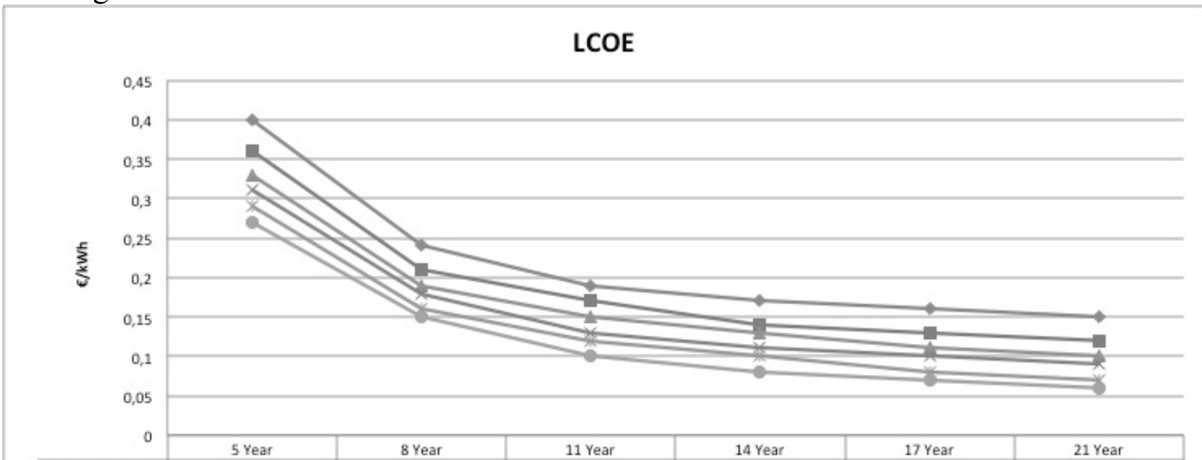
4.2 Conclusions: LCOE: Levelled Cost Of Energy (Electricity)

The two cases of study showed two opposite market situation, really distance from a reasonable investment. The question is: what is the profitable right price to sell the energy for this plant? The Levelled Cost Of Energy or Levelled Energy Cost (LEC) answers this question. LCOE is a convenient summary measure of the overall competiveness of different generating technologies. It represents the per-kilowatt-hour cost of building and operating a generating plant over an assumed financial life and duty cycle. Components for the calculation of LCOE are capital costs, fuel costs, fixed and variable operations and maintenance (O&M) costs, financing costs, and an assumed utilization rate for each plant type.

$$(4)\ LCOE = \frac{\sum_{t=1}^{n} \frac{C_t+O_t+F_t+O_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

- ✓ LCOE: Levelized Cost Of Energy
- ✓ C_t: capital cost
- ✓ O_t: Operation (fixed and variable) and maintenance cost
- ✓ F_t: Fuel cost
- ✓ O_t: Other cost
- ✓ E_t: Energy produced
- ✓ n: life of plants
- ✓ r: rate of discount

It will consider hereinafter as is varying the LCOE with the changing of plant's life, and how this system could be economic. The nominal discount rates for this model are 15%, 12%, 10 %, 8%, 6%,4%; the energy produced by the plant every year is 4,485,120kWh, the Capex is 3,000,000 €, Opex is 31,396 € every year. There aren't another costs of plant for this model, and there aren't revamping in the all life of this plant (the revamping is including in operation year cost). It is observed that the prices vary from a maximum of 0.40 € / kWh to a minimum of 0.06 € / kWh, where the NPV is 4% and the stakeholder admits payback time in 21 years from the investment. But no one good economical investor wants to do an investment to have a return at the end of the plant's life (in the better case) and no one clever state policy invests on loss industry, therefore the considering PV plants and CAES system are not momentarily affordable. The PV plants is reasonable just for the power micro generation for users that pay the energy above 0.20 €/kWh. This is the case of Italy, where the GSE (Italian National Grid Operator) recognizes the SEU (Users Efficient Systems) for operators of PV energetic establishment. In this case the price of electricity could be more than 0.20 €/kWh. If is looking the equation (4), the price of energy will be lower in two way: or decreasing the numerator or increasing the denominator.



	5 Year	8 Year	11 Year	14 Year	17 Year	21 Year
LCOE @15%	0,4	0,24	0,19	0,17	0,16	0,15
LCOE @12%	0,36	0,21	0,17	0,14	0,13	0,12
LCOE @10%	0,33	0,19	0,15	0,13	0,11	0,1
LCOE @8%	0,31	0,18	0,13	0,11	0,1	0,09
LCOE @6%	0,29	0,16	0,12	0,1	0,08	0,07
LCOE @4%	0,27	0,15	0,1	0,08	0,07	0,06

Figure 5. LCOE variation

In the first case it will be possible that the technology will become less expensive (Opex, Capex and other costs will be cheaper). The denominator is composed by the energy producing that is:

$$(5)\ \ E = \int_{t1}^{tf} P dt = P\Delta t = P(t_f - t_1)$$

Where t_f=t hours of plant's operation and t_1=0. The power of photovoltaic system depends on the yield factor η, the irradiance I_0 (W/m^2), the surface S (m^2), the angle of inclination of the module with respect to incident solar radiation ($\sin\alpha$):

$$(6)\ \ P = \eta \cdot I_0 \cdot S \cdot \sin\alpha$$
$$(7)\ \ E = \eta \cdot I_0 \cdot S \cdot \sin\alpha \cdot t$$

In the present state of technology, to increase the energy, it should increase the performance of the plant. The yield Factor of the actual plant is 19% ; so the equation is:

$$(8)\ E = \eta \cdot K => 4.485.000 = 0{,}19 * K => K = 23.605.263\ kWh$$
$$(9)\ \ K = I_0 \cdot S \cdot \sin\alpha \cdot t$$

K is the potential of the energy that the plant can produce in one year if the η could be 100%. Is provided below the equation (4) introducing the equation (8) and (9), is looking:

(10)

$$LCOE = \frac{\sum_{t=1}^{n} \frac{C_t + O_t + F_t + O_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{\eta \cdot K}{(1+r)^t}}$$

Therefore, if the efficiency of the plant will be increasing, the LCOE will be decreasing, making economically the photovoltaic system. In the same time, the CAES system could be a good business if it will be combined with PV system.

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