CIEEMAT | 2024
VIII Ibero-American Congress on Entrepreneurship, Energy, Environment, and Technology

Proceedings of the

CIEEMAT 2024

VIII Ibero-American Congress on Entrepreneurship, Energy, Environment, and Technology

Rio de Janeiro, Brazil
October, 14-16, 2024

CEFET/RJ
ipb INSTITUTO POLITÉCNICO DE BRAGANÇA
POLITÉCNICO DE PORTALEGRE
BR PETROBRAS
Finep INOVAÇÃO E PESQUISA
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO
GOVERNO FEDERAL BRASIL UNIÃO E RECONSTRUÇÃO
FAPERJ Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro
CONFEA CREA mútua

Proceedings of the

CIEEMAT 2024 | VIII Ibero-American Congress on Entrepreneurship, Energy, Environment, and Technology

Editors
Ângela Paula Ferreira, Instituto Politécnico de Bragança, Portugal
Fabiana de Oliveira Ramos, Federal Center for Technological Education of Rio de Janeiro, Brazil
Laíce de Souza Scotelano, Federal Center for Technological Education of Rio de Janeiro, Brazil
Margarete Heleno da Silva, Federal Center for Technological Education of Rio de Janeiro, Brazil
Ronney Arismel Mancebo Boloy, Federal Center for Technological Education of Rio de Janeiro, Brazil

Book Cover
Soraia Maduro, Instituto Politécnico de Bragança, Portugal

Publisher
Instituto Politécnico de Bragança (IPB)
Campus de Santa Apolónia
5300-253 Bragança - Portugal

December, 2024

ISBN: 978-972-745-349-8
Handle: http://hdl.handle.net/10198/30674
DOI: 10.34620/978-972-745-349-8
URL: https://dippg.cefet-rj.br/ppges/index.php/pt/cieemat-principal
e-mail: cieemat88@gmail.com

Utilization of Excess Energy in Photovoltaic Plants Caused by Clipping: Efficiency Comparison between Battery and Green Hydrogen Storage Solutions

Beatriz Souza Horn[1,2,3], Orlando Soares[1] and Paulo Brito[2]
[1] Instituto Politécnico de Bragança, Portugal
[2] Valoriza - Research Center for Valorization of Endogenous Resouces, Portalegre Polytechnic University - IPP, Portugal
[3] Federal Center for Technological Education of Rio de Janeiro - CEFET/RJ, Brazil
beatrizhorn16@gmail.com, osoares@ipb.pt, pbrito@ipportalegre.pt

Abstract

When a photovoltaic plant project is sized, the system can be oversized to achieve greater utilization of the generation curve. However, during peak production times on days with higher irradiance, the generation curve may be cut (clipping), resulting in unused excess energy. This unused energy can be a challenge, especially for energy trading plants, as they are limited in injecting this energy into the grid at the same time as production. This study proposes turning this challenge into an opportunity by suggesting energy storage for later injection into the grid. For this, a comparison of efficiency between battery storage and green hydrogen storage solutions is performed. The analysis considers the same initial conditions for both storage options, along with the respective estimated losses for each process. The objective of this work is to compare the energy utilization profile over a 25-year lifespan of a photovoltaic plant for the two storage systems analyzed, considering scenarios with and without replacement of storage systems. The results of this study, which only compares the energy efficiency ratio, highlight a greater stored energy for the battery system and a trend with more attenuated variations for the green hydrogen system.

1. Introduction

In photovoltaic plant projects, it is possible to perform an overdimensioning, adding a peak installed power of DC (Continuous Current) photovoltaic modules higher than the rated power AC (Alternating Current) of the inverter. Thus, in moments of low irradiance, the additional photovoltaic modules will minimize this impact by maximizing the total energy produced. However, in moments of high irradiance, as the inverters are not able to transform all DC energy into AC due to the limitation of the nominal installed power, this energy is lost. This phenomenon can be called clipping, since there is a cut in the generation curve.

To circumvent this issue, the agent generators and traders of photovoltaic solar energy seek market solutions to utilize the generated excess energy. One of the most sought-after solutions is energy storage, for later injection into the grid during low irradiance periods. Conventionally, batteries are used. However, there are other storage methods, such as hydrogen. Specifically green hydrogen, which is produced by electrolysis of water, through a renewable source in continuous current. In this sense, hydrogen becomes an option for analysis of the charging and discharging process in its production and transformation chain up to storage, because it presents characteristics applicable to photovoltaic plants.

Therefore, the objective of this work is to compare, over 25 years of useful life of a photovoltaic plant, the efficiency of battery storage systems with the green hydrogen storage systems, as contour solution options to avoid losses of excess energy caused by clipping.

2. Characteristics of storage systems

Based on the two solutions presented, it is possible to compare some main characteristics to analyze their performance. Table 1 demonstrates these characteristics for the battery or hydrogen storage options. Three items from this table can be highlighted for further development: Energy Density, Useful Lifetime/Lifespan, and Technical Maturity (TRL -Technology Readiness Level).

Energy density demonstrates the amount of energy that can be stored in a given volume. The higher this value, the more energy can be stored, and it is possible to supply power to a load for longer, before needing to be recharged again. Hydrogen has this aspect as an advantage over batteries.

The Lifespan corresponds to the period of use in service of an asset, while generating economic benefits. In this analysis, the lifespan of the green hydrogen storage system is generally longer. However, the time indicated for complete replacement of both systems must be considered so as not to compromise quality operation.

The Technical or Technological Maturity Level (TRL) is an important factor for analysis. because it defines at what stage the technology is in the level of progress of research and development activity. It is worth mentioning that this factor is mutable according to the analysis period. Between these two storage systems, the TRL of the battery is higher than that of green hydrogen.

Attribute	Battery	Hydrogen	References
Response Time	ms	min	(Assia Chadly, 2022)
Storage Time	Minutes/Days	Hours/Weeks	(Botteon, 2020)
Storage Capacity	kWh-MWh	MWh-GWh	(Fonseca, 2022)
Energy Density	1-100 Wh/kg	100-1000 Wh/kg	(Javier Tobajas, 2022) (Mukrimin Sevket Guneya, 2017)
Lifespan	Varies from 5-20 years	Varies from 20-40 years	(Boucar Diouf, 2015) (Hui Liu, 2012)
Efficiency	Varies from 85–98%	Varies from 50–60%	(Assia Chadly, 2022) (Farrancha, 2019)
Technical Maturity	More mature technology	Less mature technology	(Lucas Macedo da Silva, 2022)

Maintenance	System replacement when requested	Reduces the frequency of equipment replacements	(Esteves, 2017)
Toxicity and Environmental Risk	Harmful to the environment	Low greenhouse gas emissions	(Lucas Macedo da Silva, 2022)
Estimated Investment Cost	450 €/kWh	2800 €/kWh	(Barbosa, 2019)

Table 1: Battery and Hydrogen Storage Attributes

3. Methodology

The methodology of this work follows the steps below to use the same conditions of a designed plant to compare the energy efficiency between battery and green hydrogen storage methods.

3.1. Sizing of the photovoltaic plant and initial energy for storage

In order to obtain a better measurement of results, average sizing values for installed power and clipping in photovoltaic plants were chosen. For installed power in Wp (Watt peak), the value of 300 MWp was chosen for use in this study, based on the most recent powers of plants installed around the world (Brasil Energia, 2017) (Canal Solar, 2021) (Canal Solar, 2024). For clipping, an average ratio of 1.3 between DC power and AC power was chosen (Leonardo Micheli, 2024). Based on these premises, the example plant in question would result in a maximum power transformed by the inverters of approximately 230 MW.

For that, an ideal clipping of 30% is estimated. This value of energy not used based on the ideal conditions of the plant will not be the stored value, need to pass through discounts for estimated losses. These losses can be divided between losses from climatic conditions and operational conditions to characterize a profile more consistent with reality. Losses due to climatic conditions reflect the meteorological variation that the location where the photovoltaic plant is installed may suffer. Losses due to operational conditions represent any interference with photovoltaic plant equipment and preventive or corrective maintenance routines.

To estimate the acceptable average loss value, we used the acceptable average value of 75% of Performance Ratio – PR (Gabriel Bastos Plantickow, 2021). The PR demonstrates the performance of the photovoltaic plant through the ratio of generated energy and optimal energy based on installed power and variations in climatic conditions. Therefore, with this reference value, the total losses of climatic and operational conditions result in an average of 25%. In this scenario, when there is clipping, considering the discount of losses, it is estimated that only 5% of the installed power can be stored. For this case study, resulting in an average unutilized power value of 15 MW. Considering 6 Peak Sun Hour (PSH) per day (Samira, 2021), it returns an average unused energy per day of 90 MWh for storage.

With the purpose of evaluate the annual performance of each storage system, 90 days of possible clipping were considered per year, in order to contemplate at least the summer season, which allows greater solar irradiance (Silva, 2022).

3.2. Battery Storage

For the battery option, lithium-ion batteries were chosen for presenting higher energy density, greater efficiency and longer life cycle, compared to lead acid batteries and other technologies (Bárbara A. L. Paixão, 2020). Currently, a viable option for photovoltaic plants is the BESS (Battery Energy Storage System). This system stands out for its advantages of balancing the electrical grid, providing backup energy during interruptions and improving the overall stability of the grid. However, this system was not dimensioned in this work; only technical characteristics of this type of battery were considered for the efficiency study.

For the battery storage option, the following losses were considered: Round-trip efficiency and Self-discharge rate.

The first factor considered reflects the round-trip efficiency, charge and discharge, of the battery system, which is represented by a curve provided by the manufacturer in line with the operating rate (C rate) of the battery system or by an efficiency percentage. The C rate represents the charge and discharge rate of an energy storage element relative to its maximum capacity. In a battery with a capacity of 30 Ah, if for a rate 1 C there is full discharge in 1h, for a rate 2 C, it is faster, the battery will discharge in half an hour its entire capacity, for example. For this efficiency, the value of 90% was considered (Canadian Solar, 2021).

The second factor considered is the rate of self-discharge, the batteries are self-discharge gradually even without being in operation and without existing current. This is due to chemical reactions that happen inside the cell, even in inertia. Lithium-ion batteries have self-discharge rate less than 5% per month (Maria de Fátima Negreli Campos Rosolem, 2020).

The round-trip efficiency was applied to the initial daily energy to be stored of 90 MWh, resulting in a final energy, after charging and discharging by the battery storage system, of 81 MWh per day.

Considering the gradual self-discharge and changes in efficiency by temperature, it was considered an annual efficiency of 95% in the first year of operation, 97% per year until the twentieth year of operation (which represents the final year of useful life indicated by the manufacturer) and 94% per year until the twenty-fifth year, considering the round-trip efficiency drop (Canadian Solar, 2021).

For the analysis of the results, two scenarios were considered. The first scenario does not consider replacement of the storage system to replace batteries completely. Thus, it is possible to analyze the efficiency until the twenty-fifth year of operation of the plant, end of the useful life of the photovoltaic system, without interference (Brito, 2020). And the second scenario considering only one replacement to replace all equipment, in the thirteenth year of operation of the plant, depicting possible maintenance decisions. In this last scenario, the efficiencies are considered as the start of operation of the system.

3.3. Green Hydrogen Storage

For hydrogen storage option, the production of green hydrogen through local electrolyzer in the photovoltaic plant was chosen. This choice was made by producing from a renewable source, in the same production site, avoiding transportation costs and storage space is not a very big impact in this case.

As for the return of the final energy, the coupling of a fuel cell was chosen after the compression and storage of the hydrogen produced by the electrolyzer. This scheme can be better explained through the image below (Veiga, 2022).

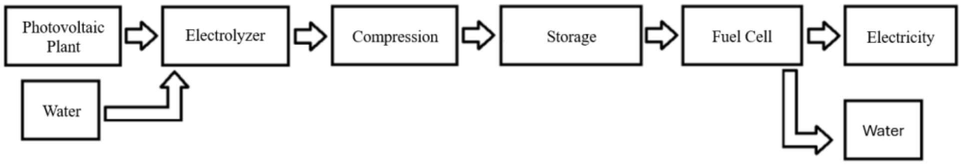

Figure 1: Charging and discharging scheme of energy stored by green hydrogen

This option will be divided into charging (electrolyzer), storage (gaseous hydrogen) and discharge (fuel cell).

For the moment of charge was used an electrolyser model PEM (Proton Exchange Membrane). The electrolyser is a device that allows hydrogen to be produced by means of a chemical process (electrolysis). Water electrolysis is the chemical decomposition of water (H_2O) into oxygen (O_2) and hydrogen (H_2) by the effect of an electric current passing through the water. This model stands out for coupling to photovoltaic plants due to its ability to respond quickly to power fluctuations. The PEM type electrolyser can operate under variable energy regime.

This is one of the differences when compared with alkaline electrolysers, because the transport of ions in this model presents a greater inertia. A factor of 80% was considered as the efficiency of the PEM electrolyzer, a higher efficiency when compared to the AWE (Alkaline Electrolyzers) and SOE (Solid Oxide Electrolyzers) models, for example (Seddiq Sebbahi, 2022).

Therefore, considering the initial energy at 90 MWh/day or 15 MWh, applying the efficiency of the PEM electrolyzer, the result is 12 MWh. Converting this energy to hydrogen quantity (Nm3/h), through 4.5 (kWh/Nm3) for this electrolyser (Seddiq Sebbahi, 2022), 2667 Nm3/h or 240 kg/h of hydrogen is generated.

From this generation capacity, it was considered a PEM electrolyzer with capacity of 4000 (Nm3/h) (Thyssenkrupp Nucera, 2022). Compared to other dimensions, this one has an ideal operating range of 400 (10%) to 4000 (100%), contemplating a good range of power oscillations.

Two options were raised for storage: liquid hydrogen and gaseous hydrogen. Since the gaseous hydrogen method has lower losses, this was chosen, since in the process of liquid hydrogen there would be losses by evaporation (Monteiro, 2023). To reflect this scenario, a minimum loss of 2% was estimated, applied to the volume of hydrogen before entering the fuel cell. Thus, the hydrogen volume found at 240 kg/h at the end of the load becomes 235 kg/h at the beginning of the discharge.

For the discharge moment, the PEMFC (Proton Exchange Membrane Fuel Cell) was considered. This Proton Exchange Membrane fuel cell transforms the chemical energy, released during the electrochemical reaction of hydrogen and oxygen, into electrical energy. This model stands out for its higher power density compared to the others (Farrancha, 2019).

For the fuel cell, an efficiency of 55% and a power density of 4.5 kW/m3 were estimated (Farrancha, 2019). From this, a calorific value of 4.5 kWh/Nm3 was considered, that is, 50 kWh/kg. Using this calorific value in the hydrogen volume of 235 kg/h, 11.7 MWh/h is obtained at the beginning of the discharge. Applying the considered efficiency of 55%, at the end of the discharge, 6.5 MWh/h is obtained, generating 38.8 MWh/day.

After all the transformations of the green hydrogen storage process, comparing the final energy of 38.8 MWh/day with the initial of 90 MWh/day, can be observed an overall efficiency of this process in 43%.

For the hydrogen cycle, considering the coupled system of electrolyzer, compression, storage and fuel cell, a degradation of 2.64% is estimated after 2 years of operation (Ender Ozden, 2017). From this, performing a linear forecast, an annual degradation of 1.32% is obtained. Therefore, the system presents 98.68% efficiency per year.

Similar to the battery storage system, for analysis and comparison of the results, the same two scenarios were demonstrated, one considering replacement of the equipment in 13 years of operation and the other not.

4. Results

The results of this study were based on the premises mentioned above, which can be summarized in Table 2.

Attribute	Battery	Green Hydrogen
Initial Energy Stored per Day (MWh)	90	90
Clipping Days per Year	90	90
Initial Energy Stored per Year (MWh)	8100	8100
Charge and Discharge Efficiency (%)	90%	43%
Annual Efficiency Year 1 (%)	95.00%	98.68%
Annual Efficiency Year 2 to 20 (%)	97.00%	98.68%
Annual Efficiency Year 21 to 25 (%)	94.00%	98.68%

Table 2: Assumptions Considered

From these defined and applied premises, two graphs were generated, presented in figures 2 and 3, respectively, to compare the storage profile of both options over 25 years. The first does not consider system replacements and the second considers complete replacement of the systems in the thirteenth year of operation.

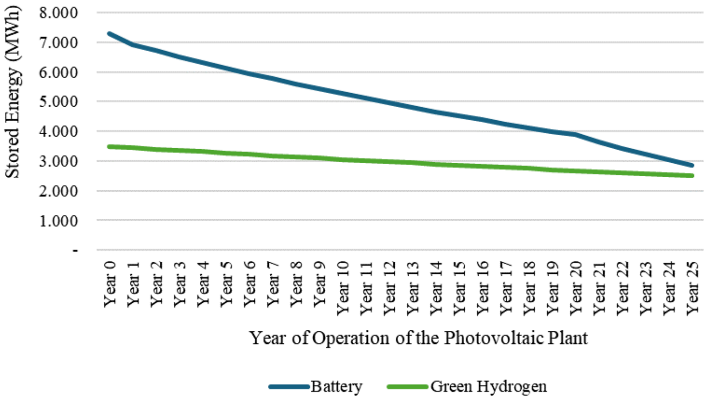

Figure 2: Comparison of results without system replacement

Analyzing the first scenario, it is observed that the initial energy of the green hydrogen storage system is approximately half of the initial energy of the battery storage system. This is a result of the low efficiency of the green hydrogen system compared to the battery system, after charging and discharging, 43% and 90%, respectively. The low efficiency of the green hydrogen system is a consequence of the number of transformations involved in the whole process and consequently higher losses until the energy to be discharged.

It is noticed that the self-discharge rate of the battery directly influences the energy curve of this system, showing a significant decrease in the value of stored energy over the years. Relating the year 25 to the year 0, the battery system has an efficiency of 39%, while the green hydrogen system has an efficiency of 72%.

Therefore, if there is no replacement of the system equipment, the final energy in year 25 is closer to the initial energy in year 0 in the green hydrogen storage system. But, because the initial energies are different and there is a higher initial energy for the battery system, this system has more stored energy in year 25. However, the value presented in both systems in year 25 is similar between them, even with the large initial difference. Presenting more similar energy values over the years and more approximate curves.

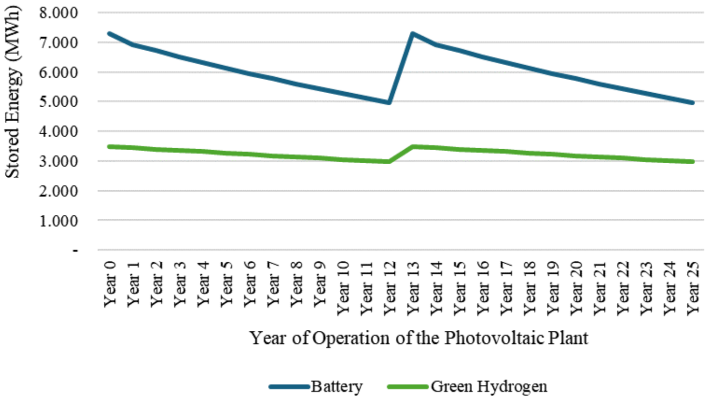

Figure 3: Comparison of results with system replacement

The objective of considering a second scenario with the replacement of the systems was to evaluate the change in the energy stored curve, considering that it is a probable maintenance action to be carried out over 25 years.

In this scenario, it can be observed that the increase in efficiency and consequent stored energy is greater for the battery system. The green hydrogen system, on the other hand, presents a more subtle efficiency gain. This factor can be decisive in an investment analysis with the objective of improving the efficiency of the system.

From year 13 onwards, with the performance of new equipment and efficiency similar to that of the year 0, energy curves are distancing. However, continuing to consider annual efficiency drops, the curves tend to approximate over the years.

In this scenario, relating the year 25 to the year 0, the battery storage system returns an efficiency of 68% and the green hydrogen storage system of 85%. Comparing this scenario with the scenario that does not consider replacements, the efficiency gain for the battery system is clear, from 39% to 68%. However, the green hydrogen storage system does not show such a significant gain, 72% to 85%.

The annual energy stored is higher in the battery storage system, in both scenarios, for all years. The efficiency drop at the end of 25 years is lower for the green hydrogen storage system in both scenarios.

Although this study considered some characteristics of a BESS system with lithium-ion batteries, which includes battery costs, plus the cost of the electronic control system and a longer useful life, considering a more conservative scenario and variations in other technologies present in the market, the average replacement times for the systems are 4 years for the battery and 15 years for hydrogen (Sergio Silva, 2010). For the hydrogen system, not all components need to be replaced in 25 years, such as the cylinders that reach the end of their useful life at the end of the photovoltaic plant's operation (Sergio Silva, 2010). However, in an analysis of total replacement of the two systems, it is observed that in 25 years, the battery system would be replaced 4 times and the hydrogen one time. However, in a total replacement analysis of the two systems, it is observed that in 25 years, the battery system would be replaced 4 times and the hydrogen one time. Considering the investment costs of both systems mentioned in Table 1, as initial investment and replacement cost, the total cost of the battery system would be 2250 €/kWh and hydrogen 5600 €/kWh. Therefore, the battery system becomes more advantageous than just the initial investment of the hydrogen system.

Table 3 highlights the main results of both systems.

Attribute	Battery	Green Hydrogen
Initial Energy Stored per Day (MWh)	90	90
Final Energy Stored per Day (MWh)	81.0	38.8
Daily Charge and Discharge Efficiency (%)	90%	43%
Initial Energy Stored in Year 0 (MWh)	7290	3492
Efficiency in 25 years without replacement (%)	39%	72%
Efficiency in 25 years with replacement (%)	68%	85%

Table 3: Results

5. Conclusion

The study concluded that, now, energy storage in batteries is more efficient than green hydrogen storage. This higher efficiency of batteries is due to the smaller number of transformations involved in the process, resulting in lower losses. Batteries stand out for solid technology and wide applicability, while green hydrogen offers advantages such as long-term storage, longer service life, and potential for exploration of by-products such as oxygen and hydrogen for sale.

The presented graphs suggest that if the green hydrogen storage system reaches a higher Technical Maturity Level (TRL) and the process of transformations generate less losses, it may be possible for the lines on the graphs to cross before year 25. This would result in a higher efficiency for this system, compared to the battery system, after a certain year of operation.

For a more complete energy and sustainable analysis, it is important to consider the auxiliary consumption of equipment and the use of water in the process of producing green hydrogen. Although the study focuses on efficiency, the future technical and financial analysis would be necessary to assess the return on investment and long-term viability of both storage options. Thus, the choice between batteries or green hydrogen will depend on specific objectives, installed capacity of the plan, surplus energy, technologies chosen, initial investments (CAPEX), operating expenses (OPEX) and the expected operating time of the system.

References

Assia Chadly, E. A. (2022). Techno-economic analysis of energy storage systems using reversible fuel cells and rechargeable batteries in green buildings. Retrieved from https://www.sciencedirect.com/science/article/pii/S0360544222003693

Bárbara A. L. Paixão, D. I. (2020). Comparação de Vida Útil entre Bancos de Baterias de Íon-lítio e Chumbo-ácido no Contexto da Compensação de Energia com Fotovoltaicos e Tarifa Branca. Retrieved from https://www.academia.edu/download/95313452/2153-Article_Text-4190-1-10-20210223.pdf

Barbosa, R. (2019). Hidrogénio e armazenamento de energia. Retrieved from https://www.ordemengenheiros.pt/fotos/editor2/eventos/ricardo_barbosa.pdf

Botteon, A. M. (2020). Um olhar mais atento à infraestrutura de hidrogênio. Retrieved from https://www.linkedin.com/pulse/um-olhar-mais-atento-%C3%A0-infraestrutura-de-hidrog%C3%AAnio-botteon/

Boucar Diouf, R. P. (2015). Potential of lithium-ion batteries in renewable energy. Retrieved from https://www.sciencedirect.com/science/article/pii/S0960148114007885

Brasil Energia. (2017). Argentina começa construção de usina solar de 300 MW. Retrieved from https://brasilenergia.com.br/energia/argentina-comeca-construcao-de-usina-solar-de-300-mw/

Brito, T. H. (2020). Estudo da Viabilidade Econômica da Instalação de Energia Solar Fotovoltaica Ligada à Rede, no IFPB, Campus Princesa Isabel. Retrieved from https://repositorio.ifpb.edu.br/handle/177683/1606

Canadian Solar. (2021). Preliminary Technical Information Sheet BEES. Retrieved from https://static.csisolar.com/wp-content/uploads/2021/01/14093918/CanadianSolar_CSES351A6-3500KVA-14MWH-BESS-r7_J1.pdf

Canal Solar. (2021). Solis fornece inversores para usina de 300 MW instalada em planícies de maré. Retrieved from https://canalsolar.com.br/solis-fornece-inversores-para-usina-de-300-mw-instalada-em-planicies-de-mare/

Canal Solar. (2024). Projeto de 300 MW no Deserto de Tengger é comissionado na China. Retrieved from https://canalsolar.com.br/projeto-de-300-mw-no-deserto-de-tengger-e-comissionado-na-china/

Ender Ozden, I. T. (2017). PEM fuel cell degradation effects on the performance of a stand-alone solar energy system. Retrieved from https://www.sciencedirect.com/science/article/pii/S0360319917313289

Esteves, A. (2017). Célula Combustível versus Bateria Comum Comparando dois Sistemas de Geração de Energia. Retrieved from https://www.linkedin.com/pulse/c%C3%A9lula-combust%C3%ADvel-versus-bateria-comum-comparando-dois-silva/

Farrancha, P. N. (2019). Operation of a fuel cell with biohydrogen obtained from food waste. Retrieved from https://repositorio.ul.pt/bitstream/10451/40596/1/ulfc125189_tm_Pedro_Farrancha.pdf

Fonseca, F. C. (2022). O papel do hidrogénio na transição energética: oportunidade ou distração? Retrieved from https://www.linkedin.com/pulse/o-papel-do-hidrog%C3%A9nio-na-transi%C3%A7%C3%A3o-energ%C3%A9tica-ou-correia-da-fonseca/

Gabriel Bastos Plantickow, B. P. (2021). Solar Energy: Study on the Economic Feasibility of the Implementation of a Photovoltaic System in a Single-family Residence in Colatina(ES). Retrieved from http://revista.unesc.br/ojs/index.php/revistaunesc/article/view/317/124

Hui Liu, A. A. (2012). Analysis of Ontario's hydrogen economy demands from hydrogen fuel cell vehicles. Retrieved from https://www.sciencedirect.com/science/article/pii/S0360319912006301

Javier Tobajas, ,. F.-T.-S. (2022). Resilience-oriented schedule of microgrids with hybrid energy storage system using model predictive control. Retrieved from https://www.sciencedirect.com/science/article/pii/S030626192101374X?via%3Dihub

Leonardo Micheli, M. M. (2024). Quantifying the impact of inverter clipping on photovoltaic performance and soiling losses. Retrieved from https://www.sciencedirect.com/science/article/pii/S0960148124003823?ref=pdf_download&fr=RR-2&rr=89f178fb1b9903e2

Lucas Macedo da Silva, V. d. (2022). Baterias, Células a Combustível e Hidrogênio: Alternativas Para o Armazenamento de Energia. Retrieved from https://www.abepro.org.br/biblioteca/TN_WPG_390_1936_43352.pdf

Maria de Fátima Negreli Campos Rosolem, R. F. (2020). Desenvolvimento de Bateria de lítio-íon para Serviços Ancilares. Retrieved from https://anaiscbens.emnuvens.com.br/cbens/article/view/910/910

Monteiro, J. M. (2023). Simulação Numérica do Abastecimento de um Tanque a Hidrogénio a Caudal Constante. Retrieved from https://recipp.ipp.pt/bitstream/10400.22/24242/1/Tese_4854.pdf

Mukrimin Sevket Guneya, Y. T. (2017). Classification and assessment of energy storage systems. Retrieved from https://www.sciencedirect.com/science/article/pii/S1364032116308218?via=ihub

Samira, M. B. (2021). Design and Construction of a mini-solar power station connected to the electricity grid. Retrieved from https://www.sciencedirect.com/science/article/pii/S1876610212008879

Seddiq Sebbahi, N. N.-B. (2022). Assessment of the three most developed water electrolysis technologies: Alkaline Water Electrolysis, Proton Exchange Membrane and Solid-Oxide Electrolysis. Retrieved from https://www.sciencedirect.com/science/article/pii/S2214785322024063

Sergio Silva, M. S. (2010). Sistema Híbrido Solar Fotovoltaico, célula a combustível e baterias aplicados a comunidades isoladas na região da Amazônia brasileira. Retrieved from ttps://anaiscbens.emnuvens.com.br/cbens/article/view/1425/1416

Silva, J. (2022). Sobrecarregamento - Relação CC/CA. Retrieved from https://www.solplace.com.br/blog/informacoes-tecnicas-5/sobrecarregamento-relacao-cc-ca-15

Thyssenkrupp Nucera. (2022). Large-scale water electrolysis for green hydrogen production. Retrieved from https://thyssenkrupp-nucera.com/wp-content/uploads/2022/11/thyssenkrupp-nucera-green-hydrogen-solutions-brochure.pdf

Veiga, L. E. (2022). Hidrogénio Verde e sua Implementação no Sistema Elétrico Nacional. Retrieved from https://repositorio-aberto.up.pt/bitstream/10216/144576/2/587806.pdf