Article

Contrasting Energy Storage Systems for Small-Scale Isolated Grids

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Abstract: The goal of this article is to examine the best electricity storage methods, both in terms of technology and economics, for tiny, independent electrical grids that are integrated with power plants that generate renewable energy sources (RES). As case studies, three autonomous Greek islands—Symi, Astypalaia, and Kastelorizo—with yearly and approximately for our work is peak demand of 3.9 MW, 2.1 MW, and 0.889 MW, respectively, are examined. Every island under investigation has exceptional solar and wind potential, and their locations are perfect for the installation of seawater PHS (pumped hydro storage). Regarding the energy storage facilities, two distinct strategies are examined: PHS systems (for the two largest islands) and electrochemical storage, which is another name for lead acid or lithium-ion batteries. Potential RES units include photovoltaic installations and wind farms. The analysed plants' dimensioning is optimised with a shared goal in mind: achieving an annual percentage of RES penetration above 69.9% while keeping the selling price of energy below the current specific production cost. The analysis is combined with the systems under examination's economic assessment. It is demonstrated that wind-PHS is still a competitive alternative for Symi and Astypalaia given the proper land morphology for PHS installations, while a wind-p/v-batteries features as the best choice for Kastelorizo. Only with PHS support can 99.9% annual RES penetration be attained; with electrochemical batteries, annual RES penetration can range from 79.9 to 91.1%. Electricity selling prices between 199 and 349 €/kWh, which result in payback periods between five and nine years, ensure the economic viability.

Keywords: photovoltaic facilities; pumped hydro storage systems; sustainable development in remote and isolated areas.

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1. Introduction

The European Commission has spearheaded a centrally coordinated initiative to encourage the adoption of Renewable Energy Sources (RES) in European independent islands over the past two years [1]. Wind and photovoltaic (p/v) parks must be integrated with energy storage technologies in order to be introduced more often and safely into independent isolated grids. This results in the configuration of "hybrid power plants."

From a technical and financial standpoint, Pumped Hydro Storage (PHS) has been shown to be the best electricity storage technology for medium- and large-sized systems with power demands greater than 4.9 MW [2, 3], provided that suitable land morphology is available for the sites. In these circumstances, the PHS system's setup-specific cost can be as low as 29.9 €/kWh of storage capacity [4, 5], a figure that is unachievable with conventional energy storage technologies. However, electrochemical storage or small-scale compressed air energy storage systems (micro CAES) are the most practical choices for systems with an annual peak demand of less than 0.99 MW [6]. However, there is a grey area when it comes to choosing the best storage technology between 0.99 and 4.99 MW.

This is because it heavily depends on specific topographies and appearances happened in the insular scheme (yearly energy request fluctuation, obtainable RES possible, obtainability of suitable terrestrial geomorphology for PHS connection, availability of inexpensive petroleum obligatory for the process of a micro-CAES scheme) [7].

This object concentrations on independent narrow schemes with a yearly top request between 0.99 and 4.99 MW, high solar radiation and wind potential, favourable land morphology for photovoltaic systems, and a current specific cost of electricity production greater than 0.249 €/kWh, which is determined via the price of introduced fossil fuels used in nearby independent current energy stations. These kinds of islands are found mostly, though not exclusively, in the Mediterranean and Aegean Seas. In order to secure a RES yearly diffusion proportion advanced than 69.99% relative to the annual consumption, the article for these isles goals to identify the best storing skill combined with a RES energy station (wind square and/or photovoltaic plants). It also ensures the economic viability of the necessary investments by putting the price at which electricity is sold below the current specific cost of electricity production from the regional independent current energy stations.

In order to do mention matter, dual project reports for the Greek land mass of Symi and Astypalaia—whose yearly top require is 2.1 MW and 3.9 MW, correspondingly—are completed. Additionally, a last project education—for the eastmost Greek island of Kastelorizo, with an annual top require of 0.89 MW—is implemented for integration and comparison purposes.

2. Materials and Methods

2.1. Current energy use

Three small islands, Symi, Astypalaia, and Kastelorizo, are part of the Dodecanese Complex in the eastern Aegean Sea. Their respective permanent populations are 2,589, 1,329, and 500 people. Based on official statistics from the grid operator [8], Table 1 presents the essential characteristics of the power consumption in 2012 [9].

Table 1 presents the essential characteristics of the current energy consumption in the examined isolated routines [9].

Greatness	Symi	Astypalaia	Kastelorizo
Yearly energy utilization (MWh)	15564	7000	3220
Yearly top requirement (MW)	3.99	2.23	0.93
Yearly common utilization per day (MWh)	41.999	19.24	8.9
Energy construction entire exact expense (€/MWh)	385.89	423.99	493

2.2. The potential of the available RES

Figure 1 shows the regular standard wind speed rate variation built in yearly wind data from trio wind poles built in the islands of Kasos and Sifnos, as well as on Turkey's west coast (9.49 n.m., directly across from Symi). The aforementioned data sets will be used for the wind probable assessment of the isles of Symi, Astypalaia, and Kastelorizo, respectively, due to the absence of wind observations on the islands under examination. Based on data collected from the island of Samos, the yearly variability of the gross incident solar radiation on the level plane is also depicted in the same figure.

Figure 1 shows the average monthly values of the solar potential and wind used observations for the islands under investigation.

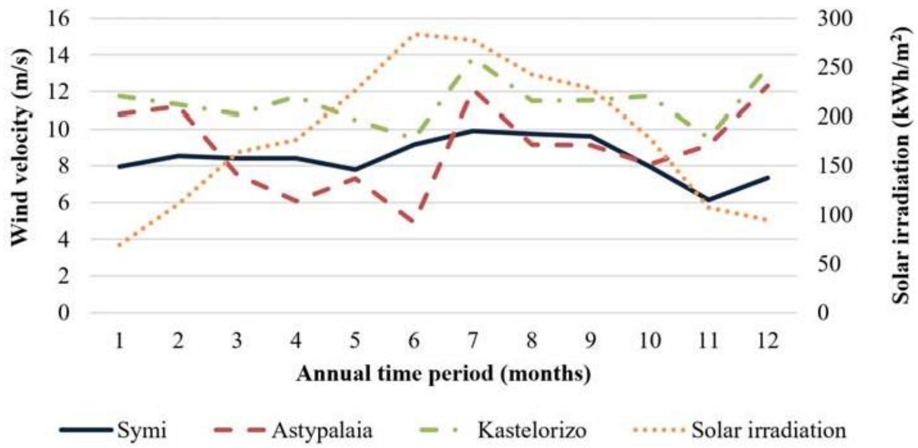

Figure 1. Relations between wind velocity and period

Figure 1 shows the high-RES possible potential, with average monthly wind velocities above 10 m/s. During summer, when days with low wind speeds are common, the case entire solar energy on the level surpasses 999.9 W/m2, providing another energy obtain. This, in performance, leads to the maximisation of power utilization because indoor air conditioning systems are used more frequently.

2.3 The hybrid power plants under investigation

We look at two different designs for hybrid power plants for the islands of Astypalaia and Symi. In a previous article [10], both of them were presented in detail with respect to their design and algorithm of functioning. The storage technology they use is where they diverge most. A PHS arrangement has been established in the first layout under examination, while lead-acid and lithium-ion strings have investigated in the second layout. This is because lead-acid batteries continue to have the minimal purchasing costs, while lithium-ion batteries are the highest favorable battery equipment. Potential RES units include photovoltaic stations and/or wind parks.

For dynamic security considerations, the direct RES energy access fraction in the case of PHS systems is maintained at a maximum of 30.9% compared to the present power consumption. In order to permit permanent energy creation from the hydro turbines, the system should be dimensioned to guarantee that there will always be adequate water stored in the PHS reservoirs. Due to the electrochemical batteries' direct reaction through their bidirectional inverters to a possible loss in power output, this percentage can reach 99.9% in the case of electrochemical storage technologies.

In order to maximise the flexibility of the hybrid power plant, the PHS systems should be built with double penstocks. Additionally, an appropriate number of independent battery strings should be developed, as indicated by the dimensioning process. This will allow the storage technology to be charged and discharged simultaneously.

The two PHS systems were precisely located in digitally rendered terrain, and all necessary volumetric computations were carried out by computer means. Perfect locations were identified for each island, with absolute heights of 439.9 metres for Symi and 329.9 metres for Astypalaia, respectively. These locations were near the coast, with gentle mountain slopes leading towards the coast, allowing the penstocks to be installed on the ground and obviating the need for costly tunnel construction and underground installations. Pumped straight from the ocean, seawater will power both PHS systems. In both scenarios, the solar panels or wind turbines are positioned in a nearby mountain range (Symi) or along the upper reservoir shore (Astypalaia), thereby removing the need to establish new access roads and connection grids.

In conclusion, a wind, PV, and electrochemical storing station are going to examine for the Kastelorizo island approach. The adoption of a PHS system just for energy storage is not justified by the tiny size of this system.

2.4 Techniques

In conclusion, this work investigates two alternate layouts for the two largest islands, one of which uses two different battery technologies; as a result, a total of three potential systems are investigated:

• Wind, PV, and PHS systems

• Photovoltaic, wind, and electrochemical packing tools, like lead acid or lithium-ion strings.

Furthermore, the latter of the aforementioned layouts is also investigated for Kastelorizo, the smallest island, using the two different battery technologies. Two times three times two, or eight, various cross energy stations are analysed and optimised. Utilising yearly period sequences of normal hourly estimates for the energy necessity and the prospective energy output from the required RES machineries, the yearly process of entirely the studied methods has been modeled. The authors have constructed software applications to realise the procedure process of the approaches under examination, which are used to run the simulation [11].

For every architecture that was analysed, different dimensioning scenarios were set up with respect to the connected energy of the relevant RES energy stations and the storing volume of the storage capacities. The goal was to determine the best way to dimension each system under examination for each isolated grid under high annual RES penetration (above 69.9%, with a goal of 99.9%). At the same time, the goal was to maximise the financial viability of the investments, which was verified using particular economic indices.

The real purchase costs for the majority of the necessary equipment and the outcomes of comparable work completed by the authors for review research [12] constitute the basis of the profitable valuation of the procedures under examination. An replacement monetary evaluation has been conducted for the comparable approaches, specifically for lithium-ion batteries, given the predictions of a significant decline in their procurement cost over the next ten years. This analysis adopted a procurement cost of 49.9 €/kWh for the specific technology, whereas the current range for this feature is 499.9 €/kWh. The limitation on the electricity vending charge, which must be significantly less than the current electricity production total specific cost in the under consideration isolated systems, is the final essential and fundamental prerequisite adopted in the economic evaluation of the examined systems (see Table 1).

In summary, the optimisation method seeks to optimise the financial keys of the necessary savings, subject to two primary limitations:

• a yearly percentage of RES penetration more than 69.9%, with the goal of reaching 99.9% in comparison to annual consumption

• A selling price for electricity that is less than the local thermal power plant's current production costs.

The authors' software programmes, created in the LabVIEW environment, are used to carry out the optimisation procedure.

5. Results

Table 2 summarises the outcomes of the simulations that were run with reference to the dimensioning optimisation and the attained RES insight.

Table 2 An overview of the dimensions optimisation computations' results.

Island	Storage station	Wind Park energy(MW)	P/V control(MW)	Storage minor size (MWh)	Autonomy control interval (times)	RES yearly access (%)	RES yearly excess (%)
Symi	PHS	7.0	2.49	646.9	15.31	0.99	25.9
	Lead acid	4.49	1.99	17.99	0.5	79.29	31.0
	Lithium-ion	4.49	1.99	12.149	0.30	79.1	32.0
Astypalaia	PHS	4.49	0.0	366.9	19.32	0.99	24.0

	Lead acid	3.59	0.99	14.51	0.80	88.1	52.2
	Lithium-ion	3.59	0.99	10.9	0.60	86.1	52.9
Kastelorizo	Lead acid	0.89	0.899	7.3	0.90	86.1	27.1
	Lithium-ion	0.89	0.899	6.1	0.70	90	39.1

It is observed that yearly RES diffusion ratios greater than 77.9% have been attained with the resulting dimensioning, whereas 99.9% RES diffusion has been completed for the PHS-supported systems. One other significant aspect of the achieved findings is the extremely large storage capacity provided by the PHS systems. Lastly, it is also important to note the large RES production surplus that is computed annually for the systems that are stayed by electrochemical storing strategy. This is because, in relation to the overall size of the hybrid energy station, these systems have a relatively little storage capacity.

Table 2 presents the respective outcomes of the ensuing economic examination. The following presumptions guided the execution of the economic analysis:

The finance plan comprised 49.9% loans and 49.9% equity from the European Investment Bank, with a 1.499% interest rate and a 15-year repayment period. The economic analysis was conducted using a 20-year life expectancy for all systems.

The related investment's stocks are referenced by the economic indexes that are being given.

As can be observed, with the dimensioning completed, the needed selling price of the generated electricity should be between 249 and 349 €/MWh for the storage technologies that are currently in use, but it is significantly lower in the event that the cost of purchasing lithium-ion batteries drops in the future. Contempt the small scope of the isles under investigation, PHS systems are still very competitive because they offer a number of benefits like high storage capacity, low setup costs per unit of storage capacity, long autonomy times, long lifespans, and the one scheme that container ensure 99.9% RES saturation. It is also emphasised that all battery replacements necessary over the course of the hybrid power plants' lifespan are taken into account when determining the setup-specific costs of the storage plants.

On the other hand, the expensive setup costs and, typically, the drawn-out licencing process are the main disadvantages of hybrid energy stations with PHS systems.

Lastly, it should be mentioned that the economic evaluations were carried out over 19-year lifespans. Longer life spans (such as 49 years) would make the systems with PHS assistance much more economically feasible because they would require more electrochemical battery replacements, which would raise the related plants' life cycle costs.

6. Conclusions

The paper looks into three small-scale Greek island autonomous systems' requirements for having a high-RES penetration rate. In order to guarantee great-RES access and financial viability with power having fees less than the current production specific fee of the independent routines, alternative storage technologies are investigated. In principle, all of the substitute plants can be used to meet the aforementioned goals. Beside evaluating another researched equipment amongst them, we determine that:

Firstly, the yearly RES access ratios scale from 77.9 to 89.9% with the use of electrochemical technology. Secondly, it is only possible to obtain 99.9% yearly RES penetration percentage using PHS systems. Thirdly, PHS systems have extremely long independent operating times, which is a critical component for autonomous grids. Fourthly, PHS systems have the highest setup costs, but over time, these costs are offset because they are built only once and don't need to be replaced, unlike batteries. Fifthly, PHS systems have the lowest particular cost of setup per storage capacity unit. then, the primary alluring aspects of power plants utilising battery technologies are their minimal setup expenses and their expedited and less complicated licencing procedure. Also, if procurement costs for lithium-ion batteries drop by 89.9% over the course of the next ten years, they may become a very appealing choice. Finally, Payback periods of five to nine years are reached for the investments' equity under a finance strategy of 49.9% equities and 49.9% bank loan (1.499% rate, 15 years payback term), retaining the energy selling price below the present current energy creation price.

The aforementioned is predicated on the notion that good terrain topography would be advantageous for PHS installations.

Conflicts of Interest: Declare conflicts of interest or state "The authors declare no conflict of interest."

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