A STUDY ON ENERGY STORAGE AND MANAGEMENT FOR GRID OPTIMIZATION IN ISOLATED AREAS.

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Abstract: The remote and rocky districts confront lasting issues with their electric system, for example, solidness issues; sudden drops in voltage and power quality that influence individuals' day by day life at home and their gadgets' execution. The explanations behind the low quality of power are because of the matured, remote neighborhood dispersion organizes and the regularly unforgiving climate conditions particularly amid winter months. Encouraging the framework in switch arranges is our proposed arrangement which will diminish power should be transmitted over incredible separations. Vitality generation in remote areas could be profitable on the off chance that it incorporated the usage of nearby sustainable power sources. The arrangement of generation, stockpiling and administration of vitality could give more prominent system steadiness which would then prompt better power quality, diminishment of potential misfortunes and disappointments under particular conditions. The present investigation concentrates on the utilization of sustainable sources to make a keen vitality stockpiling framework with the objective to accomplish the network benefits dissected. By inspecting as of now accessible advances and considering their potential business applications sooner rather than later alongside their costs, it gives the idea that a promising methodology is to utilize inexhaustible in a half and half mode joined with batteries for vitality stockpiling. The article builds up a vitality framework (counting photovoltaic, wind and hydroelectric power stations), which offers vitality as indicated by the request progressively with fitting displaying. The point of the article is to make a framework for delivering, putting away and overseeing energy by utilizing sustainable sources and batteries at insignificant natural effect.
Key-Words*:* energy storage; hybrid systems; renewable energy; batteries

1 Introduction

The remote and mountainous areas face problems with their electricity grid. Over 1.5 billion people worldwide still lack access to grid electricity, most living in small remote villages or islands which are isolated from utility. Power supply extension to those areas is not easy due to economic and geography issues [1]. On the other hand, the main grid offers much more energy in these areas to cover energy needs, overcome large losses and absorb energy demand throughout a year. Large scale renewable energy sources (RES) projects (wind farms, hydro power stations) cannot solve the problem as the large amounts of energy they produce are directly connected to the nearest medium voltage power station and offer their energy to the grid. Small scale renewable energy projects (small hydropower, roof photovoltaic) cannot eliminate the problem as their energy production depends on solar radiation, water availability and is not synchronized with consumption. In fact, only 1/3 of production and consumption are synchronized, and excess production is injected into the grid that plays the role of a large battery [18]. The grid extension options represent more expensive electricity provision for places far away from the existing power grids [20]. As renewable' deployment developed, scientists examined the possibility to combine different RES in order to improve the overall system efficiency. Such an analysis can in principle be performed for both a specific geographical location and involving a wider area such as a prefecture or even a country [2].

The RES are usually intermittent, unpredictable and weather-dependent. Therefore, a continuous and reliable power supply is hardly possible without energy storage. By employing a smart energy storage system (SESS), the surplus energy can be stored whenever power generation exceeds demand and then is released to cover the periods when net load exists, providing a robust back-up to intermittent renewable energy [3].

This research develops an energy off-grid model that aims to produce energy through RES, storing excess energy in new technology batteries and with an appropriate planning to offer it for consumption in real time reducing or completely eliminating the dependence of the grid. This novel approach offers significant benefits for both the penetration of RES and the stabilization of the main grid and describes a process of developing an energy model that aims at independence from the grid and the ability to fully electrify a settlement [4].

Transmitting the locally-produced renewable energy (RE) of remote areas to other places is generally not an option, because of their distance from cities and consumption hubs. Trying to avoid such complications, regulatory authorities usually set a threshold on the maximum power capacity of RES in these areas. This threshold is generally low in order to keep the system's stability on the safe side [19].

The penetration of renewable in small isolated grids can be significantly enhanced if storage can be applied. Although lots of work is being done for the development of new storage techniques and methods it is still useful to show the results and benefits of storage at specific real applications. Those benefits can be already harnessed based on traditional storage approaches like pump hydropower storage (PHS). Pumping has been traditionally examined either as a grid balancing means or as the main driver using wind power.

Recent research shows that the RES penetration increases along with the operational safety of the grid. This can be achieved only if the predictability of renewable power generation is established, or energy storage is incorporated into the grid system, or a smart algorithm is used in terms of generation unit operational schedule [5, 6]. Additionally, the need for increased power generation capacity can be avoided by the RES penetration increase that can be realized [7]. Based on the above needs a preliminary study has been performed to point out specific actions that are necessary to overcome the various obstacles. The results are summarized below.

If proper energy storage is achieved, the operator would have a real benefit to relax the grid and the operation of the conventional power plants. An important parameter is that the storage should be suitable for both increasing the power demand by getting power during the low demand periods, and generating power for the grid during the high demand periods. The storage capacity should be enough to give to the operator the independence needed to schedule operation of the existing conventional units. Operation schedule of the conventional power units and the existing renewable power plants is another important task. Net metering introduces new important parameters which will affect the demand profile thus creating additional difficulties. The development of a smart algorithm which would take into account all the above mentioned parameters will assist the operator efforts towards proper operational schedule.

Moreover, power grids and electricity which lead to the inhabited areas are quite rundown and shoddy. The reason for this particular situation is due to the fact that the network routes are long, combined with bad weather conditions causing power cuts and long periods black out. Public Power Corporation (PPC) is making an effort to provide protection to these areas, yet the inhabitants say they continue to face problems especially during unstable months. Bothsummer- where the power consumption increases due to the high demand - and winter -where the weather conditions create damage to the network- are challenging.

2 Background

The biggest challenge RES face is the high cost of storing clean energy and supplying it for consumption. Although a large number of studies carried out to apply different storage technologies to power systems, very few of them have been implemented into practice. Energy storage in a power system can be defined as any installation or method, usually subject to independent control, with the help of which it is possible to store energy generated in the power system, keep it stored and use it in the power system when necessary [8].

Despite technology development, there are still two energy storage technologies that have reached market maturity; pump storage and batteries.

PHS is the most prevalent and mature energy storage technology, with 129 GW of installed capacity worldwide, 22 GW of which is used in the US. Pumped storage is a very versatile technology capable of providing valuable benefits from intra-hour through multiple-day time periods [9]. Pumpedstorage stations usually produce energy during the day, when energy demand is high and operate in exactly the opposite way during the night, when energy consumption is significantly lower. During the night-hours, the turbines rotate in the opposite direction, pumping water upstream and storing energy that will be transformed to electricity in peak hours [2]. It consists of a pair of reservoirs in which there are installed pumps, which raise the water to the upper reservoir when there is excess electricity. When demand is high then water is discharged from the upper reservoir to the bottom and electricity generates factor and covers the demand deficit. Fig.1 describes the process of such a PHS operation. Pumping is considered to be a relatively inexpensive, low-cost technology for large-scale projects. Generation and pumping can be accomplished either by single-unit, reversible pump turbines or by separate pumps and turbines. The switch between pumping and generating can occur within minutes; depending on the installation [10].

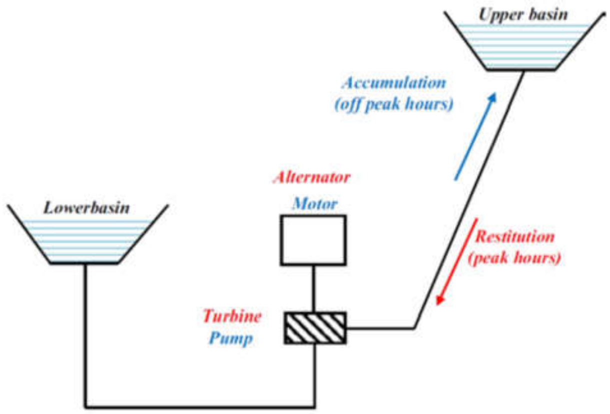

Fig.1 The process of a pumped hydro storage [10].

The second technology involves the batteries which have internationally attracted the interest of big investors, because their cost is getting smaller and their profitability is rising. Batteries have exactly the same purpose as recharging and aim to be integrated into an energy storage and management system. Large battery manufacturers (Panasonic, LGChem, Tesla, Daimler Benz (Mercedes), etc.) have already invested billions in this technology, while countries such as Germany, USA, Australia, Canada and Britain have announced that they are entering domestic storage energy using new technology batteries. The construction of the first hybrid system in the whole Mediterranean (wind, photovoltaic, battery) is taking place in Greece, specifically in the small and remote island of Tilos [11]. The project is headed by Technological Educational Institute (TEI) of Piraeusand is consisted by a group of 13 partners from 7 countries along with three other partners from Greece [12]. Recently, the PPC has expressed its intention to install batteries in other Greek remote islands. In California, TESLA has installed such systems called "battery farms" and is capable of serving 15,000 households. Currently, significant development is going on in the battery technology. Different types of batteries have been developed some of which are available commercially but others are still in the experimental stage [13].

A battery is an electrochemical device (Fig. 2) which has the ability to deliver, in the form of electric energy, the chemical energy generated by electrochemical reactions [14]. These reactions are set in train inside a basic cell, between two electrodes plunged into an electrolyte, when a load is connected to the cell's terminals [10]. The reaction involves the transfer of electrons from one electrode to the other through an external electric circuit. A battery consists of single or multiple cells, connected in series or in parallel or both depending on the desired output voltage and capacity [15]. The batteries are rated in terms of their energy and power capacities. For most of the battery types, the power and energy capacities are not independent and are fixed during the battery design [13].

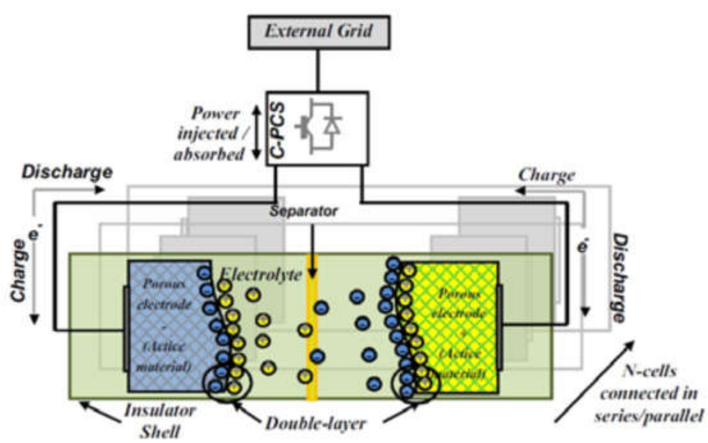

Fig.2 The capacitor storage system [10].

2.1 Study site

As a study area, a mountainous settlement has been selected in Central Greece, located at an altitude of 1000m and consisted of approximately 200 permanent residents. Near this settlement there is a stream which has a constant

discharge and is suitable for the development of a small hydroelectric power plant (SHPP) [22]. Also, there is solar irradiation to operate the solar photovoltaic system (SPVs) and potential for wind development.
An energy model combining SPVs, wind and SHPPin order to produce energy and batteries for energy storage and management has been developed in the study area.

Table 1 shows the constitution of the above model.

RES	Capacity (KW)	Energy
Wind	50	Production
Solar	40	Production
Hydro power	100	Production
Batteries	100	Storage & Management

Table 1 Energy production, storage and energy management system.

The operation of the SESS will be as follows: RES will supply the batteries with energy throughout their service life. The batteries will provide the local network according to real-time energy demand. The main goal is to keep network demand steady and the batteries to eliminate the intense fluctuations. Furthermore, it is to maintain the penetration of RES at 30% (according to the Greek Law), relax the main grid, make it more stable and avoid the spikes.

With this way, the batteries will function as a virtual dam, which will be able to support the system's needs throughout the year. The article describes three scenarios / combinations and leads to the optimal system performance solution.

2.2 Data collection

For the development of the energy model, the data used were provided by public organizations, private companies and existingliterature. Table 2 shows the sources that the data were collected from.

Table 2 The input data used for the development of the model.

	Data	Provider	Year	Step
Energy Demand	Timeseries	PPC	2014	15΄
SPVs	Timeseries	Software	2014	15΄
Wind	Timeseries	Wind Mast	2014	15΄
SHPP	Timeseries	PPC	2014	30D

2.3 Analysis, approach, scenarios

The energy model was developed for the year 2014, which is the reference year for this study. Fig.1 and Fig.2 show the produced energy throughout this year.

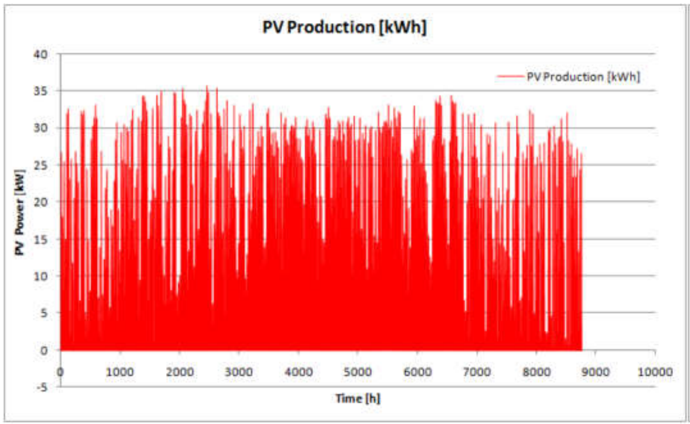

Fig.1 SPVs energy production

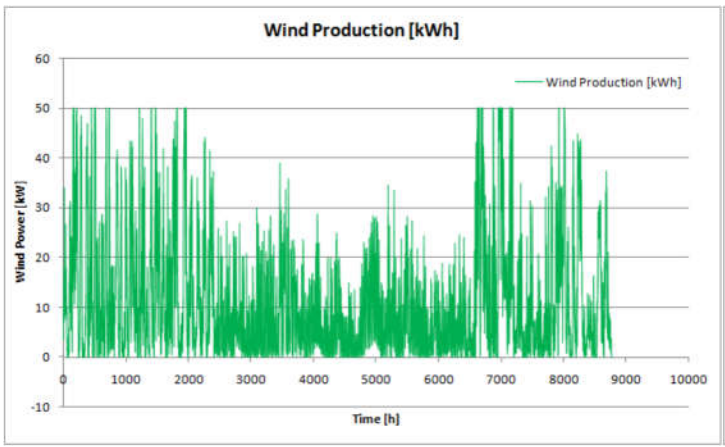

Fig.2 Wind Energy Production

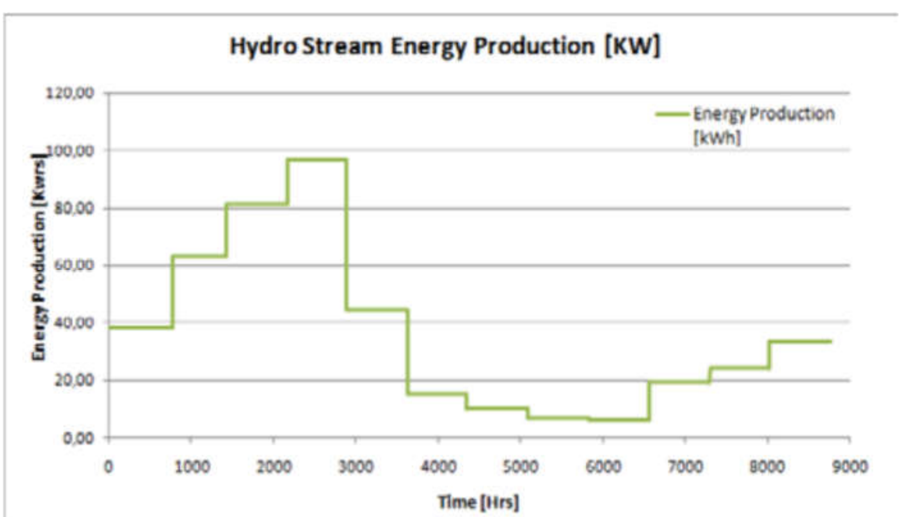

Fig.3 SHPP Energy Production.

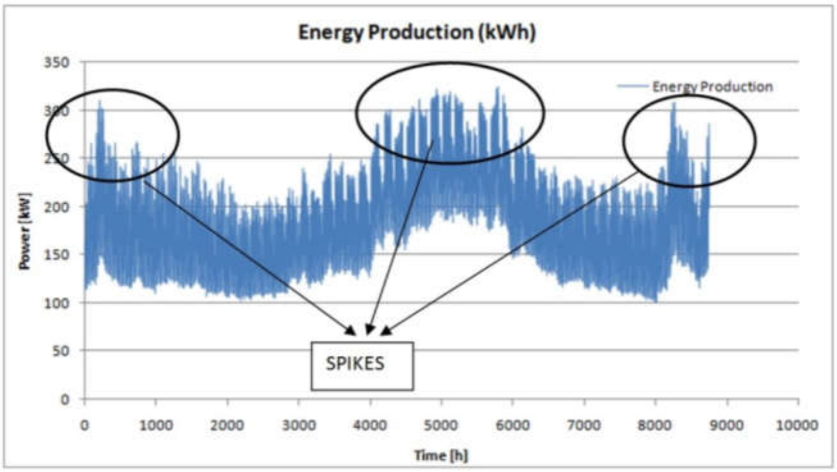

Fig.4 The energy production during the year 2014.

Fig.3 shows the power output from the small hydroelectric power station. The energy produced does not exceed 100 KW duringwet months and reaches around 30 KW during dry months. Fig.4 shows the power supply of the main grid in the settlement for the year 2014. The graph values are fixed at 15 minutes. The chart points outthe daily fluctuations as well as a significant demand within summer.Because the main grid finds difficult to follow the above daily fluctuations or any sharp changes in demand, it provides much more energy for the continued proper operation of the system, in order to cover the variability of demand.In this article, three scenarios of RES development will be studied. The purpose of the application is to remove the strong fluctuations in demand and eliminate the spikes.
The smart energy model was developed for three scenarios:

1st Scenario	SPVs & Wind
2nd Scenario	SPVs, Wind & SHPP
3rd Scenario	SPVs, Wind, SHPP & Batteries

The limitation of application is not to exceed the penetration the threshold of 30%. The best scenario would be one that would further stabilize demand.

3 Results

The model set up all data for the year 2014 and extracted the results for the three scenarios.
Scenario 1: SPVs& Wind

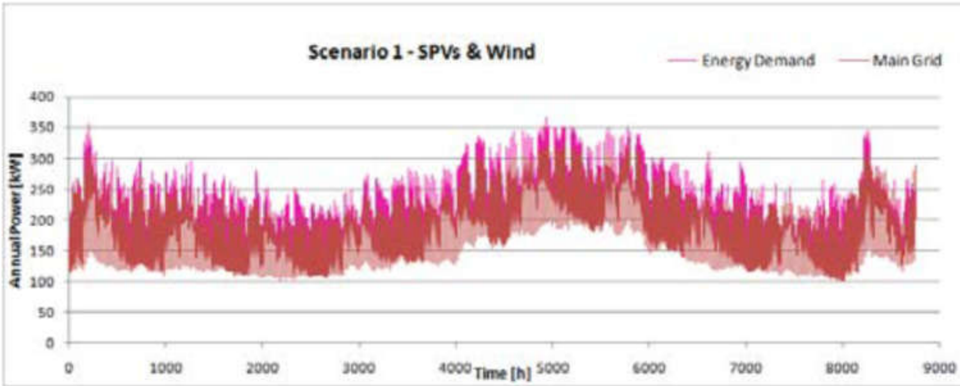

Fig.5 The Energy Demand with SPVs & Wind.

Fig.5 shows the power generation from SPVs and Wind. Demand from the main grid has declined, but fluctuations still remain. It saves energy but does not improve the network operation.

Scenario 2: Solar PV, Wind & Hydro

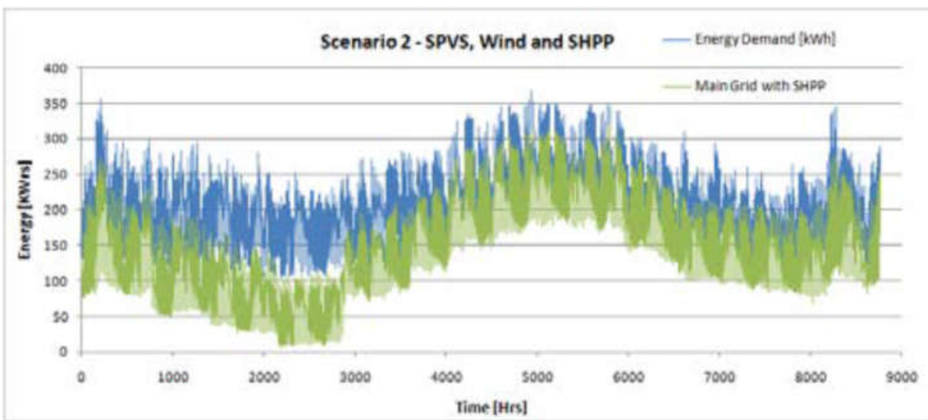

Fig.6 The Energy Demand with SHPP.

Fig.6 shows the effect of the hydro power connection on the main grid. There is energy savings, but demand fluctuations are much greater. This connection is not acceptable to PPC and such an application could not work.

Scenario 3: Solar PV, Wind, Hydro & Batteries

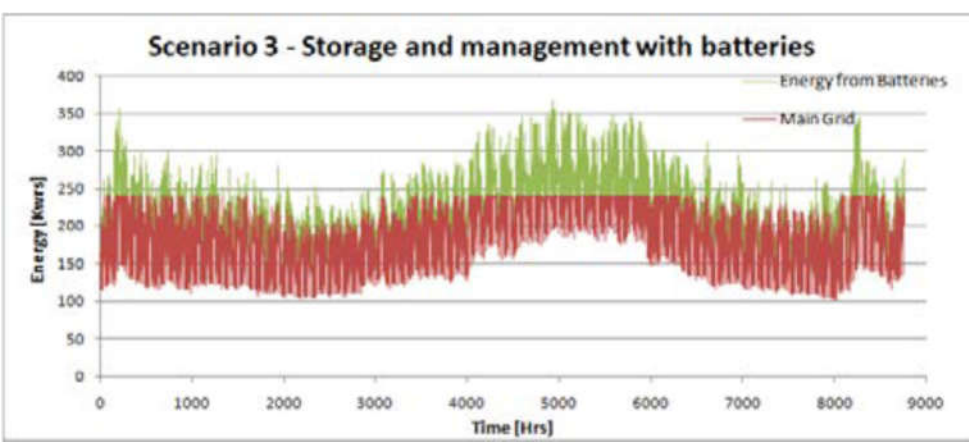

Fig.7 The Energy Demand with Batteries.

Fig.7 shows the role of batteries to save and manage energy. Batteries feed the network according to demand in real time, while RES either feeds the network or charges the batteries. The main grid will provide 240 KW of energy throughout the year and the rest will be covered by the RES. The energy saving is significant as intense fluctuations and spikes will be met by batteries. The main grid will provide less energy, which will be constant throughout the year.

3.1 Penetration

A number of serious problems can appear when trying to maximize the percentage of electrical energy demand that can be covered by direct feeding of RES energy into small- or medium-sized electrical system. At high levels of demand, the variations in the active power generated (due to variations in the penetration of the RES) cause disturbances between the power generation and power demand of the system, giving rise to frequency and voltage variations which could lead to dangerous operating conditions [16]. To avoid serious problems (that could affect the safety and stability of the electrical system) RES has to be limited to a specific percentage of the conventional synchronous capacity connected to the grid, which in turn depends on the load of the system [17].

The aim of the article is to raise the penetration of the RESas much as possible and at the same time maintaining the limit set by the Government. In Greece, the level of penetration of renewable energy into the grid is 30% and within this limit should be linked all the RES that are available for development [18].

The following three charts show the percentage of penetration for the above 3 scenarios. The first and third scenarios do not exceed the threshold of 30% while the second scenario far exceeds the threshold.

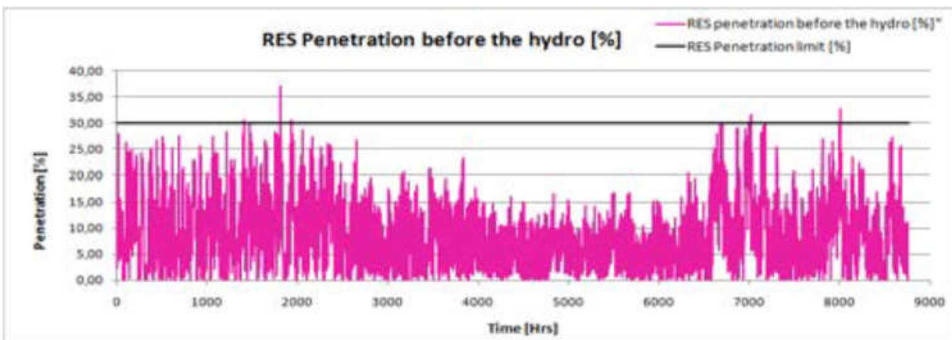

Fig.8The RES penetration from Wind and SPVs.

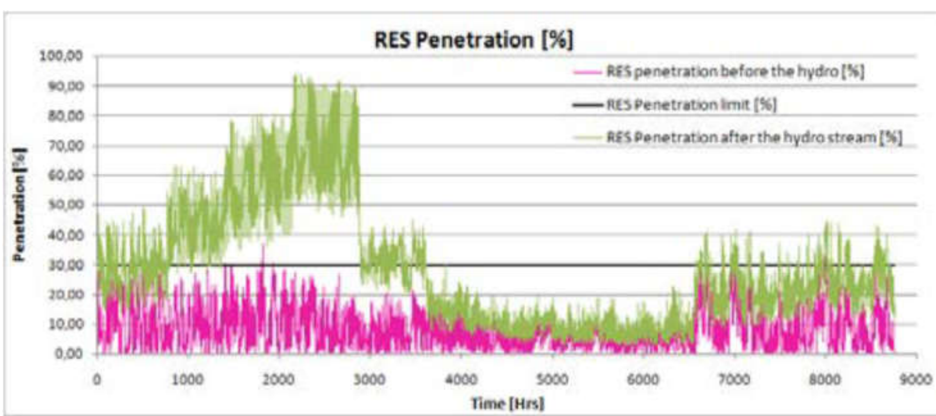

Fig.9 The RES penetration with the SHPP.

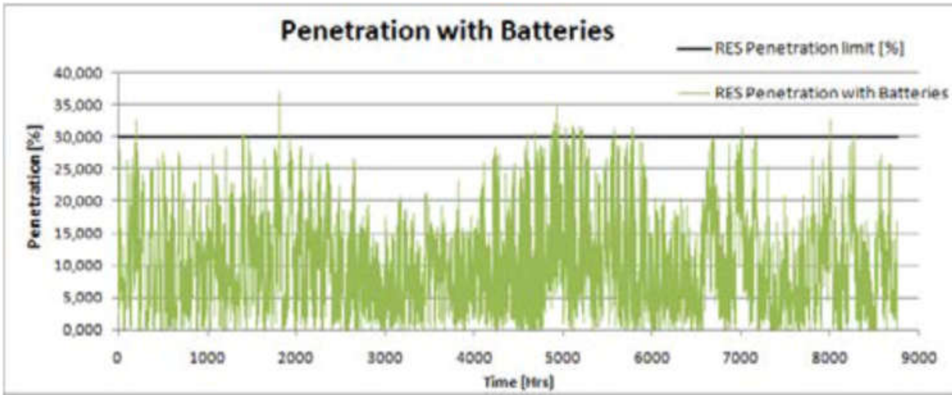

Fig.10 The RES Penetration with the Batteries.

Summary of the results described included characteristicsof the three scenarios are shown in Table 3.

Table 3 The summarized results.

Scenario	Threshold of 30%	Avoid spikes	Stabilize the grid	Allowance the connection
1	YES	NO	NO	YES
2	NO	NO	NO	NO
3	YES	YES	YES	YES

3.2 Target, stabilized and reliable grid

The grid, which provides electricity to the regions, should be reliable. The reason is to meet the grid needs as much as possible, avoid sudden voltage drops and interruptions. Therefore, the grid receives electricity in the reverse direction and becomes reinforced. So the frequent voltage drops along with the network support problems are almost eliminated.

4 Conclusions

In this article, a new approach to energy storage and management is developed. Such a configuration could have significant benefits in isolated grids where stabilization should be met. An optimization of RES performance by using small scale batteries is made. The results are positive and encouraging both economically and environmentally. Application in mountainous areas shows that not only the RES penetration goals are met but enhanced grid stability and secure of the operation of the existing RES power plants are also fully achieved.

On the one hand, SESS can save large amounts of energy offered by PPC to electrify sensitive areas. With proper management and saving energy, remote areas will reduce their energy footprint and significantly increase the quality of the energy they are supplied with.

On the other hand, this model results in an overall increase in the penetration of the RES. This latter contribution is highlighted in European Union energy policy and the defined climate targets [19]. It is possible to add other amounts of energy from RES and with appropriate planning to lead to settlements fully electrified and independent of the main grid. Additionally the need for new conventional power plant development is minimized. The present methodology could be applied in any autonomous grid where RES penetration and stabilization of the grid is needed.

The battery storage technology will play a major role in the reliable and economic operation of smart electric grids [13] with significant amounts of renewable power. Batteries would not only assist in operating the future electricity grids reliably but could also encourage theusage of renewable generating sources. As far as the battery technology is concerned, there will be significant development in reducing the battery cost in future and improving their reliability.

The European Union has invited all Member States to organize and plan the National Energy Strategy and its design. The objective of this report is to analyze the energy measurements information through smart metering of the Energy Information System, to lead the transition to targeted actions and digital energy services such as Smart Grid known as Services Intelligent Electrical Networks.

Abbreviations

PPC Public Power Corporation
PHS Pumped hydropower storage
PV Photovoltaic
RE Renewable energy
RES Renewable energy sources
SPVs Solar photovoltaic system
SHPp Small-scale hydropower plant
SESS Smart Energy Storage System

References:

[1] The energy access situation in developing countries: a review focusing on the least developed countries and Sub-Saharan Africa. New York and Geneva: World Health Organization (WHO) and United Nations Development Programme (UNDP); 2009

[2] Kougias, I.; Bódis, K.; Jäger-Waldau, A.; Monforti-Ferrario, F.; Szabó, S. Exploiting existing dams for solar PV system installations. Prog. Photovolt. Res. Appl. 2016, 24, 229–239.

[3] Technical feasibility study on a standalone hybrid solar-wind system with pumped hydro storage for a remote island in Hong Kong Tao Ma*.

[4] Droege, P. (Ed.) 100% Renewable: Energy Autonomy in Action; Routledge: London, UK, 2012.

[5] Aihara, R., Yokoyama, A., Nomiyama, F., Kosugi, N., Optimal operation scheduling of pumped storage hydro power plant in power system with a large penetration of photovoltaic generation using genetic algorithm, PowerTech, June 2011

[6] Denholm P., Hand M., Grid flexibility and storage required to achieve very high penetration of variable renewable electricity, Energy Policy, Energy Policy Volume 39, Issue 3, March 2011, Pages 1817–1830

[7] Hadjipaschalis I., Poullikkas A., Efthimiou V., Overview of current and future energy storage technologies for electric power applications, Renewable and Sustainable Energy Reviews, Volume 13, Issues 6–7, August–September 2009, Pages 1513-1522

[8] N.K.C. Nair, N. Garimella, Battery energy storage systems: assessment for small-scale renewable energy integration, Energy and Buildings 42(2010) 2124–2130.

[9] Energy storage: Applications and challenges. ECOFYS.

[10] Renewable energy systems design assistant for storage: http://www.ecn.nl/resdas.

[11] Tilos, the first autonomous renewable green island in Mediterranean: A Horizon 2020 project.

[12] Green Islands in Europe and Prospects for Greek Islands. The Tilos Project J.K. Kaldellis*, G. Salagiannis, N.C. Ilia, P. Stinis, K. Dimakis.

[13] Battery energy storage technology for power systems—An overview.

[14] R.A. Huggins, Energy Storage, Springer Science LLC, USA, 2010.

[15] J. Baker, New technology and possible advances in energy storage, Energy Policy 36(2008) 4368–4373.

[16] Ross, M.; Abbey, C.; Bouffard, F.; Jos, G. Multiobjective optimization dispatch for microgridswith a high penetration of renewable generation. IEEE Trans. Sustain. Energy 2015, 6, 1306–1314

[17] Tant, J.; Geth, F.; Six, D.; Tant, P.; Driesen, J. Multiobjective battery storage to improve PV integration in residential distribution grids. IEEE Trans. Sustain. Energy 2013 , 4, 182–191.

[18] Official Government Gazette of the Hellenic Republic. Ministerial Decree 8295/95 (PPC-Independent Producer). Volume 2 (385). Available online: http://www.rae.gr (accessed on 4 November 2016).

[19] Patsialis, T.; Kougias, I.; Kazakis, N.; Theodossiou, N.; and Droege, P. Supporting Renewables' Penetration in Remote Areas through the Transformation of Non-Powered Dams. Energies, 2016, 9(12), p.1054.

[20] Szabó, S.; Kougias, I.; Moner-Girona, M.; Bódis, K. Sustainable energy portfolios for small island states. Sustainability 2015, 7, 12340–12358.

[21] Kougias, I.; Szabó, S.; Monforti-Ferrario, F.; Huld, T.; Bódis, K. A methodology for optimization of the complementarity between small-hydropower plants and solar PV systems. Renew. Energy 2016, 87, 1023–1030.
[22] Patsialis, T.; Kougias, I.; Ganoulis, J.; Theodossiou, N. Irrigation dams for renewable energy production. Econom. Water Manag. Agric. 2014, 12, 270–294.