Decarbonizing Unije Islands thanks to a proper Exploitation of Renewables via PV-Battery and PV-Desalination Hybrid Energy Systems

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***Abstract*— In this paper activities that will be performed in the framework of INSULAE H2020 project[1] in Unije Lighthouse islands are presented, describing hybrid Renewables and advanced storage solutions (Battery and Power-to-water via desalination) systems that will be thereby installed and operated to guarantee local island decarbonization and island energy independency.**

The paper presents two of the 9 innovative Use Cases and demonstration activities that will be demonstrated in INSULAE Lighthouse islands, with a Focus on the two to be promoted in Unije, namely

UC-1: Joint management of hybridized RES and storage (Designed and developed under REA, UNIZAG-FSB and RINA-C responsibility)

UC-2: Smart integration and control of water and energy systems (Designed and developed under REA, UNIZAG-FSB and local water system operator responsibility)

Unije is a Croatian island situated in the northern part of the Adriatic Sea, with less than 100 permanent inhabitants, but with a remarkable summer presence of tourists.

Targeting its decarbonization, Unije is currently installing a local PV plants with a power capacity close to 1 MW, which will be optimally operated thanks to the integration with a Battery Energy Storage System (BESS) and thanks to smart operation of the local water system based on a desalination plant operating demand response schemes optimally managing water reservoirs.

In this paper preliminary activities that will bring to the design and engineering of these two demonstrations and optimization initiatives will be presented, also introducing the general context of INSULAE project and energy decarbonization initiatives that will be implemented in the island of Unije.

Keywords: renewables, battery, storage, power to water, island decarbonization, hybrid power and storage system

I. INTRODUCTION

In the EU, 15 million people live on 2,400 inhabited islands, whose energy systems are usually small and isolated microsystems. Their energy systems are often 3 to 4 more expensive, 2 to 3 more polluted, up to 10 times more inefficient and strongly dependent to fossil fuels.

Scaling up renewables and energy storage are the key challenges that can lead to a more stable supply of cheaper and cleaner energy, as well as to an island energy self-sufficiency and security of supply, while contributing to the fight against climate change.

Overall, the decarbonisation of the islands will increase both their energy/resource/economic resilience and economic viability and thus will bring significant benefits including an increased economic stability of the island, less exposure to volatile fuel prices, more self-reliant electricity supply etc.

To encourage island decarbonization, in May 2017 the European Commission, together with 14 Member States, signed the "Political Declaration on Clean Energy For EU Islands" under the Maltese Presidency.

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[1] This project has received funding from the European Union’s Horizon 2020 research and innovation programme under Grant Agreement No 824433.

This Declaration was born out of the recognition that islands and island regions face a particular set of energy challenges and opportunities due to their specific geographic and climatic conditions. The opportunities have the potential to make Europe's island communities innovation leaders in the clean energy transition for Europe and beyond.

Following this declaration the EU Commission, rolled out different initiatives setting up in 2018 a Secretariat to deliver the objectives of the Clean Energy for EU Islands Initiative and financing since 2018 different innovation actions and R&D funded projects in the framework of Horizon 2020 programme. One of these initiatives is INSULAE project[2].

The main goal of INSULAE is to foster the deployment of innovative solutions aiming to the EU islands decarbonization by developing and demonstrating at three Lighthouse Islands (Madeira, Bornholm, Unije) a set of interventions linked to seven replicable use cases/technological innovations.

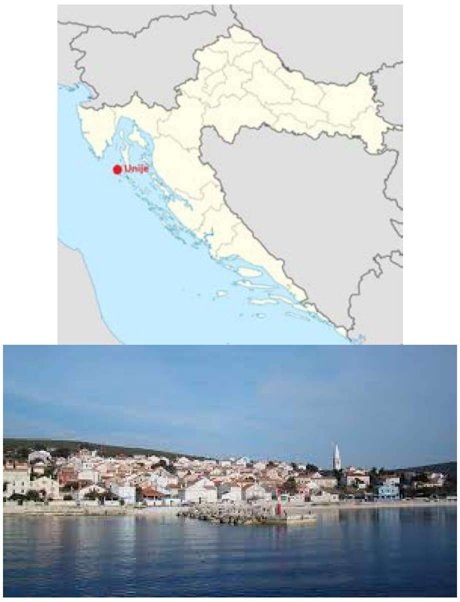

Figure 1. Unije Island[3]

Three of these use cases will be studied and demonstrated in Unije island (Fig.1), contributing to reduce energy fragility and high fossil fuel dependency of Unije island.

UC-1: Joint management of hybridized RES and storage (Designed and developed under REA, UNIZAG-FSB and RINA-C responsibility)

UC-2: Smart integration and control of water and energy systems (Designed and developed under REA, UNIZAG-FSB and the local water manager responsibility)

UC-3: Empowerment of islands' energy communities through 5G and IoT technologies for flexibility services. (Designed and developed under REA, UNIZAG-FSB and Fundacion CIRCE - INSULAE project coordinator - responsibility).

In the following paper preliminary design activities performed to demonstrate UC-1 and UC-2 will be presented.

II. THE ISLAND OF UNIJE

Unije is a Croatian island situated in the northern part of the Adriatic Sea, see Figure 1. Its size is 19,92 km2, with a 280 houses single village. The population throughout the year is less than 85 residents and grows up to 400 residents during the summer. Unije also has a small port with daily connections to nearby islands and some mainland cities, and an airport for commercial and private aircraft. All this needs to be electrically supplied. For the power supply, Unije has different voltage levels: 110 kV (connection to the external grid), 35 kV, 21 kV, 10 kV and 0,4 kV.

Besides, the island has several transformers that allow transformation between the different voltage levels. Unije island is interconnected with Cres-Lošinj archipelago and both islands are connected to the mainland grid by a 110 kV submarine cable

To address the issue of the decarbonization (as it can be seen in figure 2 indeed is that Unije energy balanced is mostly covered by fossil), Unije island is studying the implementation of two photovoltaic parks, called PV Unije of about 1 MW each.

In the second of the two, also valorising INSULAE partners' experience, a Battery Energy Storage System will be introduced thanks to RINA-C support. Furthermore, smart control measures for the water system and its integration with electricity grid are part of the project. Smart operation of the water system using demand response technology can allow for optimal operation of the water tanks and reservoirs reacting to the electricity price and the optimization of the self exploitation of PV Plants production.

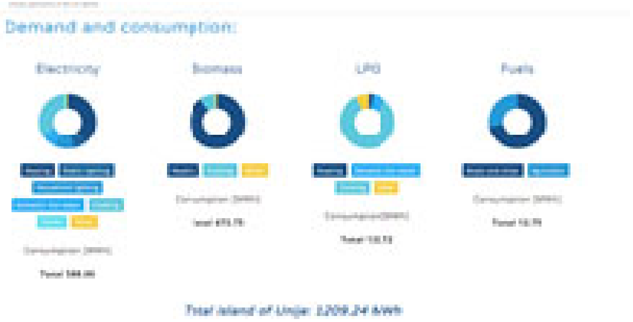

Figure 2. Unije Energy Balance

III. MODELING UC-1: JOINT MANAGEMENT OF HYBRIDIZED RES AND STORAGE - ASSUMPTIONS

UC-1 will foresee the installation and optimal management of a MW-scale PV plant integrated with a Li-ion Battery Energy Storage System (BESS) that had the goal to guarantee clean energy independency to the island of Unije as well as grid stability considering the peripherical grid position of the island on the local network.

The main technical specifications of PV system are given in Table 1.

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[2] www.insulae-h2020.eu

[3] www.visitlosinj.hr

Installed power	1270 kW
Nominal voltage	3 x 230 / 400 V
Nominal frequency	50 Hz
Nominal power factor	≥ 0.95
Efficiency	97%
Operation type	In parallel with distribution grid
Purpose	For production in the distribution grid

TABLE I. PV SYSTEM SPECIFICATIONS

Operationally, PV plant and battery storage system will be built simultaneously. The expected mode of operation is that the battery system stores excess energy from the power plant and discharges it to the grid during periods when there is no sun, i.e. when the solar power plant not produced. The expected consumer of electricity produced are consumers on the Island of the Unije, but also nearby islands of Susak, Srakane and Lošinj, via undersea medium voltage cable (10 kV).

The design of the BESS and the definition of some guidelines about its management has been constrained by the available resources in terms of budget of the project. RINA-TECH UK has undertaken a selection of modelling scenarios for a range of proposed BESS sizes, starting from the initially proposed design specs of 1 MW/1 MWh battery capacity.

The simulations have been performed to assess the performance and utilisation of the BESS to meet the local energy demand while operating in conjunction with the solar PV asset. The expected total PV generation exceeds indeed the local demand across the year, this surplus energy could be used to feed other islands within the network subject to the network operator clarifying grid stability within the area.

III.I Modeling the demand

In order to test the originally proposed 1MW/1MWh BESS and refine the BESS sizing capacity if required, RINA-TECH UK has assessed the likely usage profile of the battery system given the forecast irradiance at the site against the seasonal demand profile. **Fehler! Verweisquelle konnte nicht gefunden werden.**Fig.3 outlines the PV generation and Scenario A and B demand curves established to undertake this assessment.

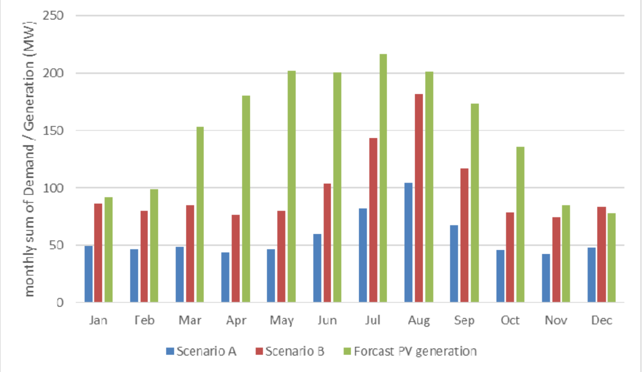

Figure 3. Forecast monthly generation and demand profiles (MW daily sum based on available data duly adapted by RINA-TECH UK)

In order to understand the likely charge and discharge regime of the BESS against the island demand and available PV generation RINA have developed the synthesised demand profile based on the following process.

The *"Prilog 5_mjerenja200809_15min.xls"* data from 6th August 2009 is the only metered demand data made available for Unije. As such, this was considered the most applicable of available data in order to understand the likely intraday demand profile of the island. This daily demand profile shape was assumed to be similar across the year in the scenarios modelled.

To establish a synthesised demand profile for the island RINA-TECH UK used the annual seasonal demand profile as identified in previous research[4]. By digitising the seasonal profile data within this paper, this was used to establish seasonal scaling factors. Seasonal scaling factors for each day are based on the ratio of the daily peak demand to the peak demand on 6th August (the same date as the metered data available). These scaling factors establish the seasonal demand curve and accounts for increased summer demand on a small island due to aspects such as tourism. The demand curve is then applied to the metered demand data to synthesis the annual demand curve while reflecting the expected intraday demand profile the Project would be expected to meet.

RINA has established two demand profile scenarios following this methodology;

- **Scenario A:** is based on scaling the synthesised demand profile against the measured data. As outlined above.
- **Scenario B:** is a conservative case where the Scenario A demand profile has been further uplifted in order to increase the annual maximum demand to equal the rated capacity of the 400kVA transformer installed on Unije. Given this transformer sizing it is expected that this would represent the highest demand on the island.

III.II Modeling the irradiance profile

The Unije irradiance profile and associated PV yield estimate has been made available by HEP (the investor and owner of the plant) as part of the existing Unije PV feasibility assessment. The forecast annual PV generation profile for the Unije PV project which was used within the BESS modelling scenarios is shown in Figure 3: the sum of the monthly forecast PV generation exceeds the expected sum of monthly demand for all months, except Scenario B in December. However, as demonstrated in Figure 4 below, consumer demand and PV generation are not aligned, with peak demand periods occurring later in the evenings. As such, energy storage is required to align the generation profile of the PV with the demand profile of the island.

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[4] K. Mavroyeoryos, I. Engonopoulos, H.Tyralis, P.Dimitriadis, D. Koutsoyiannis - "Simulation of electricity demand in a remote island for optimal planning of a hybrid renewable energy system" – Energy Procedia, Volume 125, September 2017, Pages 435-442

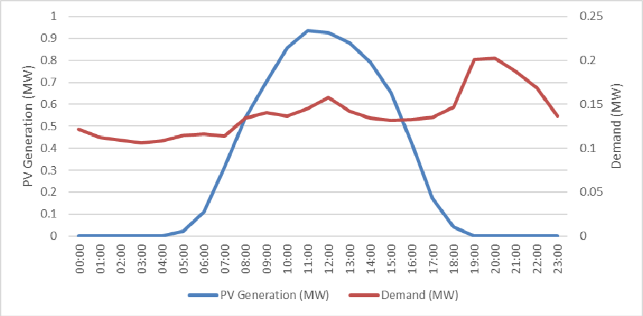

Figure 4. Daily irradiance and demand profile

III.III CAPEX Assumptions

RINA-TECH UK has undertaken an assessment of the likely system configuration which could be procured based on a selection of price points, always considering the constraint of project budget

This assessment is based on global Li-ion BESS prices which have been collated by RINA-TECH UK based on a number of competitive tender processes and it has discussed the Project in general terms with a number of leading BESS vendors in order to better inform the likely energy to power capacity which could be procured for the Project at Unije. This assessment brought to demonstrate the sensitivity as well as how modification of the energy to power ratio will influence CAPEX (Fig. 5)

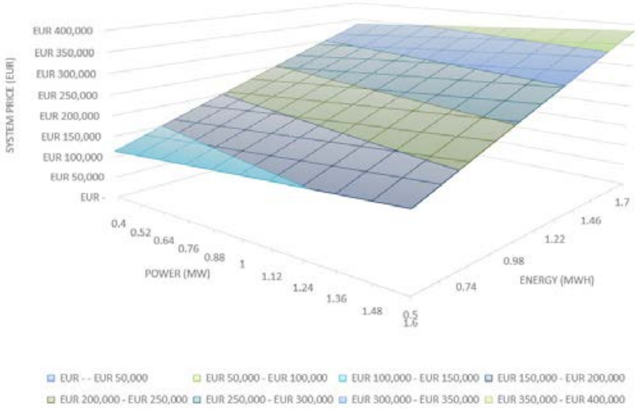

Figure 5. BESS CAPEX Trends

The BESS solutions examined in the next paragraphs were considered while assuming a CAPEX constraint of approximately €300,000±10% and considering all CAPEX costs related to BESS supply except additional site mobilisation works and further subcontracting works.

III.IV Dispatchability Assumptions

Given the limited availability of demand side data, at this stage a generic BESS specification and dispatch profile has been developed with robust assumptions in order to facilitate increased renewable generation and grid stability. The primary function of BESS has been developed in order to maximise the demand load served on Unije by local generation resources, i.e. the PV and BESS. As such, it has been assumed that the PV generation would primarily meet any local demand with excess generation being absorbed by the BESS.

During instances where the PV generation is not capable of meeting the local demand, the BESS would meet this demand assuming there is sufficient State of Charge (SoC) to do this. Where neither the PV nor BESS are able to meet demand, it is assumed that load would be served by grid import. Similarly, in periods of high irradiance and low demand, instances where the PV meets local demand requirements and the ESS SoC is at 100%, it has been assumed that the PV generation would be clipped. This energy could alternatively be exported to the wider grid, network limitations with this increased renewable resource would need to be clarified with the network operator.

The BESS dispatch profile has been refined based on results obtained from a selection of initial modelled scenarios. It was realised that the island was subject to rapid demand spikes (from the network operators perspective) associated with the PV coming online and the BESS reaching its SoC low point (i.e. no usable energy capacity available). In order to mitigate these rapid demand spikes on the network, RINA-TECH UK integrated ramp rate control within the BESS dispatch functionality in order to eliminate instances of near instantaneous loss of local generation.

This ramp rate control modified BESS behaviour to reduce its power set-point based on its current SoC position. This enabled the BESS to meet Unije demand with the energy capacity available while enabling a controlled transition from the load being met by local generation to being serviced by the distribution grid connection. RINA-TECH UK consider this control functionality to provide increased grid stability while enabling the BESS to achieve a high level of utilisation.

IV. MODELING UC-1: JOINT MANAGEMENT OF HYBRIDIZED RES AND STORAGE - RESULTS

This section provides an overview of how the BESS solutions modelled behave based on demand profiles established. The results for the Scenario A demand profile are initially presented. As shown in Fig.3, the Scenario B profile developed has an increased demand requirement over the assessment year, as such these subsequent results provide a more conservative estimate of the local demand which can be met by the Project.

IV.I Scenario A assessment

Preliminary assessment – BESS 1MW/1MWh

The initial scenario modelled was used to determine the expected utilisation of the 1MW/1MWh BESS (which was the size originally proposed by INSULAE Project Unije partners during the site visit in Unije). To assess the suitability of this BESS energy to power sizing, the performance at periods of Unije peak demand (summer) and low demand (winter) were examined (Fig.6 – Fig.7).

As seen in Fig.6 (the peak demand time of year), the residual demand (grey column) not served by the Project occurs towards the end of the evening peaks and during the night. Additionally, across both the high and low demand periods PV generation exceeds demand (green line) and cannot be absorbed by the BESS as its SoC has reached 100%. As discussed above, this PV generation could provide reverse power flow from the island, providing clean generation to neighbouring islands on the network throughput periods of the day.

Alternatively, if Unije had a BESS with an increased energy capacity, additional PV generation could be absorbed and released by the BESS to be used to meet the local demand during peak demand periods of the year. Additionally, given the peak demand of the island being considered less than 400kW (based on the island transformer capacity) it was deemed unnecessary to specify the BESS with a 1MW power rating. As such, RINA-TECH UK has undertaken a selection of discrete iterative modelling scenarios to determine an energy to power ratio that is capable of reducing the residual demand for the island not serviced by the Project.

The subsequent scenarios modelled were targeted at reducing the annual residual energy demand figure (estimated up to 75.46MWh) and keeping 0.4 MW as power capacity (based on island transformer capacity.

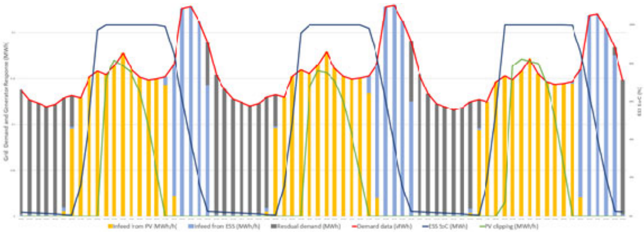

Figure 6. Scenario A peak demand, 1MW/1MWh BESS

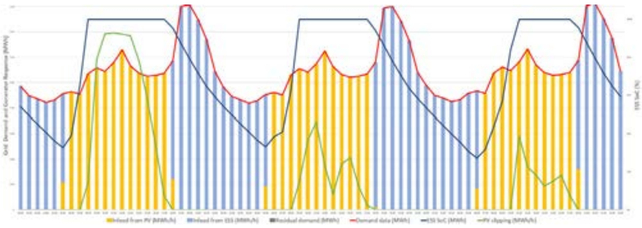

Figure 7. Scenario A minimum demand, 1MW/1MWh BESS

First attempt – BESS 0.4 MW/1 MWh

As an initial CAPEX saving exercise, the rated power of the BESS was reduced to be in-line with the 400kVA rated capacity of the distribution transformer for Unije. No material difference between the results of the 1MW/1MWh BESS and this 0.4MW/1MWh system were realised in terms of the residual demand not served. BESS 0.4MW/1.6MWh

Second attempt – BESS 0.4 MW/1.6 MWh

Then it has been explored the impact of including additional BESS energy capacity (MWh) which could be realised while still adhering to the CAPEX considerations outlined in previous sections. As such a selection of energy rating were considered with a 0.4MW/1.6MWh solution offering the highest energy rating for the CAPEX limitation.

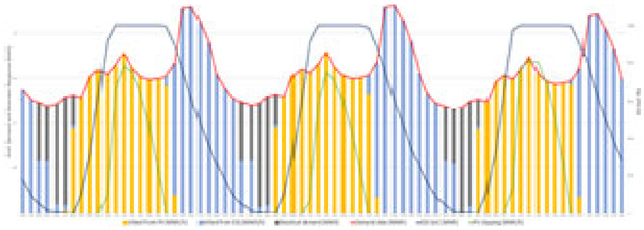

Figure 8. Scenario A peak demand, 0.4MW/1.6 MWh BESS

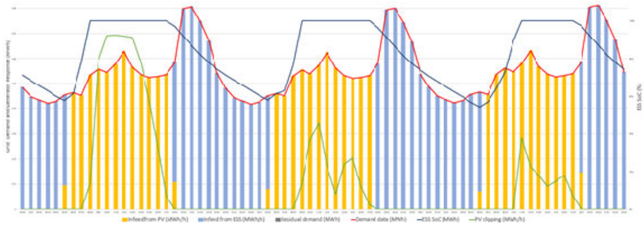

Figure 9. Scenario A minimum demand, 0.4MW/1.6MWh BESS

By increasing the usable energy capacity of the BESS from 1MWh to 1.6MWh the residual demand for Unije which required generation capacity from the island interconnector has been reduced to 25.53MWh. This amounts to a reduction in demand not served by Renewables by approximately 66% between the 0.4MW/1MWh and 0.4MW/1.6MWh solutions assessed.

Third attempt – BESS 0.3 MW/1.6 MWh

To assess the merit of the 0.4MW/1.6MWh system sizing outlined above, the annualised performance of 0.3MW/1.6MWh BESS has been studied too. As expected, the residual demand not served has increased. This is primarily due to the BESS no longer being able to respond at the same power requirements during periods of high PV generation and peak demand. We note that nominal further CAPEX savings are expected to be realised by reducing the rated power of the BESS in this Scenario A assessment. Additionally, given it is presently assumed that the Project being able to serve Unije peak demand requirements would be considered of high value to the network operator this 0.3MW/1.6MWh system sizing was not considered for the proposed design.

IV.II Scenario B assessment

As outlined in previous section, this section looks at a similar BESS modelling process against the more conservative Scenario B demand profile. The results and trends are materially similar to those detailed oben. As expected, due to the increased demand requirements, a greater magnitude of Unije demand in not served by the Project. We note that this further emphasises the BESS operational sensitivity to the assumed input demand profile.

Preliminary assessment – BESS 1MW/1MWh

As seen in Fig.10 and Fig.11, the residual demand (grey columns) not served by the Project occurs during the evening peaks and during the night. The primary distinction between Scenario A and B is that even during the periods of minimum demand there is a requirement for grid infeed to meet Unije demand, compared with Fig.7 **Fehler! Verweisquelle konnte nicht gefunden werden.** where the Project was able to meet the demand profile without input from the distribution network.

Similarly, the volume of PV generation still exceeds demand (green line) and cannot be absorbed by the BESS as its SoC has reached 100%. As discussed in Scenario A, this generation could provide reverse power flow from the island, providing clean generation to neighbouring islands on the network. Alternatively, this surplus PV generation energy could be used to meet the local demand if the BESS had an increased energy capacity.

As done before, given the peak demand of 400kW it was deemed unnecessary to specify the BESS with a 1MW power rating. As such, a selection of iterative modelling scenarios (also according to lessons learnt from Scenario A) was undertaken to determine energy to power ratio that was capable of minimising the residual demand for the island not served by local renewables by the project.

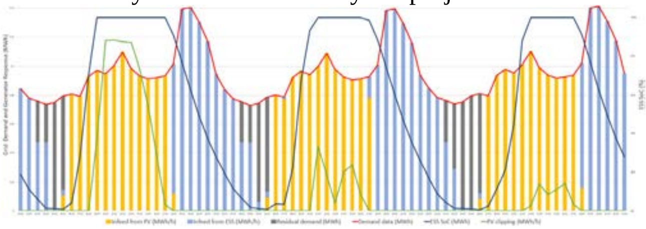

Figure 10. Scenario B peak demand, 1MW/1MWh BESS

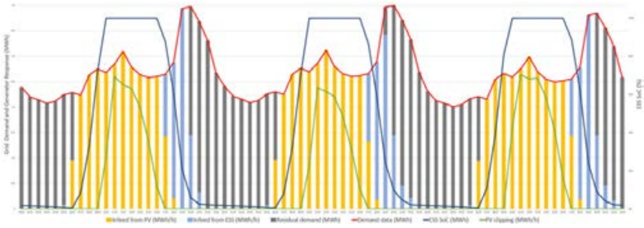

Figure 11. Scenario B minimum demand, 1MW/1MWh BESS

Best sizing from scenario A – BESS 0.4 MW/1.6 MWh

As seen in scenario A, by increasing the usable energy capacity of the BESS from 1MWh to 1.6MWh the residual demand for Unije which required generation capacity from the island interconnector has been reduced to approximately 223.76MWh. This amounts to a reduction in demand not served by local renewables by approximately 40%, thus proving that a BESS Design 0.4 MW/MWh can be considered the best option even in scenario B (Fig.12 – Fig.13).

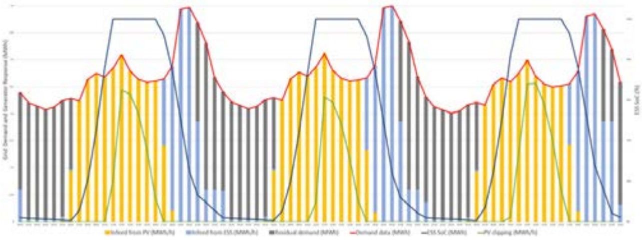

Figure 12. Scenario B peak demand, 0.4 MW/1.6 MWh BESS

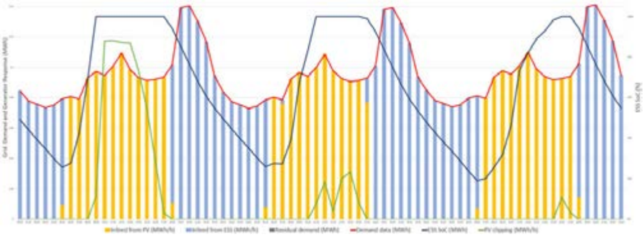

Figure 13. Scenario B minimum demand, 0.4 MW/1.6 MWh BESS

Based on the scenario modelling results presented above, INSULAE Unije partners identified in a Li-ion BESS systems with a capacity of 0.4MW/1.6MWh as the best solution to maximize local renewables exploitation at local level and minimizing grid purchasing to cover Unije demand.

V. UC-2: SMART INTEGRATION AND CONTROL OF WATER AND ENERGY SYSTEMS

In order to further maximize local renewable exploitation as well as to increase overall local energy efficiency, the local water system electrical loads will be properly monitored and controlled in accordance to PV+BESS plant production.

The current state of water supply on the island of Unije includes a brackish water well, a desalination plant (with a total power load of around 14 kW considering the desalination unit and circulation/auxiliary pumps - it is worthy to highlight that the desalination unit building is already equipped with few PV panels on the rooftop), a distribution network in the settlement currently under construction, its own sources of water collection (rainwater), a public tank near the church, and water supply by aquifer.

Private water tanks as part of residential households are used to store rainwater and water from aquifer. Water is pumped from house cisterns with a house hydrophore and distributed to the distribution installation. Public cisterns are of large volume and are located near the school ($350m^3$), church ($350\ m^3$) and local committee building ($850m^3$). Until the construction of the desalination unit, the cistern near the church was the main one and was replenished with water from the aquifer, while the other cisterns were replenished with rainwater.

The brackish water is pumped from the existing U-1 well in the field with new pumps with a capacity of 2 l/s. The previous pumps were powered by a diesel generator, and the newly installed ones were connected to a low-voltage distribution system that could be therefore grid connected (thus to be controlled in accordance to Unije PV production). The water from the well is forced into a pressure pipeline that goes all the way to the desalination unit. After the desalination unit, the water from the 40 m^3 purified water tank within the desalination unit is transported all the way to the tank near the church.

The current distribution network does not connect the hydrophore with residential houses, but with 10 hydrants that are spread throughout the settlement. If necessary, hydrants and house cisterns are connected by surface distribution. Prior to the start of works, the settlement was supplied with water from an aquifer, a tanker with a volume of 250-1000 m^3, depending on the need. Apart from the Unije, the aquifer is also used on other islands of the Cres-Lošinj archipelago where there is a lack of water in the summer months. The aquifer connects to a shaft located on the waterfront and the water is distributed throughout the village to an individual house cistern by improvised surface distribution.

In the framework of INSULAE project this water system (and particularly the desalination plant and reservoir-connected pumps) will become a smart-load in order to maximize renewable self-exploitation and its management will directly dialogue with the PV+BESS management system. In order to do so, in this moment the local water network company is identifying where to install smart sensors and actuators in order to better understand where to more efficiently implement power-to-water and optimized pumping strategies

VI. CONCLUSIONS

This paper presents an introduction to the demonstration activities that will be implemented in Unije island in the framework of H2020 INSULAE Project, with particular reference to UC-1 and UC-2 that will be thereby demonstrated.

The goal of these two use-cases and of their demonstration is to showcase that, even in small and peripherical/remote island of an archipelago, the integration of Renewables (PV) can become a suitable opportunity not only to increase energy resilience/independency of the island, but also to provide grid stability to the main grid in the case of interconnected islands, particularly thanks to the integration of storage and smart loads as a "power-to-water system" can be, thus creating a "multi-vector hybrid plant".

Next imminent steps for the demonstration of above presented activities are:

- UC-1: start of the construction of the PV plant, start of the procurement of the BESS according to specified energy/power capacity solutions and of the development of optimized PV+BESS energy management strategies also capitalizing monitoring data via RINA analytics tool as well as thanks to the proper dialogue with "Power-to-water" system.
- UC-2: installation of identified sensors and actuators where to implement power-to-water and optimized pumping strategies.

What will be demonstrated in Unije will be lighthouse for many other small islands in Europe which are currently fossil fuel dependent, wisely implementing "On-the-shelf" solutions. Models, cost functions and approaches presented in this paper would be helpful to facilitate the replication and even eventual upscale of above mentioned use cases and decarbonization strategies.

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