IANOS: Innovative energy storage solutions for the decarbonization of geographical islands

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Abstract. Geographical Islands experience harsh climate conditions resulting in diminished reliability of their grid. IANOS, a project funded by the European Commission, is developing technologies to overcome these challenges and allow for the secure decarbonisation of islands. The project will deploy and use storage technologies in two islands: Terceira, in Portugal, and Ameland, in the Netherlands. These include a 100kW/3kWh flywheel; thirty-five 2kW private fuel cells; sixteen 3kW/3kWh electrochemical batteries; two large-scale Battery Energy Storage System (BESS); a biobased saline battery of 120kWh; and twenty-four heat batteries of 3.5kWhth. These technologies, managed by an intelligent Virtual Power Plant (iVPP) also developed within the project, will be used for the maximisation of demand-side self-consumption, as well as for the provision of ancillary services, targeting the maximum economic and environmental benefit for the population and the island's grid. In this paper, the specifications of each storage technology are described, as well as the impacts on the grid stability. The role of storage technologies in the decarbonisation of geographical islands will be emphasized.

1 Introduction

An estimated 4.6% of European citizens were living in geographical islands in 2021 [1]. Since these geographies tend to be subject to harsh climate conditions and rely mostly on fossil fuels [2], it is a necessity that a common framework for decarbonising islands is developed. IANOS – IntegrAted SolutioNs for the DecarbOnization and Smartification of Islands is a project financed by the European Commission under the Horizon 2020 programme [3] [4], which appears precisely with the intent of developing this decarbonisation plan. The project involves two main islands: Terceira, in Portugal, and Ameland, in the Netherlands, and will install energy management and storage technologies, and an innovative intelligent Virtual Power Plant (iVPP), having in mind the improvement of grid reliability. The iVPP, being the brain of the project, monitors all assets using optimisation and forecasting techniques to manage the innovative technologies, allowing the system to be decarbonised while benefiting the comfort and economy of the population.

1.1 Terceira Energy Ecosystem

Terceira is the third largest, and the second most populated island in the Azores archipelago, with 55,300 inhabitants. [5] In 2021, Terceira's installed capacity generated 193GWh of electricity, with approximately 38% provided by RES (Renewable Energy Sources). [6] Fuel oil is still the dominant energy source in the island (62%). Regarding electricity consumption, in 2021 it reached a total of 179GWh, with residential consumers representing the most significant segment. [6]

1.2 Ameland Energy Ecosystem

Ameland is an island in the Netherlands with a total population of 3,800 people. [7] It is connected to the mainland electrical grid and to the mainland natural gas grid. The total energy usage in Ameland is approximately 136GWh per year. [8] The largest consumers are the building sector and the transport sector, while heat has a low consumption on the island. Most of the energy used in Island comes from the connections with the mainland. The peak demand in the island is 6MW. [8]

2 IANOS Use Cases and Impacts on the Island's Decarbonization

Pursuing the decarbonization of these islands, nine distinct Use Cases (UC) will be implemented, as presented in Table 1. In this paper, three of these UCs will be presented in more detail, namely the ones where storage technologies take a predominant role to the UCs' success.

Table 1 Use Cases and their respective example actions

Sectors	Use Cases	Example actions
Energy efficiency and grid support for extremely high-RES penetration	1) Community demand-side driven self-consumption maximization	PV and Wind, biobased battery systems
	2) Community supply-side optimal dispatch and intra-day services	Energy asset scheduler, flexibility forecast
	3) Island-wide, any-scale storage for fast response ancillary services	Flywheel system
	4) Demand side management and smart grid methods to support power quality and congestion management services	Smart energy routers, hybrid heat pumps
Decarbonization through electrification and support from non-emitting fuels	5) Decarbonisation of transport and the role of electric mobility in stabilizing the energy system	Vehicle-to-Grid (V2G) Electric Vehicles chargers
	6) Decarbonizing large industrial continuous loads through electrification and locally induced generation	Underwater Tidal Kite
	7) Circular economy, waste streams and gas grid decarbonization	Digester, gasifier
	8) Decarbonisation of heating network	H2 storage, heat pumps
Local Energy Communities	9) Active Citizen and LEC Engagement into decarbonization Transition	Local cooperative organization actions

2.1 Use Case 1 - Community demand-side driven self-consumption maximisation

IANOS Use Case 1 focuses on the optimization of behind-the-meter assets on residential households, with the objective of maximizing RES self-consumption. In this UC, the intelligent Virtual Power Plant (iVPP) will be monitoring the loads, PV generation and storage at local and neighbourhood level. In Terceira, the innovative storage technologies to be installed are heat batteries and smart electric water heaters, whilst in Ameland biobased saline batteries will be used, all of them monitored by the IANOS' iVPP itself. [9]

2.2 Use Case 3 - Island-wide, any-scale storage utilization for fast response ancillary services

This UC aims at the provision of fast ancillary services by storage systems. The goals are to ensure a stable power distribution when reliability of the grid is compromised. Storage technologies of different scales will be used to balance the grid, aiming at improving continuity of the supply and avoiding grid congestion. The main innovation is the flywheel in Terceira controlled by the iVPP, whilst Ameland will use private fuel cells, [9]

2.3 Use Case 6 – Decarbonising large industrial continuous loads through electrification and locally induced generation

The aim of UC6 is to use electrification and local generation for decarbonising large consumers. It is limited to the decarbonisation of the natural gas platform off the coast of Ameland, maximizing consumption of local RES. Participating in this UC are a micro-CHP, a solar farm, wind turbines, a wave-energy power source and the natural gas platform, [9].

3 IANOS Storage Technologies and iVPP

IANOS aims at developing a decarbonisation path for islands using innovative technologies. Included in these are storage innovations, developed to increase RES self-consumption or support grid management. Also an iVPP was developed in the project, which will aggregate the project's assets.

3.1 Innovative Storage Technologies

3.1.1 Heat Batteries

The heat batteries use Phase Change Materials (PCM) capable of efficiently store heat for hot water systems and space heating. These batteries are compact and require no periodic maintenance, [10]. In IANOS, twenty-four batteries will be installed in residential houses, and monitored by the iVPP which will use them in an aggregated way.

3.1.2 Smart Electric Water Heaters

In IANOS, five smart electrical water heaters will be installed, including a non-intrusive monitoring and control system composed by sensors, a microcontroller, an actuator, and a remote-control module that allows them to be utilized in an aggregated way. The devices can target the optimization of the user experience and provide flexibility, [10].

3.1.3 Flywheel

The IANOS flywheel, differs from conventional ones as it uses a hub-less outer-rotor design, reducing radial stress and allowing for the full use of the material tensile stress properties, resulting in higher energy density. It will be controlled by the iVPP to contribute to the grid management UCs and provide services such as fast frequency regulation, [10].

3.1.4 Smart Energy Router

The Smart Energy Router (SER) is an inverter promoting smart management of the flows to and from different sources, such as the grid, RES, and storage systems. Two SER will work as intermediary between the iVPP control layer and the field equipment in IANOS, [10].

3.1.5 Biobased Saline Battery

A 120kWh saline battery completely recyclable and with a natural self-cooling system. The biobased battery has no thermal runaways and can be assembled on remote sites in a mobile way. In IANOS, it will be between a RES and the end user, and controlled by the iVPP, [9].

3.1.6 Distributed Methane Fuel Cells

Thirty-five 2kWe methane Solid Oxide Fuel Cells (SOFC) will be used inside residencies. These fuel cells deliver 2.3 kW of electrical power and 0.6 kW of thermal power. The iVPP will be in control of the cells so that their flexibility is used for grid management, [11].

Table 2 presents a summary of the specifications of each technology used in the mentioned UCs in the project IANOS.

Table 2 Technical specifications of the innovative storage technologies to be implemented in IANOS

Heat Batteries		**Smart Electric Water Heaters**	
Water content	3.2 L	Rated Power	2000 W
Equivalent hot water cylinder size	74 L	Nominal AC Voltage	230 V / 50 Hz
Electrical efficiency	81.4 %	Dimensions (HxD)	960 mm x 500 mm
Annual consumption	542 kWh	Capacity	100-150 L
Flywheel		**Smart Energy Router**	
Max Power Rating	100 kW	Max. ESS power	5,000 W
Max Energy Rating	3 kWh	Rated ESS voltage	500 V (DClink)
Recharge Time	130 sec @100kW	Max. ESS charging / discharging current	15 A
Self-Discharge	1 h	Rated power (400/230V, 50Hz, PF=1)	5,000 W
Biobased Battery		Power factor range	0.7 lag to 0.7 lead
Nominal voltage	552 V	Max. current	3 x 7.25 A
Storage capacity	120 Ah, 400 Vac	Harmonic distortion	< 5 %
Max. charging rate	12 KW	Dimensions (W x H x D)	400mm x 800mm x 400mm
Max. discharging rate	> 15 KW	**Distributed Methane Fuel Cells**	
Discharge efficiency	> 96% @ 20 °C	Electrical Power	2.3kW
Dimensions (L x W x H)	2,170mm x 1,654mm x 1,560mm	Thermal Power	0.6 kW

3.2 Intelligent Virtual Power Plant

The IANOS iVPP plays a crucial role in orchestrating and coordinating both the assets and services employed in the previously mentioned use cases. Its primary function is to administer and organize the various services, including the management of the aforementioned assets, in real-time through the Centralized Dispatcher (CD) tool. The CD contains the central decision-making logic required to develop an optimized dispatch plan for all assets controlled by the iVPP. The main objectives of the CD are:

1. Maximizing self-consumption through the exploitation of renewable energy sources, either in individual households or at the neighbourhood level.
2. Provide ancillary services to the grid utilizing storage technologies.
3. Provide ancillary services to the grid by leveraging energy flexibility from demand resources.

To accomplish the defined objectives, the CD carefully considers both technical and economic constraints. This includes factors such as the State of Charge (SoC) of batteries and the minimization of the operational costs. The monitoring of the entire system is made possible by the implementation of a scheduler. This scheduler enables the execution of services at predefined time intervals, ensuring timely monitoring of assets. Additionally, an API based on REST architecture is implemented, providing endpoints for accessing the services offered by the iVPP. By performing this role, the iVPP ensures efficient system operation and facilitates coordination among the assets and services. The iVPP accomplishes its tasks through three functionalities, designed to enhance system performance:

1. **Data collection –** Performed through a gateway developed in the context of IANOS.
2. **Coordination and Monitoring –** Ensuring all assets are managed efficiently by coordination and monitoring their operations, while it facilitates effective coordination among the assets and services.
3. **Recording of services execution –** The iVPP maintains daily log files to record the execution of services. Important for ensuring the system's reliability and identifying any potential issues during operation.

The iVPP within the IANOS project serves as an intermediary component in the system architecture, optimizing asset management, and carrying out tasks such as data collection, coordination and monitoring services. Finally, it is important to mention that the in-depth analysis of the optimization techniques that are utilized by the CD is beyond the scope of this paper and will be described in future publications.

4 Conclusions

The UCs described will greatly impact the energy grid of both demonstration islands, as well as affect positively their environmental and economical ecosystem. As the project is now in the commissioning and deployment phases, there are yet to be produced real results of the implementation of the UC. However, according to the previous study of the project and taking into account the current island context, it is expected that the project has considerable effects on the decarbonisation of these energy systems and the local grids. Additionally, benefits for the population are also expected. Namely, some of the expected impacts are in Table 3, [12].

Table 3 IANOS impacts on demonstration islands' decarbonisation *[12]*

IANOS Impact	Target Value
Reduced Fossil Fuels consumption	379.7 GWh/y (in total for both islands)
RES Utilization	83.6 GWh/y (for both islands)

Increased Battery Storage Capacity	Terceira: 15MW, 10.5MWh Ameland: 2.8MW, 3.13MWh
Increase self-consumption	5%
Reduce energy bills of end users	>15%
Increased demand side system flexibility	>9%
Increased system stability	6-12%

IANOS will be finalized in September 2024 after a year of demonstration. The technologies presented in this paper will be implemented, some in Terceira, others in Ameland, with the aggregation and optimised management of the iVPP. As of this moment, the positive impact of the project in the islands is due to the creation of awareness in the populations towards the necessity of decarbonisation. The concrete results of the demonstrations will be published after the end of the project and available to be replicated in any island.

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