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ScienceDirect
Energy Reports 9 (2023) 403–409
www.elsevier.com/locate/egyr

2022 3rd International Conference on Power, Energy and Electrical Engineering (PEEE 2022)
18–20 November 2022

Integration of CCHP microgrids in NZEB with critical loads under high PQR requirements, a position paper

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Received 13 December 2022; accepted 3 January 2023
Available online xxxx

Abstract

In recent years, many projects have been developed to reduce the energy consumption of buildings, both from the point of view of energy efficiency and the integration of renewable energies. However, few projects are related to the problem of integrating DER in environments dominated by high-tech equipment, the so-called "critical loads": data centers, railroad stations, airports, and hospitals. The European Interreg Sudoe IMPROVEMENT project aim is to renovate existing public buildings where critical loads predominate, converting them into nearly zero-energy buildings (NZEB), and for this purpose, it integrates combined cooling, heat, and power (CCHP) microgrid with renewable and other distributed energy resources (DER) like hybrid energy storage systems (ESS). With still one year to go before the end of the project, the consortium partners present in this position paper the latest progress of their respective work packages to date.

Peer-review under responsibility of the scientific committee of the 3rd International Conference on Power, Energy and Electrical Engineering, PEEE, 2022.

Keywords: Microgrids; Nearly zero-energy building; Energy storage systems; Energy management systems; Combined cooling, heat & power; Power Quality and Reliability

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https://doi.org/10.1016/j.egyr.2023.01.003

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1. Introduction

The Interreg SUDOE Program supports regional development in southwestern Europe as part of the Interreg European territorial cooperation objective, financed by the European Regional Development Fund (ERDF). The Program promotes transnational cooperation to solve common problems, such as low investment in research and development, low competitiveness of small and medium-sized enterprises, and exposure to environmental risks, acting on five priority axes: research and innovation, the competitiveness of SMEs, low-carbon economy, combating climate change, and environment and resource efficiency. The IMPROVEMENT project https://www.improvement-sudoe.es/ "Integration of combined cooling, heating and electricity microgrids in public buildings with zero energy consumption under high energy quality and service continuity requirements" (SOE3/P3/E0901) has a budget of 2.5 million euros and is 75% co-financed by the Interreg SUDOE program and the European Regional Development Fund (ERDF) under Priority Axis 3, Low Carbon Economy.

In recent years, many projects have been developed to reduce the energy consumption of buildings, both from the point of view of energy efficiency and the integration of renewable energies [1–4]. However, few projects are related to the problem of integrating DER in environments dominated by high-tech equipment, the so-called "critical loads" [5]: data centers, railroad stations, airports, and hospitals. Given their extreme sensitivity to electrical disturbances, the quality and continuity of the power supply are essential for healthcare services, especially if lives are at stake. Emergency power supports only critical functions – for example, operating rooms, intensive care, and emergency rooms – which account for 20%–50% of hospital services. As the number and severity of weather events increase, power availability is needed for 100% of hospital services. In addition, these types of buildings use a lot of steam, and hot water and, in general, in the SUDOE region, require a huge amount of energy for air conditioning. The use of technologies such as the Internet of Things (IoT) and Big Data would lead to further energy savings, as it will allow us to know and predict the energy consumption at the equipment level.

2. Objectives and key innovations of the project

The IMPROVEMENT aim is to renovate existing public buildings where critical loads predominate, converting them into nearly zero-energy buildings (NZEB), and for this purpose, it integrates combined cooling, heat, and power (CCHP) microgrid with renewable and other distributed energy resources (DER) like hybrid energy storage systems (ESS). This would involve the following specific objectives: (1st). - Improve thermal efficiency through solar heating and cooling production and the incorporation of active and passive techniques for NZEB. (2nd). - Improve Power Quality and Reliability (PQR) in buildings with critical loads by developing a fault resilient control system for microgrids, with active neutral point control supported by an Innovative IoT PQ supervisory system. (3rd). - Integrate advanced energy management systems (EMS) for renewable microgrids with a hybrid storage system under criteria of minimum degradation, the minimum cost of use of the storage system, and maximization of renewable energy consumption.

As presented in Fig. 1, the IMPROVEMENT project will improve microgrids not only by using their flexibility to allow energy exchange in grid-connected mode or transition to an islanded mode in case of disturbances or faults but also by reducing the presence of harmonics or imbalances through the integration of specific power electronics devices. The IMPROVEMENT project will advance the use of hybrid energy storage solutions. The development of advanced algorithms based on Model-Based Predictive Control (MPC) will enable higher energy density ratios to give autonomy and competitiveness to microgrids. The IMPROVEMENT project will integrate advanced trigeneration technologies (CCHP) by complementing geothermal, phase change thermal storage with ice that will benefit from the utilization of a normally discarded by-product. The IMPROVEMENT project will create a specific business model and implementation plan aimed at creating wealth and employment in the SUDOE region and reducing energy consumption in public buildings in the usual weather conditions of the SUDOE region.

3. Position and work in progress

The participation of the General Management of Energy of the Junta de Andalucía has the aspect of contributing to its vision as the competent body in energy policies in a region. Based on this, it participates in the different working groups created in the project for the development of the foreseen actions, contributing its knowledge on the subject, in the activities related to the exploitation and transfer of results, and in the design of the regulatory actions proposed because of these actions.

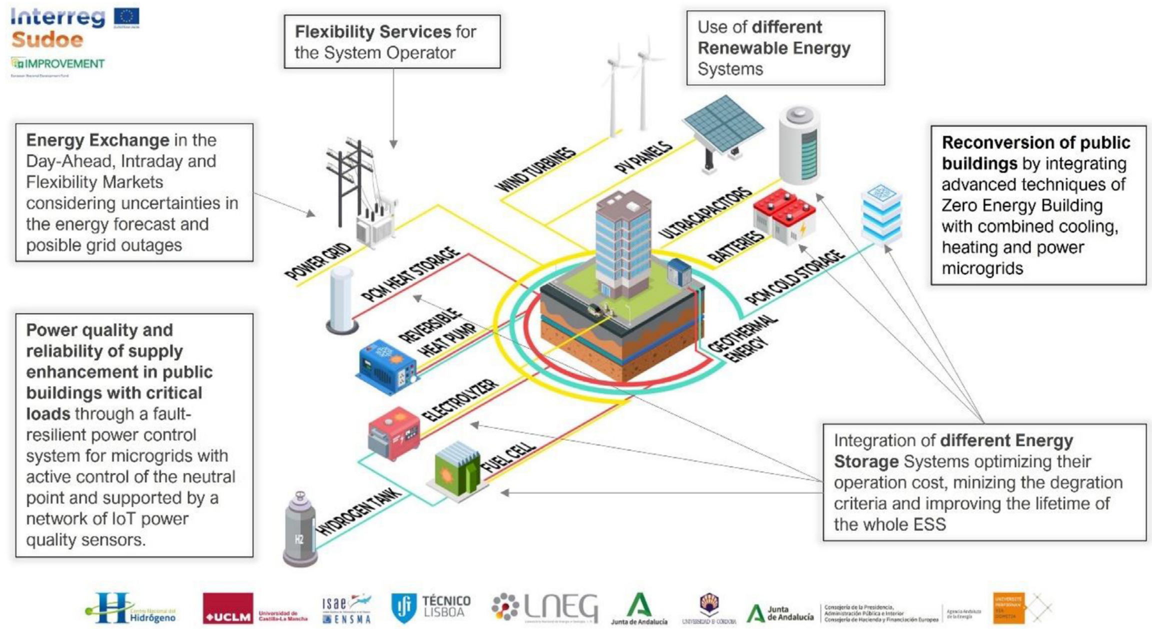

Fig. 1. IMPROVEMENT main innovation approaches.

On the other hand, the strategies and implementation plan to be developed in the project will be useful in the processes of elaboration of new energy strategies, as well as in other public instruments to be developed. The main objectives are, analyze legislation and associated administrative procedures, review barriers to full deployment of the technology, and elaborate recommendations to facilitate the expansion of the technology. To this end, the project's regulatory and certification framework review study is contemplated, which analyzes the regulatory problems for the implementation of the proposed technology and the requirements for its certification, studying the regulatory framework of the different countries and identifying the limitations of each country. In this context, two documents will be prepared as follows:1st.-Review and a proposal of the regulatory framework. 2nd. - Review study of the technical codes and national markets, both within and outside the SUDOE area. Although it seems that some of the requirements are similar in all the associated countries, there are significant differences in their interpretation and application. Some of the issues that are intended to be addressed are risk assessments, health, and safety requirements and conformity assessment procedures integrated environmental obligations. Environmental impact assessment procedures. It is important to evaluate the possible applications of IMPROVEMENT results in the different regulatory frameworks and to determine the constraints for each country in the SUDOE area and countries with the same climatology.

The priority targets defined by the European Union for the Horizon 2030 program and in the Green Deal 2050 are a great challenge and are making a decisive contribution to the promotion of energy efficiency and the integration of renewable generation in all sectors and a decisive contribution to the mitigation of effects of climate change. European Plans of Energy and Climate is an important part of the measures of each Member State (in Portugal, through the PNEC 2030) specifically aimed at urban rehabilitation, promotion of energy efficiency, and the integration of renewable energies in buildings as a strategy to reduce dependence on fossil fuels alignment of the national economy with a trajectory of carbon neutrality. The IMPROVEMENT project is perfectly aligned with the Portugal national plans for Energy and Climate by applying and validating new approaches for conversion of existing service buildings in high energy efficiency tending to nZEB in the covered regions by the Interreg SUDOE program. The project partners from Spain, France, and Portugal are focused on the integration of renewable energy systems (RES) and the development of energy efficiency (EE) in public buildings with sanitary and comfort demands or/and high standards of energy supply for operating high-tech medical and scientific equipment. A Pilot Area is being developed and operated by Portuguese partners LNEG and IST as a real case study housed in the public facilities of LNEG Lisbon with the aim of testing, validating, and demonstrating an innovative management system for micro-grids for maximum efficiency and priority use of renewable generation from solar thermal, PV and Wind, for combined heating and cooling comfort, electricity, and hybrid energy storage systems. The Pilot Area has a total occupancy of 170 m^2 shared by offices, meeting room, and auditorium used for technical sessions and scientific presentations purposes. It had been requalified to nZEB target with the implementation of energy passive measures – natural illumination and shading devices, efficient lighting, thermal insulation, PCM materials, electric renovation – and energy micro-grid with the renewable generation of thermal and electrical systems. The renewable thermal power system for space heating and cooling through fan-coils in Pilot Area is a highly efficient Heat Pump air/water 14.5 kW assisted by a Solar Water Heating (SHW) set of solar vacuum collectors (4.8 m^2) with a 300 L thermal storage and a 1000 L water tank as an inertial element. The set is completed by a Domestic Heating Water (DHW) with hybrid PV-T solar collectors (4.2 m^2) with a 300 L thermal storage for hot water preparation. The renewable electric power system comprises 4 kWp PV power and a 2.5 kW T. Urban micro wind turbine nominal power both installed at the roof-top of the Pilot Area. The micro-grid is also equipped with a grid-forming power control unit (bi-directional inverter Sunny Island 4248) and an energy storage system, composed of 24 conventional lead–acid batteries, with a nominal voltage of 48 V, a capacity C120 of 660 Ah, and an energy storage capacity of 31.68 kWh. A hierarchy of load supplying by renewable power systems and batteries when the micro-grid is operating in isolated mode was defined according to load priority criteria – ex. dimmable LED lights and charging Schuko plugs – or non-priority load – ex. fan-coils and Schuko plugs. For the project, especially in what concerns the characterization of the thermal efficiency and comfort of the pilot, LNEG installed a supervision control, data acquisition system, and building operation with web monitoring interfaces.

The energy management of integrated power and thermal energy systems in buildings using renewable resources has been poorly addressed in the literature, despite the large quantity and quality of research works regarding power systems and thermal systems individually. The main justification in the view of Instituto Superior Técnico-ULisboa is that in general these systems are designed, implemented, and manage by different groups of professionals (electrical engineers for power and mechanical engineers for thermal systems), the regulations of the project are different and thus historically the industry has been tackling these two problems independently. One of the objectives of the IMPROVEMENT project is to capture the potential synergies of implementing and managing both systems in an integrated way, for example, using the thermal storage systems also to store renewable power generation or using the thermal power systems for demand response actions in power management. As the integration increases the complexity of the individual systems, it is necessary to resort to complex energy management approaches, like model-based predictive approaches to obtain successful management.

The Spanish National Hydrogen and Fuel Cell Technology Testing Centre (CNH2) is focusing on two fundamental aspects related to the pilot plant of the project. On the one hand, we are expanding the thermal system, which consists of a geothermal heat recovery system, combined with an energy storage system in the form of heat and the form of cold employing phase change material. On the other hand, we are immersed in the development of an energy management algorithm for the pilot microgrid, which consists of a hybrid energy storage system composed of batteries, supercapacitors, hydrogen, solar panels, and wind turbines. This algorithm will be able to control the use of the hybrid storage system to optimize costs of energy use from the grid (buy from the grid at the cheapest time or sell at the most expensive) and reduce the degradation of the equipment (use batteries instead of hydrogen because it reduces the degradation in certain situations), all this from a resilience criterion able to ensure the power supply to the critical loads of a system when there is an outage with the power grid.

PROMES-CNRS's contribution to the IMPROVEMENT project is first the development of computationally tractable algorithms for thermal energy and users' thermal comfort management in public buildings facing critical loads, equipped with electrical and thermal microgrids. PROMES-CNRS is also contributing to the development of an advanced energy management system (EMS). Our case study is a building with different thermal zones in Portugal whose thermal microgrid is composed of solar collectors (SCs), a hot water tank (HWT), a thermal energy storage (TES) system, a heat pump (HP) and fan coil units (FCUs). The SCs provide heat to the HWT. The TES system is fed by both the HWT and the HP. By releasing stored heat, the FCUs supply air at the desired temperature to heat the building's rooms. Two control strategies are proposed by PROMES-CNRS. The first control strategy combines PID (proportional–integral–derivative) and rule-based controllers. PID controllers are used to manage the SCs, the FCUs, and the temperature in the building's rooms. A rule-based controller is used to manage the TES system. From 6 a.m. to 6 p.m., users' thermal comfort is ensured by tracking a temperature set-point using a PID controller. A second control strategy, which is a refinement of the first one, is under development. Users' thermal comfort will be managed by using a model-based predictive controller (MPC), to decide for the right moments to turn on and off the heating, ventilation, and air-conditioning (HVAC) system, while minimizing electricity consumption. Another predictive controller will be part of the strategy: the TES's rule-based controller will be replaced by an MPC controller, with the valves of the SCs and the FCUs controlled by the PID controllers. The aim behind this predictive strategy is to maximize heat production while minimizing the heat pump use.

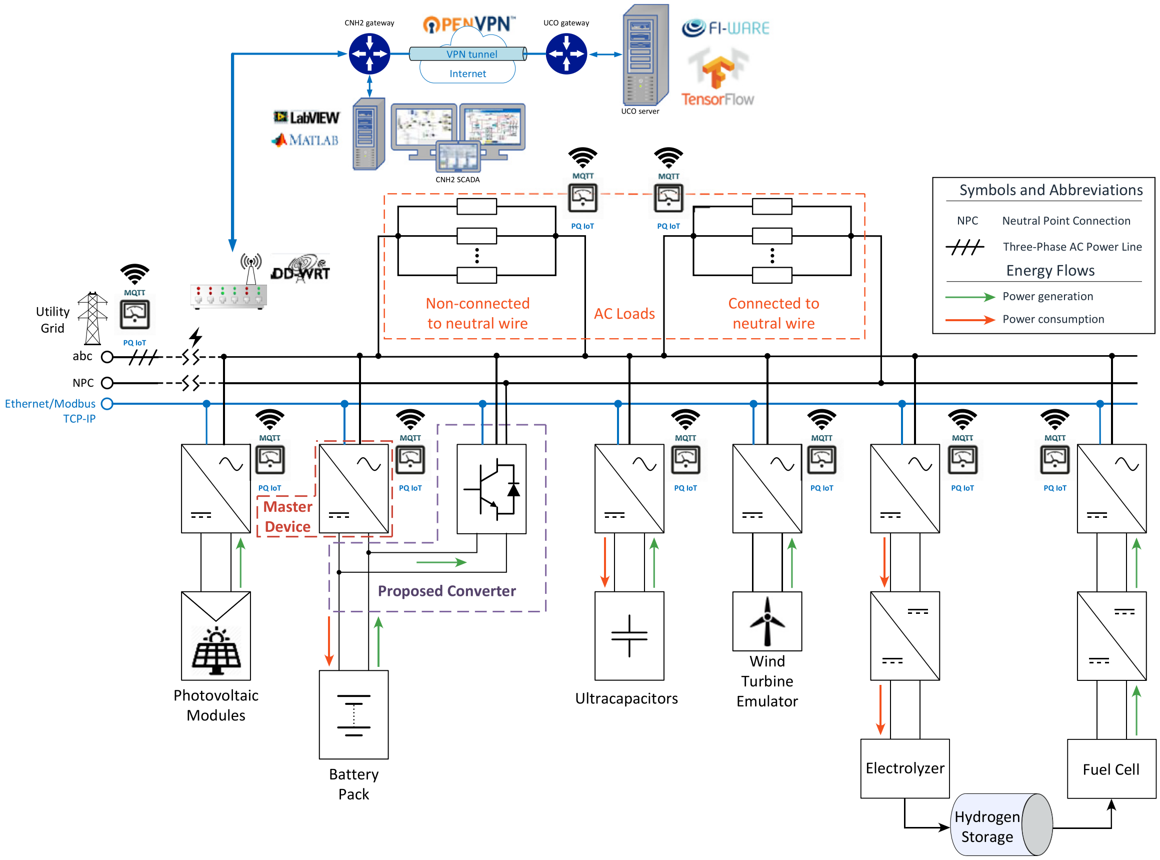

Fig. 2. IMPROVEMENT microgrid project scheme.

The Universidad de Castilla la Mancha is focusing on the integration of a shunt active power filter in a microgrid (MG) such as that of IMPROVEMENT's Spanish pilot plant (shown in Fig. 2) would significantly enhance the power quality of the installation and its reliability, especially when working in islanded mode. The loads, energy storage systems, and distributed generators would cause current harmonics to flow throughout the MG, as well as reactive power and zero and negative current sequence components. When the MG operates connected to the utility grid, the main drawbacks caused by such disturbances comprise an increase in the power losses and a reduction of the active power exchanged with the electrical system [6]. In addition, when the MG operates in islanded mode and is, therefore, disconnected from the utility grid, stability issues may arise due to the weakness of the resulting grid. The insertion of a shunt active power filter (APF) can help to mitigate these perturbations and, hence, the associated issues that they may cause. For example, the compensation of the reactive power demanded by the loads in the MG will increase the amount of active power that the MG can exchange with the utility grid. Moreover, the compensation of the current disturbances that occur during the islanded operating mode will decrease the influence that such perturbations would have on the operation of the inverter that generates the voltage waveforms. Thus, the presence of an APF contributes to increasing both the reliability of the MG and the robustness of the islanded mode operation against power quality issues.

The University of Cordoba places this project within the framework of "Grid-Interactive Efficient Buildings" [7] in which critical loads predominate. These can be viewed from two points of view: (1) as an individual building, and

(2) as part of the electrical grid. First, they are first and foremost energy efficient, incorporating both passive and active strategies to become near-zero energy buildings. Passive design measures may include building orientation, thermal insulation, or efficient windows. While active strategies may include improving thermal efficiency through solar heating and cooling production. Or integrate advanced energy management systems for renewable microgrids with hybrid storage systems. But the feature that makes them unique is their ability to interact with the local power grid, operating as a demand flexibility resource. A successful demand flexibility strategy requires: Adopting a people-centered design to understand the consumer and involve them in flexibility plans. Understanding in depth and predicting customers' energy usage patterns. As this will involve optimization at thousands of daily connection points. The Internet of Things (IoT) and machine learning (ML) could be instrumental in massively managing and orchestrating such diverse customers [8]. Thus, first, the importance of detailed energy metering must be emphasized. Submetering as opposed to bulk metering, involves measuring the energy consumption of individual units or appliances in the building [9]. Submeters would provide crucial information for more granular measurement of energy consumption data. Unfortunately, submetering remains limited due to the costs of meters and the technical complexity of installation, operation, and disaggregation. But it is not only the submetering of electricity consumption that is relevant. The importance of reliable, high-power quality (PQ) continues to grow as the ongoing digitalization of our societies broadens and deepens. In addition, the integration of distributed energy resources (DER) can lead to PQ problems and violations of operational limits in the power system when their penetration exceeds a certain value, called Hosting Capacity HC [10,11]. Demand flexibility management can be used to manage hosting capacity under PQ constraints. Therefore, the disaggregated and continuous measurement of certain PQ indicators employing the IoT platform developed, as depicted in Fig. 3, can contribute to a more accurate assessment of resources in the MG [12].

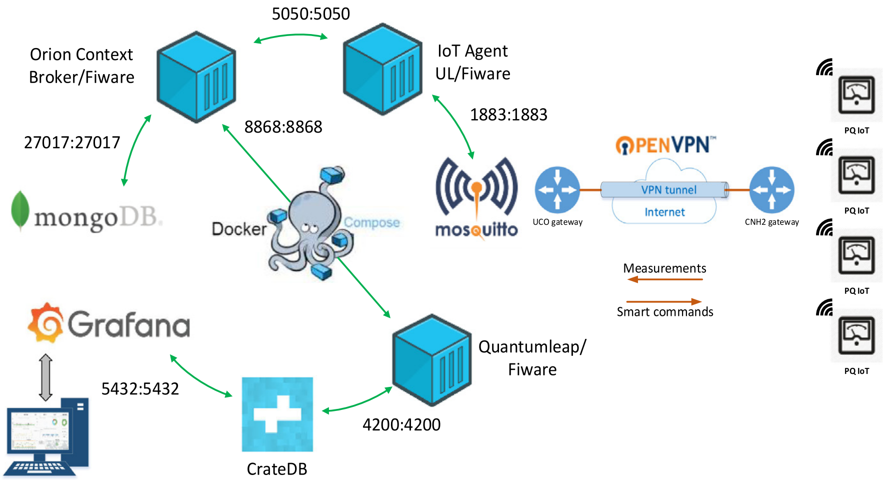

Fig. 3. - FIWARE ecosystem architecture developed.

4. Conclusions

The benefits of the project are directed to public entities that own buildings, energy authorities, and agencies, and to public regulatory bodies (which update the current regulatory framework). All these entities are represented in the Consortium. IMPROVEMENT's approach focuses on the development and demonstration of technology that reduces the carbon footprint of public buildings with critical loads, generating a parallel influence on political decision-making bodies. Through transnational cooperation, it is expected to share efficient investment in new technologies to reduce the high consumption of public buildings with critical loads contributing to the European Energy Goals 2030. Increase the ability to influence public authorities to make the right decisions. Overcome the barrier associated with different energy policies in different countries by improving replicability. Develop innovative solutions to overcome the regulatory, legal, and financing barriers faced by public authorities to undertake this type of project.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgments

This research is supported by Project IMPROVEMENT (grant SOE3/P3E0901) co-financed by the Interreg SUDOE Programme and the European Regional Development Fund (ERDF).

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