Convocatoria 2022 - «Proyectos de Generación de Conocimiento»
Formato Memoria Científico-Técnica Proyectos Individuales

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IMPORTANT – The research proposal cannot exceed 20 pages. Instructions to fill this document are available in the website. If the project cost is equal or greater than 100.000 €, this document must be filled in English.

1. DATOS DEL PROYECTO

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TÍTULO DEL PROYECTO (ACRÓNIMO): Técnicas de Control Predictivo Resiliente para la Gestión de Sistemas de Energía Renovables incluyendo Hidrógeno Verde (REGREENH2)

TITLE OF THE PROJECT (ACRONYM): Resilient Predictive Control Techniques for Management of Renewable Energy Systems including Green hydrogen (REGREENH2)

2. JUSTIFICATION AND NOVELTY OF THE PROPOSAL.

2.1. *Adequacy of the proposal to the characteristics and purpose of the selected modality*.

This proposal is included in the priority area of "Clima, Energía y Movilidad" with the subject involved in the following topics:

- EYT (Energía y Transporte) and sub-area Energía (ENE)
- PIN (Producción industrial, ingeniería civil e ingenierías para la sociedad) and sub-area IEA (Ingeniería eléctrica, electrónica y automática)

Objectives of REGREENH2 are the development of resilient predictive control strategies including fault-tolerant systems, risk management and machine learning algorithms, which will be applied to hydrogen-based energy systems. It includes the development of methodologies that contemplate digital twins (DT) to be applied to the control of electrolyzers, their integration with renewable generation and vehicles.
The project has been selected as "orientado" due to the expected contributions and the involved research are in the specifc subject of hydrogen-based energy systems where the hydrogen generation is from Renewable Energy Sources (RES) . The results will be validated on a test bench located in the Hylab laboratory (H2LAB) of the university of Seville and extended to mobile platforms such as aerial systems (Unmanned Aerial Vehicles (UAVs)) and ground vehicles (Fuel Cell Electrical Vehicles (FCEV)), as well as distributed systems within the framework of Energy Communities (EC).

2.2. *Justification and expected contribution of the project to the generation of knowledge on the theme of the proposal. Starting hypothesis*.

Starting Hypothesis

Due to the current energy dependence of society, the climate change and the introduction of renewable sources in the production, the availability and correct functioning of Energy Management Systems (EMS) are strategic issues to be dealt with. Currently, EMS are very focused on achieving systems that present a remarkable optimization of demand as well as a high degree of fault and risk tolerance to incorporate renewable sources and mobile platforms.

This situation requires new schemes for the future electricity grids, where distributed generation, demand response and energy storage systems may be easily integrated. Companies have a great commitment to maintain and fulfil a high degree of availability and reliability in processes. All of them rely on the development of control systems capable of driving the processes to a reliable scenario despite the occurrence of unexpected events. Do not consider them could cause the system objectives differ dramatically from those initially raised. Therefore, a primary objective in control systems is to make them more resilient. By resilience, it is meant the system's ability to contain the maximal impact of anomalies, such as faults, attacks, and to recover to an acceptable performance level.

In addition to power and energy capabilities, hydrogen, as a storage medium, has received a lot of attention due to its flexibility. Hydrogen differs from the conventional idea of energy storage in that it separates the production, storage, and use of hydrogen (Valverde et al, 2016). Electrolyzers can reduce excess wind/solar power peaks by producing hydrogen from water, making them an attractive solution for RES penetration. A fuel cell uses the stored hydrogen to respond quickly to loads and thus provides a short-term power deficit. In addition to being used in fuel cells, hydrogen production can be used for other purposes, such as fueling vehicles, or it can be distributed through the gas network.

Recent advances in green hydrogen production have focused on increasing the efficiency and scalability of electrolysis, the process by which hydrogen is produced from water using electricity. This includes the development of new, more efficient electrolysis technologies, as well as the use of renewable energy sources such as solar and wind power to drive the electrolysis process. Additionally, there has been a significant increase in investment in green hydrogen production, with many companies and governments announcing plans to develop large-scale green hydrogen projects. This is leading to a decrease in the cost of green hydrogen production, making it more economically viable as a source of clean energy.

Model Predictive Control is a widely used methodology in industry and in EMS (Bordons et al, 2020). It stands out for the relevant characteristics it presents compared to other control policies, such as the use of a model to predict the output, easy handling of constraints, weighting factors for the error and control effort and the incorporation of delays.

Considering the previous issues, this proposal is focused on the development of resilient predictive control strategies including fault-tolerant systems, risk management and machine learning algorithms, which will be applied to hydrogen-based energy systems. The main functions that can be requested to the resilient control system are:

- Facilitate the integration of electrolyzers and RES in EMS. and incorporate fuel cells in the energy facilities.
- Detect and isolate faults driving the system to an acceptable and reliable scenario despite the occurrence of unexpected events.
- Consider external information to be able to make better economic and demand forecasts. The economic dispatch, which involves sharing power among distributed generators and Energy Storage Systems (ESSs), will reduce operational costs while maintaining reliability.
- Consider the outputs of the developed DT for the case studies in the control loop to get better performance.

This proposal will address the problem of integrating the green hydrogen value chain in some energy platforms based on MPC by considering the previous requirements.

Resilient control strategies for energy systems

The uncertainty that may arise in energy systems can be differentiated if it is associated with internal factors, such as faults in the operation of the system, or, instead, with external factors, such as the price of energy or generation with solar or wind plants, which are highly dependent on the weather. In this sense, the work of (Petrollese et al, 2016) uses an MPC strategy applied to a hydrogen-based energy systems that includes RESs and BESSs, where planning considers both the short and long term. For long-term planning, statistical weather and load forecasts are obtained, and real-time management of the microgrid makes use of a predictive controller that considers the previous forecasts. It can be concluded that internal and external uncertainty factors must be dealt with in different time scales and priorities.

From the point of view of internal uncertainty, the following works reveals some MPC approaches to deal with internal uncertainties into the formulation of dynamical systems. For example, the work of (Bahakim et al, 2014) proposes the introduction of stochastic time-varying disturbances into the model of the controller, and in (Su et al, 2021) an MPC is applied to a distribution system considering plug-in EV uncertainties. Also, in the work of (Velarde et al, 2023) several stochastic MPC methods are tested on a real benchmark using tree-based scenarios and probabilistic constraints applied to a hydrogen-based microgrid. Additionally, control systems can improve their functionality by incorporating fault tolerance mechanisms. Fault Detection and Isolation (FDI) techniques comprise a very widespread subject with an extensive and relevant bibliography (Issermann, 2006) due to the performance improvements that can be reached in the control scheme. Faults in converters, out of order in fuel cells, errors in the reading of the batteries or loss of efficiency in solar panels, are common faults that can appear in energy systems. If these faults are detected in time, and activities are carried out accordingly, losses could be minimized. The join of MPC approaches and fault-tolerant strategies can be an interesting field to explore. In (Izadi et al, 2010) a fault-tolerant MPC approach is proposed where the fault identification is used to adapt the system to the post-fault model. In (Minchala et al, 2015) a Kalman Filter is used to estimate the new post-fault model for the MPC, and also, the combination adaptive algorithms with a PID controller is proposed. In (Boehm et al, 2018) a plug-and-play FDI for a large-scale system with stochastic uncertainties is proposed with two alternative reconfigurations: the unplugging of the faulty subsystem or fault accommodation. In (Marquez et al, 2021) a new formulation of a reconfiguration module to be integrated in the MPC control loop drives the energy system to a safe condition in the case of faults. Also, a novelty design of the thresholds to reject false-alarm faults using chance constraints and historical data with measurement and modelling errors is described here. Very recent publications are driven to the optimization of the mitigation of fault through reconfiguration (Zafra-Cabeza et al, 2023; Márquez et al, 2022) using additional MPCs.

Prognosis can be used to improve fault tolerance by identifying potential faults before they happen and implementing preventive maintenance or replacement of components. By predicting when a component is likely to fail, it is possible to schedule maintenance or replacement in advance, avoiding unexpected downtime or system failure. See for example (Teng et al 2020) where a robust model-based approach for bearing remaining useful life prognosis in wind turbines is applied. In this sense, prognosis could be used to describe the predictions made by a DT, as it can help identify and predict future issues or problems with a physical system. By providing a virtual representation of a physical system, a DT can help to improve the prognosis overall performance.

From the point of view of external uncertainties, another approach that has been well received in the industry to deal with is Risk Management (RM) (Zafra-Cabeza et al, 2011, Vahedipour-Dahraie, 2017). Risk management in control involves identifying potential risks that could negatively impact a project and implementing strategies to mitigate or avoid those risks. This can include identifying potential hazards, assessing the likelihood and potential impact of those hazards, and implementing controls to prevent or minimize harm. In the context of risk management, a DT can be used to identify potential risks and hazards associated with the physical system, and to evaluate the effectiveness of different risk mitigation strategies before they are implemented in the real world. This can help to proactively identify and manage risks, reduce the likelihood of accidents and incidents, and improve the overall safety and reliability of their operations.

Other methodology to be exploited is the design of fault-tolerant control strategies by means of a data–driven approach relying on fuzzy logic (see for example Simani et al, 2022). In particular, fuzzy modelling enables one to approximate unknown nonlinear relations, while managing uncertain measurements and disturbance.

The application of the above-mentioned techniques to the control of electrolyzers integrating RES, and fuel cells embedded in the energy facilities will represent an advance in the optimisation of energy management.

Digital twins (DT) and Cybersecurity

In addition to the prediction of dynamic variables, the use of DT of physical entities has innumerable benefits such as testing, maintenance planning, improved controller design, fault detection and cyber-attacks, among others. It is possible to have innovative energy services based on intelligent recommendation systems and DT (Onile et al, 2021).

One of the most popular cyber-attacks is the injection of false data. Techniques based on DT will be used for the detection of this sophisticated attack, following the work already started in (Chicaiza et al, 2022).

Distributed control techniques for interconnected systems

The so-called microgrids are installations at the household level involving both generation, storage and consumption, which are allowed to trade power actively with the grid and other microgrids (Bollen et al, 2010). Focusing on microgrids where there are multiple, independent and geographically dispersed decision-makers, which involve the sharing and trading of energy among members, they can be considered as Energy Communities, according to the adopted term in European Union (EU, 2019). Empowering renewable energy communities to produce, consume, store and sell renewable energy will also help advance energy efficiency in households, support the use of renewable energy and at the same time contribute to fighting poverty through reduced energy consumption and lower supply tariffs.

In energy communities, the usage of distributed MPC (DMPC) architectures becomes a necessity. These architectures allow for each decision-maker to have autonomy over their own control decisions, while still ensuring coordination and optimization across the entire system, as each agent representing different entities with potentially different economic interests. See for example in (Garcia-Torres et al. 2018), where a control algorithm based on DMPC is applied to optimize the economic schedule of a network of interconnected microgrids that comprise hybrid energy storage systems. Decentralized and distributed architectures rely on data and control information being exchanged between agents, which may lead to vulnerabilities such as security or privacy breaches (Zia et al, 2020). Additionally, hierarchical schemes may be necessary in these architectures since an upper coordination layer is often required, adding another possible point of failure. These issues can be addressed using blockchain technology, which has become popular in the last years. Blockchain technology emerged alongside Bitcoin in 2008 with the release of the technical paper Bitcoin: A Peer-toPeer Electronic Cash System (Nakamoto, 2008). The two foundational objectives were to erase third parties in energy trading and enable secure peer to peer (P2P) interactions without the need for a central authority. This is achieved by the usage of cryptography, consensus mechanisms, and an inherently decentralized nature, which dramatically reduces the possibility of cyberattacks.

Providing energy communities (ECs) with functionalities that make them more efficient and resilient is a current priority. There are many fields to be investigated and applied in ECs: introduction of uncertainties and improvement of distributed schemes (Sivianes 2022), fault tolerance properties (Zafra-Cabeza el al., 2023), risk management, or design of DT (Chicaiza et al., 2021). In the last case, DT can also be used to monitor and analyse real-time data from the energy community; this allows for early detection of any issues and rapid response to prevent any disruption of energy supply. Agents in ECs may be enriched with hierarchical schemes adopting a two-layer control architecture to deal with both faults and risks to optimise the reconfiguration of the system if appropriate (Zafra-Cabeza et al., 2011) . The communication about fault data between agents of an EC may provide better performance in the reconfiguration of the whole EC. If agents of an EC comprise EVs or FCEVs, the problem to optimize becomes more complicated and requires more complex tools to implement.

Green hydrogen generation

Hydrogen is becoming a great opportunity for energy storage, something that could be crucial to cope with variability and stochastic behavior of renewable energy sources, like wind or solar. Moreover, if renewable energies are used together with electrolyzers, they will allow CO_2 emissions reduction. Electrolyzers are devices which use *DC* current and water in order to produce hydrogen, so if the DC electricity comes from renewable energies, the process will be green.

In current context lots of projects are being developed in order to demonstrate in real plants the feasibility of green hydrogen production via water electrolysis for different uses. As an example, *Spanish Government*, which has published a *Hydrogen roadmap* (Ministerio 2020), relies on green hydrogen production and storage in order to recover from *COVID-19* crisis. The current situation is the development of electrolyzers-based plants in the MW-scale production, with the goal of working in the GW-scale by 2030 (International 2019).

During their operation, electrolyzers are exposed to dynamic input currents, as in the case of renewable energy production, and can suffer important temperatures variations, which is undesirable (Ogumeren 2020). Thus, in a coupled PV-hydrogen system, electrolyzer temperature must be controlled and supervised. A trade-off temperature between performance (high temperature) and durability (upper limit temperature) must be set and the control system must ensure that deviations in electrolyzer temperature are within a tight range. In fact, unexpected variations in produced renewable power, as well as the intermittent changes in bus voltage (mainly produced by regulation with batteries) and electrolyzer start-up phases are identified as critical phenomena in electrolyzer performance and hydrogen production (Bergen 2008).

In this context, this project intends to further investigate in electrolyzer temperature control. For this purpose, an MPC controller will be designed in order to regulate the temperature of the stack at its nominal value. The effect of fast disturbances (input current from renewable energy) will be considered including a feedforward mechanism in the predictive controller, with the idea of anticipating to dynamic current scenarios. This MPC will be in an upper layer, sending the setpoint to the PID controller of the heat exchanger. The control strategy will include all the resilient capabilities developed along the project.

Within the development of non-conventional energies sources for RPAS propulsion, in order to achieve the desired levels of autonomy it is necessary to investigate the use of alternative energy sources to those commonly used in RPAS. Various experimental aircraft have been developed using photovoltaic solar energy or fuel cells (Coxworth, 2015), but they have not gone beyond the experimental prototype stage. Just as commercial vehicles powered by fuel cells already exist on the market (Toyota, 2015), the use of these in aircraft is an open issue. The integration of the fuel cell, batteries, photovoltaic input is an issue that has not been addressed in great detail yet, although, having been addressed in ground vehicles (Arce, 2009), its extrapolation to aircraft can be successful thanks to the expertise of the working team.

Follow up of previous projects:

This proposal is a natural follow-up of the national-funded project SAFEMPC (PID2019-104149RB-I00). In that project, issues of EMS applied to micrograds were addressed such as (i) stochastic and distributed MPC techniques, (ii) development of algorithms to optimise the demand side response and (iii) fault-tolerance methodologies. The work done up to now has helped discover the weaknesses and open issues in this field. Some of them will be undertaken in this new proposal such as the generation of hydrogen, its use in vehicles or the extension to energy communities. Other projects that have been developed in this area for some of the research group are AGERAR (Almacenamiento y Gestión de Energías Renovables en Aplicaciones Comerciales y Residenciales) and TTUES (Transporte Turístico Urbano Eléctrico Sostenible), funded by the INTERREG programme of the European Commission.

Novelty of the proposal:

The novelty of the resilient approach we propose is mainly based on:

1. Predictive control methodologies to be developed in energy facilities considering data-driven fault-tolerance mechanisms and risk management supported by DT, giving rise to a hierarchical control scheme.
2. This project will investigate predictive control techniques applied to electrolyzers with RES.
3. The energy platforms that will be considered will be based on green hydrogen and batteries. The H2LAB contains a programmable power supply and an electrolyzer (among others) that will be used to validate the control. An UAV with an embedded Fuel Cell and a FCEV will be adapted to be used in this project. Also, typical energy communities will be considered as benchmarks to validate the proposed algorithms. Some of the energy communities will be implemented on the blockchain.
4. Formulations will be extended to energy communities in order to favour the implementation of distributed systems where each participant may be a prosumer or consumer. REGREENH2 will also explore the decentralized nature of energy communities and will provide algorithms to be applied to the control and optimization of their operation.
5. This project will develop DT for the energy platforms to be able to foresee undesired behaviours and get better performance.

This proposal will also encourage increasing the close collaboration existing with one of the most active group in the field of microgrids: that of Prof. Josep M. Guerrero, at the University of Aalborg (Denmark). Other groups with notable activity in this area are the Power Systems Laboratory, of ETH Zurich, and the Hybrid Vehicle Research group of the University of Warwick in the United Kingdom. Recently, the research group has started collaboration with Profs. Negin Shariati and Dylan Lu, from the Faculty of Engineering and Information Technology at the University of Technology Sidney. There is also a long-lasting collaboration with Prof. Julio Normey-Rico at UFSC in Brazil, which has been renewed by a join project starting in 2022 (funded by the Brazilian Government) regarding hydrogen systems. We are also collaborating with Prof. Andreas Wirsen, from Fraunhofer Institute, in the field of DT. In Spain, there are excellent research groups at the Polytechnic University of Catalonia (UPC), with researchers such as Vicenç Puig, Robert Griñó, Joseba Quevedo or Carlos Ocampo, working on issues related to this field. The group of Prof. Luis Martínez-Salamero of the Rovira i Virgili University has experience in the control of electrical systems and fuel cells. The groups of the Universities of Almería (Profs. Manuel Berenguel and Francisco Rodríguez), Valladolid (Profs Fernando Tadeo and María Jesús de la Fuente) and Huelva (Prof. José Manuel Andújar) also have experience in microgrids and energy systems. Regarding hydrogen, the Fuel Cell Control Laboratory at IRI in the UPC (Profs. Ramón Costa and María Sierra) has a solid background. The group of Prof. Jordi Renau, at Fundación Universitaria San Pablo CEU is also working in energy storage and hydrogen.

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<u>En los proyectos de modalidad de investigación orientada</u>:

2.3. Justificación y contribución esperada del proyecto a solucionar problemas concretos vinculados a la prioridad temática seleccionada.

This proposal is included in the priority area of "Clima, Energía Y Movilidad" with the topics EYT (Energía y Transporte) in the sub-area Energía (ENE), and PIN (Producción industrial, ingeniería civil e ingenierías para la sociedad) in the sub-area IEA (Ingeniería eléctrica, electrónica y automática).

Expected contributions:

1. Encourage the generation of green hydrogen and the use of hydrogen-based vehicles. The issues driven in the generation of knowledge of the project (section 2.2) will be applied.

2. Promote the creation of energy communities, endowing them with resilient characteristics for optimal energy management and improving distributed architectures. Empowering renewable energy communities to produce, consume, store and sell renewable energy will also help advance energy efficiency in households, support the use of renewable energy and at the same time contribute to fighting poverty through reduced energy consumption and lower supply tariffs.
3. The use of DT and improved fault and risk mechanisms can be used to identify potential risks and hazards associated with the physical system and to evaluate the effectiveness of different risk mitigation strategies before they are implemented in the real world. This can help organizations to proactively identify and manage risks, reduce the likelihood of accidents and incidents, and improve the overall safety and reliability of their operations.

3. OBJETIVES, *METHODOLOGY AND WORK PLAN*.

3.1. *General and specific objectives*.

According to this background, the general objectives of this project are:

- GO1: Design and development of resilient EMSs integrating cybersecurity, risk assessment, fault-tolerance and mitigation.
- GO2: Design and development of DT for the considered benchmarks.
- GO3: Develop decentralized mechanisms for energy trading in energy communities including EV/FCEV.
- GO4: Develop resilient control methodologies for green hydrogen generation, addressing the control of electrolyzers connected to RES and operating at intermittent regime.
- G05: Develop hierarchical architectures to priorize objectives.
- GO6: Provide a decision-aid tool for energy communities in terms of energy trading optimization including green hydrogen.
- GO7: Development and implementation of the experimental hydrogen-based facilities.
- GO8: Dissemination of results and achievements in the project in the international scientific community and in entities related to the field of the project.

Specific objectives:

- EO1: Develop fuzzy models to approximate unknown nonlinear relations, while managing uncertain measurements and disturbance.
- EO2: Development and implementation of the hydrogen-based UAV EMERGENTIA
- EO3: Development and implementation of the FCEV, FOX
- EO4: Design reconfiguration mechanisms by considering the outcomes of the DT, and the fault-tolerant algorithm. The proposed actions will drive the system to a safe and reliable scenario by connecting/disconnecting generation and storage elements or changing operation parameters.
- EO5: Integration of the RES and electrolyzers in the H2LAB

3.2. *Description of the methodology*.

To achieve these objectives, the combination of the following methodologies will be used:

- Distributed, Hierarchical and Stochastic Predictive Control.
- Advanced Fault-tolerant systems and Risk Management techniques considering historical values and mathematical models.
- Machine Learning methods to provide intelligent control systems for an optimal on-line adjustment, power regulation, loss reduction and fault recovery.
- System Modelling.

3.3. *Work plan and schedule.*

According to the objectives defined in Section 3.1, the project will be divided into the following work packages, where tasks, deliverables, milestones, participants, and execution periods are described for each work package. Next, the components of the research team and work team are described:

- Research group: Carlos Bordons Alba-IP1 (CBA), Ascensión Zafra Cabeza-IP2 (AZC), Miguel Ángel Ridao Carlini (MARC), Sergio Esteban Roncero (SER), Amparo Núñez Reyes (ANR), Juan Manuel Escaño González (JMEG), Alejandro del Real Torres (AdRT), Eduardo López González (ELG), Fernando Isorna Llerena (FIL), Kumars Rouzbehi (KR), Person to hire LAB (PtH1), Person to hire (PtH2). Notice that two researchers from INTA are part of the team, since they will provide its expertise in hydrogen systems and UAVs.
- Work Team: Pablo Velarde Rueda (PVR), Antonio Gallego (AG), Andrés Hernández Rivera (AHR), Manuel Sivianes Castillo (MSC), Guilherme Raffo (GR), Manuel Mora Nieto (MMN), Víctor Manuel de Frutos Casado (VMFC). This work team has been selected due to the experience and knowledge of the different dealt issues in the project. For example, Pablo Velarde and Andrés Hernández are focused on distributed and stochastic systems, Antonio Gallego has a great experience in control strategies to solar plants, Manuel Sivianes is a pre-doctoral student working in energy communities and blockchain, Guilherme Raffo and Víctor Manuel de Frutos Casado (working at AIRUBUS) are working on hydrogen-based UAVs and Manuel Mora is also working with hydrogen-based ESSs.

WP0: Coordination and Project Management

This work package will be active for the entire duration of the project.

- *Task T0.1.* Responsible researchers will *supervise* that all tasks were executed on a scheduled basis. General meetings of the project will be held in with the participation of the members of the working groups, on an annual basis or when the situation requires it.

Responsible	Carlos Bordons and Ascensión Zafra
Deliverables	D0.1: Intermediate Report (S3) D0.2: Final Report (S6)
Milestones	M0.1: Kick-off Meeting (S0) M0.2: 1st Annual Meeting (S2) M0.3: 2nd Annual Meeting (S4) M0.4: 3rd Final Meeting (S6)

WP1: Resilient control strategies for energy management

- *Task T1.1:* Analysis and development of stochastic, data-driven and event-triggered control models to be integrated in the fault-tolerance and risk-averse mechanisms that will be implemented in the energy platforms. Study of different key performance indexes to be evaluated in the proposed algorithms. Implementation and comparison of different approaches evaluating selected key performance indexes.
- *Task T1.2*: Analysis and design of the multicriteria objective functions for the controllers and their priorisation, and their application to the energy facilities (EV and UAV). Integration in the control problem. Collect historical data from the energy facilities in different operation scenarios to be considered for the machine learning methods.
- *Task T1.3*: Set the procedure to identify and quantify the uncertainties and reconfiguration strategies in the energy facilities. Define the data to be obtained. The coordinators of the

package related to energy facilities (WP5, WP6 and WP7) will receive advice about this method to be able to obtain the required information.

Objectives	GO1,GO5, GO8, EO4
Responsible	Ascensión Zafra Cabeza
Participants	CBA, ELG, SER, PVR, AHR, PtH2, JMEG, ANR,AdRT
Deliverables	D1.1: Report on developed resilient techniques (S6)
Milestones	M1.1: Report on uncertainties, objective functions and available historical data on the energy facilities. (S3)

WP2: Distributed control techniques for interconnected systems

- *Task T2.1:* Analysis and development of distributed, stochastic and hierarchical optimization algorithms to be implemented in the energy communities, including EV/FCEV. Identifying and selecting appropriate consensus algorithm for the platform. Study of different key performance indexes to be evaluated in the proposed algorithms. Implementation and simulation. Comparison of the different approaches evaluating selected key performance indexes.
- *Task T2.*2: Analysis and development of the cybersecurity techniques in distributed systems by considering the data-driven fault-tolerant mechanisms proposed in WP1. Implementation and simulations. Identification of critical attacks from agents that can be identified as false faults.
- *Task T2.*3: Adaptation of the Fault-Tolerant mechanism developed in WP1 in a distributed context. Definition of the information to share between agents and the setting of fault detection in a cooperative way.
- *Task T2.*4: Implementation of the distributed algorithms in Blockchain. Research and analysis of current blockchain solutions for energy communities. Design and development of the blockchain-based platform for energy community validation. Evaluate the scalability and performance of the platform under different scenarios and conditions.

Objectives	GO3, GO5,GO6, GO8
Responsible	Ascensión Zafra-Cabeza and Carlos Bordons
Participants	MARC, MSC, PVR, AG, ANR, PtH2, GR, AHR, AdRT
Deliverables	D2.1: Presentation of the functionalities of the developed framework applied to energy communities to incentive the proliferation (S6).
Milestones	M2.1: Build a set of functionalities to be applied to energy communities (S6)

WP3: Development of Digital Twin (DT)

- Task T3.1: Research on fuzzy and machine learning techniques to be used for the design of DT. Comparison of the different approaches according to some Key Performance Indexes.
- Task T3.2: Develop DT for energy installations and vehicles, integrating them with the development of WP4, WP5, WP6 and WP7.

Objectives	GO1, GO2, GO8, E01
Responsible	Juan Manuel Escaño (JMEG)
Participants	CBA, MARC, AZC, KR, GR, SER, ELG, PtH2, AHR, ANR
Deliverables	D3.1: Report on the Algorithms used to implement the DT.
Milestones	M3.1: DT of the energy facilities.

WP4: Green hydrogen generation.

This workpackage is devoted to the design of control techniques for a safe and efficient control of electrolyzers. The main challenge is to control temperature when the unit is connected to a RES (mainly PV plants), with intermittent source of DC current. The WP will start developing a model and then a temperature controller, that will be devised including the resilient techniques developed in WP1. Later, the problems associated to the integration with RES will be solved.

- *Task T4.1:* Development of a DT of the electrolyzer. The twin will be based on electrochemical and thermodynamics equations and also on the available data coming from experiments on the electrolyzer that will be installed in the laboratory.
- *Task T4.2*: Development of temperature control techniques. Resilient techniques devised in WP1 will be adapted to temperature control. The controller will be first tested on the DT and later on real electrolyzer in H2LAB.
- *Task T4.*3: Control techniques for the integration with RES. Adaptation of the resilient mechanisms developed in WP1 to the electrolyzer connected to the existing PV plant. An MPC with feedforward for the current disturbances will be devised and tested.

Objectives	GO2, GO4, GO8, EO5
Responsible	Carlos Bordons Alba
Participants	MARC, AZC, PtH2, MMN, GR, VMFC,SER,ELG,FIL
Deliverables	D4.1: Report on control techniques applied to electroyzers (S6)
Milestones	M4.1: DT of the electrolyzer (S4) M4.2: Temperature controller for the electrolyzer connected to RES (S6)

WP5. Development and validation on aerial vehicles

- Task T5.1: Redesign, adaptation of the aerial platform EMERGENTIA which comprise the study of aerodynamic, structures, propulsion and stability and control of the aircraft to the given payload, define manufacturing process, and conduct manufacturing.
- Task T5.2: Performance Analysis to quantify the power requirements according to the different mission profiles.
- Task T5.3: Development of 6DOF simulator to evaluate the performance and maneuverability of the aircraft both in open loop and closed loop to minimize risks during flight phases. Integration with WP3, to build the DT, and with WP4 to incorporate the fuel cell
- Task T5.4: Integration of the resilient control and guidance strategies developed in WP1 and WP3.
- Task T5.5: Systems integration verification and validation of all the components.
- Task T5.6: Flight Test Campaigns to have a well detailed flight test campaign which includes ground testing, and flight test opening the envelope, from simple flights (with more conventional power sources like batteries) to more advanced flight.

Objectives	EO2, EO4, GO1, GO2, GO7, G08
Responsible	Sergio Esteban Roncero (SER)
Participants	CBA, AZC,SER, GR, PtH1, PtH2, VMFC, MMN
Deliverables	D5.1: Report on the development and operation of EMERGENTIA (S6)
Milestones	M5.1: Set-up of the UAV EMERGENTIA (S3)

WP6. Development and validation on ground vehicles

- Task T6.1: Redesign, adaptation of the ground platform FOX which include: (i) Update the ECU system with a new hardware and operating system, tentatively RTlinux, (ii) complete the vehicle with a hydrogen system, a fuel cell and a hydrogen storage system based on hydrides.
- Task T6.2: Performance Analysis to quantify the power requirements according to the different mission profiles.
- Task T6.3: Development of a simulator based on the DT with collaboration with WP3.
- Task T6.4: Develop an EMS system for the hybrid vehicle, including the resilient mechanism defined in WP1. Development of the control strategies based on WP1.
- Task T6.5: Systems integration verification and validation of all the components.
- Task T6.6: Test Campaigns: design of the laboratory tests and in specific circuits.

Objectives	EO3, EO4, GO1, GO2, GO7, GO8
Responsible	Miguel Ángel Ridao Carlini (MARC)
Participants	CBA, AZC, ELG, FIL, PtH1, PtH2, MMN, VMFC
Deliverables	D6.1: Report on the development and operation of FOX vehicle (S6)
Milestones	M6.1: Set-up of FOX (S3)

WP7. Development of algorithms and validation on energy communities using Blockchain

Objectives	GO1, G02, G03, G05, G06, G08, E01, E04
Responsible	Carlos Bordons Alba y Ascensión Zafra Cabeza
Participants	PVR, MARC, MSC, ANR, AdRT, PtH1, PtH2
Deliverables	D7.1: Control techniques applied to ECs (S6)
Milestones	M7.1: Provide the functionality framework for an agent of the EC (S6)

- Task T7.1: Definition of the EC benchmark considering batteries, electrolyzers, fuel cells and EVs/FCEVs. Set the methodology to build the model for a general agent in the EC.
- Task T7.2: Application of the distributed and hierarchical architecture in the EC following the results in WP2. Development of the control strategies including objectives to optimize and weights.
- Task T7.3: Development of a simulator based on the DT with collaboration with WP3.
- Task T7.4: Implementation of the smart contract functionality to enable transactions and operations within the EC, as well as the security and privacy measures to protect the platform and its users. Also, a user-friendly interface for community members to access and interact with the platform will be developed.
- Task T7.5: Test Campaigns: design of the laboratory tests on the benchmark. Conducting an economic and financial analysis of the platform and its potential impact on the energy community.
- Task T7.6: Generate a functionality framework for agents in an EC to facilitate the penetration of EC in the energy market.

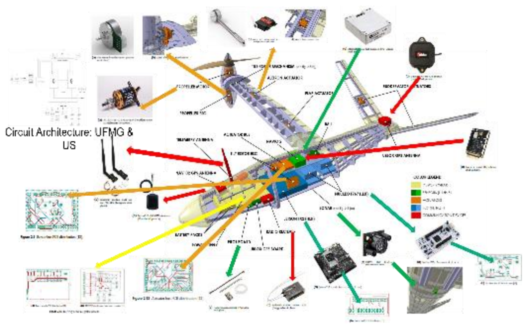
WP8 : Management and Dissemination

- Task T8.1. This task is dedicated to the dissemination of the results obtained during the progress of the project, including both the final results for the scientific community and related companies and entities, as well as the exchange of partial results between the project researchers.

Objectives	G08
Responsible	Carlos Bordons and Ascensión Zafra
Participants	The entire research team and working team
Deliverables	D8.1: website of the project(S6)
Milestones	M8.1: Opening the project website (S1)

Available resources in the project

The proposal is based on the availability of three experimental energy platforms which will be taken as initial (see Figure 1); all of them are located at the University of Sevilla (US).



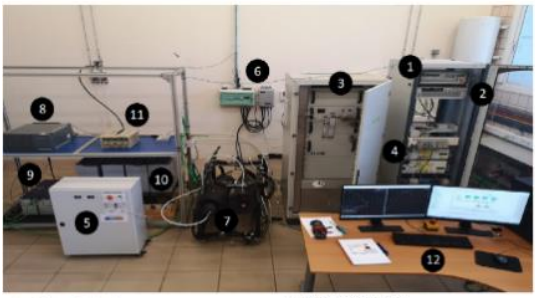


Figure 1. Energy Facilities (a) Emergentia UAV (b) FOX vehicle and (c) H2LAB

1. The UAV EMERGENTIA. This prototype is being developed in EMERGENTIA project (RTI2018-101519-A-I00). The aircraft has been designed to be easy to operate and fast to deploy; to this mean, guidance, navigation and control algorithms have been developed taking into account the requirements of Search and Rescue Missions missions, while ensuring safe communications and operations of the drone using advanced cyber physical systems.
2. The FCEV FOX. The FOX vehicle is based on the chassis of a Silver Car S2 conventional racing car. It was slightly modified for the best fitting of the new elements (in-wheel motors, power converters, batteries, sensors, etc.), while bodywork is the same as the original S2 car. The main components of the vehicle are: motors (7kW), LiFeMnPO4 batteries controlled by a commercial Battery Management System (BMS), sensors: During the modelling phase, sensors are used to validate the model and during normal operation, sensors (Inertial Measurement Unit, GPS, Accelerator and brake sensors) and a ECU implemented in a PC-104 hardware with QNX.
3. The H2LAB microgrid is made up of electronic load and programmable power supply (among others) that may be used in this project to validate the electrolyzer and simulate energy communities.

A valuable aspect of this proposal is that researchers from INTA are involved in it. They have extensive experience working with hydrogen devices and, if necessary, INTA equipment can be used.

Chronogram

<table>
<tr><th></th><th colspan="2">Year 1</th><th colspan="2">Year 2</th><th colspan="2">Year 3</th></tr>
<tr><th>WP\Sem</th><th>S1</th><th>S2</th><th>S3</th><th>S4</th><th>S5</th><th>S6</th></tr>
<tr><td rowspan="2">WP0</td><td colspan="6">T0.1</td></tr>
<tr><td>M0.1</td><td>M0.2</td><td>D0.1</td><td>M0.3</td><td></td><td>D0.2
M0.4</td></tr>
<tr><td rowspan="3">WP1</td><td colspan="6">T1.1</td></tr>
<tr><td colspan="2">T1.2</td><td colspan="4">T1.3</td></tr>
<tr><td></td><td></td><td>M1.1</td><td></td><td></td><td>D1.1</td></tr>
<tr><td rowspan="5">WP2</td><td colspan="6">T2.1</td></tr>
<tr><td></td><td></td><td colspan="3">T2.2</td><td></td></tr>
<tr><td></td><td colspan="4">T2.3</td><td></td></tr>
<tr><td colspan="3"></td><td colspan="3">T2.4</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>D2.1, M2.1</td></tr>
<tr><td rowspan="2">WP3</td><td rowspan="2"></td><td colspan="2">T3.1</td><td colspan="2">T3.2</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>D3.1, M3.1</td></tr>
<tr><td rowspan="4">WP4</td><td colspan="4">T4.1</td><td></td><td></td></tr>
<tr><td></td><td colspan="4">T4.2</td><td></td></tr>
<tr><td></td><td></td><td colspan="4">T4.3</td></tr>
<tr><td></td><td></td><td></td><td>M4.1</td><td></td><td>D4.1, M4.2</td></tr>
<tr><td rowspan="4">WP5</td><td colspan="6">T 5.1</td></tr>
<tr><td colspan="2">T5.2</td><td colspan="3">T5.3, T5.4</td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="3">T5.5, T5.6</td></tr>
<tr><td></td><td></td><td>M5.1</td><td></td><td></td><td>D5.1</td></tr>
<tr><td rowspan="4">WP6</td><td colspan="6">T6.1</td></tr>
<tr><td colspan="2">T6.2</td><td colspan="3">T6.3, T6.4</td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="3">T6.5, T6.6</td></tr>
<tr><td></td><td></td><td>M6.1</td><td></td><td></td><td>D6.1</td></tr>
<tr><td>WP7</td><td colspan="2">T7.1</td><td>T7.3</td><td colspan="2">T7.2, T7.3</td><td></td></tr>
<tr><td></td><td colspan="2"></td><td></td><td colspan="2">T7.4, T7.5</td><td>T7.5, T7.6</td></tr>
<tr><td></td><td colspan="2"></td><td></td><td colspan="2"></td><td>M7.1, D7.1</td></tr>
<tr><td rowspan="2">WP8</td><td colspan="6">T8.1</td></tr>
<tr><td>M8.1</td><td></td><td></td><td></td><td></td><td>D8.1</td></tr>
</table>

3.4. *Identification of critical points and contingency plan.*

In general, the work plan is considered to be feasible. However, there may be some risks associated with the achievement of some of the objectives, especially those related to the experimental validation of methods (GO6). The experimental platforms may present operation difficulties due to breakdowns or faults of devices that cannot be easily fixed. In that case that some experiments could not be done, they would be replaced by high-fidelity simulations using the available simulator "Simugrid" and Psim libraries if needed, or using other existing platforms in INTA locations (FCEV, EV and FC). If the UAV EMERGENTIA cannot be used, a ready-to-fly UAV could be bought. It is not expected that the rest of objectives present difficulties.

3.5. Previous results of the team in the theme of the proposal.

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4. *IMPACT OF THE RESULTS*.

4.1. *Expected impact on the generation of scientific-technical knowledge in the thematic area of the proposal*.

The proposed objectives in REGREENH2 are focused on the penetration of green hydrogen and the Energy Communities in society. In order to overcome these challenges, the project is concentrated on the design and development of novel methods for obtaining resilient energy management systems and on the consideration of efficient mechanisms for energy trading among agents of a EC. The project's expected impact can be summed up as follows:

- Novel techniques and algorithms on how to improve the energy transition to EC in the electrical system focusing on the resilient aspect during the operation, the fault-tolerance and the renewable generation.
- The development of a functionality framework applied to EC to promote the proliferation on them and made easy the implementation.. It will integrate new control strategies based on Stochastic and Distributed Model Predictive Control, considering explicitly the uncertain nature of renewable generation, loads, degradation of equipments, etc..
- Development of DT about the energy facilities to improve the performance of the operation.
- Characterization of the sources of uncertainties in hydrogen-based vehicles using innovative Machine Learning and fuzzy techniques.
- Innovative experimental plants, where algorithms and methods developed in this project can be tested and analysed.
- The team will get experience and know-how to face the future challenges of the Energy Transition working with real vehicles and new business models, permitting a future collaboration with involved companies and participation in proposals in European Programmes.

4.2. *Social and economic impact of the expected results.*

The objective of reducing greenhouse gas emissions is shifting to more environmentally friendly and sustainable energy sources. Renewable energy already plays an important role in society, not only which is more energy-dependent, but also which is more aware of environmental issues.

In addition to the general emission reduction via diversification of primary energy sources, REGREENH2 could also contribute to environmental protection by increasing energy efficiency within the system. In the context of general society, the influence of the penetration of ECs and hydrogen-based vehicles could easily reach well beyond the power industry and might even eventually change the way of life of many people and redefine the conceptions and habits of even more. In short, three major social benefits can be identified from REGREENH2: i) Raise public awareness and foster incentives for energy saving and emission cutting, ii) Creation of new research and job opportunities and iii) Contribution to the deployment of green smart cities with fully penetration of RES in the distribution grid.

This project is consistent with the recent agreement on renewable energy directives between the European Parliament, the European Commission and the European Council, which sets a target of 32% percent of the energy consumption of renewable energies by 2030. The penetration of ECs will contribute to promote energy self-consumption, a main issue in Spanish national and regional regulations. Specifically, the Real Decreto-Ley 15/2018, including urgent actions for the energy transition, facilitates the installation and use of renewable energy plants with energy storage systems.

4.3. *Plan for scientific communication and internationalization of the results (indicate the forecast of open access publications).*

REGREENH2 contemplates the workpackage WP8 focused on the dissemination of the results and it will be active throughout the project.

- Publications in specialised literature: The dissemination of the project results to the scientific and academic audience will be carried out through publications in technical journals.
- Open access journals will be selected so that project results can be available to the entire scientific community. The project budget considers **4** publications in open access journals. This could change if licenses of the University of Seville are available.

4.4. *Plan for dissemination of the results to the most relevant groups for the theme of the project and to society in general.*

Effective communication and dissemination both within and outside the team is an important issue in this project. Dissemination activities are essential to inform the different organizations involved of the progress and results of the project. The target audience is the team's researchers, other research groups addressing these topics, interested private companies and regional and national administrations. The main diffusion activities will be:

- Publications in specialized literature as described in Section 4.3
- Contributions to technical conferences: Conferences are also a key way to disseminate the results, so attendance to conferences and workshops related to the objectives of the project are envisaged. Some of them are: ECC, ACC, CDC, IFAC World CONGRESS, SAFEPROCESS, SEST.
- Project website: It will be developed where any generated knowledge of direct value, public deliverables and articles, events, etc. will be published in order to stimulate exploitation and dissemination.

In cases where it is applicable:

4.5. *Transfer plan and valorization of results.*

The interest and collaboration with companies, technical associations and platforms related with these technologies are very important for the success of the project. In this line, the team has collaborated in other research projects with companies as AYESA, Endesa, EDF, Enel, GPTech, Idener, Acciona, Flexiwatt Smartgrids, etc. and related institutions as Asociación Española de Hidrógeno. Specifically, the companies AYESA, Abengoa Innovación, Flexiwatt Smartgrids and IDENER have expressed interest in the development and results of the project. Some of the results of this project could be used by the company Negratin in the project of energy supply to the new particle accelerator that is being built in Granada (IFMIF-DONES).

The project can generate results (algorithms and control procedures mainly) whose intellectual property must be protected by patents or other mechanisms. The preparation, with the contributions of the companies interested in the proposal, of an intellectual property management plan and the exploitation of the results is foreseen.

4.6. *Summary´s management plan of the planned data.*

The data that we will use in this project will be obtained from the experimental plants in different working points in order to build the most accurate models and enrich the formulation in the DT. This project does not involve processing of personal data.

<u>Typology:</u> Identified faults and risks, their frequency and magnitude. Powers, currents, state of batteries, level of Hydrogen in tanks, temperature in electrolyzers.
<u>Format:</u> Matlab
<u>Who</u>: Research Team and Work Team
<u>How</u>: Private access to a website

When: During the execution of the project
Repository: Storage in license tool provided by the University of Seville (currently OneDrive and Hdvirtual).

4.7. *Effects of gender inclusion in the content of the proposal*.

We estimate that there will be no effects of gender inclusion in the context of the proposal. For any incovenience, we can adopt the recommendations of the University of Seville in its Equality Plan: https://igualdad.us.es/wpblog/wp-content/uploads/2021/12/III-Plan-de-Igualdad-US_2022-2024.pdf
We can stand out that the parity rate is 50% in IPs.

5. *JUSTIFICATION OF THE REQUESTED BUDGET*.

The budget includes personnel expenses for 1 graduate and 1 laboratory technician for 3 and 1 years, respectively. Execution expenses are focused on conference attendances, courses, visits to research centers, publications (including open access) , inventory material for the energy facilities (Electrolyzer, fuel cell, H2 tank, converters, embedded computers) , maintenance actions, small electrical material and others.

For the completion of the tasks, it is necessary to hire a graduate in Engineering during the three years of the project (PtH2). The tasks that will be carried out are those related to the software implementation of the methodologies that are being devised, as well as the programming of the different algorithms developed throughout the project. In addition, it will be necessary to hire a laboratory support technical (Formación Profesional de Grado Superior) staff (PtH1) during one year of the project to be dedicated to the start up and tuning of the experimental platforms (H2LAB, UAV and EV), and he/she will be essential for the accomplishment of the different tests and data collection.

6. TRAINING CAPACITY.

6.1. *Training program planned in the context of the requested Project*.

The PhD students will enter the doctoral programme “Automatic, Electronic and Telecommunication Engineering” of the University of Sevilla. (http://institucional.us.es/webdiaet/), whose accreditation has been renewed by DEVA (Dirección de Evaluación y Acreditación de la Junta de Andalucía) in 2019. There are around one hundred students enrolled in this programme. Additionally, PhD students who need credits to complete their training period can do the Master on Electronics, Robotics and Automatic Control in the University of Sevilla. Most of the research team participate in these doctoral and master programmes.

The doctoral activities will be completed with stays in an outstanding research group. It is scheduled a four-month stay in the group of Prof. Negin Shariati (UT Sydney) for Manuel Sivianes, who is the PhD student assigned to the previous DPI project. It is expected that the student can attend courses given by visiting professors (as an example, the following professors dictated courses in the doctoral programme in 2022: Sergio Rapuano, Robert W. Newcomb, Salvador Hidalgo, Christos Antonopoulus, Tobias Geyer, Carlos Canudas, Romeo Ortega and Masaki Inoue). The attendance to one or two of the main conferences in the field (IFAC, CDC, ACC, ECC, IEEE IECON, etc.) is foreseen.

6.2. *Theses completed or in progress within the scope of the research team (last 10 years).*

1. Aguilar Casado, Juan. Reconfigurable and Integrated Framework for Microgrids Optimal Operation. 2022.

2. Diogo Ortiz Machado. Contributions to Exergy- Based Model Predictive Control of Renewable Energy Systems 2022.
3. Márquez Quintero, Juan José. Control predictivo tolerante a fallos aplicado a microrredes. 2021.
4. Báez González, Pablo. An integrated framework for modeling and control of P2P energy interactions based on MPC.2020.
5. Velarde Rueda, Pablo. Stochastic Model Predictive Control for Robust Operation of Distribution Systems, 2017.
6. Fele, Filiberto. Coalitional model predictive control for systems of systems, 2017.
7. Ramírez de la Pinta, Javier. Integration of service robots in the smart home, 2017.
8. Muros Ponce, Francisco Javier. Cooperative game theory tools in coalitional control networks, 2017.
9. Da Costa Mendes, Paulo Renato. Predictive Control for Energy Management of Renewable Energy Based Microgrids, 2016.
10. Escaño González, Juan Manuel. Control Predictivo basado en modelos borrosos. Reducción de la complejidad mediante el análisis de componentes principales funcionales, 2015.
11. García Torres, Félix. Advanced Control of Renewable Energy Microgrids with Hybrid Energy Storage System, 2015.
12. Domínguez Frejo, José Ramón. Model Predictive Control for Freeway Traffic networks, 2015.
13. Marcos Rodríguez, David. Contributions to power management and dynamics control in hybrid vehicles, 2014.
14. Gallego Len, Antonio Javier. Control Predictivo de Sistemas de Energía Solar Distribuidos, 2014.
15. Luque Sendra, Amalia. On randomized algorithms and their applications in robust optimization, 2014.
16. Valverde Isorna, Luis. Gestión de energía en sistemas con fuentes renovables y almacenamiento de energía basado en hidrógeno mediante control predictive, 2013.
17. Manuel Sivianes Castaño (in progress). Distributed algorithms applied to EMS.
18. Andrés Hernández (in progress). Dealing with system uncertainties: A fault-tolerance approach.
19. Víctor Manuel de Frutos (in progress). Contributions of control techniques applied to hydrogen-based UAVs.
20. Manuel Mora Nieto (in progress). MPC applied to electrolyzers integrating RES.

6.3. Scientific or professional development of graduate doctors.

The scientific and professional development of graduated doctors can be considered as very positive, so that most, either in the university or within companies, continue their research activity. Specifically, Antonio Gallego, Juan Manuel Escaño, Kumars Rouzbehi and José Ramón Domínguez Frejo, carry out teaching and research activities in the Department of Systems Engineering and Automatic Control of the University of Seville, as Teaching Assistant, Associate Professor, Ramon y Cajal grant and Associate Professor, *respectively.* Amalia Luque is in the department of Design Engineering of the same university. Other graduates doctors are in other universities: Pablo Velarde (Universidad Loyola en Sevilla), Felix García Torres (Universidad de Córdoba), Filiberto Fele (Imperial College London). Paulo Renato da Costa Mendes is currently at the Fraunhofer Institute (Kaiserlautern, Germany) and Diogo Ortiz is at the Universidade Federal de Rio Grande do Sul in Brazil. Other graduates develop their activity within a company or institute but with an important research component: Luis Valverde (ATA renovables), David Marcos (Ormazábal), Pablo Baez (IDENER), Juan Aguilar (SOPRA) and Francisco Javier Muros (ENDESA).

7 SPECIFIC CONDITIONS FOR THE EXECUTION OF CERTAIN PROJECTS.

Not applied