Convocatoria de ayudas de Proyectos de Investigación Fundamental no orientada

TECHNICAL ANNEX FOR TYPE A or B PROJECTS

1. SUMMARY OF THE PROPOSAL (the summary must be also filled in Spanish)

PROJECT TITLE: Predictive COntrol techniques for efficient management of reneWable Energy micro-gRids. (POWER)

PRINCIPAL INVESTIGATOR: Carlos Bordons Alba

SUMMARY
(brief and precise, outlining only the most relevant topics and the proposed objectives):

This project deals with the analysis, study and application of modeling, control and optimization strategies (in the framework of Model-based Predictive Control, MPC) to achieve an efficient energy management in renewable energy micro-grids. The problem is composed by different control levels, because decisions about the final use of the available energy have to be made and there are therefore different objectives (minimizing the use of conventional fossil energy sources, economic, environmental and quality aspects, etc.) that give rise to a hierarchical control problem that requires coordination and cooperation between systems and that will be addressed using control techniques including "economic" MPC, Real Time Optimization (RTO) and cooperative and distributed MPC, being also necessary to develop models, estimators and predictors of the energy generation and demand stages.

The three basic objectives of the coordinated project are:

1. Development of methodologies for obtaining models of renewable energy micro-grids. The micro-grid paradigm will be extended to include heterogeneous sources and loads. The calculation of reduced models suited for analysis and design will be especially relevant.
2. Development of model predictive control strategies for renewable energy micro-grids, including cooperative MPC formulations for the optimal economic management of heterogeneous energy systems. The main focus will be on the development of strategies with potential applicability in complex processes.
3. Implementation and validation of the strategies in selected experimental plants. This will facilitate the development of the different tasks of the project over realistic conditions. Systems in which the energy comes from different sources (that should be combined for an optimal and safe exploitation) will be considered.

The fulfilment of the preceding goals would be a significant contribution in this field and it would have a real impact on this kind of processes. Therefore this proposal has aroused interest in different companies such as Hynergreen, Greenpower, Fundación Cajamar, Rijk Zwaan or Auenergy, naming only a few. The proposal is also a natural continuation follow-up of previous work carried by four of the research groups integrating the consortium, which has been extended to include an emergent group. The team has a remarkable experience in control systems backed by many papers published in some of the most cited scientific journals. We feel that significant contributions will be made because the research team has a wide experience in MPC and energy systems and will benefit from close cooperation with other European research teams.

TITULO DEL PROYECTO: TÉCNICAS DE CONTROL PREDICTIVO PARA LA GESTIÓN ENERGÉTICA EFICIENTE DE MICRO-REDES CON ENERGÍAS RENOVABLES

RESUMEN
(breve y preciso, exponiendo sólo los aspectos más relevantes y los objetivos propuestos):

El proyecto trata sobre el análisis, estudio y aplicación de estrategias de modelado, control y optimización basadas en el campo del Control Predictivo basado en Modelo (MPC) para conseguir una gestión eficiente de la energía en micro-redes que contienen fuentes de energías renovables. El problema se compone de diferentes niveles de control, ya que se deben tomar decisiones sobre el uso final de la energía disponible y existen por tanto diferentes objetivos a cumplir (minimizar el uso de combustibles, aspectos económicos, medioambientales o de calidad, etc.). Esto da lugar a un problema de control jerarquizado que será abordado incluyendo técnicas como "MPC económico", Optimización en Tiempo Real (RTO) y MPC cooperativo y distribuido. También será necesario desarrollar modelos, estimadores y predictores para las etapas de generación y demanda de energía.

Los tres objetivos básicos del proyecto coordinado son:

1. Desarrollo de metodologías para la obtención de modelos de micro-redes que contengan fuentes de energías renovables. Se extenderá el paradigma de las micro-redes para incluir fuentes y cargas de naturaleza heterogénea. Será especialmente relevante el cálculo de modelos reducidos que sean adecuados para el análisis y el diseño.
2. Desarrollo de estrategias basadas en Control Predictivo para micro-redes con fuentes renovables, incluyendo formulaciones de MPC cooperativo para la gestión económica óptima de sistemas energéticos heterogéneos. Se hará especial hincapié en el desarrollo de estrategias con potencial aplicabilidad en procesos complejos.
3. Implementación y validación de las estrategias en plantas experimentales seleccionadas. Esto facilitará el desarrollo de las diferentes tareas del proyecto sobre situaciones realistas. Se considerarán sistemas en los que el aporte energético provienes de diferentes fuentes, que deben ser combinadas adecuadamente para una explotación óptima y segura.

El cumplimiento de los objetivos anteriores representaría una contribución significativa en este campo y tendría un impacto real en esta clase de procesos. Por ello, esta propuesta ha despertado interés en diferentes empresas tales como Hynergreen, Greenpower, Fundación Cajamar, Rijk Zwaan o Auenergy, entre otras. La propuesta es también una continuación natural de trabajos previos llevados a cabo por cuatro de los grupos del consorcio, que se ha extendido para incluir un nuevo grupo emergente. El equipo resultante posee una considerable experiencia en control de sistemas energéticos, soportada por los numerosos artículos publicados en revistas de prestigio. Creemos que se pueden aportar contribuciones significativas ya que el equipo tiene una sólida experiencia en MPC y sistemas energéticos y se beneficiará de las estrechas relaciones con otros grupos de investigación europeos.

2. INTRODUCTION (maximum **5** pages)

Aim of the project

Efficient energy generation and consumption is a key factor to achieve ambitious goals for sustainable development and activities related to air pollution and climate shifting. Efficient and safe power distribution along with minimised and balanced power consumption is an important part of the economic activity of most developed countries. One of the largest issues is that the distribution networks have to supply energy at greatly varying demands. Abrupt changes in the large-scale energy demand status can cause severe problems to the production facilities, and since these changes cannot be accurately predicted they can lead to outages.

As it is explained in the "*Documento de visión de la Eficiencia Energética en España (View of the Energy Efficiency in Spain)"* (PTE-EE, 2009) during the next 25 years the energy sector worldwide will need investments of around 20 millions of millions dollars, where 60% will be devoted to the electricity sector. Moreover, countries like Spain have to import more than 80% of the primary energy in a context of deepening economic crisis and volatility of commodity prices. Only through energy efficiency can consumption be diminished while maintaining the same services and benefits, without affecting our quality of life, protecting the environment, ensuring a better energy supply system and promoting a sustainable use.

The project will address issues that are related to energy management in micro-grid frameworks. The micro-grid concept assumes a cluster of loads and micro-sources operating as a single controllable system that provides power to the system. Some benefits of these micro-grids can be (Jiayi et al., 2008, Zambrano et al., 2008): "enhance local reliability, reduce feeder losses, support local voltages, voltage sag correction or provide uninterruptible power supply functions". The project will study and evaluate models of extended utilisation of micro-RES (Renewable Energy Sources) e.g. solar/photovoltaic panels, mini-windmills.

The project aims to **develop Model Predictive Control (MPC) formulations for the optimal economic management of heterogeneous energy systems integrated in a micro-grid**. Since (Robust) Model Predictive Control (Camacho and Bordons, 2004) is capable of providing optimal control strategies that guarantee the fulfilment of the operating constraints in spite of the incomplete information on future supplies and demands, it is considered here as the keystone for the enhanced management of micro-grids. Since a micro-grid can operate in grid-connected mode or in island-mode, different types of solutions will be provided. The problem of energy management in isolated (or island-mode) grids will the tackled by the use of "economic" MPC (Rawlings, 2009), while cooperative MPC formulations (Magni and Scattolini, 2006), will be developed for the optimal economic management of interconnected energy systems. A key aspect will be the development of methodologies for micro-RES generation synchronization, and energy storage and distribution.

There are many open issues relating micro-grids that this project intends to address. One important issue is micro-RES energy generation synchronization and energy storage and distribution. Due to the features of renewable energies, it is usually required an additional energy source to operate with the system when the stored energy or the renewable energy source are scarce or are not present. Moreover, the problem is more interesting when there exist several possibilities for using the produced energy, and it is necesary to selec how the energy is distributed among subsystems, where different objectives can arise (minimizing the use of conventional energy sources, economic and quality aspects...). A key factor is to try to adapt the demand to the production of energy (and vice-versa), where modeling, predictive control and supervision techniques play an important role.

Thus, both low-level (systems and equipment level) and high-level (setpoint optimization, process coordination, dynamic real-time optimization) modeling and control objectives arise in the scope. Several of the high-level objectives that will be treated in this project are: adaptation of energy production to demand (Arahal et al., 2008), planification of energy production, storage and use (Cirre et al., 2009), forecasting of environmental variables (Pawlowski et al., 2010), efficient management of energy storage policies (Arahal et al., 2008; Giri and Mhesh, 2002), integration of economical aspects in energy management (Biegler, 2009, Cirre et al., 2009), comfort control (Castilla et al., 2010). Some of the low-level objectives will be related to the development of hybrid and nonlinear predictive control strategies to compensate for the intrinsic delays associated to solar plants (Roca et al., 2009a), modeling and control of heat pumps (both single and double effect) (Roca et al., 2009b), climate control (ventilation, heating, solar cooling, CO2,(Rodríguez et al, 2008)), and control of electric vehicles (Hori, 2004). These low-level objectives are a natural continuation of the previous project DPI2007-66718.

The use of Distributed MPC for microgrid management can solve a number of specific operational problems. First of all, microsources may have different owners, and several decisions should be taken locally so centralized control is difficult. Furthermore microgrids operate in a liberalized market; therefore the decisions of the controller of each unit concerning the market should have a certain degree of "intelligence". Finally the local micro-source besides selling power to the network have also other task: producing heat for local installations, keeping the voltage locally at a certain level or providing a backup system for local critical loads in case of a failure of the main system (Hatziargyriou et al., 2005). These tasks suggest the importance of the distributed control and autonomous operation.

The result of the project **will be validated by means of different applications**. In particular, the cooperative MPC formulations will be applied and validated in the context of two environments that include energy generation, consumption and storage. The first one, located at the University of Almería (UAL) and the Plataforma Solar de Almería-CIEMAT, includes a bioclimatic building – CIESOL – (Castilla et al., 2010), a greenhouse (Rodríguez et al., 2008) and a solar desalination plant (Roca et al., 2009a) (This installation can work both in grid-connected mode or island mode). These units are characterized by the use of solar energy for electricity and process heat production for HVAC, lighting, drinkable water production, transport in electric vehicles and electricity supply for machinery and equipment. The second installation is a laboratory plant located at the University of Sevilla that includes renewable energy, hydrogen storage, a fuel cell, electric loads and Plug-in Hybrid Vehicles (PHVs), (Del Real et al., 2009). This laboratory plant was built by the consortium in a previous project (DPI2007-66718-C04) and it will now be extended to consider PHVs . The results of the project related to isolated systems (or island-mode operation) will be validated in two situations: a demonstration facility producing drinkable water in remote communities through local renewable energies situated in Borj Cedria, Tunisia, and a fuel cell hybrid vehicle (FCHV), that will be developed in the project framework. Notice that hybrid vehicles are of great interest to the project, since they can act as loads (drawing energy from the grid), as storage devices (storing energy in their batteries) and as generators (supplying stored energy when needed).

State of the art :

Control and prediction for energy efficiency

The role of automatic control on the efficient management of energy has been widely recognized from different points of view at the level of individual buildings (Haberl and Claridge, 1987), blocks (Bouvy and Lucas, 2007), environment (Adlhoch et al, 2007) and energy (Berenguel, 2005), among others. . One the control techniques that has attracted the attention of process industry to satisfy the increasing need for improving systems economics, efficiency and quality under globalized market environment is the so-called real-time optimization (RTO) (Engell 2006). In (Tani 2009) are presented results from a very successful implementation of a RTO.

The objective of the RTO is to maintain the plant operation near economic optimum. RTO control layer is located between the production planning/scheduling and local controller levels and it is typically based on steady-state model of the plant to calculate set-points (or zones) of controlled and manipulated variables for multivariable controllers. The steady nature of the model used in the RTO usually leads to a loss of optimality due to the frequency of the execution, unreachable targets due to uncertainties or disturbances. Integration of real-time optimization and control is an essential task for profitable process operation in a highly competitive environment. This motivates the development of dynamic real-time optimization (D-RTO) strategies that can be used to merge and replace the tasks of (steady-state) real-time optimization (RTO) and model predictive control (MPC) (Engell 2006, Wurth 2009 and Biegler 2009). Recently a novel stabilizing MPC capable to integrate RTO and MPC has been proposed in (Limon 2008). Stability, constraint satisfaction as well as optimality has been proved for this controller (Ferramosca 2009). On the other hand, a predictive control technique capable to cope with economic performance index in the derivation of the control law has been recently presented (Rawlings 2009). In this economic MPC, the cost function to optimize is directly the economic performance index, not the tracking error to the set-points. This new framework will be used in this project to study predictive control techniques to integrate both real time optimization and economic criterion.

When the system to be controlled results from the interconnection of different subsystems (as energy micro-grids), a profitable control technique should take in to account simultaneously the efficient operation of the each subsystem while the quality requirements are fulfilled. Distributed predictive techniques (Venkat 2008) seem appealing control techniques for solving such a problems. However economic optimality, integration of the RTO, etc are still open problem to be studied.

For an efficient energy management, accurate information of energy consumption is needed in order to know how it behaves in short and medium-term. In the literature, several works can be found to model the energy use for buildings (Zimmermann, 2002), but many problems are still open as an appropriate system identification (Oloffsson et al., 2009), an user behavior model (Hoes et al., 2008) or including weather forecast models. Storage devices play an important role in energy systems to balance the system following disturbances and/or significant load changes (Giri and Mahesh, 2002). The correct management of the micro-source integrated with storage is a means of power quality control. The necessary storage can adopt several forms; batteries or super-capacitors on the DC bus for each source; direct connection of storage devices (batteries, flywheels, etc.); heat storage, etc. The use of hydrogen as energy storage is a promising option, with involves the management of the renewable hydrogen production and the electricity generation by fuel cells (Del Real et al., 2009) and has very different applications, such as automotive (Arce et al., 2007, 2008) and stationary power generation applications (Del Real et al., 2007). In energy systems, heat storage plays also a very important role.

There exist many systems where disturbance estimation would be needed to improve the overall performance of the control system. Some examples can be found in control systems for renewable power generation, especially for solar energy, where the solar radiation is used as the main energy source. Solar radiation is a changing variable that can be perturbed by clouds, temporal dust concentration, vapor concentration, etc. For this reason, a prediction model of the solar radiation is required to optimize the process performance and minimize the use of auxiliary energy sources (Berenguel et al., 1998; Camacho et al., 1997). Prediction of wind speed is also required for control and management of wind energy power systems (Mellit et al., 2005). The wind energy cannot be scheduled and there is always a great uncertainty about the final production.

Microgrids

The paradigm of microgrids (MG) was introduced by (Lasseter, 2002; Lasseter and Piagi, 2004) as a system approach which views generation and associated loads as a subsystem or microgrid. During disturbances, the generation and corresponding loads can be separated from the distribution system to isolate the MG's loads from the disturbance (and therefore maintaining service) withouth harming the transmission grid's integrity. Although originally related to electrical grids, the concept was extended to a cluster of loads and microsources operating as a single controllable system that provides both power and heat to its local area (Jyaiyi et al., 2008). Nowadays, the coordinated operation and control of Distributed Energy Sources (DER) together with controllable loads and storage devices, such as flywheels, energy capacitors and batteries are central to the concept of MG.
MG can operate interconnected to the main distribution grid, or in an islanded mode, and they can also be interconnected to other MGs, giving rise to a more complex system.

There exists a research project where the MG include fuel cell as main generators (Funabashi and Ryuichi, 2006), but there are no reports about MGs integrating fuel cells (FC), renewable energy generators and hybrid vehicles as loads. Notice that FCs have developed considerably in the last years since they good candidates for clean electricity generation both in stationary and automotive applications (Bordons et al., 2006). There are many open issues in the control of FC systems, such as the control of the generator itself (Gruber et al., 2009) or the control of hybrid systems where the FC is integrated (Arce et al., 2009). One special case of a hybrid systems including FCs is the hybrid vehicle, which could have a part to play in future road transport., mainly as a battery electric vehicle with fuel cell range extender (Offer at al., 2010). This platform also has the benefit of building on a technology road map that begins with plug-in ICE hybrids in the near future. This will cause a deep integration between road transportation needs and the electrical grid which must be deeply analyzed.

Due to the great complexity of such energy systems including intermediate storage and multiple, decentralized and intermittent generators, new approaches have to be done in order to model and control these new systems. In (Geidl et al., 2007) a modeling framework is proposed which enables integration of an arbitrary number of energy carriers as well as chemical reactants and products, introducing the *energy hub* concept, defined as a general interface among energy producers, consumers and the transportation infrastructure. Such general formulation allows high flexibility. Moreover, the energy hub concept has also been recently adapted in other research fields proving its flexibility, i.e., modeling of PHEV (Plug—in Hybrid Electric Vehicles) (Galus and Andersson, 2008).

Related research groups:

Related to heterogeneous energy systems, the group of Goran Andersson (ETH, Zurich) has a wide expertise in the mathematical formulation of these systems. The group of ISA-USE published a joint paper. In relationship with Predictive Control should be mentioned the group headed by Manfred Morari (ETH Zurich). The group ISA-USE is involved in an European project (Feednetback) in close colaboration with ETH. Also important is the group of Alberto Bemporad (University of Siena). Different collaborations with Alberto Bemporad had led to the publication of three journal papers.

A very active group in Spain related to the subject of this proposal is the Advanced Control of Energy Systems of the Polythecnic Univertsity of Catalonia. Researchers of this group work in electronics converters (Enric Fossas, Ramón Costa, who collaborate with the UAL group) and in fuel cell systems, including Hybrid Vehicles (Jordi Riera, María Serra) or energy efficiency (Robert Griñó). The group led by Luis Martínez-Salamero at the Universidad Rovira i Virgili has a wide experience in the control of electrical systems (mainly electronic converters) and they have worked with ISA-USE on optimizing efficiency of FC systems, publishing a joint paper. The group of Sebastián Dormido (UNED) has a solid background on MPC and they are working on predictive control (in collaboration with the UAL group) and modelling of fuel cells. There are other two active groups in Spain working on FC applications: José Manuel Andújar (Huelva) and Domingo Guinea (Instituto de Automática Industrial, CSIC). Also, the decentralized control of networked systems is one of the main lines of research of the group of J. Rodellar, at the Universitat Politècnica de Catalunya (UPC).

With respect to other european groups, we highlight the research in the stability analysis of different MPC decentralized strategies by L. Magni and co-workers at the Università degli Studi di Pavia. De Schutter's group at TU Delft (Netherlands) are focusing their research on hierarchical and decentralized model predictive control of large-scale systems. This is also one of the lines of research of the group led by Wolfgang Marquardt at RWTH Aachen University, Germany (ISA-USE is closely collaborating with them in the European Project HD-MPC). In this context, the group of T. Parisini at the University of Trieste, also plays a relevant role.

Among non-European groups, we mention here tthe groups of James B. Rawlings (University of Wisconsin-Madison), Richard M. Murray's group (California Institute of Technology), and Krogh's group (Carnegie Mellon University). In relation to hydrogen, the group of Anna Stefanopoulou (Michigan) is working with applications to hybrid vehicles and fuel reforming. There is a close contact between this group and ISA-USE.

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3. OBJETIVES
(maximum **2** pages)

- **3.1** Describe the reasons to present this proposal and the **initial hypothesis** which support its objectives (maximum **20** lines)

Efficient energy generation and consumption is a key factor to achieve ambitious goals for sustainable development and activities related to air pollution and climate shifting. Since efficient and safe power distribution along with minimised and balanced power consumption is an important part of the economic activity, the development of new techniques for energy management is fully justified.

Model Predictive Control (MPC) is the most natural approach to the optimal control of processes subject to constraints. This explains why MPC is the advanced control strategy that has a greatest establishment in the process industry. However, there are still many open issues related to MPC techniques to be applied to energy systems, such as cooperation, robustness, real-time optimization, etc. that must be deeply explored.

The micro-grid concept assumes a cluster of loads and micro-sources operating as a single controllable system that provides power to the system. There are many open issues relating micro-grids that this project intends to address. The use of distributed and cooperative MPC for micro-grid management can solve a number of specific operational problems. A key aspect to be studied is the development of methodologies for micro-RES generation synchronization, and energy storage and distribution.

The development of new results for the modelling, identification and predictive control of renewable energy micro-grids would imply a significant improvement in the operation, efficiency and safety of this class of relevant systems. Due to the incomplete nature of the results on this relevant topic, the methodology and strategies resulting from this project are of potential great relevance in this emerging field. As the obtained results will be validated in real processes and facilities, the transfer of improved control strategies to industry will be greatly facilitated.

- **3.2.** Indicate the **background and previous results** of your group or the results of other groups that support the initial hypothesis

All the groups that take part in the Project have a great experience in the different fields required to articulate the Project. The Project can be considered as a natural evolution of their corresponding research lines. Moreover, as the different groups have successfully cooperated in different common projects, the relationships between them will be fluid and efficient. All these will lead to an adequately orchestrated multidisciplinar Project.

The Model Predictive Control Group of the University of Seville (ISA-USE) has been working in model predictive control for more than 20 years. This dedication, along with its experience in the control of solar plants, results in the publication of three books, more than 50 international journal papers and a large number of conference papers (see the CVs of the researchers). The active partnership of the group in the Network of Excellence HyCon funded by the European Commission under FP6 and the participation of the group in two STREP projects (HD_MPC and FeedBackNet) funded by the EU under FP7, will act as a valuable background to address the specific nature of the processes considered in the Project. Other many research projects related to this proposals have been done in the last few years (see section 7) and 12 PhD Thesis have been defended in the group within the last 5 years.

The group of the University of Almería (UAL) has participated in more than 20 R+D projects related to this proposal, where the design of robust, hybrid and hierarchical model predictive control for processes subject to measurable disturbances was carried out. The previous CICYT projects DPI2002-04375-C03-03, DPI2004-07444-C04-04 and DPI2007-66718-C04-04 have been basic and fundamental to propose this new project, which is a natural evolution of these. They have given rise upon the publication of more than 50 papers in journals and more than 100 articles in Symposia, as well as 8 PhD Thesis. The Group is participating in the Proyecto Singular Estratégico ARFRISOL (PS-120000-2005-1), leaded by the Energy Efficiency in Buildings Unit, UiE3 of CIEMAT, dealing with Bioclimatic Architecture and Solar Cooling, as well as in the European project FutureFarm, where the goal is to provide solutions to energy efficiency, reducing environmental impacts and improve benefits in farm

The group of Termotecnia (TMT-USE) from the University of Seville, will play an important role in the understanding of the physics of the complex systems considered in the Project. In particular, the solid background and experience of the group in fuel cell systems and solar hydrogen plants will play a determinant role when formulating and facing the industrial challenges that stem from this class of systems. This experience comes from related industrial projects that have led to a number of publications, such as: Evaluation of hydrogen systems as energy storage systems for wind energy in Andalusia, Development of a simulation tool for hydrogen systems analysis, Sensitivity analysis for PEM fuel cells bipolar plates, Development of a MATLAB dynamic model for PEM, MC and SO fuel cells and Development of FLUENT models for heat and mass transfer process, Application of novel techniques to control the storage of electrical energy using hydrogen from renewable sources, Analysis of operating modes for electricity management from renewable energy by hydrogen storage.

The group of the University of Valladolid has specialized in control of systems with constraints, in particular Predictive Control, Robust Control and positive systems, with application to different process control problems, especially in food industry. The success of the research carried out by the group is proved by a large number of publications, industrial contracts and international collaborations. In this context, it is worth mentioning the extensive collaboration with the groups of the University of Marrakech and the INRST (Tunisia); In fact, researchers from both groups will participate actively in the proposed project. Moreover the objectives developed in this project are the natural continuation of previous projects carried out with the University of Seville and Almeria, and the European project OpenGain, The participation of this group will be decisive in the attainment of the objectives of the project, due to its experience in theoretical developments with practical implementations in the interest areas.

The previous background and results of the Automatica e Informatica Industrial (Ai2) group of CIEMAT come from several sources. With respect to modelling and control in hybrid solar desalination plants, the background comes mainly from the research activities made in the scope of AQUASOL research project, funded by European Commission (Contract nº: EVK1-CT2001-00102), and performed at CIEMAT. Nowadays, even when the AQUASOL project has finished formally, the collaboration between both groups Ai2 and AER-TEP-197 is continued with the own funds of the respective institutions, UAL and CIEMAT. In addition to the AQUASOL project, the collaboration of Ai2 with other groups inside CIEMAT with several projects, in the modelling and control design activities of different solar thermal and chemical processes, has contributed to the background of this group. In addition, the collaborations of some members of Ai2 with the research groups of Prof. Sebastián Dormido Bencomo (U.N.E.D.) and Prof. Eduardo Fernández Camácho (U.S.) have enhanced greatly the knowledge of this group.

υ **3.3.** Describe briefly the **objectives** of the project.

The three basic objectives of the coordinated project are:

1. Development of methodologies for obtaining prediction models of renewable energy micro-grids. The micro-grid paradigm will be extended to include heterogeneous sources and loads. The calculation of reduced models suited for analysis and design will be especially relevant.
2. Development of model predictive control strategies for renewable energy micro-grids, including cooperative MPC formulations for the optimal economic management of heterogeneous energy systems. The main focus will be on the development of strategies with potential applicability in complex processes.
3. Implementation and validation of the strategies in selected experimental plants. This will facilitate the development of the different tasks of the project over realistic conditions. Systems in which the energy comes from different sources (that should be combined for an optimal and safe exploitation) will be considered.

υ **3.4. For Coordinated projects** only, the **coordinator** must indicate (maximum **2** pages):

- the global objectives of the coordinated project, the need for coordination, and the added value provided by this coordination
- the specific objectives of each subproject
- the interaction among the objectives, activities and subprojects
- the mechanisms of coordination for an effective execution of the project.

In the official announcement (Article 15), it is stressed that the Call tries to break the tendency of group fragmentation, encourage the funding of coordinated projects and the association of emerging research groups and experienced groups. Also, the multidiplinary research that is able to integrate complementary knowledge of several scientific fields is encouraged too. This proposal is oriented by these principles and therefore we present an ambitious project involving a great number of researchers both from emerging and experienced groups.

The different challenges and disciplinary requirements of the project justify its coordinated and interdisciplinary nature. The union of the different groups of the proposal covers appropriately the qualification and experience necessary to attain the objectives of the project. A characteristic of the different groups that form the proposal is that they have collaborated intensively in previous projects. Thus, one of the benefits of the project is that it will make it possible to continue the joint work of the different groups.

These objectives are the natural continuation of those planned in previous projects in which the researchers integrating this proposal are involved; in particular the projects CICYT-DPI2004-07444-C04, CPROS (Hierarchical predictive control of processes under semi-continuous operation) in which the groups ISA-US, UAL and UVA participated, and CICYT-DPI2007-66718-C04 (Predictive Control of Interconnected Processes With Diverse Operating Modes) where the same groups participated, as well as TMT-US. The new group of CIEMAT (type B subproject) is an emergent group whose researchers have participated indirectly in the previous projects and have collaborated with UAL in many research projects.

Objectives of each subproject

Subproject 1: ISA-USE

1. Development of cooperative MPC formulations for the optimal economic management of heterogeneous energy systems considered in the proposal.
2. Apply the cooperative formulation to the energy generation, distribution, storage and use.
3. Exploitation and extension of the micro-grid concept to heterogeneous sources and loads, especially in the case of hybrid vehicles.
4. Use Economic MPC integrating RTO to the energy management problem in a FC range-extended hybrid vehicle.

Subproject 2: UAL

1. The development of methodologies for obtaining simplified models of energy-efficient systems and environments, involving the use of renewable energies (mainly solar energy).
2. Development of hybrid and robust predictive control strategies for this class of processes, where different hierarchical levels will also be considered, characterized by the existence of different dynamical time scales, hybrid nature and changing operation modes,
3. Development of cooperative MPC formulations for the optimal economic management of heterogeneous energy systems considered in the proposal.
4. Implementation and validation of the different strategies in a number of experimental plants with clear industrial relevance and coordination requirements, with different demands in generation, distribution and use of electricity and process heat.

Subproject 3: TMT-USE

1. Development of dynamic models of electrolyzer, aerogenerator, metal hydrides and PEM fuel Cell.
2. Bring the laboratory to implement and validate predictive control techniques.
3. Provide information and experimental results of the equipment and installation to examine the goodness of the control systems.
4. Validation of power management techniques applicable to real industry.
5. Sizing of elements of the cooling and braking system for a Fuel Cell Hybrid Electric Vehicle (FCHEV) under various operating cycles

Subproject 4: UVA
1. Modelling of renewable energies: the objective is to develop simple models of the different components in a renewable energy installation for isolated installations (photovoltaic panels, wind mills, inverters, batteries, etc) to use them for simulation of the process (for testing the control algorithms before implementation) and the predictions needed in the developed control algorithms
2. Predictive controllers for off-grid systems: The control algorithms developed in the project will be particularized for off-grid systems, where the demand from the electrical loads adapts to the energy availability.
3. Implementation and tests on demonstration facilities: The algorithms developed in the global project will be tested on a demonstration facility for the production of water using reverse osmosis.

Subproject 5: CIEMAT
1. Dynamic modelling of solar-gas hybrid desalination plants. Validation of these models.
2. Contribute to the development of advanced control strategies based on optimization criteria with respect diverse type of variables. Variants of several predictive controllers will be implemented and experimented.
3. Low level control algorithms for some of the most dominant dynamic's subsystems should be modified, trying to correct some unstabilities detected in the past in other research projects and experiences. In concrete the double absorption heat pump (DAHP) low level control system should be partially remade with respect the original statement from the manufacturer company. Although this is a low level objective, should be afforded with priority at the beginning of the project to correct these unstabilities and let to implement more advanced model base controllers.

Interaction among goals, activities, and subprojects

The chronogram in the following section shows the interaction among the several subprojects. Each task is leaded by the group with an, a priori, greater experience in the subject, but in all the tasks there is more than one group involved. This results in a significant interaction between the subprojects, and therefore, it allows a good exchange of knowledge and experience.

Coordination procedures needed to the efficient management of the project

The lead researchers of each subproject that apply to this call will guarantee that all the tasks in each subproject will be carried out as expected. Moreover, a committee to audit the project will be created. This committee will maintain regular meetings to guarantee that all the results are met within the specified deadlines. The meetings will be:

- Coordination between subprojects meetings: one kick-off meeting and then one each semester.
- Subgroups meetings to develop tasks: as often as needed.
- Meetings within each subprojects: every 15 days or weekly whenever urgent decisions are to be taken.

There will also be personal exchanges between researchers of each subproject and a flow of information via e-mail. There will be also a ftp server to be set-up and a website that will be used to diseminate the results not only between the project members, but also between other research groups, nation, or worldwide.

4. METHODOLOGY AND WORKING PLAN
(in the case of coordinated projects this title must include all the subprojects)

Detail and justify precisely the methodology and the working plan. Describe the working chronogram.

- ♦ The working plan should contain the tasks, milestones and deliverables. The projects carried out in the Hesperides or in the Antarctic Zone must include the operation plan.
- ♦ For each task, it must be indicated the Centre and the researchers involved in it.
- ♦ If personnel costs are requested, the tasks to be developed by the personnel to be hired must be detailed and justified. Remember that personnel costs are eligible only when personnel is contracted, **<u>fellowships are not eligible</u>** as personnel costs.

As shown in the task schedule, the project is composed by different tasks. From a methodological point of view, these could be classified as follows:

- ❖ Bibliographical searching and analysis: scientific literature should be evaluated and articles and research works related with the project tasks must be studied and analyzed. This searching task will be carried out mainly during the fist stage of the project and will be continued in a faded way throughout its duration. The main sources to be analyzed will be international journals, conferences and workshops preprints combined with periodic searching in the web by means of recent specialized tools, and visiting the web pages of the main research groups related to the project objectives. This task will be developed by the members of the involved groups, although some researchers of each group will be specifically in charge of the searching as well as the centralization of the data.

- ❖ Modelling of the experimental plants: applied research must be based on the experimental demonstration of the obtained results on benchmarks or study cases. In this project, this is carried out in two different stages related with its two main parts: the determination of the model and the analysis and design of the controlled system. The success and utility of the experimentation depends on a good selection of the experiments, that is, the plants and processes to be analyzed and controlled. Each process will be modelled in two different ways: a) models for control and b) models for simulation. In the first case, different dynamics and uncertainty models will be developed with diverse degree of complexity to be used in the algorithms produced in tasks 5, 6 and used in task 7 of the project. Simulation allows one to use more complex models considering a large number of states and operating constraints. The dynamics of these models must be similar to the real dynamics of the plant in order to be used for testing the developed controllers before their implementation on the real plant. This will reduce the cost of the experiments to execute.

- ❖ Development of algorithms and novel results: this task is the proper research activity and due to its creative nature, it is quite difficult to be described. The task will be based on the bibliographical searching, the own knowledge of the group and the addition of new ideas from the other research groups. Each research group must discuss together all the ideas and decide the most promising ones to be expanded, programmed, and implemented.

- ❖ Development of programs to implement the obtained algorithms and models. These tasks will be put in charge of the employed researcher under the supervision of the research group. It is worth noting that the algorithms associated to the proposed control techniques are quite more demanding than the ones used in classic control techniques and therefore, it is expected that this task will require a significant time burden.

❖ Simulation tests. Once simulation models are ready to be used, and as a previous stage to the implementation of the controllers on the experimental plants, preliminary tests will be executed in simulation. These will allow us to verify if the performance and control objectives are satisfactory. This stage may require a significant effort.

❖ Experimental proofs: throughout the project it is necessary to produce ad-hoc tests for the identification of the processes, uncertainty bounding and validation of the designed algorithms. These tests will be decided in meetings of the groups involved in the experiments. The tests will be executed according to the decided protocol and the obtained results will be analyzed in later meetings. All the obtained results must be stored in such a way that all the experiments could be replicated and that all the involved researchers are able to access the data. It is worth noting that several tasks as setting up of the plants, instruments and sensors installation, preparation of the environment for the execution of the experiments, etc. must be considered. The employed researchers will be in charge of this task.

The leader of each group is responsible for the appropriate evolution and fulfilment of the expected tasks at each stage. Moreover, a team for the supervision of the project will be created and will attend coordination meetings where the results and stages of the project will be analyzed.

It is of special interest for the evolution of the project to share information between the different groups by means of the electronic mail and a web-server and ftp-server, as well as cross-stays of researchers between the different groups involved in the project. On the other hand, the dissemination of the obtained results can be enhanced by means of the web page.

T0. Coordination and project management.

Task Leader: ISA-USE

This task is active for all the project life. The lead researchers of each subproject will supervise that all the tasks in each subproject are carried out as expected. Moreover, a committee to audit the project will be created. This committee will maintain regular meetings to guarantee that all the results are met within the specified deadlines. The different class of meetings required for the coordination of the project are:

- Coordination between subprojects meetings: one kick-off meeting and then one each semester.
- Subgroups meetings to develop tasks: as often as needed.
- Meetings within each subprojects: every 15 days or weekly whenever urgent decisions are to be taken.

Groups involved: All of them.
Task life: 36 months.

Deliverables:
D0.1: First annual Report (M12)
D0.2: Second annual Report (M24)
D0.3: Third annual Report (M36)

Milestones:
M0.1: Kick-off meeting (M1)
M0.2: 1st semester meeting (M6)
M0.3: 2nd semester meeting (M12)
M0.4: 3th semester meeting (M18)
M0.5: 4st semester meeting (M24)
M0.6: 5st semester meeting (M30)

M0.7: final meeting (M36)

T1. Development of methodologies and platforms for modeling and simulation of energy systems: generation, storage and demand

Task leader: CIEMAT

The objective of this task is to develop an adequate framework for the modelling and simulation of heterogeneous energy systems. This task will formalize a hierarchical structure of models oriented to the different tasks considered in the project: identification, estimation, analysis, synthesis and coordination/cooperation. Another important task is the development of methods to reduce the complexity of the representation of the energy coordinated systems. The starting point for addressing the different objectives will be the ample experience of the different groups in the modelling and simulation of complex systems. The multidisciplinary nature of the groups that form the project will also facilitate the development of this task. The following subtasks will be considered.

T1.1. Development of a modelling framework oriented to the control of energy systems. Energy systems traditionally have been modelled using first principles (mass, energy and moment balances). The elemental components of these models are based using concentrated parameters (DAE) and with spatial distribution (PDAE). The interfaces of the models will be a-causal and will use standard libraries of object-oriented modelling languages for energy systems. The complexity of some of the subsystems yields physical relations and conservation laws in the lumped parameter form. The application of some of the modelling frameworks adopted in the context of decentralized control will also be considered to obtain an appropriate modelling paradigm for this class of systems. The proposed framework should be capable of characterizing the generation, distribution, storage, use and demand of energy, mainly in the renewable energies framework.

Groups involved: CIEMAT, ISA-USE, UAL, UVA, TMT-USE.
Task life: 18 months.
Deliverables:
D1.1.1: Report on a modelling paradigm for control of energy systems (M18)
Milestones:
M1.1.1: Definition of a modelling framework for control of energy systems (M18)

T1.2 Development of a modelling and simulation environment. This subtask is articulated in the following objectives: Design of an environment that manages the causality and different natures and times scales of the system in order to allow changes in the system structure, operation modes and different energy sources. Development of a methodology suited for the integration of each of the specific subsystem simulation tools. Strategies to optimize the time needed to perform the simulations. Real time simulation (using inline-integration techniques).

Groups involved: CIEMAT, ISA-USE, UAL, UVA, TMT-USE.
Task life: 18 months.
Deliverables:
D1.2.1: Report on a modelling and simulation environment (M18)
D1.2.2: Report on a library of reusable models both for simulation and control purposes of heterogeneous energy systems (M18)
Milestones:
M1.2.1: Library of reusable models both for simulation and control purposes of heterogeneous energy systems (M18)

T2. Methodologies for identification and prediction of generation and demand

Task leader: UAL

As one of the main objectives of this research project focuses on the efficient management of energy available in the entire system, a thorough analysis of the energy requirements of each process and the estimated energy sources available to meet energy demands is necessary. The result of this work will be of particular interest for the development of tasks related to aspects of control as the basis for determining the cost functions that can be used in multi-objective control problems (including terms for revenues from energy sales, penalties, production costs and plant aging, between others). This is of special interest in the framework of model predictive control algorithms, where future values of disturbances are required for optimization purposes (these values are usually set to the actual value). The prediction horizon can vary depending on the application and it can be consider as short term for prediction up to 60 minutes, or long-term forecast for hourly, daily, and monthly prediction values.

Therefore, the availability of at least approximated future estimations could considerably improve the control results. The main subtasks will be:

T2.1. Primary energy/disturbance forecast. Renewable energy plants are characterized by the fact that the primary energy source (sun, wind, ...) cannot be controlled and varies during the day. In that sense, renewable energy plants have to be started each day and usually depend on auxiliary conventional energy sources. Thus, the identification and prediction of these primary energy sources (that also act as disturbances from the control point of view) is of particular interest to optimize the process performance, minimize the use of auxiliary energy sources and planning to optimize the electrical grid based on the requested demand. Both time series based models and artificial neural networks models will be studied.

Groups involved: CIEMAT, ISA-USE, UAL, UVA, TMT-USE.
Task life: 18 months.
Deliverables:
D2.1.1: Report on methodologies for estimating primary energy in micro-grids (M18)
Milestones:
M2.1.1: Algorithms providing estimators and predictors of primary energy sources (M18)

T2.2. Electricity and energy demand forecast. One of the main objectives of this project is to provide methodologies for cooperative control of energy systems in micro grids. Thus, in order to maximize the use of renewable resources, it is necessary to estimate the energy demands within the micro-grid to help taking decisions about energy storage and final use of energy. The energy coming from renewable sources can be used for many purposes: lighting, transport, climate and comfort demands fulfilment, crop production, water desalination, ..., or even to be stored for future use. Thus, the purpose of this task is to find estimators of the main energy demands in micro-grids. In particular: predictors of insider climate variables; predictors of electricity demand and storage: lighting, cars, …; predictors of energy demand and storage: buildings, greenhouses, water desalination plants, …

Groups involved: CIEMAT, ISA-USE, UAL, UVA, TMT-USE.
Task life: 18 months.
Deliverables: D2.2.1: Report on methodologies for estimating electricity and energy demand in micro-grids (M18)
Milestones: M2.2.1: Algorithms providing estimators and predictors of electricity and energy demand in micro-grids (M18)

T3. Validation of the proposed methodologies for modelling, identification and prediction.

Task leader: ISA-US

The proposed procedures and tools for modelling, identification and prediction must be demonstrated on some experimental plants in order to demonstrate their results and efficiency. For the achievement of the proposed goal, the following steps should be considered:

- Development or conditioning of the different plants
- Modelling of each plant based on first principles (or prior knowledge) according to the proposed modelling methodology (related to task 1)
- Analysis of the software tools to be used in the identification and validation of the model (related to task 2)
- Definition of the tests to be executed in each plant for validation of the model, estimation and diagnosis.
- Analysis of the obtained results and validation the obtained model
- Execution of the proposed algorithms for estimation and diagnosis and validation of the obtained results.

The different plants to be used throughout this project have been proposed by each involved group aiming the following properties: real scale of the process, industrial interest, exhibition of interconnected and changing modes of operation, availability for the experiments. The chosen processes for the validation are the following:

a) Almeria-CIEMAT installation

This test bed system is located at the University of Almería, the Plataforma Solar de Almería-CIEMAT and the Estación Experimental Las Palmerillas-CAJAMAR, includes a bioclimatic building – CIESOL, a greenhouse, a solar desalination plant and electrical vehicles. The system is shown in figure 3.1.

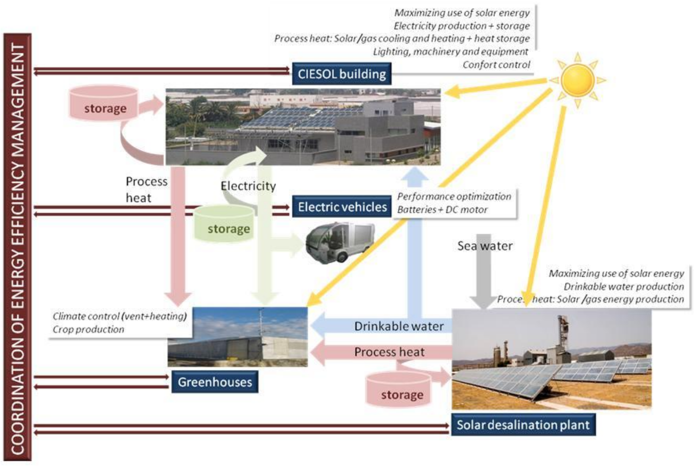


Figure 3.1. Layout of the test bed system where cooperative MPC will be applied

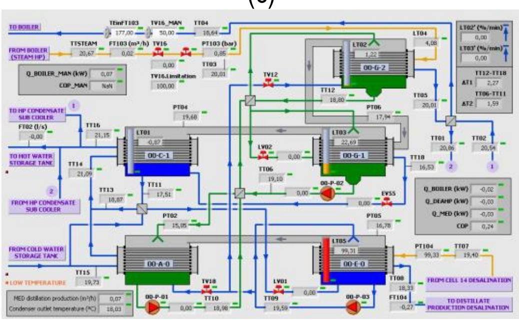
Building: CIESOL is a bioclimatic research center located at the University of Almería. In this building, active control of inside comfort can be carried out by means of a solar cooling and heating system, automated windows and blinds. More than 300 sensors (temperature, humidity, …) are installed to allow estimation of inside variables and comfort control. The roof of the building is composed by both photovoltaic cells (for producing electricity for lighting and other uses of the building) and solar collectors (for producing process heat). The full solar cooling system consists in a field of solar flat collectors which is used to supply hot water to an absorption machine generating chilled water for air conditioning.

Solar desalination plant: The AQUASOL system (figure 3.2) basically consists of a CPC (Compound Parabolic Concentrator) solar collector field, two water storage tanks, a multi-effect distillation plant (MED) and a double effect absorption heat pump (DEAHP) coupled to a gas boiler. The MED plant consists of 14 effects at decreasing temperatures from cell 1 to 14 and. Seawater is pumped to the first cell where first evaporation is produced at the same time that the rest of seawater goes to the following cells by gravity. To get the first seawater evaporation, in the first cell there is a heat exchanger working with water from primary tank. Specifically, for the optimal MED operation, it is necessary an inlet heat exchanger water temperature of 66.5ºC. This temperature is possible to reach with heat from the solar field and also with the absorption heat pump. Energy supplied by the collectors and DEAHP is transferred to the primary tank using water as the heat transfer fluid. To reduce the overall fossil energy expenditure, the low-pressure steam from the last cell is used in the DEAHP, which decreases consumption from 200 kW to 90 kW. The AQUASOL plant can operate in three different modes; solar, fossil and hybrid. This plant constitutes an excellent test-bed (unique in the world) for testing control strategies with switching operating modes.


(a)


(b)


(c)



(d) (e)

Figure 3.2. AQUASOL Solar desalination plant: (a) Solar field, (b) storage tanks and building of the solar desalination plant at PSA and (c) double effect heat pump (d) SCADA of the DEHP (e) MED desalination plant

Greenhouse: The experiments of this project will be carried out in a "Parral" type greenhouse with a symmetric curved flat roof greenhouse with five North-South oriented spans of 7.56 x 23.2 m (877 m^2 total soil surface) and height ranging from 2.8 m to 4.4 m. The control actuators installed in the greenhouse are automated flap roof and rolling lateral continuous ventilators. For heating purposes a petrol heater is employed as well as aerial tubes with hot water that can come from a conventional boiler, a biomass boiler or from a solar collector. A complete fertirrigation system has been installed. Many sensors (outside and inside climate, and others) and actuators (ventilation and heating) are permit monitoring and control. The greenhouse could be seen as the interconnection of several energy sources: the outside climate, the fertirrigation system, the heating system and the natural ventilation system, thus exhibiting different operation modes. Therefore, this plant is a good study case for hierarchical predictive control of a system using solar energy for photosynthesis and heating purposes and incorporating generation and demand objectives (different time scales).

Electrical vehicles: the development of the project includes the use and storage of electrical energy generated using renewable energies in electric vehicles, used for transportation and agricultural tasks. The project will develop algorithms to try to optimize the energy efficiency of these vehicles, as well as to optimize routing between different locations in the selected energy-efficient environment.

b) Laboratory-scale renewable energy micro-grid

This laboratory plant is located at the University of Seville. The system includes renewable energy, an electrolyser, hydrogen storage, a fuel cell and also plug-in hybrid vehicles. One of them will be a real vehicle, developed in this project (also used as an isolated system test bed), and the others will be emulated by batteries connected to the grid, to test the charge-discharge process of real vehicles. Figure 3.3 shows a block diagram and a photo of the system.

The plant is equipped with a 6 kW programmable power supply to simulate cycles of electricity generation from various renewable sources (wind speed curves of wind turbines, radiation curves in photovoltaic and solar thermal plants, etc.), a PEM electrolyser (1 kW) for hydrogen production, a hydride tank for H_2 storage, a PEM Fuel cell of 1.5 kW, electronic loads of 2.5 kW to simulate different use conditions of the grid use and finally various auxiliary systems required for the operation of the plant: waste water, cooling water, hot water, nitrogen inerting, gas detection, etc..

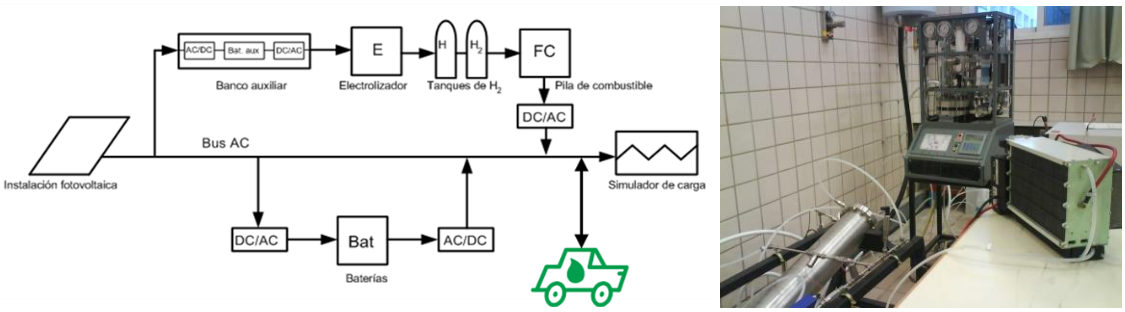


Figure 3.3. Block diagram of the proposed plant and photo of the existing facilities in the lab (electrolyzer, fuel cell, hydride tank and load).

c) Fuel Cell Hybrid Vehicle

An electric vehicle will be developed in the project framework to validate the results of the project regarding isolated systems. Also, it will be connected to the renewable energy micro-grid described previously, as a plug-in hybrid vehicle. The groups of USE has a wide experience in the development of hybrid vehicles, participating in

DELFIN and HERCULES Projects, both of them with the main objective of the development of a Fuel-Cell Hybrid Vehicle.

In the proposed vehicle, the electrical motors are fed by different energy systems, (a fuel cell, batteries and ultra-capacitors). These energy systems are connected to a DC bus through DC/DC converters. The DC/DC converter which connects the fuel cell to the DC bus is unidirectional and rises the fuel cell voltage to the DC bus voltage. The other converters are bidirectional, allowing regenerative braking and battery/ultra-capacitors recharging. Also a bidirectional DC/AC converter is needed to connect the DC bus and the electric motor. The control strategies and algorithms will be implemented on ECUs, based on PC-104 architecture.

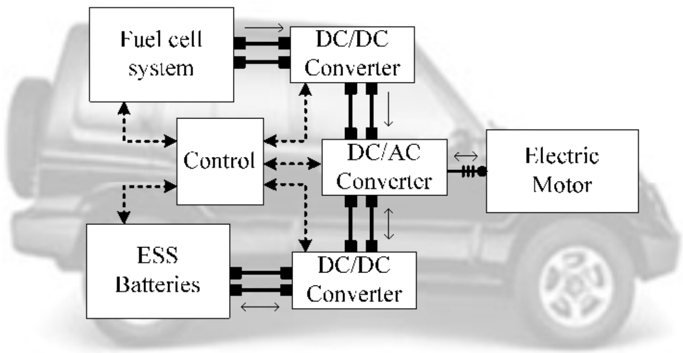


Fig 3.4. Fuel Cell Hybrid Vehicle

A chassis of a commercial car, already available, will be used. The specifications of the vehicle will be fully defined in the framework of the project. The equipment will be selected and purchased and finally the different systems will be integrated in the vehicle.

d) Reverse Osmosis Desalination Plant

In order to gain real experience with the new system concept a demonstration facility in Borj Cedria, Tunisia, will be used. It is placed in a region of adequate wind and solar radiance. The power supply system comprises the following components: A photovoltaic generator with 80 silicon mono-crystalline PV modules with a total capacity of 185 Wp, a wind turbine with 15 kW maximum power installed on a 25 m height tower, a battery bank with a total capacity of 30 KWh and a Diesel Generator with 20 KVA. Three synchronised single-phase battery inverters are interconnected to form a three-phase system. The battery inverter is the master and the others provide an output with a phase difference of 120" and 240° respectively. The nominal power output of this system is 11 kW. Unbalanced loads can be supplied if the total load on each single phase does not exceed the limitations given for one battery inverter 3.6 kW. All three inverters are connected to the same battery bank. The total energy of the PV and wind inverters connected to the AC-bus should not exceed the battery inverters nominal power. As load a Reverse Osmosis (RO) desalinization unit is available, that produces up to 24 m3/day.

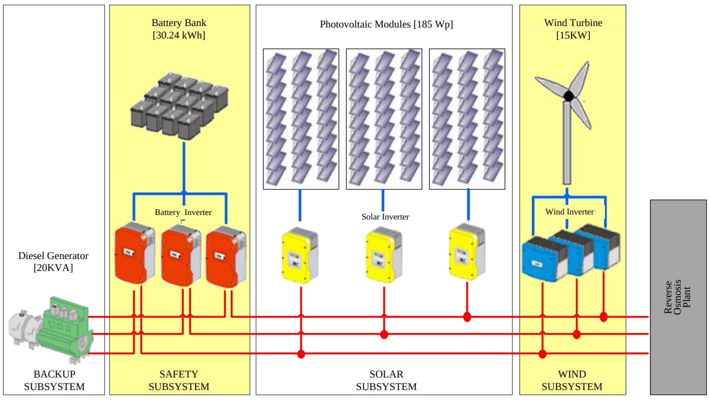


Figure 3.5. Renewable-energy desalination plant.

The subtasks will be:

T3.1. Development and/or conditioning of experimental plants

The work in this subtask will include conditioning of the existing plants, that is, the installation of the necessary sensors, actuators, communication and computing equipment to allow experimentation in this project. Nevertheless, the most important activity in this task will be the design, development and integration of a fuel cell hybrid vehicle based on a commercial existing vehicle.

Groups involved: ISA-US, CIEMAT, UAL, UVA, TMT-US.
Task life: 24 months.
Deliverables:
D3.1.1: Report on conditioning of Almeria-CIEMAT installation (M18)
D3.1.2: Report on conditioning of the Laboratory-scale renewable energy micro-grid (M18)
D3.1.3: Report on conditioning of Reverse Osmosis Desalination Plant (M18)
D3.1.4: Report on development of an fuel cell hybrid car (M24)
Milestones:
M3.1.1: Almeria-CIEMAT installation conditioned (M18)
M3.1.2: Laboratory-scale renewable energy micro-grid conditioned (M18)
M3.1.3: Reverse Osmosis Desalination Plant conditioned (M18)
M3.1.4: fuel cell hybrid car developed (M24)

T3.2 Development of models of innovative installations used in the project. This subtask is devoted to develop models for the demonstration plants used in the project, based on the methodologies and libraries developed in tasks T1.1 and T1.2. The main components of the installations to be modelled are:

- Electricity generators based on renewable energies: solar and wind electricity generators.
- Process heat generators: mainly solar collectors.
- Heat pumps (both single and double effect) to be used for solar water desalination and solar cooling).
- Special components: solar cooling systems, multi-effect distillation plants, fuel cells, electrolyzer, metal hydride
- Storage systems: both thermal and hydrogen storage.
- Energy containers: buildings, greenhouses, vehicles (hybrid and electrical).

Groups involved: CIEMAT, ISA-US, UAL, UVA, TMT-US.
Task life: 18 months.

Deliverables:

D3.2.1: Report on models of Almeria-CIEMAT installation (M24)
D3.2.2: Report on models of the Laboratory-scale renewable energy micro-grid (M24)
D3.2.3: Report on models of Reverse Osmosis Desalination Plant (M24)
D3.2.4: Report on models of the fuel cell hybrid car (M24)

Milestones:

M3.2.1: Models of the experimental plants (M24)

T3.3. Validation of the methodologies on the experimental plants

This task includes the analysis of the software tools to be used in the modelling, identification and prediction, the definition of the tests to be executed in each plant for validation of the model, estimation and diagnosis and, finally the analysis of the obtained results.

Groups involved: CIEMAT, ISA-US, UAL, UVA, TMT-US.
Task life: 18 months.
Deliverables:

D3.3.1: Report on validation and analysis of results on Almeria-CIEMAT installation (M30)
D3.3.2: Report on validation and analysis of results on the Laboratory-scale renewable energy micro-grid (M30)
D3.3.3: Report on validation and analysis of results on the Reverse Osmosis Desalination Plant (M30)
D3.3.4: Report on validation and analysis of results on the fuel cell hybrid car (M30)

Milestones:

M3.3.1: Experimental plants validated (M30)

T4. MPC formulations for the optimal economic management of isolated energy systems

Task Leader: UVA.

This task addresses the synthesis of controllers for isolated energy systems. For this, a methodology will be developed to use the possible degrees of freedom in the energy demand to regulate energy withdrawal. Thus, this task will develop algorithms based on adapting energy demand to energy production (and vice versa) through the use of the predictive control algorithms and the methodologies developed in Task 2, validated in Task 3. Economic performance and optimal energy management will be taken explicitly into account in the derivation of the proposed predictive control technique. The proposed methodology will be translated to the proposed study cases on isolated energy micro-grids: the water production plant and the vehicle.

T4.1. Economic MPC and supervisory control for optimal energy management. Predictive control techniques typically focus on the tracking error throughout plant transients. However, from an optimal management point of view, the cost function to optimize should be the criterion used to measure the economic profit of the plant. Firstly, this task will deal with the study of the economic performance index to be considered in the predictive control of isolated energy systems. This will be closely related to the results derived from tasks 1, 2 and 3. The derived cost function will make that existing theory on predictive control cannot be directly applied and the study of the formulation of such problem will be carried out.

Groups involved: ISA-USE, UAL, UVA
Task life: 12 months.

Deliverables:

D4.1.1: Report on cost functions for Economic MPC and supervisory control for optimal energy management (M18)

Milestones:

M4.1.1: Economic performance indexes for economic MPC (M30)

T4.2. Integrating RTO in economic MPC. Once the economic MPC for the optimal management of the isolated energy micro-grids is proposed, in this second task the problem of changing operating point will be investigated. In effect, most of the controllers are subject to changes on the equilibrium point where the plant is operated. These changes may be a consequence of modifications on the economic criterion (derived for instance from variations on the market), or external disturbances (as for instance the effect of load changes or eventual failures in a subsystem) among others. This problem is typically addressed by an hierarchical structure, based on an real time optimizer in the upper level which calculates the new set-point for the lower level predictive controllers. This real time optimizer does not take into account issues such as transient performance or feasibility of the predictive control laws. In this task, an economic predictive control law which integrates the RTO will be studied. Thus, the derived predictive control law merge the standard two-level structure in only one providing optimal energy management.

Groups involved: ISA-USE, UAL, UVA
Task life: 12 months.
Deliverables:

D4.2.1: Report on integrating Real Time Optimization in Economic MPC (M18)

Milestones:

M4.2.1: Methods developed for integrating RTO in economic MPC (M18)

T4.3. Stabilizing design of the proposed predictive methodology. This task will study the stability of the proposed predictive methodology. Firstly, a suitable stability framework will be investigated. Then stabilizing conditions of the proposed economic MPC will be proposed leading to stabilizing design methodology. Then these conditions will be extended to the predictive control technique for changing operation points, where feasibility guarantee problem plays a relevant role.

Groups involved: ISA-USE, UVA
Task life: 12 months.
Deliverables:

D4.3.1: Report on the stability of economic MPC (M24)

Milestones:

M4.3.1: Methods developed for stabilizing economic MPC (M24)

T4.4. Particularization of the methodology for water production using reverse osmosis and renewable energies. As first case study, this project will study the frequent situation in remote communities of producing drinkable water through local renewable energies. There is a tendency now to produce water for these communities using Reverse Osmosis (RO). Unfortunately these RO Systems consume plenty of electrical energy, mainly due to the high-pressure pumps needed to compensate the osmosis pressure. As it has been mentioned, the main difficulty found when using renewable energies off-grid, is the short-term unreliability of the power supply (in the presence of clouds, wind gusts, etc). Thus, it is usually the fact that some days there is a waste of excess energy, and other days the renewable energy is not enough to supply the instantaneous demand. Thus, big storages tank and are frequently needed (which are costly and increase losses by evaporation), and the desalination facilities have to be shut down when there is no energy supply (which is not recommended, as they are very sensitive to improper shutdowns). In this subtask the predictive methodologies previously presented will be adapted to this specific problem, in order to adapt water production to water consumption. Thus, water consumption is closely monitored, so predictions of consumptions can be used to schedule cleaning times and rate of water production, using the algorithms developed in this project.

Groups involved: UVA, ISA-USE.
Task life: 12 months.
Deliverables:
D4.4.1: Report on the particularization of the methodologies for water production using reverse osmosis (M36)
Milestones:
M4.4.1: Algorithms particularized for water production using reverse osmosis plants (M36)

T4.5. Particularization of the methodology to vehicles. Since a hybrid vehicle can be considered as an isolated micro-grid, the energy management of the vehicle will be addressed using Economic MPC integrating RTO. In order to do that, a hybrid vehicle will be developed during the project, using the previous experience of the groups in the "Hercules" project, where a FCHV was developed by the consortium. An existing vehicle will be equipped with a small FC and electric motors to develop a range-extended plug-in electric vehicle. The control strategies will be implemented in embedded controllers using several ECUs (Electronic Control Units). It is expected that the vehicle will have independent motors on each wheel, where there is a low-level controller for each wheel and a general control system or chassis control in a second level. By using this approach and model predictive control methods, different improvements are expected to be achieved: improved adhesion between tire and road, high performance braking, efficient control of position (turn and slip) and expected driving conditions (state of the road).

Groups involved: ISA-USE, UAL, UVA, TMT-USE.
Task life: 12 months.
Deliverables:
D4.4.1: Report on the particularization of the methodologies to hybrid vehicles (M36)
Milestones:
M4.4.1: Algorithms particularized for hybrid vehicles (M36)

T5. MPC cooperative formulations for the optimal economic management of interconnected energy systems

Task Leader: ISA-USE

Although Energy micro-grids can be operated solely, they usually are interconnected in a network of micro-grids. From an economic point of view, the network acts as a whole system that should be globally controlled to provide the optimal energy management. However, each micro-grid is typically controlled locally, leading to a loss of optimality even in the case that each micro-grid is optimally operated. In order to reduce this loss and enhance the efficiency of the whole system, each local predictive controller should cooperate. This task is focused to the study of the cooperative predictive control law from an economic point of view. Particular interest deserves the economic criterion of the whole plant which will be the real measure of the goodness of the cooperative control technique. The derived predictive controllers will be particularized for the proposed study cases: the CIESOL-AQUASOL-Greenhouse system and the Laboratory-scale Renewable Energy micro-grid.

T5.1. Formulation of cooperative MPC for optimal energy management. This task will extend the economic predictive control derived in Task 4.1 for isolated energy micro-grids to the case of interconnected micro-grids. Thus, cooperative control techniques will be extended to the proposed economic cost function. The economic optimality of the different cooperative predictive control techniques will be analyzed according to the economic index of the whole plant. Cooperation procedure and communication requirements will be studied.

Groups involved: ISA-USE, UAL, UVA.
Task life: 12 months.
Deliverables:
D5.1.1: Report on newly developed formulation of cooperative MPC for optimal energy management (M12)
Milestones:
M5.1.1: Methods developed for cooperative MPC for optimal energy management (M12)

T5.2. Integration of RTO in cooperative MPC. Once the economic cooperative MPC for energy micro-grids is proposed, in this second task the problem of changing operating point will be investigated. This is particularly interesting for interconnected systems, since the operation point is a global equilibrium point that may change as a consequence of a disturbance (or economic change) in any of the micro-grid that compounds the whole system. The results on changing operation points for isolated micro-grids derived in Task 4.2 will be the base of the integration of the RTO in the cooperative economic MPC. However the problem is far more complex since feasibility of each predictive control must be ensured under any change in any of the micro-grids. Furthermore, economic optimality of the whole system must be studied.

Groups involved: ISA-USE, UAL, UVA.
Task life: 12 months.
Deliverables:
D5.2.1: Report on integration of RTO in cooperative MPC for optimal energy management (M24)
Milestones:
M5.2.1: Methods developed for integrating RTO in cooperative MPC for optimal energy management (M24)

T5.3. Stabilizing design of the cooperative predictive controllers. This task will study the stability of the proposed predictive methodology. Firstly, a suitable stability framework will be investigated. Then stabilizing conditions of the proposed economic MPC will be proposed leading to stabilizing design methodology. Then these conditions will be extended to the predictive control technique for changing operation points, where feasibility guarantee problem plays a relevant role.

Groups involved: ISA-USE, UAL, UVA.
Task life: 12 months.
Deliverables:
D5.3.1: Report on the stability of cooperative predictive controllers (M24)
Milestones:
M5.3.1: Methods developed for stabilizing cooperative predictive controllers (M24)

T5.4. Particularization of the methodology to the experimental plants The approaches and algorithms developed in tasks T5.1, T5.2 and T5.3 will be particularized to real systems, specifically to the experimental plants CIESOL-AQUASOL-Greenhouse platform and Laboratory-scale Renewable Energy micro-grid

Groups involved: CIEMAT, UAL, ISA-USE, TMT-USE
Task life: 12 months.
Deliverables:

D5.4.1: Report on the particularization of the methodologies to the CIESOL-AQUASOL-Greenhouse platform (M36)
D5.4.2: Report on the particularization of the methodologies to the Laboratory-scale Renewable Energy micro-grid (M36)

Milestones:

M5.4.1: Algorithms particularized for the CIESOL-AQUASOL-Greenhouse platform (M36)
M5.4.2: Algorithms particularized for the Laboratory-scale Renewable Energy micro-grid (M36)

T6. Robust design of optimal economic predictive controller

Task Leader: ISA-USE.

In the previous task 4 and 5, predictive control methodology for energy micro-grids will be derived. These will deal with the case of both isolated and interconnected energy micro-grids. Optimality and stability of these controllers will be also studied. This task is aimed to extend the proposed control techniques to the case when there exists uncertainty in the prediction model. Firstly, robustness analysis of the economic MPC will be studied. Then, the proposed predictive controllers based on the nominal prediction models will be robustified to deal with the possible uncertainties. Furthermore, the cancellation of the effect of the uncertainty on the economically optimal operation point will be studied. In the case that uncertainty/disturbance are significant, these must be taken into account in the predictions in order to provide optimality to the controlled system. This will be studied in the last subtask.

T6.1. Robustness analysis of the optimal economic predictive controller. It is well known that predictive controllers may exhibit zero-robustness. This makes compulsory the robustness analysis of the proposed predictive methodologies for their practical application. In this subtask, the existing results on this topic will be extended to the proposed stability framework and robustness conditions will be proposed for the economic MPC.

Groups involved: ISA-USE, UAL, UVA.
Task life: 12 months.
Deliverables:

D6.1.1: Report on robustness analysis of the optimal economic predictive controller (M24)

Milestones:

M6.1.1: Robustness analysis of the optimal economic predictive controller (M24)

T6.2. Robust design of the predictive controllers based on nominal predictions. A first approach to the robust design of predictive controllers is to robustify the nominal predictive controller to achieve certain degree of robustness. This can be done by considering the global effect of the uncertainty on the predicted trajectories and adapting the terms of the optimization problem accordingly. These ideas will be translated to the economic MPC proposed in tasks 4 and 5 and robust nominal predictive controllers will be proposes. Robust feasibility problem, which is relevant for the practical application of the controller, will be studied. Economic optimality of the uncertain system will also be studied.

Groups involved: ISA-USE, UAL, UVA.
Task life: 12 months.
Deliverables:

D6.1.1: Report on newly developed algorithms for robust design of predictive controllers (M24)

Milestones:

M6.1.1: Methods for robust design of predictive controllers (M24)

T6.3. Offset cancellation in optimal economic MPC under changing operation points. Once of the main effect of the uncertainty or unexpected disturbance on the controlled plant is a possible modification of the operation point far from the economic one. Then from an economic point of view, it would be interesting that this discrepancy where removed. This task will study this problem and model disturbance methodology will be extended to the economic case. An interesting issue on this problem is to take into account the economic criterion in the removal, since may happen that the disturbance makes the system more profitable.

Groups involved: ISA-USE, UAL, UVA.
Task life: 12 months.
Deliverables:
D6.3.1: Report on offset cancellation in optimal economic MPC (M30)

T6.4. Robustly optimal formulation of the economic MPC. In the case that the uncertainty is large enough or that the optimality degradation of a nominal prediction-based robust MPC is significant, a more involved robust predictive control technique may be used. Such controllers typically consider a closed-loop formulation of the robust predictive controllers. Furthermore optimal robust criterion, such as min-max, or H_∞ are taken into account. The aim of this subtask is to study the extension of such robust predictive formulations to the economic predictive control technique. Closed-loop performance as well as robust feasibility under possible changes in the operation point will also be studied.

Groups involved: ISA-USE, UAL, UVA.
Task life: 12 months.
Deliverables:
D6.4.1: Report on robustly optimal formulation of the economic MPC (M30)
Milestones:
M6.4.1: Algorithms for the extension of robust predictive formulations to the economic predictive control technique (M30)

T7. Validation of the proposed control strategies on the representative plants.

Task Leader: TMT-USE

The obtained analysis tools and algorithms will be validated over the experimental plants in order to demonstrate their properties and benefits. The objective is not to validate each of the developed controllers in all the reference plants, but to apply the controller considered to be more suitable for each plant. This selection will be done in such a way that most, if not all, of the proposed controllers, are tested in at least one experimental plant. The steps taken to validate a particular controller require in general of the following steps:

1. Design the test to be executed in the plant and its validation protocol.
2. Implementation of the controller.
3. Re-configuration of the plant and preparation of the test.
4. Execution of the test.
5. Analysis of the obtained results.

The task is composed of the following subtasks:

T7.1. Preparation of experimental systems: This subtask consists of making the necessary modifications in the reference plants so that the experiments can be carried out. There will be a joint development with different groups of test plan to define the main parameters to evaluate the role of different operational criteria considered: technical, economic, energy efficiency, security of supply, etc.

Groups involved: ISA-USE, UAL, TMT-USE, CIEMAT
Task life: 12 months.
Deliverables:
D7.1.1: Report on the modification done to the experimental plants (M12)
Milestones:
M7.1.1: Modifications done to the experimental plants (M12)

T7.2. Preparation of experiments: This subtask consists of preparing the experiments on the reference plants so that the experiments can be carried out. This, in general, will involve slight changes in both plants.

Groups involved: ISA-USE, UAL, UVA.
Task life: 12 months.
Deliverables:
D7.2.1: List of experiments to be carried out (M18)

T7.3. Carrying out the experiments: This subtask consists of running the programmed experiments. This may involve a substantial amount of time as each of the experiment will typically last for various days for the energy plants and several hours in the case of the hybrid vehicle.

Groups involved: ISA-USE, UAL, TMT-USE, CIEMAT.
Task life: 10 months.
Deliverables:
D7.3.1: Report on the evolution of the experiments (M36)
Milestones:
M7.3.1: Experimental results validated (M36)

T7.4. Analyzing the results: This subtask consists of analyzing the results of the experiments and producing the appropriate reports. The data will be made available to all members of the group and the analysis will be examined at the task leaders meetings.

Groups involved: ISA-USE, UAL, TMT-USE, UVA, CIEMAT.
Task life: 6 months.
Deliverables:
D7.4.1: Report on the analysis of the results (M36)
Milestones:
M7.4.1: Experimental results analysed by all the groups (M36)

T8 Dissemination of the results.

Task Leader: ISA-USE.

This task is devoted to the diffusion of results, either final ones that can be useful to the rest of the scientific community or for interchange of partial results of the project between their members. This will mainly cover the creation of a web page of the coordinate project and a database for data exchange of the different test plants involved in the project.

The task will also consider the writing of papers to be submitted to the main control conferences (IEEE CDC, IFAC world Congress, ACC an European Control Conferences) and in addition conferences related to the reference applications. The results will also be submitted to the main journals in the field, such as Automatica, IEEE Trans. In Automatic Control, Journal of Process Control, Journal of Power Sources and Control Engineering Practice.

Groups involved: All
Task life: 36 months.
Deliverables:
D8.1.1: Project Website (M36)
Milestones:
M8.1.1: Opening of the project website (M6)

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4.1 CHRONOGRAM MODEL

This chronogram must indicate the persons involved in the project, including those contracted with project funds.
Underline the name of the person responsible of each task.

4.1 CRONOGRAMA / CRONOGRAM

SUBPROJECT 1: Universidad de Sevilla, Departamento de Ingeniería de Sistemas y Automática (Acronym: ISA-USE)

Acronym	*Name*	*Role*	*Entity*
CBA	Carlos Bordons Alba	Main Researcher (Dr., employee)	ISA-USE
TAC	Teodoro Rafael Álamo Cantarero	Researcher (Dr., employee)	ISA-USE
MARC	Miguel Angel Ridao Carlini	Researcher (Dr., employee)	ISA-USE
DLM	Daniel Limón Marruedo	Researcher (Dr., employee)	ISA-USE
DRR	Daniel Rodríguez Ramírez	Researcher (Dr., employee)	ISA-USE
DMPS	David Muñoz de la Peña Sequedo	Researcher (Dr., employee)	ISA-USE
FDN	Fernando Dorado Navas	Researcher (Dr., contracted employee)	ISA-USE
ANR	Amparo Nuñez Reyes	Researcher (Dr., contracted employee)	ISA-USE
AZC	Ascensión Zafra Cabeza	Researcher (Dr., contracted employee)	ISA-USE
IAA	Ignacio Alvarado Aldea	Researcher (Dr., contracted employee)	ISA-USE
JKG	Jorn Klass Gruber	Researcher (contracted employee)	ISA-USE
JMMT	José María Maestre Torreblanca	Researcher (contracted employee)	ISA-USE
AAR	Alicia Arce Rubio	Researcher (contracted employee)	ISA-USE
JMEG	José Manuel Escaño González	Researcher(contracted employee)	ISA-USE
CON_ISA1	Contratado que se solicita	Contracted that is asked for	ISA-USE
CON_ISA2	Contratado que se solicita	Contracted that is asked for	ISA-USE

SUBPROJECT 2: Universidad de Almería (Acronym: UAL)

Acronym	Name	Role	Entity
FRD	Rodríguez Díaz, Francisco	Main Researcher (Dr., employee	UAL
MBS	Berenguel Soria, Manuel	Researcher (Dr., employee)	UAL
JMU	Moreno Úbeda, José Carlos	Researcher (Dr., employee)	UAL
JGD	García Donaire, Julián	Researcher (Dr., employee)	UAL
MPG	Pérez García, Manuel	Researcher (Dr., employee)	UAL
JSL	Sánchez-Hermosilla López, Julián	Researcher (Dr., employee)	UAL
JAH	Álvarez Hervás, José Domingo	Researcher (Dr., contracted employee)	UAL
RGS	González Sanchez, Ramón	Researcher (FPU ME Spanish Government scholarship holder)	UAL
MCN	Castilla Nieto, María del Mar	Researcher (FPDI Andalusia Government scholarship holder)	UAL
CON_UAL	Contratado que se solicita	Contracted that is asked for	UAL

SUBPROJECT 3: Universidad de Sevilla – Grupo de Termotecnia (Acronym: TMT-USE), Instituto Nacional de Técnica Aeroespacial (Acronym: INTA)

Acronym	Name	Role	Entity
FRI	Manuel Felipe Rosa Iglesias	Main Researcher (Dr. employee)	TMT-USE
JGM	José Guerra Macho	Researcher (Dr. employee)	TMT-USE
JPL	Francisco Javier Pino Lucena	Researcher (employee)	TMT-USE
LVI	Luis Valverde Isorna	Researcher (contracted employee)	TMT-USE
AIP	Alfredo Iranzo Paricio	Researcher (contracted employee)	TMT-USE
ELG	Eduardo M. López González	Researcher (employee)	INTA
CON_TMT	Contratado que se solicita	Contracted that is asked for	TMT-USE

SUBPROJECT 4: Universidad de Valladolid (Acronym: UVA)

Acronym	*Name*	*Role*	*Entity*
TAA	Teresa Alvarez Alvarez	Main Researcher (Dr., employee)	UVA
FTR	Fernando Tadeo Rico	Researcher (Dr., employee)	UVA
MAGB	Miguel Angel García Blanco	Researcher (Dr., employee)	UVA
JSS	Johanna Salazar Salas	Scholarship holder	UVA
MF	Mesquine Fouad	Researcher (Dr.)	External
AB	Abdellah Benzaouia	Researcher (Dr.)	External
HE	Hamza Elfil	Researcher (Dr.)	External
CON_UVA	Contratado que se solicita	Contracted that is asked for	ISA-UVA

SUBPROJECT 5: CIEMAT

Acronym	*Name*	*Role*	*Entity*
LYM	Luis J. Yebra Muñoz	Main Researcher (Dr., employee)	CIEMAT
JBC	Javier Bonilla Cruz	Researcher (employee)	CIEMAT
LRS	Lidia Roca Sobrino	Researcher (Dr., employee)	CIEMAT
DMP	Diego Martínez Plaza	Scholarship holder	CIEMAT
DAP	Diego César Alarcón Padilla	Researcher (Dr., employee)	CIEMAT
AVD	Alfonso Vidal Delgado	Researcher (employee)	CIEMAT
JFN	Joaquín Fernández Navarro	Researcher (employee)	CIEMAT
ACA	Alberto De la calle Alonso	Researcher (employee)	CIEMAT
MBH	Marta Benavides Hidalgo	Scholarship holder	CIEMAT-UAL

<table>
<tr><th>Tasks</th><th>Centre</th><th>Persons</th><th>First Year (*)</th><th>Second Year (*)</th><th>Third Year (*)</th></tr>
<tr><td>T0. Coordination and Project management</td><td>Leader: ISA-US
UAL
UVA
TMT-US
CIEMAT</td><td>CBA
FRD
TAA
FRI
LYM</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td></tr>
<tr><td>T1. Development of methodologies and platforms for modelling and simulation of energy systems: generation, storage and demand</td><td>Lider: CIEMAT</td><td></td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>x|x|x|x|x|x| | | | | |</td><td>| | | | | | | | | | |</td></tr>
<tr><td>T1.1. Development of a modelling framework oriented to the control of energy systems</td><td>CIEMAT
ISA-USE
UAL
UVA
TMT-USE</td><td>LYM, JBC,LRS,DMP
CBA,MARC,AAR
MPG, FRD, JMU, MBS
FTR, JSS, CON_UVA
JPL,LVI</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>x|x|x|x|x|x| | | | | |</td><td>| | | | | | | | | | |</td></tr>
<tr><td>T1.2 Development of a modelling and simulation environment</td><td>CIEMAT
ISA-USE
UAL

UVA
TMT-USE</td><td>DAP,AVD,JFM
MARC,AZC, FDN
MPG,JAH,MCN,
FGD,CON_UAL
FTR, JSS, CON_UVA
JPL,LVI</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>x|x|x|x|x|x| | | | | |</td><td>| | | | | | | | | | |</td></tr>
<tr><td>T2. Methodologies for identification and prediction of generation and demand</td><td>Leader:UAL</td><td></td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>x|x|x|x|x|x| | | | | |</td><td>| | | | | | | | | | |</td></tr>
<tr><td>T2.1. Primary energy/disturbance forecast</td><td>CIEMAT
ISA-USE
UAL
UVA
TMT-USE</td><td>LYM,ACA,MBH
DRR, ANR, IAA
FRD,MCN,JAH
FTR, JSS, CON_UVA
JPL,LVI,ELG</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>x|x|x|x|x|x| | | | | |</td><td>| | | | | | | | | | |</td></tr>
<tr><td>T2.2. Electricity and energy demand forecast</td><td>UVA
CIEMAT</td><td>FTR, JSS, CON_UVA
ACA,LYM,LRS</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>x|x|x|x|x|x| | | | | |</td><td>| | | | | | | | | | |</td></tr>
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<tr><td></td><td>UAL
TMT-USE</td><td>MARC, FDN, JMEC
MBS,MPG,JAH,MCN
JPL,LVI,ELG</td><td></td><td></td><td></td></tr>
<tr><td>T3. Validation of the proposed methodologies for modelling, identification and prediction</td><td>Leader: ISA-US</td><td></td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>x|x|x|x|x|x| | | | | |</td></tr>
<tr><td>T3.1. Development and/or conditioning of experimental plants</td><td>ISA-US

CIEMAT
UAL
UVA
TMT-US</td><td>CBA, MARC, IAA, JMEG, CON_ISA1, CON_ISA2
JBC,LRS
JAH,MCN,CON_UAL
MGB
JPL,LVI</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>| | | | | | | | | | |</td></tr>
<tr><td>T3.2 Development of models of innovative installations used in the project</td><td>CIEMAT
ISA-US
UAL

UVA
TMT-US</td><td>DMP,DAP,AVD
DRR, FDN, AMN, AZS
FRD, MCN,MPG
JGD,JSH,RGS
FTR,JSS
JPL,LVI</td><td>| | | | | | x|x|x|x|x|x</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>| | | | | | | | | | |</td></tr>
</table>

<table>
<tr><td>T3.3. Validation of the methodologies on the experimental plants</td><td>UVA

CIEMAT
ISA-US
UAL

TMT-US</td><td>FTR, JSS, CON_UVA, HE
LYM,LRS,JBC,MBH
AZN,CON_ISA1
IAA, JMMT, JMEG
JAH,JGD,MCN
RGS,CON_UAL
JPL,LVI</td><td>| | | | | | | | | | |</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>x|x|x|x|x|x| | | | | |</td></tr>
<tr><td>T4. MPC formulations for the optimal economic management of isolated energy systems</td><td>Leader: UAL</td><td></td><td>| | | | | | x|x|x|x|x|x</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td></tr>
<tr><td>T4.1. Economic MPC and supervisory control for optimal management</td><td>ISA-USE
UAL
UVA</td><td>DLM, JKG, JMMT
MBS,FRD,JAH,MCN
TAA, JSS, AB, MF</td><td>| | | | | | x|x|x|x|x|x</td><td>x|x|x|x|x|x| | | | | |</td><td>| | | | | | | | | | |</td></tr>
<tr><td>T4.2. Integrating RTO in economic MPC</td><td>ISA-USE
UAL
UVA</td><td>TAC, DLM, AZC, ANR
MBS,FRD,JAH,MCN
MGB</td><td>| | | | | | x|x|x|x|x|x</td><td>x|x|x|x|x|x| | | | | |</td><td>| | | | | | | | | | |</td></tr>
<tr><td>T4.3. Stabilizing design of the proposed predictive methodology</td><td>ISA-US</td><td>DMPS, DLM, IAA,</td><td>| | | | | | | | | | |</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>| | | | | | | | | | |</td></tr>
<tr><td>T4.4. Particularization of the methodology for water production using reverse osmosis and renewable energies</td><td>UVA
UAL</td><td>FTR,AB,MF
FRD,MBS</td><td>| | | | | | | | | | |</td><td>| | | | | | | | | | |</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td></tr>
<tr><td>T4.5. Particularization of the methodology to vehicles</td><td>ISA-US

UAL
UVA
TMT-USE</td><td>MARC, AAR, JMEG, CON_ISA1
JSH,RGS,JGD
TAA
JPL,ELG,LVI,AIP</td><td>| | | | | | | | | | |</td><td>| | | | | | | | | | |</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td></tr>
<tr><td>T5. MPC cooperative formulations for the optimal economic management of interconnected energy systems</td><td>Leader: ISA-US</td><td></td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td></tr>
<tr><td>T5.1. Formulation of cooperative MPC for optimal energy management</td><td>ISA-USE
UAL

UVA</td><td>CBA, FDN, JKG
MBS,FRD,JAH, MCN,RGS
TAA</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>| | | | | | | | | | |</td><td>| | | | | | | | | | |</td></tr>
<tr><td>T5.2. Integration of RTO in cooperative MPC</td><td>ISA-USE</td><td>DLM, DMPS, ANR</td><td>| | | | | | | | | | |</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>| | | | | | | | | | |</td></tr>
</table>

<table>
<tr><td></td><td>UAL

UVA</td><td>MBS,FRD,JAH,
MCN,RGS,JGD
MGB</td><td></td><td></td><td></td></tr>
<tr><td>T5.3. Stabilizing design of the cooperative predictive controllers</td><td>ISA-USE

UAL

UVA</td><td>TAC, DMPS, IAA,
JMMT
MBS,FRD,JDA,
MCN,RGS
AB,MF</td><td>| | | | | | | | | | |</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>| | | | | | | | | | |</td></tr>
<tr><td>T5.4. Particularization of the methodology to the experimental plants</td><td>CIEMAT
UAL

ISA-USE

TMT-USE
UVA</td><td>AVD,JFN,ACA
JSH,RGS,MCN,
JGD,CON_UAL
CBA, JMEG,
CON_ISA2
JPL,ELG,LVI,AIP
CON-UVA</td><td>| | | | | | | | | | |</td><td>| | | | | | | | | | |</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td></tr>
<tr><td>T6. Robust design of optimal economic predictive controller</td><td>Leader: ISA-US</td><td></td><td>| | | | | | | | | | |</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>x|x|x|x|x|x| | | | | ||</td></tr>
<tr><td>T6.1. Robustness analysis of the optimal economic predictive controller</td><td>ISA-USE
UAL</td><td>DLM, DRR, JKG
JCM,MBS,FRD,
JAH,MCN,RGS</td><td>| | | | | | | | | | |</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>| | | | | | | | | | |</td></tr>
<tr><td>T6.2. Robust design of the predictive controllers based on nominal predictions</td><td>ISA-USE
UAL</td><td>TAC, DMPS,IAA
JCM,MBS,FRD,
JAH,MCN,RGS</td><td>| | | | | | | | | | |</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>| | | | | | | | | | |</td></tr>
<tr><td>T6.3. Offset cancellation in optimal economic MPC under changing operation points</td><td>ISA-US
UAL</td><td>DLM, ANR, AAR
JCM,MBS,FRD,
JAH,MCN,RGS</td><td>| | | | | | | | | | |</td><td>| | | | | | x|x|x|x|x|x</td><td>x|x|x|x|x|x| | | | | |</td></tr>
<tr><td>T6.4. Robustly optimal formulation of the economic MPC</td><td>ISA-US
UAL

UVA</td><td>DLM,TAC
JCM,MBS,FRD,
JAH,MCN,RGS
FTR,AB,MF</td><td>| | | | | | | | | | |</td><td>| | | | | | x|x|x|x|x|x</td><td>x|x|x|x|x|x| | | | | |</td></tr>
<tr><td>T7.-Validation of the proposed control strategies on the representative plants</td><td>Leader: TMT-US</td><td></td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td></tr>
</table>

<table>
<tr><td>T7.1. Preparation of experimental systems.</td><td>TMT-USE

ISA-USE

CIEMAT</td><td>FRI,JGM,JPL,LVI,
FJP,AIP,ELG,
CON_TMT
CBA, DLM, FDN,
CON_ISA1,
CON_ISA2
DMP,AVD,JFN,ACA</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>| | | | | | | | | | |</td><td>| | | | | | | | | | |</td></tr>
<tr><td>T7.2. Preparation of experiments.</td><td>TMT-USE

ISA-USE

UAL</td><td>AIP,ELG,
CON_TMT
CON_ISA1,
CON_ISA2
FRD,JAH, CON_UAL</td><td>| | | | | | x|x |x|x |x |x</td><td>x|x|x|x|x| | | | | | |</td><td>| | | | | | | | | | |</td></tr>
<tr><td>T7.3. Carrying out the experiments.</td><td>TMT-USE
UAL
ISA-USE

CIEMAT
UVA</td><td>JSH,RGS,MCN,
JGD,CON_UAL
CON_ISA1,
CON_ISA2
HE,CON_UVA
TAA,JSS,HE,CON_UV</td><td>| | | | | | | | | | |</td><td>| | | | | x|x |x |x|x|x|x</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td></tr>
<tr><td>T7.4. Analyzing the results.</td><td>ISA-USE
UAL
TMT-USE
UVA
CIEMAT</td><td>TAC,CBA,JKG
MBS,JAH,RGS
FRI,JPL,LVI
TAA
LYM,LRS,DAP</td><td>| | | | | | | | | | |</td><td>| | | | | | | | | | |</td><td>| | | | | | | | x|x |x|x</td></tr>
<tr><td>T8.- Dissemination of the results</td><td>Leader: ISA-US
UAL
TMT-USE
UVA
CIEMAT</td><td>CBA
FRD
FRI
TAA,FTR,MGB
LYM</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td><td>x|x|x|x|x|x|x|x|x|x|x|x</td></tr>
</table>

(*) Mark an X inside the corresponding boxes (months)

5. BENEFITS DERIVED FROM THE PROJECT, DIFUSION AND EXPLOTATION OF RESULTS
(maximum **1** page)

The following items must be described:

- Scientific and technical contributions expected from the project, potential application or transfer of the expected results in the short, medium or large term, benefits derived from the increase of knowledge and technology.
- Diffusion plan and, if appropriate, exploitation plan of the results.

Expected contributions and benefits of the project

The global objective of the project is the development of a general framework for the model predictive control of renewable energy micro-grids. The expected benefits of this project are the following ones:

- Provide novel results in modelling, identification and control for a most relevant and fundamental field for the future of energy management in Spain: renewable energy micro-grids.
- Develop novel forecasting techniques which allow a flexible and efficient operation of the processes enhancing the economic operation of this class of systems which are subject to a great variability in both the generation and the demand.
- Achieve a technology transfer to potential the industry of energy production and distribution, process industry, car industry, etc.
- Research and development of novel results on the alternative energy source based on hydrogen technology. Hydrogen appears to have the potential to allow us to "overcome" the fact that fossil fuels are finite and reduce the environmental impact from their combustion. This could be achieved by the combination of hydrogen produced from renewable and Fuel Cells in such a way that a sustainable future, in terms of resource availability and environmental protection, holds.
- Research on techniques for an optimal management of different energy sources.

Summarizing, the benefits are twofold: developing novel scientific results on the modelling, analysis and controller design of interconnected multimodal systems and transferring these results to industry.

Adaptation to the priorities of the official announcement and of the *National Programme*

This proposal fits to the Programa Nacional de Diseño y Producción Industrial, directly evolved in several of the general objectives of this program, mainly in those related to the improvement of the processes, components and production procedure, and with the improvement of the information management and production organization. On the other hand, this project is allocated in the so-called basic research, and fits the priorities established in the National Program:

- Research activity motivated by ambitious and innovative objectives related with industry aspects.
- The proposed research integrates technologies based on system properties
- The project integrates different knowledge areas in innovative applications.

The specific fields of the National Program dealt by this project are the following ones:
1.- Modelling of systems and products. Experimental modelling. 2.- Simulation of systems and products. 7.- Monitoring and on-line data analysis. 8.- Advanced control of processes and systems. 9.- Detection and fault diagnosis. 10.- Complex systems and large scale networks. Hybrid and cooperative systems. 11.- Decision making aid systems and process optimization.

Dissemination plan

The usual way to disseminate the scientific results by the involved researchers is by papers or technical communications in books, book chapters, journals and international conferences and workshops (see curricula). It is expected to publish the obtained results in the most relevant international journals, such as IEEE Trans. On Automatic Control, Automatica, Control Engineering Practice, IEEE Trans. On Control Systems Technology, Journal of Process Control, IEEE Trans. On Industrial Electronics and Journal of Power Sources; as well as international conferences such as: IFAC (International Federation of Automatic Control) World Congress,

European Control Conference (ECC), Conference on Decision and Control (CDC) and American Control Conference (ACC).
Another way to make the obtained results accessible to the research community is by means of the web page. This can be used as a server of publications and technical reports and could also be used as forum for the research groups interested in the topic of the project. The members of the project are experienced in this sort of dissemination of results, as for instance, ISA-USE has been responsible of the dissemination activities in three European projects (PRIMA, AESOP and HD-MPC).

Exploitation of the results

The groups involved in this project are experienced in research activities related to companies as well as in research projects funded by the European Community and the Spanish ministry. This sort of projects, as for instance NEOXITE, AESOP or HD-MPC, has allowed interacting with companies potentially interested in the results derived from the proposed project such as Siemens, BP, INOCSA and PROCISA among others. Other research projects with national funding have encouraged the collaboration with Spanish companies and, therefore, there exists a potential interest of companies such as Hynergreen, Abengoa Solar NT, Greenpower and others.
The proposal has received the support of several companies. The UAL subproject is supported by Fundación CAJAMAR-Estación Experimental Las Palmerillas, which is the Foundation of the bank CAJAMAR devoted to technology transfer to agriculture and that is actively involved in the development of the project providing its installations to perform real tests. The proposal is also supported by the multinational Rijk Zwaan, which is going to build a energy-efficient agricultural technical park and is thus very interested in the results of this project and by the spin-off CADIA Ingeniería, as one of its business lines is the energy efficiency management.

6. BACKGROUND OF THE GROUP

(In the case of a coordinated project the topics 6. and 6.1. must be filled by each partner)
(maximum **2** pages)

~~**Indicate the previous activities and achievements of the group in the field of the project:**~~

If the project is related to other previously granted, you must indicate the objectives and the results achieved in the previous project. If the project approaches a new research field, the background and previous contributions of the group in this field must be indicated in order to justify the capacity of the group to carry out the project.

Subproject 1: ISA-USE: The main ingredients of the project are MPC, distributed energy systems and the applications: fuel cells, hybrid vehicles and energy micro-grids. The group has previous experience in these topics to a varying degree. The group members do their teaching and research activities in the Dpto. de Ingeniería de Sisternas y Automática de la Universidad de Sevilla. Most research tasks of the group members have been done on topics affine to that of this proposal. This research has produced books and journal and conference papers that can be found in their curricula. The research has been also done within several research projects in the last years. The group has been working in MPC for more than 15 years. The IP co-authored one of the few existing MPC books (Model predictive control 2nd edition, 2004, a first version of this book was published in 1995) and a significant number of publications. The group has a significant number of projects in the areas of Model predictive control funded by the Spanish government:

- Control Predictivo de procesos industriales con funcionamiento discontinuo. (DPI2001-2380-C02-01)
- Control Predictivo para procesos con incertidumbres acotadas. (DPI2002-4375-CO2-01)
- Control Predictivo integral de procesos en operación semicontinua (DPI2004-07444-C04-01)
- Control Predictivo de Sistemas Híbridos. (DPI2005-04568).
- Control Predictivo de Procesos Interconectados con Modos de Operación Diversos (DPI2007-66718-C04-01)

These projects aim at solving important aspects of MPC other than the one dealt with in this proposal. The group has also participated in European projects and networks of excellence, funded by the Regional government and by Companies that covered MPC. Research projects have also been developed with other relevant companies and institutions such as Telvent, PROCISA, Atlantic Copper, Hynergreen or INTA. These projects can be seen in the list of funded projects.

Subproject 2: UAL: The team of the University of Almería is mainly integrated by members of the research group "Automatic Control, Electronics and Robotics" (TEP-197 code of the Andalusian R&D Plan), also assigned to the Mixed Center UAL-CIEMAT CIESOL devoted to Solar Energy and related topics. The last year this group has gained the 2nd absolute position in score and funding at the University of Almería (1st in production technologies) and the 8th of 105 groups in production technologies at Andalusian level. It has an extensive experience in issues related directly or indirectly with the thematic of the project. The researchers have participated in more than 20 R+D projects related to this proposal, where object-oriented modelling techniques of thermosolar plants and greenhouses were studied, the design of robust, hybrid and switching model predictive control for processes subject to measurable disturbances was carried out and the proposal and development of a hierarchical control structure was tackled, also taking into account the multiobjective approach. The previous CICYT projects QUI99-0663-C02-02, DPI2001-2380-C02-02, DPI2002-04375-C03-03, DPI2004-07444-C04-04 y CICYT DPI2007-66718-C04-04 have been basic and fundamental to propose this new project, that is a natural evolution of these. Furthermore, they have given rise upon the publication of more than 50 papers in journals and more than 100 articles in Symposia, as well as 9 PhD Thesis. On the other hand, the research group is actively collaborating in the framework of the European project *FutureFarm*. Furthermore, the team also has an ample experience in the practical application of the developed control techniques, fundamentally in the field of intensive agriculture and the control of thermosolar plants, fields in which books such as "Advanced control of solar plants" (Springer, 1997), "Control and robotics in agriculture" (Service of Publications of the University of Almería, 2004) and "Techniques of prediction with applications in engineering" (Service of Publications of the University of Seville, 2006) have been published.

Subproject 3: TMT-USE The group TMT-USE has an important background on renewable energies, specifically in numerous projects related to processes associated with energy production and use, as well as optimization and energy efficiency. The working areas of the Group cover two main lines: integration of renewable energies in new applications and hydrogen technologies. The main experiences related with the project are:

- Evaluation of hydrogen systems as energy storage systems for wind energy
- Design, development and implementation of a hydrogen generator based on diesel reformer for PEM FCs
- Sensitivity analysis of the design parameters of a bipolar plate for PEM fuel cells.
- Modeling and implementation in a MATLAB library of PEM fuel cells, MCFC and SOFC.
- Study on improving wind energy sector in Andalucía through the use of hydrogen as a storage system for the Andalusian Energy Agency
- Participation in the working group of the International Energy Agency on the storage of electrical energy from wind into hydrogen.
- Participation in the subproject "Application of novel techniques to control the storage of electrical energy using hydrogen from renewable sources" under the project "Analysis, modeling and control of interconnected nonlinear electrical energy storage using hydrogen from renewable sources" , MICINN funded within the National Program for Design and Manufacturing for the National Plan for Scientific Research, Technological Development and Innovation from 2004 to 2007.
- Participation in the proposed research excellence of the Department of Innovation, Science and Business "Experimental Validation of a methodology for development of bipolar plates fuel cell solid polymer.
- Generation of renewable hydrogen from solar energy as fuel for an electric vehicle fuel cell: Project Hercules

Subproject 4: UVA: The UVA group is actively working on Advanced Control problems during the last decades, with practical applications in industry. In particular during the last years we can cite the project CICYT-FEDERTAP 1FD97-1450, where a simulator was developed for the sugar industry, CICYT PPQ2000-1075-C02-01, where advanced predictive control ideas were proposed and tested on industrial systems. In the project DPI2004-07444-C04-02, this advanced control ideas were further studied, with successful results in terms of theoretical results and demonstrations in practical systems.
One of the proposed benchmarks involves the use of renewable energies for water desalination. The group has experience in this kind of process, in particular with the OpenGain project, an EU-funded project (FP6-2004-INCO-MPC-3) that involved the development of desalination facilities in remote areas powered by renewable energies. Dr. Elfil Hamza, that is the responsible of the facility, and is an expert in desalination process, will actively participate in this project. A central issue is the development of advanced control methodologies: In the UVa group Prof. Benzaouia and Prof. Mesquine will be integrated, that are experts in advanced control and have been collaborating with the UVa group since 2000, including the active participation in the DPI2004-07444-C04-02 and DPI2007-66718-C04-02. As a summary of the research of the group, we can mention that between 2007 and 2010 the researchers that will participate in the project have published more than 25 papers in international journals, more than 60 papers in international conferences (ACC, CDC, CCA, etc).

Subproject 5: CIEMAT: The Automatic Control and Industrial Computing group of CIEMAT at Plataforma Solar de Almería (PSA) was formed on july of 2006. Previously some of the members of the group had been working on several research projects, mainly funded by European Commission, in the work packages related with control systems activities.Projects like "HydroSol", "PDVSA", "DISS", "HyConPV", "PCHA" and those in the table below were contributed by the Ai2 group. Nowadays this group has two main lines: research in modelling and control, and engineering support in control tasks in other CIEMAT group's projects. The projects in which the group has participated previously were all of the related with some prototype process that is based in solar energy to feed part of the energy demand of another process. The previous projects, in curriculums attached to this proposal, afford the plants and processes : desalination plants, parabolic trough solar thermal power plants with one or two-phase heat transfer fluids, central receiver solar thermal power plants, hydrogen generation plants, solar furnaces industrial applications (ceramic dryness, copper sintering and automatic calibration of concentrating PV cells), and solar detoxification of waste water.
This proposed project, in certain aspects, could be considered a normal continuation of the previously funded by European Commission AQUASOL project. In AQUASOL project several publications and a PhD was developed, were some important flaws of the process were discovered.

6.2 PUBLIC AND PRIVATE GRANTED PROJECTS AND CONTRACTS OF THE RESEARCH GROUP
Indicate the project and contract grants during the last 5 years (2005-2009) (national, regional or international)
Include the grants for projects under evaluation

Subproject 1: ISA-US

Title of the project or contract	Relationship with this proposal (1)	Principal Investigator	Budget EUROS	Funding agency and project reference	Project period (2)
DH-COMPLIANT TSI-020100-2009-359	1	Eduardo Fernández Camacho	120.096 €	PROFIT	C 2009-2012
Acumulación Térmica en caliente para refrigeración solar por absorción.	1	Carlos Bordons Alba	125.250 €	Gas Natural SDG S.A	C 2009-2010
Control Predictivo en Red (DPI2008-05818)	1	Eduardo Fernandez Camacho	534.699 €	Ministerio de Educación y Ciencia	C 2009-2012
Modelado y Control de planta Solar de Tecnologías cilindroparabólica.	1	Eduardo Fernández Camacho	24.300 €	ABENGOA Solar New Technologies. PI-0702/2009	C 2009
OLICEMATIC. Development of novel cost effective techniques to optimise olive oil production	2	Carlos Bordons Alba	123.766 €	Centre de Trasferencia de Tecnología S.L. PI-0350/2008	C 2008-2011

Hierarchical and Distributed Model Predictive of Large-Scale Systems (HD-MPC 223854)	0	Miguel Angel Ridao Carlini	228.731 €	Unión Europea	C 2008-2011
Feedback Design for Wireless Networked Systems. (FEEDNETBACK). (STREP. FP7-ICT-2007-2)	1	Francisco Rodríguez Rubio	319.458 €	Unión Europea	C 2008-2011
Control y Optimización de Sistemas Híbridos de energía renovables. (Proyecto de Excelencia) (P07-TEP-02720)	0	Eduardo Fernández Camacho	300.000 €	Junta de Andalucía	C 2008-2012
Sistema de Control para Planta de Climatización Solar	1	Carlos Bordons Alba	42.576 €	Gas Natural PI-0129/24/2007	C 2007-2008
Ingeniería de detalle de un sistema de potencia autónomo basado en reformador diesel y pila de combustible de 25kW	0	Carlos Bordons Alba	61.632 €	INTA PI-0536/2007	C 2007
Control Predictivo de Procesos Interconectados con Modos de Operación Diversos (PRINMODI)	0	Teodoro Álamo Cantarero	324.505 €	Ministerio de Educación y Ciencia. DPI2007-66718-C04-01	C 2007-2009
Convocatoria de Incentivos para la Actividad Interanual de los “Grupos de Ayuda de Investigación y Desarrrollo Tecnológico Andaluces de las Universidades” (2007/TEP116, conv. 2007)	2	Eduardo Fernández Camacho	27.529 €	Junta de Andalucía	C 2007-2008
Diseño de un Sistema de Control Integrado de Plantas Desaladoras: BEFTEL.	3	Eduardo Fernández Camacho	90.020 €	Befesa y Telvent PI-0452/2006	C 2007

Proyecto de Integración de la Energía Eólica con las Nuevas Tecnologías de Hidrógeno.	1	Carlos Bordons Alba	131.750 €	Gamesa Energias Renovables (GERSA)	C 2007
Sistema de Adquisición de Datos para electrolizador (INTA 2007)	2	Carlos Bordons Alba	11.832 €	INTA	C 2007
Refrigeración Solar por absorción en el sector terciario	1	Eduardo Fernández Camacho	438.704 €	Otros Contratos Públicos PI-0480/03/2006	C 2006-2008
Convocatoria de Incentivos para la actividad Interanual de los Grupos de Ayuda de Investigación y Desarrollo Tecnológico Andaluces, de las Universidades (2006/TEP-116, conv. 2006)	3	Eduardo Fernández Camacho	18.387 €	Junta de Andalucía	C 2006-2008
Generación de Hidrógeno Renovable desde Energía Solar, como combustible para un vehículo eléctrico de pila de combustible (HERCULES 2006)	0	Miguel Ángel Ridao Carlini	70.115 €	Ministerio de Educación y Ciencia SN-0509/24/2007	C 2006-2007
Control Predictivo Híbrido de Sistemas de Refrigeración Solar. (Proyecto de Excelencia). Proyecto TEP745	1	Eduardo Fernández Camacho	59.250 €	Junta de Andalucía	C 2006-2007
CPROS Control predictivo integral de procesos en operación semicontinua)	1	Carlos Bordons Alba	170.780 €	Ministerio de Educación y Ciencia DPI2004-07444-C04-01	C 2004-2007
ITMPC: Improving the tuning methodology for MPC	3	Eduardo Fernández Camacho	83.172 €	Comisión Europea Contrato n: TOK 3092	C 2004-2008

Red de Excelencia HYCON: Hybrid Control	1	Eduardo Fernández Camacho	385.524 €	Comisión Europea Contrato n: 511368 IST	C 2004-2009

(1) Write 0, 1, 2 or 3 according to: 0 = Similar project; 1 = Very related; 2 = Low related; 3 = Unrelated.
(2) Write C or S if the project has been funded or it is under evaluation, respectively.

Subproject 2: UAL

Title of the project or contract	Relationship with this proposal (1)	Principal Investigator	Budget	Funding agency and project reference	Project period (2)
			EURO		
Convenio de colaboración entre el Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT) y la Universidad de Almería (UAL) para la creación de un Centro de Investigaciones en Energía Solar (CIESOL)	1	Amadeo Fernández Rodríguez-Alba	100.000 (anuales)	CIEMAT-UAL	C 2005
Generación fotosintética de polímeros carbonados acoplada a la eliminación de CO2	2	Miguel García Guerrero	196.000	Junta de Andalucía	C 2005
Asesoramiento y formación en el diseño y desarrollo de un sistema supervisor de control de las variables climáticas en el interior de un invernadero	1	Francisco Rodríguez Díaz	10.645	ULMA C.Y E. S. COOP.	C 2005
Asesoramiento y formación en el diseño y desarrollo de sistemas SCADA avanzados y reconfigurables	1	José Luis Guzmán Sánchez	10.071	ULMA C.Y E. S. COOP.	C 2006
Monitorización de las variables climáticas para la evaluación en campo de la efectividad de filmes	2	Francisco Rodríguez Díaz	4.339	IBEROCONS	C 2006
Multiplicación de esfuerzos para el desarrollo, innovación, optimización y diseño de invernaderos avanzados (MEDIODIA)	1	Francisco Rodríguez Díaz	69.600	Fundación Cajamar Ref. OTRI 400668	C 2006-2010
Desarrollo de un prototipo de equipo autopropulsado para trabajos de pulverización y transporte en cultivos hortícolas	2	Julián Sánchez-Hermosilla López	64.380	Carretillas Amate, S.L. CONTRATO art. 11/45 LRU - 68/83 LOU	C 2006-2007

Proyecto singular estratégico sobre arquitectura bioclimática y frío solar (Arfrisol-2007)	1	Francisco Javier Batlles Garrido	292.400	Ministerio de Educación y Ciencia	C 2007-2008
Asesoramiento y formación en el diseño y desarrollo de herramientas de adquisición y control basadas en labview	2	José Luís Guzmán Sánchez	12.806	Ulma C. y E, S. Coop CONTRATO art. 11/45 LRU - 68/83 LOU	C 2007
Mejora de la eficiencia de la producción hortícola en invernadero en clima semiárido (INVERSOS)	1	Francisco Rodríguez Díaz	267.132	Fundación Cajamar Ref. OTRI 400674	C 2007
Estudio y diseño de sistemas para animación, comportamiento y robotizado de juegos inmersivos 3D	3	Francisco Rodríguez Díaz	80.476	Imagital, S.L.	C 2007
Diseño de modelos y estrategias de simulación, control, ensayo y monitorización del lazo senertrough	1	Manuel Berenguel Soria	337.982	Cobra Instalaciones y Servicios, S.A. Ref. OTRI 400679	C 2007
Análisis y evaluación de las técnicas de aplicación de productos fitosanitarios en invernaderos. Reducción del impacto ambiental y optimización técnico-económica	1	Julián Sánchez-Hermosilla López	186.668	Junta de Andalucía P07-AGR-02995	C 2007-2012
Control jerárquico de procesos con conmutación en el modo de operación: aplicaciones a plantas solares e invernaderos	1	Manuel Berenguel Soria	145.805	Plan Nacional I+D DPI2007-66718-C04-04	C 2007-2010
Predicción y evaluación de recursos energéticos solares utilizando técnicas de inteligencia artificial	2	Francisco Javier Batlles Garrido	75.000	Plan Nacional I+D	C 2007-2010
Proyecto singular estratégico sobre arquitectura bioclimática y frio solar (Arfrisol-2008)	1	Francisco Javier Batlles Garrido	506.300	Plan Nacional I+D	C 2008-2009
Modelado, automatización y robotización de un sistema de fabricación de dientes diamantados	3	Manuel Berenguel Soria	36.724	Iberina Tecnología Diamantes	C 2008-2009
Meeting the challenges of the farm of tomorrow by integrating farm management information systems to support real-time management decisions and compliance to standards (Futurefarm)	2	Jose Luis Guzman Sanchez	3.000.000	Plan Marco de la UE FP7-KBBE-2007-1	C 2008-2010
Almacenamiento de sales en torre central	2	Manuel Berenguel Soria	539.400	Gemasolar 2006, S.A	C 2008-2010
Captador solar cilindro-parabólico para aplicaciones térmicas hasta 250 ºC (CapSol)	1	Eduardo Zarza Moya	197.800	Plan Nacional I+D CIT-440000-2008-5	C 2008-2010

Investigación y desarrollo de un sistema de aprovechamiento de biomasa de invernaderos con recuperación de calor y CO2	1	Francisco Rodríguez Díaz	25.000	BESEL, S.L.	C 2008-2009
Proyecto singular estratégico sobre arquitectura bioclimatica y frio solar (Arfrisol-2009)	1	Francisco Javier Batlles Garrido	381.900	Plan Nacional I+D	C 2009-2010

Subproject 3: TMT-USE

Title of the project or contract	Relationship with this proposal (1)	Principal Investigator	Budget	Funding agency and project reference	Project period (2)
			EUROS		
Pilas de combustible. Aplicaciones para Defensa	2	Manuel Felipe Rosa Iglesias	1.400.000	INTA- Ministerio de Defensa	2003-2005 C
Banco de ensayo de pilas de combustible	2	Manuel Felipe Rosa Iglesias	120.202	FEDER INAN0123-001	2000-2002 C
Cluster Pilot Project for the integration of RES into European Energy Sectors (RES2H2)	1	Manuel Felipe Rosa Iglesias		UE V Programa Marco ENK-CT-2001-00536	2002-2007
Desarrollo de herramientas de simulación para análisis de sistemas integrados basados en hidrógeno	1	Francisco Javier Pino Lucena	18.000	INTA-Ministerio de Defensa	2004-2005 C
Análisis de sensibilidad de los parámetros de diseño de una placa bipolar con FLUENT	2	Javier Martinez	12.000	INTA-Ministerio de Defensa	2005 C

Fuel Cell Testing and Standardisation Network (FCTESNET)	1	Georges Tsoridis/ Eduardo Manuel López González	15.000	UE V Programa Marco Red Temática ENG2-CT-2002-20657	2003-2005 C
Fuel Cell Testing , Safety & Quality Assurance (FCESTQA	1	Georges Tsoridis/ Eduardo Manuel López González	45.380	UE VI Programa Marco STREP 020161 (SES6	2006-2009
Estudio de viabilidad del uso de pilas de combustible en aplicaciones aeronáuticas- "Proyecto Aquila"	1	Felipe Rosa Iglesias	200.000	Hynergreen Technologies, S.L.	2006-2007 C
Generación de hidrógeno renovables desde energía solar como combustible para un vehículo eléctrico de pila de combustible: Proyecto Hércules	1	Verónica Mesa (Hynergreen) / Manuel Felipe Rosa Iglesias	350.000	MEC	2006-2009 C
Validación experimental de una metodología de desarrollo de Placas bipolares de pilas de combustible de polímero sólido	2	Felipe Rosa Iglesias	121.771.75	Consejería de Innovación, Ciencia y Empresa de la Junta de Andalucía	2009-2010 C
Aplicación de técnicas novedosas de control al almacenamiento de energía eléctrica de origen renovable utilizando hidrógeno	0	Felipe Rosa Iglesias	80.000	MEC Ref: DPI-2007-66718-C04-03	2007-2010 C
Análisis de modos de operación para la gestión de la energía eléctrica procedente de renovables mediante el almacenamiento en hidrógeno	0	Felipe Rosa Iglesias	457.420	Consejería de Innovación, Ciencia y Empresa de la Junta de Andalucía	2010-2012
Generación de hidrógeno renovables desde energía solar como combustible para un vehículo eléctrico de pila de combustible: Proyecto Hércules	1	Verónica Mesa (Hynergreen) / Manuel Felipe Rosa Iglesias	350.000	MEC	2006-2009 C

Subproject 4: UVA

Title of the project or contract	Relationship with this proposal (1)	Principal Investigator	Budget EUROS	Funding agency and project reference	Project period (2)
CONTROL DE SISTEMAS INDUSTRIALES CON RETARDOS (FACULTE DES SCIENCES DHAR MEHREZ, FEZ, Prof. ABDELAZIZ HMAMED	1	Fernando Tadeo Rico	11600 €	AECI (A/5422/06)	C 2007-2008
Optimal Engineering Design for Dependable Water and Power Generation in Remote Areas Using Renewable Energies and Intelligent Automation	1	César de Prada Moraga	162285 €	European Commission within the Sixth Framework Programme (Reference FP6-2004-INCO-MPC-3)	C 2007-2009
Supervision of Multimodal Process Based on Model-Free Learning Control (SUMULFREE)	1	Fernando Tadeo Rico	73100€	mcyt-CICYT DPI2007-66718-C04-02	C 2007-2010
GR85-INFRAESTRUCTURA-GESTIÓN ÓPTIMA DE SISTEMAS COMPLEJOS	2	César de Prada Moraga		Junta de Castilla y León	C 2008-2010
COMMANDE DES SYSTEMES HYBRIDES. Proyecto Conjunto de Investigación. (Univ. Caddy Ayyad, Marrakech, Prof. Abdellah Benzaouia)	2	Fernando Tadeo Rico		AECI, A/788/07	C 2008-2009
SISTEMAS HÍBRIDOS DE CONTROL (Univ. Caddy Ayyad, Marrakech, Prof. Abdellah Benzaouia)	2	Fernando Tadeo Rico	2000€	AECI, B/7882/07	C 2008-2009

REGULACIÓN AVANZADA DE PROCESOS: INVERNADERO, SECADERO Y SISTEMA ELÉCTRICO (Univ. Sfax, Prof. Mohammed Chaabane).	1	Fernando Tadeo Rico	23100€	A.E.C.I, Programa de Cooperación Interuniversitaria Hispano-Tunecina (A/9428/07)	C 2008-2009
COMMANDE DES SYSTEMES HYBRIDES 2009 (Univ. Caddy Ayyad, Marrakech, Prof. Abdellah Benzaouia)	2	Fernando Tadeo Rico	9300€	A.E.C.I, Programa de Cooperación Interuniversitaria Hispano- Marroquí 2009 (A/016513/08 - 181 CPV99 541A301 692.03)	C 2009
CONTROL AVANZADO DE PROCESOS INDUSTRIALES (Univ. Sfax, Prof. Mohammed Chaabane)	2	Fernando Tadeo Rico	8890€	A.E.C.I, Programa de Cooperación Interuniversitaria Hispano-Tunecina 2009 (A/016517/08)	C 2009-2010
POSITIVE OBSERVATION AND STABILIZATION FOR POSITIVE LINEAR SYSTEMS (Prof. Uwe Helmke, Univ. Würzburg)	2	Mustapha Ait Rami	11000€	MiCinn, Acción Integrada Hispano-Alemana 2009 HD2008-0043	2009
Sensórica Inteligente Para El Control En Linea De Calidad En El Procesamiento De Alimentos (SMARTQC)	3	Antonio Alonso (CSIC, Vigo)		Proyecto CICYT, Ciencia y Tecnología de los Alimentos(ALI), AGL2008-05267-C03	C 2008-2011
APPLICATION RATIONNELLE DE L'ÉNERGIE SOLAIRE À LA COMMANDE AVANCÉE DES SYSTÈMES AGRICOLES (Univ. De Sfax, Prof. Mohamed Chaabane)	1	Fernando Tadeo Rico	9135€	A.E.C.I, Programa de Cooperación Interuniversitaria Hispano- Tunecina 2010 (A/023792/09)	C 2010
Control De Sistemas En Red (Faculte Des Sciences Dhar Mehrez, Fez, Prof. Abdelaziz Hmamed)	2	Mª Teresa Álvarez Álvarez	7520€	AECI (A/024215/09)	C 2010
Aplicación de técnicas de Control de Procesos para el Control de Servidores Web	3	Mª Teresa Álvarez Álvarez	11600€	Junta de Castilla y León (EDU/1599/2007- EDU/1610/2008 – bocyl 03/07/2008) VA037A08	C 2008-2010

GreenFuture: Water and Energy for Sustainable Greenhouses in Arid Regions	1	Fernando Tadeo Rico	3014200€	EuropeAid (EuropeAid/128500/C/ACT/Multi): Solicitado 15 Enero 2010	S 2010-2014

Subproject 5: CIEMAT

Title of the project or contract	Relationship with this proposal (1)	Principal Investigator	Budget EUROS	Funding agency and project reference	Project period (2)
ENHANZED ZERO DISCHARGE SEAWATER DESALINATION USING HYBRID SOLAR TECHNOLOGY (AQUASOL)	1	Julián Blanco Gálvez (CIEMAT)	3.254.177 €	EU-DGXII , VI Frame Work programme, Contract: nº EVK1-CT-2001-00102.	2002-06 (C)
CONTROL PREDICTIVO PARA PROCESOS CON INCERTIDUMBRES ACOTADAS (PREDINCER)	1	Eduardo Fernández Camacho (Universidad de Sevilla)	360.000 €	CICYT	2002-05 (C)
CONVENIO DE INVESTIGACIÓN PARA EL DESARROLLO DE SISTEMAS Y HERRAMIENTAS DE CONTROL PARA PLANTAS SOLARES	1	Manuel Berenguel Soria (Universidad de Almería)	81.000 €	CIEMAT	2002-06 (C)
CONTROL PREDICTIVO JERÁRQUICO DE PROCESOS EN OPERACIÓN SEMICONTINUA. (CPROS)	1	Carlos Bordons (Universidad de Sevilla)	76.895 €	CICYT	2004 – 2007 (C)
ENERGY STORAGE FOR DIRECT STEAM SOLAR PLANTS (DISTOR)	1	Rainer Tamme (DLR)	4.452.256 €	EU DG-XII , VI Frame Work programme, Contract nº SES6-CT-2004-503526	2004-07 (C)

PETRÓLEOS DE VENEZUELA S.A. (PDVSA)	1	Manuel Romero Álvarez (CIEMAT)	17.350.000 US$	PETRÓLEOS DE VENEZUELA S.A. (PDVSA)	2002-07 (C)

7. TRAINING CAPACITY OF THE PROJECT AND THE GROUP
(In the case of Coordinated Projects this issue must be filled by each partner)

This title must be filled only in case of a positive answer to the corresponding question in the application form.
Justify that the group is able to receive fellow students (from the Suprograma de Formación de Investigadores) associated to this project and describe the training capacity of the group. In the case of coordinated projects, each subproject requesting a FPI fellowship must fill this issue.

> Note that all necessary personnel costs should be included in the total budget requested. The available number of FPI fellowships is limited, and they will be granted to selected projects as a function of their final qualification and the training capacity of the groups.

Subproject 1: ISA-USE:

The group has a wide experience in training and supervising junior researchers. There are 10 doctors in the group and therefore the group could be able to supervise at least 10 PhD students. It is expected that during this year the PhD Thesis of the other two members of the group will be finished, in such a way that the number of doctors at the beginning of the project will be 12. The ability to supervise and train researchers is guaranteed by the fact that 12 PhD Thesis have been defended in the group within the last 5 years, three of them of foreign researchers and financed by their own universities.

The members of the research group play an important role in the doctorate course of their Department that received the so called “quality mention”. The group organizes seminars where many relevant researchers of recognized prestige have participated during the last years, as: Ray de Carlo (USA), Ioan Landau (FR), Joao Gomez (BR), Alberto Bemporad (IT), Eric Kerrigan (UK), Steve Yurkovich (USA), Sophie Tabouriech (FR) , Roberto Tempo (IT), Rick Middleton (AUS) and Anna Stefanopoulou (USA).

The group has been member of the European Network of Excellence HYCON: "Hybrid Control: Taming Heterogeneity and Complexity of Networked Embedded Systems" funded by the European Commission within the IST programme (http://www.ist-hycon.org/), that has as objectives, in addition to the accomplishment of cooperative research, training of young researchers. The network organizes courses for PhD which have been attended regularly by the PhD students of our group. Now the group is participating in the new call (HYCON2) which is currently under evaluation. Also related to European projects, the group currently takes part in “HD-MPC” and “FeedNetback”, two STREP projects where the following head researchers (among others) take part: Bart de Schutter (NL), Wolfgang Marquardt (DE), Riccardo Scattolini (IT), Carlos Canudas (FR), Karl Henrik Johansson (SE), Anders Rantzer (SE), Moritz Diehl (BE) and Didier Dumur (FR). The group is also the coordinator of the Marie Curie action “Improving the tuning methodology for MPC”. The main objective of this action is the training of the PhD students of the group. Two researchers of the group has stayed recently at Imperial College (UK), in the group of Prof. Pistikopoulous, who is expected to co-supervise a PhD thesis of one of our students.

Due to the variety of reference plants and to the novelty of the technology involved (renewable energy, fuel cells, electric vehicles); we think that the project has a considerable formative component to train researchers and technicians in these new and promising technologies. Several thesis related to solar energy has been defended in our group and one related to fuel cell systems will be presented this year.

Subproject 2: UAL

The applicant group has 7 doctors, 5 of who teach in two master programs at the University of Almería. The project leader, Francisco Rodríguez, is the coordinator of the inter-departmental Master on Industrial

Computing, while Manuel Berenguel was coordinator of the Master on Advanced Computing Techniques during the biennium 2002-2004. Both masters give access to the Doctorate Program in Informatics of the University of Almería, which has the “quality mention” of ANECA. Although it is expected that the thesis of the other two members of the group will be finished soon, the group is able to supervise at least 3 PhD thesis related to this project. Eight of the members of this proposal belong to the research group “Automatic Control, Electronics and Robotics” TEP-197 of the Andalusian R+D Plan. The last year (2009) this group has gained the 2nd absolute position in score and funding at the University of Almería (1st in production technologies) and the 8th of 105 groups in production technologies at Andalusian level.

During the last four years 5 PhD Thesis have been defended and directed by members of the group and some are currently being finished, having established collaborations with researchers of other Spanish and foreign Universities (some of them participating in the doctorate with “quality mention”), like Prof. K.J. Aström and T. Hägglund from the Lund Institute of Technology (Sweden), Prof. Robin de Keyser from the University of Gent (Belgium), Prof. Daniel Rivera of the Arizona State University (USA), Prof. Joao Lemos from the Instituto Superior Tecnico de Lisboa (Portugal), Julio Normey of the University of Santa Catarina (Brazil), Antonio Visioli from the University of Brescia (Italy), Ryszard Klempous from the Wroclaw Politechnic University (Poland) and Prof. Eduardo Fernández Camacho and Sebastián Dormido (Spain). Moreover, one of the members of this proposal (M. Berenguel) has participated as teacher in the “quality mention” doctorate programmes “Computer Science and Automatic Control” of UNED and “Automatic Control, Telematics and Robotics” of the University of Seville. Three of the members of this proposal (including the main researcher) are also teaching in a Master about Solar Energy in the University of Almería.

Some of the members of the group are also departmental coordinators of Erasmus and Leonardo Programs at the University of Almería, managing more than 15 students per year.

It has been thus considered convenient to apply for a scholarship holder because there exists a research line with great interest to develop a PhD Thesis. In the case of being assigned, the new scholarship holder would be located in one of the new Labs of the research group, having access to all the computing facilities and equipment and high technology related with the project. He/she would obtain and excellent experience in the collaboration with the Solar Platform of Almería, within the framework of the CIESOL Center (which actual Director is Dr. Manuel Pérez, one of the researchers of this project) and of course the accomplishment of stays in other international centers of prestige would be stimulated, as has been done in the case of FPU scholarship holders in previous projects, that have been for instance in Lund Institute of Technology of ETH in Zurich. Furthermore, he/she would have the possibility of completing their theoretical-practical formation in the Experimental Station “Las Palmerillas”, belonging to Cajamar Foundation, as the Head of this installation (associate prof. in the University of Almería), has shown a great interest in the results of this project.

Subproject 3: TMT-USE

The Termotecnia group is a working group located at the School of Engineering of Seville, constituted by professors of the same one, with demonstrated training and research capacity. The group has large experience in multidisplinary programs of doctorates that cover complementary areas such: Fluid mechanics, thermal energy, chemical technology, control and power management, etc.

Specially relevant are the contacts with other National and International research groups, due to the participation in joint projects related with renewable energies that guaranteed the training capacity of the group. The number of doctors of the group is two, and is expected that one thesis will be finish during this year and two more will be finished the next year. All the thesis are related with this project and this line of investigation.

The laboratory of the group is equipped with the basic infrastructure to undertake its task. And the participation of the members in similar projects gives the necessary experience to cover new challenges.

Subproject 4: UVA:

The group of Process and Systems Engineering in which the predoctoral student will integrate is a recognized group headed by Prof. César de Prada. The group has a long experience in formation of students for research: in particular we can point out the Master in Process Engineering and Systems (verified by ANECA) and the previous doctorate courses (that having a high number of students is considered Quality Doctorate by the Ministry of Education). Thanks to this distinction and additional funding every course many distinguished professors visit the group to give courses and supervise students. Moreover the students have additional funding for visiting foreign research groups, that is greatly encouraged for their formation. Thus, many of the students carry out long visit to foreign institutions such as Oxford, Strathclyde, Imperial College, NTNU-Trondheim, Ghent, Dortmund, Stuttgart, etc. Also the group gives regularly Master degrees funded by the European Commission (Alpha programme) to foreign students, where half the professors are foreign outstanding lecturers.

In addition to that, the department has a big number of research projects (international, national and regional programs) for both basic and applied research, many of them with industries. In this context, the group accepts regularly foreign visitors in sabbatical year. During the sabbatical they collaborate in research and PhD dissertations as co supervisors: during the last years we can mention the stays of Prof William Colmenares, Dr. Ernesto Martínez and Prof. Abdellah Benzaouia.

Finally, the group participate actively in an associated research center (CTA, Centro de Tecnología Azucarera), that is important for the students to understand real problems in industry.