DERri
Distributed Energy Resources
Research Infrastructures

TEMPLATE FOR PROPOSAL UNDER DERRI

User-Project Proposal:

User-Project Acronym	*DEVAGRA*
User-Project Title	*Development of a vector control algorithm for a grid-connected renewable agent*
Main-scientific field	*Renewable sources, power quality*
Specific-Discipline	*Control in Power Electronics*

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Activity type and legal status* of Organization	*Is a public university located in Cartagena, Murcia (Spain), with schools fundamentally about technology and business.*
Position in Organization	*Scholarship holder PhD Thesis student.*
Short description	*Received the degree in electromechanic engineering from the University Central of East, Dominican Republic in 2007, received a master in renewable energy at the UPCT in 2010, since November 2010 is PhD Thesis student.*

* Higher Education Institution (1) – Public research organization (2) – Private not-for-profit research organization (3) – Small or Medium size private enterprise (4) – Large private enterprise (5) – other (specify)

Additional Users in the Proposing Team:

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Activity type and legal status* of Organization	*Is a public university located in Cartagena, Murcia (Spain), with schools fundamentally about technology and business.*
Position in Organization	*Assistant professor in electronic*
Short description	*Received the MS degree de in electronic engineering from the University of Oriente, Cuba, and the PhD degree at the University of Valladolid, Spain, in 1990 and 2000, respectively. His main research interest are the design of*

	high performance power electronic conditioners with PWM DC/DC and DC/AC converters, the modelling and simulation of vector control of grid-connected renewable agents and the design of actives filter for increasing its power quality, and the implementation of the control algorithms in DSPs and /or FPGAs microcontroller devices.

* Higher Education Institution (1) – Public research organization (2) – Private not-for-profit research organization (3) – Small or Medium size private enterprise (4) – Large private enterprise (5) – other (specify)

(Repeat for all Users)

Date of submission	*February 29 2012*
Re-submission	YES_______ NO__X__
Proposed Host TA Facility	*University of Strathclyde's Distribution Network and Protection Laboratory in the United Kingdom (TA13)*
Starting date (proposed)	*September 2012*

Summary of proposed research (about ½ page)

Renewable agents connected to the low-voltage 3-phase utility grid as well as traditional sources of energy must obey certain standards in both the control and the power quality. The utility grid has several disturbances such as harmonic distortions and unbalances. In addition, the inverter used in the grid-connected renewable agents produces high frequency ripples due to the switching nature of the electronic device (IGBT or Mosfet), which adds some negative effects in the power quality.

The connection of renewable agents to the utility grid must be properly controlled; this control system must be designed according to the expected operating conditions of the primary energy source (different values of irradiance, variation of wind speed, quantity of energy in the fuel cell, etc.) and of the utility grid conditions (Unitary Power Factor, synchronization, islanding protections, etc.).

To overcome the so-mentioned facts above, new algorithms of vector control have been designed focusing on improving the performance of the connection of primary renewable energy agents to the low-voltage 3-phase utility grid.

This proposal is trying to implement a vector control algorithm for renewable agents. The control algorithms will be tested by using the hardware-in-the-loop simulation techniques in which the plant will be modelled and run in real time, whereas a real controller will embed the control algorithms for its validation. In this way, some perturbations which are not possible to evaluate in a real situation, must be imposed to the real-time simulation of the 3-phase low voltage utility grid.

In addition, it also has the possibility to do a voltage control of the capacitor voltages in order to manage stand-alone systems or to support the grid in a micro-grid system.

State-of-the-Art (about 1 ½ page)

Renewable agents connected to the low-voltage 3-phase utility grid: *News sources of energy (Photovoltaic, Wind, Fuel Cell, etc) have been connected to the utility grid with the aim of injecting good power quality as a collaborative effort towards the mitigation of the greenhouse effect and environment pollution, together with the reduction of fossil fuel, coal and nuclear energy dependency. The connection* *with the utility grid is achieved through the use of voltage source inverters (VSI) as power conditioners, whose control is usually performed in current source mode so as to make it more efficient with controllable power factor and capable of extracting the maximum available power from the primary renewable energy sources.*

Fuel cell systems: *Fuel cells are static energy conversion devices that convert the chemical energy of fuel directly into Dc electrical energy. Fuel cells have a wide variety of potential applications including micro power, auxiliary power, transportation, stationary power for buildings, and cogeneration applications. Most significant advantages it has are the low emission levels of greenhouse gas emissions and high energetic density [1].*

Fuel cells are generally classified for the type of electrolyte that use and the electrolyte type dependent of the temperature range at which to operate the fuel cell and its degree of processing required. The most common type of fuel cell at low temperatures are the alkaline (AFC) which operate at temperatures which range from 50 to 200 degrees Celsius, fuel cells of phosphoric acid (PAFC) and the polymers electrolytes membrane (PEMFC). This system have a low voltage input provided by the fuel cell and usually power conditioning systems, including inverters and dc-dc converters, are often required in order to supply normal customer load demand or send electricity into the grid.

Photovoltaic systems (PV): *Photovoltaic cell is an electric device that produces electric energy when exposed to direct sunlight and connected to a load. PV has not moving parts inside it, for this reason there are not friction losses. PV systems have a low voltage and more such units can be connected together to obtain the required voltage and power. Like fuel cell systems, it is necessary a power conditioning system for PV. It is necessary to increase the voltage level of the system; this task can be done in the DC or AC stage of the system. For smoothing the output current, an LCL filter is normally used between the system and the utility grid.*

Voltage Source Inverter (VSI): *A VSI converter works as a power conditioner for industrial systems, transforming the dc nature of the input power to the ac nature of the output one, according to its design and load specifications. For fuel cell or PV grid-connected systems, the purpose is to control the power flow between the PV Generator or the fuel cell and the utility grid, as well as the power factor of the inverter-grid connection with high power quality; the power flow is achieved with a voltage regulator allowing the proper dc bus voltage in a link capacitor according to the maximum power point, meanwhile the power factor is controlled with a current regulator [2].*

Maximum power point tracking MPPT: *To obtain the maximum power of the PV modules, an algorithm capable of obtaining the maximum power at a given irradiance and temperature is needed. This algorithm maximizes the voltage and current product. There are several manners to achieve the maximum power point among them there may be mentioned: Perturb-and-observe (P&O) method, Incremental conductance (INC) method and Constant voltage method.*

Current Control of a Voltage Source Inverter: *Several strategies can be employed for the vector control of the inverter 3-phase line currents. Among them, d-q control, hysteresis control, deadbeat control and, more recently, proportional-resonant controllers are the most widely used [3]. The current vector control must guarantee the highest power quality, together with a controllable power factor of the inverter-grid connection.*

References

[1] M. Hashem Nehrir and Caisheng Wang "MODELING AND CONTROL OF FUEL CELLS. Distributed Generation Applications" John Wiley & Sons, Inc.,2009.

[2] Alexis B. Rey Bou, Rafael García Valverde, Francisco de A. Ruz-Vila, José M. Torrelo Ponce, "An integrative approach to the design methodology for 3-phase power conditioners in Photovoltaic Grid-Connected systems" in Elsevier, Energy Conversion and Management, vol. 56, 2012, pp 80–95.

[3] Frede Blaabjerg, Remus Teodorescu, Marco Liserre and Adrian V. Timbus, "Overview of Control and Grid Synchronization for Distributed Power Generation Systems" in IEEE Transactions on Industrial Electronics, vol. 53, no. 5, 2006, pp. 1398–1409.

Detailed Description of proposed project : Objectives – Expected Outcome – Fundamental Scientific and Technical value and interest (2-3 pages)

Our aim in this proposal is the implementation of a vector control to a voltage source inverter that will be used as a power conditioner and that will be the link between the primary renewable energy source and the low-voltage 3-phase utility grid. Its block diagram is depicted in the next figure.

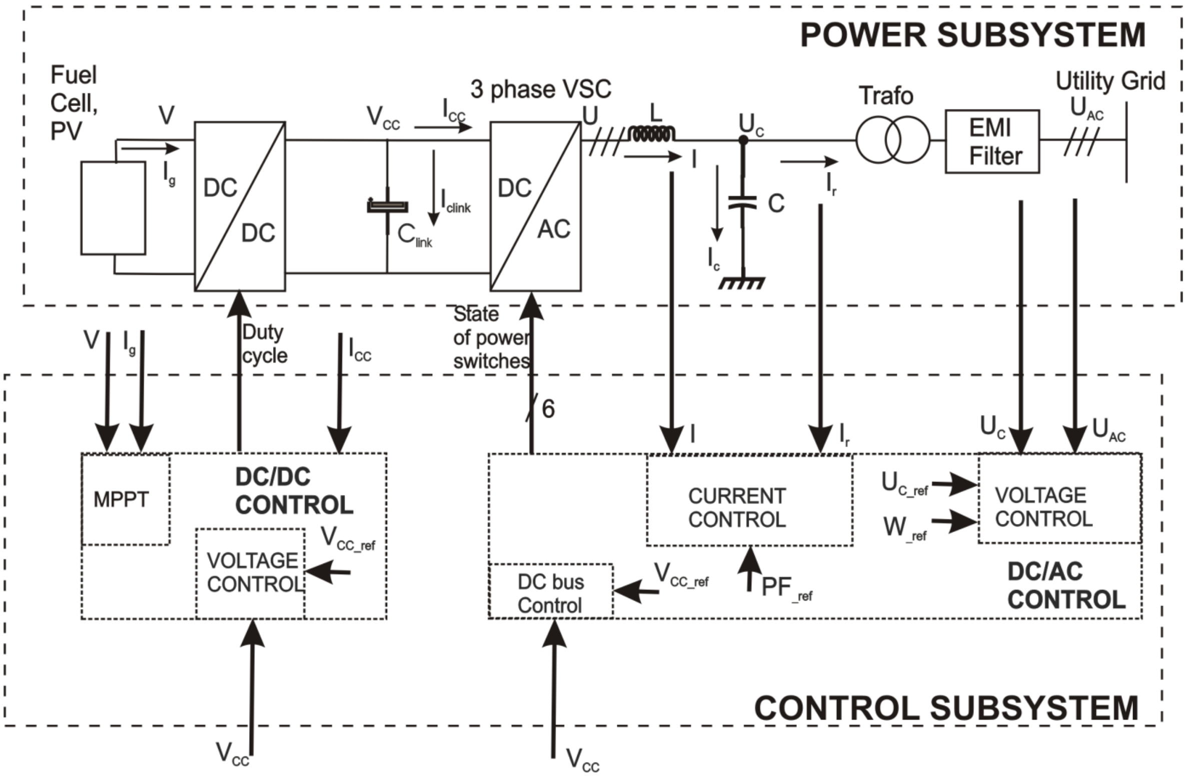

Fig. 1 Fig. 1 Block diagram of the Power and Control Subsystems for a 3-phase grid-connected system.

For renewable energy grid-connected systems, the purpose is to control the power flow between the primary renewable energy source and the utility grid, as well as the power factor of the inverter-grid *connection with high power quality. Ideally the utility grid behaves as a sinusoidal voltage source and then, a current source control mode is preferable. It is necessary that the renewable agent (in a distributed generation system) guarantees the maximum efficiency by controlling the power factor of the inverter-grid connection, making use of the reactive power theory which allows the control of the instantaneous active and reactive powers in decoupled d-q axes.*

This system is divided into two subsystems: the control and power subsystems.

Control subsystem: The Control Subsystem is fed by several sensed signals coming from the Power Subsystem and is the responsible of keeping the desired output even when perturbations occur at the input and output variables. Its main modules are the Synchronization Algorithm for attaining a controllable power factor in the connection, the MPPT algorithm in order to extract the maximum available power of the PV generator for a specific irradiance and temperature, the two inner Current Regulators, and the outer dc bus Regulator. This control has been performed using PI controllers.

The outer loop regulator compares the DC voltage in the Link capacitor with the reference which comes from the block that executes the MPPT algorithm, while the inner control loop uses two controllers to regulate the d-q components of the line currents.

For the inner control loop a d-q vector control approach is used and the Clarke and Park transformations are applied.

In this work, the objective will be fulfilled with the use of hardware-in-the-loop simulation techniques: the primary renewable energy source, the 3-phase inverter, the LCL filter and the 3-phase low-voltage utility grid will be modelled and run in real time, whereas a real controller will embed the control algorithms for its validation.

Number of tests to be carried out:

1. *The real-time simulation of a free distorted and balanced 3-phase low-voltage utility grid is carried out in order to test the behaviour of the grid. The results are compared with the results of simulations in order to validate this test.*
2. *The real time simulation of the primary renewable energy-inverter-undistorted and balanced 3-phase low-voltage utility grid is carried out in order to test the behaviour of the whole system, mainly in the validation of the control algorithms. In this case, a real controller is embedded in the loop (hardware-in-the-loop-simulation)*
3. *Is the same as step 2, but with a harmonic distortion to the 3-phase low-voltage utility grid as perturbation: low order harmonics will be added to the fundamental voltage in order to evaluate its influence in the control algorithm and in the power quality*
4. *Is the same as step 2, but with unbalanced 3-phase low-voltage utility grid as perturbation: the influence of 3-phase voltage unbalances in the power quality and in the dc bus will be investigated*
5. *To repeat steps 2, 3 and 4 when the fundamental nominal frequency varies.*

Originality and Innovation of proposed research – Broader Impact (1-2 pages)

It is intended to develop and test new algorithms for vector control of Voltage Source Inverter (VSI) used in the control of renewable agents connected to the perturbed low-voltage 3-phase utility grid. It is not possible to test the control algorithms in a real situation due to the public nature of the utility grid; so, the control algorithms will be tested in a distorted and unbalanced utility grid with the use of the hardware-in-the-loop simulation techniques yielding an innovative and cheap approach to deal with this situation and *making, at the same time, the control algorithms more accurate and effective as possible, while the avoiding possible failures.*

Finally, we think that the proposed work will facilitate definitely the integration of renewable energy agents in the electrical system.

Proposed Host TA Infrastructure/Installation – Justification (about one page)

The University of Strathclyde's real-time hardware-in-the-loop simulation facilities within their D-NAP laboratory are suitable for performing this work. This is because they have experience in building models of convertors with small time-step simulations e.g. Advanced Propulsion Motor System (APMS) for a contract from Converteam [4]. This study was based around control hardware-in-the-loop which is what this new proposal seeks to use to demonstrate the novel control algorithms also. They also have significant experience in testing difficult scenarios for the operation of inverter connected sources, e.g. harmonics or loss of mains [8].

A major need for this proposal is simulating the power system and power system transients, and the electronic commutator and network bridge, with sufficient fidelity. The University of Strathclyde have experience in creating solutions for this integration and would be able to complete this new project.

The real time digital simulator that will be employed for the study is the RTDS® Simulator produced by RTDS Technologies [5]. The dedicated Real-time System Computer Aided Design (RSCAD) [6] software is a real-time version of the Power System Computer Aided Design (PSCAD) simulation software [7]. It is a dedicated modelling package for use with the RTDS and provides the main interface to the RTDS. It has a graphical user interface and has extensive model libraries that permit a wide range of electrical system architectures and components to be modelled. RSCAD will be used used to model the components of the inverter proposed to be controlled by the new controller and also the power system.

Several of the RSCAD libraries will be employed in the model: the power system component library; the control system component library; and the small time step component library, which was key to this particular proposal's requirements. The main power system simulations within RSCAD and the RTDS normally operate with a 50 μs time step. However, the small time step simulations, which interface with the power system simulation, and are used to accurately represent high frequency switching and circuit dynamics within power electronics based power conversion systems, operate with time steps in the range 1 to 4 μs. The University of Strathclyde have used all these facilities in multiple projects and should be able to easily adapt their knowledge to this proposal.

References

[4] S. Loddick, U. Mupambireyi, S. Blair, C. Booth, X. Li, A. Roscoe, "The Use of Real Time Digital Simulation and Hardware in the Loop to De-Risk Novel Control Algorithms," Power Electronics and Applications (EPE 2011), Proceedings of the 2011-14th European Conference on, 2011 , pgs. 1 – 10.

[5] http://www.rtds.com/hardware/hardware.html.

[6] http://www.rtds.com/software/rscad/rscad.html.

[7] https://pscad.com/products/pscad/.

[8][Crolla, P., Roscoe, A.J., Dysko, A., Burt, G.M. ,"Methodology for testing loss of mains detection algorithms for microgrids and distributed generation using real-time power hardware-in-the-loop based technique," Power Electronics and ECCE Asia (ICPE & ECCE), 2011 IEEE 8th International Conference on, 2011

[9] Roscoe, A.J. ; Finney, S.J. ; Burt, G.M., "Tradeoffs Between AC Power Quality and DC Bus Ripple for 3-Phase 3-Wire Inverter-Connected Devices Within Microgrids," Power Electronics, IEEE Transactions on, March 2011

Synergy with ongoing research (about ½ page)

There are many teams of research and development teams who are involved in the techniques of control of the renewable agents, among them the following can be named:

CEMD *-Converters, Electrical Machines and Drives Research Group: this Research Group belong to Department of Electrical and Electronics at the University Polytechnic of Bari, Bari, Italy. Its research lines in renewable energy are: Power converters for distributed power generation systems, Three-phase active rectifiers and multilevel converters: modulation and control.*

epYme *-Power Electronics and Microelectronics: This workgroup belongs to Department of Electronics Technology at the University of Valladolid, Spain. The workgroup research mainly focuses on the application of Microelectronics (FPGA and CPLD devices) to Power Electronics converters (DC/AC and AC/AC), using DSP processors implemented on FPGAs to control their MOSFET or IGBT devices on the range from 1 to 10 KW. Currently they are developing grid connected wind generators. This team works in partnership with the research team of Electrical Engineering and Renewable Energy from the UPCT.*

Institute of Energy Technology *of the University of Aalborg, Denmark: its research lines are: Renewable energy, power electronics, wind turbines, photovoltaic systems, energy saving, and energy efficiency. At this moment they are working in a project named Reliable Grid Condition Detection and Control for Single-Phase Distributed Power Generation System, this is about of the techniques for detection of the grid condition in respect to presence, impedance, phase and amplitude for single-phase and three-phase Distributed Power Generation System (DPGS), i.e. low-voltage power generation systems connected directly to households or farms.*

TIEG*-Terrassa Industrial Electronics Group: This belongs to Electronic Engineering Department of the Polytechnic University of Catalunya. Barcelona, SPAIN. Among its research lines is the design and modeling power converters for wind and PV systems.*

REDES*- Networks and Electric Energy Systems: This team belongs to Electric Engineering Department of the Carlos III University, Madrid, Spain. Its research is the Integration of wind energy into the electricity system.*

Projects collectively with other teams:

The research team of the UPCT is now working in the project entitled "Diseño y construcción de un prototipo hardware/software para la sincronización y monitorización de agentes renovables en un *sistema de generación distribuida"("Design and construction of a hardware/software prototype for synchronization and monitoring of renewable agents in a distributed generation system") granted by Fundación SENECA, Región de Murcia, Spain, Ref. 11948/PI/09.*

There are another call for proposal of non-oriented Research Projects in the National Plan 2012 (Spain) in which the research team of UPCT together with the epYme research team of the University of Valladolid have sent a proposal.

Dissemination – Exploitation of results (about ½ page)

The results from this project will be disseminated in conferences and scientific journals. Among the journals to be disseminated may be mentioned:

- *IEEE Transactions on Industrial Electronics*
- *IEEE Transactions on Industrial Informatics*
- *IEEE Transactions on Energy Conversion*
- *IEEE Transactions on Power Systems*
- *IEE Electric Power Applications*
- *Springer Verlag Electrical Engineering*
- *ELSEVIER Electric Power Systems Research*
- *ELSEVIER Energy Conversion and Management*

Some national and international conferences where the dissemination of the scientific results are also possible:

- *International Symposium on Industrial Electronics (ISIE)*
- *Power Electronics Specialist Conference (PESC)*
- *Seminario Anual de Automática, Electrónica Industrial e Instrumentación (SAAEI)*

Time schedule (about ½ page)

	Tasks	Time
1	*The real-time simulation of a free distorted and balanced 3-phase low-voltage utility grid is carried out in order to test the behaviour of the grid. The results are compared with the results of simulations in order to validate this test.*	*First week*
2	*The real time simulation of the primary renewable energy-inverter-undistorted and balanced 3-phase low-voltage utility grid is carried out in order to test the behaviour of the whole system, mainly in the validation of the control algorithms. In this case, a real controller is embedded in the loop (hardware-in-the-loop-simulation)*	*First week*
3	*Is the same as step 2, but with a harmonic distortion to the 3-phase low-voltage utility grid as perturbation: low order harmonics will be added to the fundamental voltage in order to evaluate its influence in the control algorithm and in the power quality*	*Second Week*
4	*Is the same as step 2, but with unbalanced 3-phase low-voltage utility grid as perturbation: the influence of 3-phase voltage unbalances in the power quality and in the dc bus will be investigated*	*Third week*
5	*To repeat steps 2, 3 and 4 when the fundamental nominal frequency varies.*	*Fourth Week*

Description of the proposing team (as long as needed)

The research team named Electrical Engineering and Renewable Energy, from the University Polytechnic of Cartagena Together with another team from of the Carlos III University, has developed a project named "Optimum management of the electrical utility grid with high penetration of distributed generation" (2005-2008). The Team of the UPCT have been in charge of the subproject called: "MICRO_GD: Management of micro production of DPGS connected to the of the 3-phase low voltage utility grid", obtaining the following results:

- *Design and construction of power and control subsystems of a prototype micro-producer as an agent isolated from 20 KVA. The control subsystem has been designed based on the DSP of Texas Instruments TMS320C6713B and the TMS320F2812 one.*

- *Development of algorithms for predicting the generation and adaptation to demand, and determination of the parameters of quality supply and of the wave.*

The UPCT team has built fully an architecture designed to implement the interface between of the 3-phase low voltage utility grid and the renewable agent. Among most recent publications by the research group may be mentioned:

- *[Alexis B. Rey-Boué, Rafael García-Valverde, Francisco de A. Ruz-Vila, José M. Torrelo-Ponce] "An integrative approach to the design methodology for 3-phase power conditioners in Photovoltaic Grid-Connected systems", Energy Conversion and Management ,vol 56, 2012, pp 80-95.*

- *[F. Ruz, A. Rey, J.M. Torrelo, A. Nieto, F.J. Cánovas] "Real time test benchmark design for photovoltaic grid-connected control systems", Electric Power Systems Research, vol 81, 2011, pp 907-914.*

- *[Alexis B. Rey-Boué, Francisco Ruz-Vila, José M. Torrelo-Ponce, Salvador Subiela-Valls] "Control of a flexible platform for Grid-Connected Systems using a DSP-microcontroller arrangement", International Review of Electrical Engineering (IREE), vol 6, 2011, pp 777-788.*