DERri
Distributed Energy Resources
Research Infrastructures

TEMPLATE FOR PROPOSAL UNDER DERRI

User-Project Proposal:

User-Project Acronym	SOMMCC
User-Project Title	Synchronization of microgrids by a Microgrid Central Controller
Main-scientific field	Distributed Generation Systems and architectural problems
Specific-Discipline	Control of synchronization

Lead User of the Proposing Team:

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Activity type and legal status* of Organization	Higher Education Institution (1)
Position in Organization	Phd Researcher. Estefanía Planas received the M.S. Degree in automatic and industrial electronic engineering from the University of the Basque Country, Bilbao, Spain, in 2010. She is currently working toward the Ph.D. Degree in control of microgrids in the Department of Electronics and Telecommunications of the University of the Basque Country, Bilbao, Spain. Before her graduation, she worked as a R&D Engineer in Ingeteam Traction S.A. She is also a researcher with the Applied Electronic Research Group of the University of the Basque Country. Her current activities include electrical micro-grids, distributed energy resources and control of advanced power converters like matrix converters.

* 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:

Name	
Phone	
E-mail	
Nationality	
Organization name, web site and address	
Activity type and legal	

status* of Organization	
Position in Organization	

* 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	21/02/2012
Re-submission	YES_______ NO__X_____
Proposed Host TA Facility	RSE (Italy)
Starting date (proposed)	June

Summary of proposed research

A **Microgrid Central Controller** (MCC) has been implemented which improves the voltage quality of a microgrid. The microgrid is in the research infrastructure of **Tecnalia** and is formed by two diesel generators and different resistive and reactive loads. The diesel generators work in **island** and in an **autonomous** way using the **droop control** method. This way, the microgrid is controlled following a **hierarchical control scheme**, where the local control of the generators is droop control and a MCC is connected to them in order to send the nominal values of the frequency and the voltage amplitude.

On the other hand, microgrids can work both connected and disconnected to the grid. In this case, the microgrid is always working in an autonomous way but in some cases (like damage of one diesel generator, high load, etc.) it would be interesting to connect the microgrid to the main grid. This way, it is proposed to add **a new function to the MCC that synchronizes** the voltage of the microgrid with the main grid. This way, the MCC could connect the microgrid to the main grid when the synchronism between the two voltages is reached. This synchronization could be done by means of Phasor Measurement Units (**PMU**s) or other similar dispositives.

This way, the realization of this proposed research has three main objectives:

- ✓ Addition of a new function to the MCC for synchronization of the microgrid.
- ✓ Use of PMUs or other synchronization dispositives.
- ✓ Warranty of stability of the microgrid during the connection, transient and disconnection from the main grid.

State-of-the-Art

A **microgrid** is an aggregation of multiple distributed generators (DGs), such as renewable energy sources, conventional generators, and energy storage systems that provide both electric power and thermal energy. The generating technology found in a microgrid may take many forms and an individual microgrid is likely to include a mixture of these. Sources may be small, such as domestic CHP systems or roof-top photovoltaic panels or relatively large, such as office-block-scale CHP using gas-turbines or reciprocating engines. Sources may be intermittent (photovoltaic and heat-led CHP) or fully controllable (electric-led CHP or simple diesel/gas fuelled generators) [1].

One form of controlling microgrids is the **hierarchical control scheme**, supported by a communication infrastructure. This architecture is used to monitor and control microgeneration systems and loads, ensuring the microgrid operation as a single and active cell from the viewpoint of the upstream MV (Medium Voltage) system. Thus, the MG can be operated interconnected to or isolated from the upstream MV network [2]. In this manner, the hierarchical control includes three levels [3]: Distribution network operator (DNO) and market operator (MO), **Microgrid central controller (MCC)** and **Local controllers** (LCs).

As it has been mentioned, a hierarchical control scheme with an MCC and local controllers has been implemented for controlling a microgrid. This microgrid is in the infrastructure of **TECNALIA** and it is formed by two diesel generators feeding several loads. Moreover, this microgrid works in an autonomous way, without connection with the main grid. However, typically a microgrid operates in parallel with the main grid. That is why it is interesting to **develop a function** in order to control a switch that connects the microgrid with the main grid.

Islanded microgrid can change its operational mode to grid connected operation by reconnection to the grid, needing a process of **synchronization**. Generally, a single machine simply synchronizes with the grid using a synchronizer. However, the synchronization of microgrids that operate with multiple distributed generators and loads cannot be controlled by a traditional synchronizer. This is because it is needed to control multiple generators and energy storage systems in a coordinated way. The traditional methods used to connect in parallel several EPS (Electric Power System) can be grouped into two types: **manual method**, in which the operator throws a switch close command according to the synchroramps or synchroscope with the assist of the synchcheck relay, and the second is an **automatic method** in which the autosynchronizer automatically controls the speed and voltage of the generator to make a connection to the EPS [4].

In this manner, the connection between the two grids must be made when the microgrid and the main grid are synchronized in the PCC (Point of Common Coupling) in terms of frequency and phase of their respective voltages [5]. Table 1 shows the necessary limit values of frequency, voltage and phase to achieve a synchronous interconnection between the microgrid and the main grid [5].

Aggregate rating of DR units (kVA)	Frequency difference (Δf, Hz)	Voltage difference (ΔV, %)	Phase angle difference (ΔΦ, º)
0-500	0.3	10	20
>500-1500	0.2	5	15
>1500-10000	0.1	3	10

Table 1. Limit values for synchronous interconnection between microgrid and the main grid.

On the other hand, the ability to maintain synchronism after transition to island operation is crucial from stability point of view [6]. This way, a very precise synchronization is required prior to each generator connection to the grid in order to avoid catastrophic transients. To estimate the phase-angle, **open-loop** and **closed-loop** methods are available. The closed-loop methods are commonly known as phase-locked loops (PLLs). The figures of merit of a PLL are the steady state phase-angle error, speed of response to phase, frequency and voltage amplitude disturbances, harmonic rejection, and line imbalance rejection in case of three-phase systems [6].

This way, the present project will develop a control in order to synchronize a microgrid with the main grid taking into account all this factors and will be experimentally validated in the RSE infrastructure.

References

[1] T.C. Green, M. Prodanovic, Control of inverter-based micro-grids, Electric Power Systems Research, vol. 77, pages 1204–1213, 2007.

[2] F. Resende, N. Gil, J. Lopes, Service restoration on distribution systems using multi-micro grids, European Transactions on Electrical Power 21 (2) (2011) 1327 – 1342.

[3 F. Katiraei, R. Iravani, N. Hatziargyriou, A. Dimeas, Microgrids management, IEEE Power and Energy Magazine 9, Issue 5 (2011) 54 - 65.

[4] C. Cho, J. Jeon, J. Kim, S. Kwon, K. Park, and S. Kim, Active Synchronizing Control of a Microgrid, IEEE Transactions on Power Electronics, vol. 26, No. 12, pages 3707-3719, 2011.

[5] Llaria, A. and Curea, O. and Jiménez, J. and Camblong, H. Survey on microgrids: Unplanned islanding and related inverter control techniques, Renewable Energy, vol. 36, n 8, p 2052-61, 2011.

[6] O. Vodyakho, C. S. Edrington, M. Steurer, S. Azongha, F. Fleming, Synchronization of Three-Phase Converters and Virtual Microgrid Implementation Utilizing the Power-Hardware-in-the-Loop Concept, 2010 Twenty-Fifth Annual IEEE Applied Power Electronics Conference and Exposition - APEC 2010, p 216-22, 2010.

Detailed Description of proposed project : Objectives – Expected Outcome – Fundamental Scientific and Technical value and interest

A microgrid formed by two diesel generators and several loads has been controlled following a **hierarchical control scheme** (Figure 1). This way, the generators are locally controlled by means of the **droop control method**. This control method is based on local measurements of the generators avoiding interconnections between them. Furthermore, an **MCC** has been implemented that restores the values of frequency and amplitude of the voltage of the microgrid. This MCC has been implemented in a PC by means of **MATLAB** software. The PC communicates with the diesel generators by means of **serial ports** and **modbus protocol**. The diesel generators work in island, without connection with the main grid. However, microgrids can work both in island and connected with the main grid. So, it is interesting to implement a control in order to connect the microgrid with the main grid. In order to reach this, a **synchronization algorithm** with the main grid is needed as well as a **control of a switch** that interconnects the two grids.

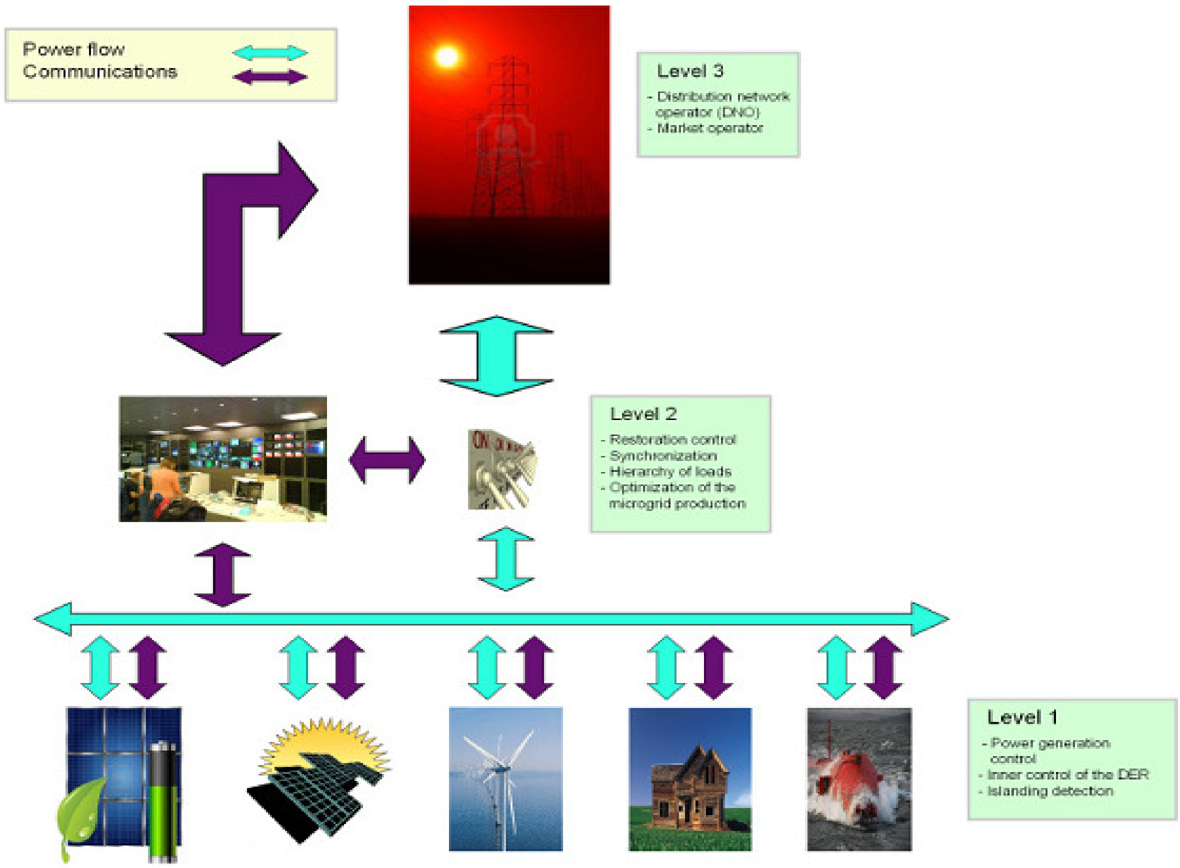

Figure 1. Hierarchical scheme control of microgrids

Objectives of the proposal

The present proposal has several main **objectives**:

- ✓ **Addition of a new function to the MCC**:

  A new function for synchronizing the microgrid with the main grid is proposed. This function will receive measurements from the microgrid and the grid and will try to reach the previous synchronization criteria in order to obtain a good connection of the grid with the microgrid. The synchronizing criteria can be resumed as follows: make the values of the phase-angle difference, slip frequency, and voltage difference as small as possible. Synchronizing the generator to the other AC power system is very important, considering that an out-of-step breaker closure generates a short-circuit current and high vibrations from the torsional oscillation of the shaft. Even though there is no detectable physical damage, the loss of life of the generators and electric equipment is still anticipated. So the explained synchronizing criteria will have to be taken into account when developing the synchronization function on the MCC.

- ✓ **Measurement of voltage phasors:**

  The synchronization function will receive phasor measurements from PMUs (Phasor Measurement Units) or other similar dispositives. These units will be connected to the microgrid and the main grid. Moreover, they will have the measurements in a specific way and will have to be sent to the MCC.

- **Warranty of stability**:
  The microgrid will have two operation modes: connected and disconnected from the main grid. Furthermore, there will be a transient between the two operation modes. This way, the stability of the system in the three situations has to be guaranteed in order to obtain a good performance of the system.

In order to fulfill the previous objectives, the next tasks are proposed:

- **Design of a synchronization algorithm**:
  As it has been commented in the proposed objectives, a synchronization criteria has to be followed in order to obtain a good synchronization between the microgrid and the main grid. This synchronization will be reached by means of changing the nominal values of the frequency and voltage amplitude references of the voltage sources. These voltage sources, moreover, will be controlled by means of the droop control. Furthermore, an analysis of the system stability connected and disconnected from the grid will be performed in order to warranty the system stability in the two operation modes, as well as in the transitory between the two operation modes.
- **Place of measurement units**:
  PMUs or other similar dispositives will be placed in the microgrid and the grid in order to obtain phasor measurements. Thanks to these units, the voltage phasors of the microgrid and the grid will be achieved.
- **Sending of the phasor measurements:**
  Phasor measurements of both the microgrid and the main grid are needed in order to reach the synchronization between the two systems. These phasor measurements can be obtained by means of PMUs or other similar dispositives. This way, a communication between the measurement dispositives and the MCC is needed and its characteristics depend on the used measurement dispositives.
- **Interpretation of the phasor measurements:**
  Once the phasor measurements are obtained, they have to be interpreted by the MCC. These signals will be in a specific way, so maybe an adaptation of the measurement signals to the MCC will be needed.

Ricerca sul Sistema Energetico SpA (RSE) in Italy is proposed as the TA infrastructure in order to carry out the tests. The following needs are required from this TA infrastructure:

- A **microgrid** to be synchronized with the main grid. This microgrid has to provide at minimum **two AC voltage sources** controlled by **droop control method**. Moreover, nominal values of frequency and voltage amplitude of the voltage sources have to be **controllable** by an external signal. The **MCC** will send frequency and voltage amplitude nominal values to these voltage sources.
- A **controllable switch** that connects the microgrid with the main grid. This switch will be controlled by the MCC, so a communication between a PC (where the MCC is) and the controllable switch is needed.
- Two **PMUs** or similar dispositives. Moreover, these dispositives will have some form of communication with the MCC too.
- Variable **controllable loads** in order to simulate different system load conditions.

Possible non expected issues and problems would be documented and analysed. Practical difficulties that could take place in the laboratory will be faced in collaboration with RSE's staff, as required.

Expected outcomes

The development of this proposed research will have several outcomes:

- ✓ The MCC will have the capacity of connecting and disconnecting the microgrid with the main grid.
- ✓ A good performance of the microgrid in the two operation modes will be guaranteed.
- ✓ The possibility of connecting the microgrid to the main grid. This interconnection is interesting in situations like overproduction or underproduction of energy in the microgrid.
- ✓ Stable operation of the microgrid during the transient between the two modes.

The performance of this research will be measured and documented in detail. The results and the conclusions drawn will be compiled in a report and also disseminated in relevant publications.

Originality and Innovation of proposed research – Broader Impact

Fuel costs evolution and geographic distribution of the reserves have conditioned energy options of the countries since more than three decades ago. More recently, environmental concerns, intense growth of emerging countries and energy sector liberation in Europe have been conditioned energy politics. This way, renewable energy sources are presented by most governs as principal candidates to cover the future demand reducing environmental impact in comparison with traditional energy sources such as carbon, fuel, etc. Distributed power systems present several advantages versus centralized power systems, such as redundancy, modularity, fault tolerances, efficiency, reliability, easy maintenance, smaller size and lower design cost. All these features are obtained thanks to the short distance between the generation and the customer, the use of reconfigurable systems, etc. However, because of their intermittence, randomness and uncertainty caused by meteorological factors, it is hard to connect renewable energy sources to utility grid directly. By integrating distributed and renewable sources, energy storage devices, a variety of loads, data acquisition and supervisory control devices, microgrids realize the interface between the distributed renewable sources and utility grid between the distributed renewable sources and utility grid.

This way, the microgrid is expected to improve the penetration ratio of green energy so that it will diminish CO2 emissions. It can also improve energy efficiency due to the nature of on-site generation, which does not incur transmission losses. This way, numerous studies of microgrids had been conducted and a number of major research projects are underway around the world. In this sense, this project would be another contribution to this field.

On the other hand, there are cases in which a microgrid operates in an islanded mode, or in a disconnected state. Islanded microgrid can change its operational mode to grid-connected operation by reconnection to the grid, needing a synchronization process. However, the synchronization of microgrids that operate with multiple DGs and loads cannot be controlled by a traditional synchronizer since it is needed to control multiple generators and energy storage systems in a coordinated way. This is not a simple problem, considering that a microgrid consists of various power electronics-based distributed generators as well as alternator-based generators that produce power together.

This way, the novelty of this project consists on synchronizing a microgrid by means of changing nominal values of frequency and amplitude voltage of the droop controlled voltage sources on it. Thanks to that, a synchronization of the two systems is obtained when it is needed. Furthermore, good performance in the two operation modes (connected and disconnected from the grid) as well as during the transient between the two modes is guaranteed.

Proposed Host TA Infrastructure/Installation – Justification

The proposed project requires an installation providing a microgrid and a controllable switch for connecting and disconnecting it from the main grid. The existence of at least two droop controlled voltage sources in the microgrid with controllable voltage and frequency nominal values is considered essential. The proposed host TA infrastructure is RSE, for the following reasons:

- ✓ A microgrid with both current and voltage sources is provided.
- ✓ Two PMUs are connected to the microgrid and the main grid.
- ✓ There is a controllable switch that interconnects the microgrid with the main grid.
- ✓ Different load conditions can be simulated since there are several load types can be connected to the microgrid.
- ✓ RSE`s staff has extensive experience in aspects of control of microgrids, synchronization, etc.

For all the above mentioned reasons, it is assumed that the infrastructure of RSE provides excellent conditions for the development of the present project.

Possible additional costs could be the hardware communications between the PC and the voltage sources as well as the communications between the PC and the controllable switch.

Synergy with ongoing research

The development of a synchronization function on the MCC will be part of PhD thesis of the candidate. A MCC has been implemented already that controls the voltage quality of a microgrid formed by several droop controlled voltage sources. So this additional function would improve the developed MCC.

On the other hand, the principal field of knowledge of the thesis is the control of microgrids and paralled connected power converters. So this research project would be an interesting contribution to this thesis. Furthermore, experimental results will complement the designed control, increasing the value of the implemented system.

The user is participating in various research projects about the described field.

Dissemination – Exploitation of results

The implemented system as well as the experimental results of the tests performed in the infrastructure would be disseminated in appropriate peer-reviewed journals and/or conferences by means of at least one research paper. Some possibilities would be:

- ✓ IEEE Transactions on Smart Grid
- ✓ IEEE Transactions on Power Systems
- ✓ IEEE Transactions on Industrial Applications
- ✓ Electric Power Systems Research
- ✓ IEEE-IECON International Confference

Time schedule

Week No. (from 1/06/2012)	***1***	***2***	***3***	***4***
Introduction to the laboratories, identification of requirements, develop safety procedures				
Synchronization function				
- Development of the synchronization function on the MCC.				
- Communications between the voltage sources, the controllable switch and the PC.				
- Adaptation of the received and sent signals from/to the PC, voltage sources and controllable switch.				
Testing period				
Analysis of results				

Description of the proposing team

Estefanía Planas received the M.S. Degree in automatic and industrial electronic engineering from the University of the Basque Country, Bilbao, Spain, in 2010. She is currently working toward the Ph.D. Degree in electric microgrids in the Department of Electronics and Telecommunications of the University of the Basque Country, Bilbao, Spain. Before her graduation, she worked as a R&D Engineer in Ingeteam Traction. She is also a researcher with the Applied Electronic Research Group of the University of the Basque Country. Her current activities include matrix converters and electric micro-grids.

List of Publications

Authors: E.Planas, E. Ibarra, E. Ormaetxea, J. Andreu, I. Gabiola.
Title: “Implementation of an Electrical Micro-Grid Through Parallelization of Matrix Converters”
Congress: 2010 International Power Electronics and Motion Control Conference (EPE-

PEMC´2010)
Publication: Proceedings of EPE-PEMC 2010 Pages. (T3) 137-142. ISBN 978-1-4244-7854-5
Place: Ohrid (Macedonia) Date: 2010

Authors: E. Planas, E. Ibarra, J. Andreu, J. L. Martín, S. Apiñaniz.
Title: "Wireless control for parallel connected converters applied to Matrix Converters"
Congress: PCIM Europe 2011
Publication: PCIM Proceedings 2011, pages. 866-871. ISBN 978-3-8007-3344-6
Place: Nuremberg (Germany) Date: 2011

Authors: Estefanía Planas, Edorta Ibarra, Jon Andreu, Iñigo Kortabarria, Igor Gabiola
Title: "Método droop: análisis del control wireless para la conexión en paralelo de convertidores de potencia"
Congress: Seminario Anual de Automática, Electrónica Industrial e Instrumentación (SAAEI 2011)
Publication: Proceedings of SAAEI'11, pages. 275 – 280 ISBN 978-84-933682-3-4
Place: Badajoz (Spain) Date: 2011

Authors: Estefanía Planas, Edorta Ibarra, Jon Andreu, José Luis Martín, José Ramón Etxebarria
Title: "Droop metodoak: potentzia-bihurgailuak paraleloan konektatzeko haririk gabeko metodoak"
Publication: Proceedings of Ekaia, vol. 24, pages 257-276 ISBN 0214-9001
Date: 2011

Participations in research projects

Project title: OPCOPOLI: Optimization of control of power converters and line transmission in electric microgrids.
Financial: Eusko Jaurlaritza/Gobierno Vasco (programa SAIOTEK). S-PE11UN002
Participants: UPV/EHU.
Date: 2011-2012

Project title: SARECONPA: Connection in parallel of power converters in electric microgrids.
Financial: Eusko Jaurlaritza/Gobierno Vasco
Participants: Universidad del País Vasco (UPV/EHU), Ecole Supérieure des Technologies Industrielles Avancées (ESTIA)
Date: 2012