DERri
Distributed Energy Resources
Research Infrastructures

ANNEX 2: TEMPLATE FOR PROPOSAL UNDER DERRI

User-Project Proposal:

Use-Project Acronym	SOPC – MicroGrids
User-Project Title	Stochastic Optimal Predictive Control for MicroGrids
Main-scientific field	Computer Science Engineering – Automatic Control
Specific-Discipline	Stochastic Optimization and Control

Lead User of the Proposing Team:

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Activity type and legal status* of Organization	Higher Education
Position in Organization	Post-Doc

* 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)

Date of submission	05/10/2010
Re-submission	YES________ NO____X___
Proposed Host TA Facility	CRES, Greece
Starting date (proposed)	February 1st, 2010

Summary of proposed research
The proposed research aims at testing experimentally the main functionalities of a central controller for MicroGrid (MicroGrid Central Controller, MGCC) designed so as to optimize the MicroGrid operation both in grid-connected and islanded mode (e.g, optimizing the production of the local distributed generators (DGs) and storages and power exchanges with the main distribution grid subject to market conditions). The proposed control scheme is based on feedback and stochastic optimization: the operative points of the MicroGrid components at each hour are computed by solving an optimization problem, which is a combination of economic dispatch and unit commitment taking into account the stochastic nature of Renewable Energy Sources (RES) and the imbalance charges due to the mismatch between the actual and the scheduled RES power outputs. Demand response policies for controllable loads are also included in the formulation of the optimization problem. At each hour, the optimum allocation of active power sources as well as load shedding/curtailment programs are obtained, based on locally measured signals. The objective is then to achieve optimal dispatch of controllable loads and generators as well as effectively utilizing the energy storage. The optimal dispatch is price sensitive and show how MicroGrid can reduce costs by selling stored energy at high prices and shave peak loads, while optimizing running costs of microsources. In addition, the stochastic optimization problem is

cast with an eye to computational load and the final objective of running the algorithm on-line, using a programmable logic controller or microcontroller. The stochastic optimization problem can be further improved by including reactive power dispatch and greenhouse gas emissions minimization.

The control system is currently under development at the Università degli Studi del Sannio; it is implemented on the specific equipment of the UniSannio laboratories using Matlab/Simulink. The operation of the CRES MicroGrid under the proposed energy management strategies will be tested under various MicroGrid operating conditions: experiments may provide more meaningful insights into the behavior of MicroGrids and the optimization routine can be assessed. Sensitivity of the design to changes of parameters and operating point as well as the system robustness against uncertainties can be also investigated. The experimental results and conclusions drawn will be compiled in a report and disseminated through publications on archival journals of Automatic Control and Power Systems. We point out the topic is still not developed in the field of the Automatic Control.

State-of-the-Art

Advantages provided by the renewable based distributed generation coupled with national or regional deregulation policies and incentives are pushing the future energy markets to invest more into renewable systems. MicroGrid is a well-known concept for integrating the distributed resources into the current power distribution network. With advanced power electronics and controls, the technology already exists to develop MicroGrid with renewable energy sources. But the installation of the renewable energy systems still requires high initial costs. Moreover, intermittent sources like wind can cause problems in grids, in physical balances and in adequacy of power. In addition, the analysis and deployment of renewable energy system is challenging because of the large number of design options, uncertainty in future fuel price, intermittent and seasonal nature of renewable power generation. The optimization of the Microgrid system is extremely important to minimize the operation costs ([9]-[11]). Several optimization scheme and energy management systems have been developed: the generation scheduling problem is commonly stated as a Mixed Integer Nonlinear Problem (MINLP), for which there is no exact solution technique. Solution methods utilize heuristic-based methods using Priority List, dynamic programming, Lagrangian relaxation, network programming approaches: these studies have strived to model the economics and thermodynamics of a MicroGrid in a detailed, but purely deterministic, setting ([4], [6]-[8], [12]).
Studies have suggested that the possible increase of the penetration of renewable energy and an improvement of the MicroGrid operations can be achieved through:

- advanced control algorithms accounting for system uncertainty;
- deployment of demand response;
- optimal use of storage devices in order to compensate the physical unbalances.

Some of these works are briefly outlined in the following.
The authors in [5] show that there is a loss in investment value from neglecting the uncertainty in both electricity and fuel prices. Moreover, it is shown that there is an economic and environmental advantage to using DER in conjunction with demand response (DR).
In order to find optimal DER adoption under stochastic prices, however, a stochastic programming approach needs to be used, possibly employing Benders' decomposition. The optimal DER operational problem under uncertainty is solved for various levels of installed capacity in [3].
The approach presented in [1] analyzes the impact of the Demand Side Bidding (DSB) on MicroGrids operation, taking into account variations in market prices, RES production, and seasonal demand for a typical LV network. Additionally, the economic impact of applying adequacy constraints, i.e. request specific part of the MicroGrid demand to be supplied by local power production, in case of intentional islanding, is estimated. This is essential to achieve seamless transition from interconnected to autonomous operation of MicroGrids. The potential of

DSB to reduce operating costs improving at the same time the quality of service to the loads of higher priority is shown.
A cooperative control system for gas engine generators and a lead-acid battery in a MicroGrid is developed in [2]. The control system enables a MicroGrid system to balance the electric power demand and supply and to simultaneously control the state of charge (SOC) of the battery. To evaluate this control system, the authors simulated its performance in balancing the control of an experimental MicroGrid facility with two reciprocating engine generators for a day in which large fluctuation in photovoltaic (PV) and wind turbine output was observed. Based on the simulation, the rated power ratio of renewable energy installed in the MicroGrid can be increased beyond 50%, and at the same time the minimum feasible capacity of the battery can be reduced to the amount sufficient to charge the rated output of the intermittent renewable energy for 15 minutes.

References

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

The optimization of the MicroGrid operations is important in order to operate the MicroGrid with high penetration of RES. One of the major difficulties in optimizing the operation of a MicroGrid is the uncertainty associated with the weather profiles. Unpredicted weather variations cause fluctuation in the power outputs of many RES such as wind and solar. Such fluctuations can cause operational challenges to maintain the generation-load balance, especially in cases of high

RES penetration. In addition, the system load are also varying: demand for electrical energy exhibits fluctuation with cyclical variations of people's life, work and climate, meanwhile generator cannot be started up or shut down at will, therefore optimally scheduling generators in advance brings great economic benefits for electrical power system. Thus the control algorithm must rely on stochastic optimization techniques and predictive algorithms.
Moreover, demand response measures are very important to improve electricity market function. Day-ahead demand response programs are designed to allow load curtailment resources to compete against generator in day-ahead market. In such programs, the customers specify level of load curtailment. Considering demand response in day-ahead optimal operation planning then need to deal with more complicated coupling constraints.
The optimal operation planning of a MicroGrid has been formulated for the day ahead. The objective function is the minimization of the running costs. The constraints enforce the energy balance, controllable generators minimum operation time and minimum stop time, maintenance costs, capacity of generators, battery, electricity price, cost of starting and stopping the generators.
The overall goal is to test a MicroGrid central control algorithm with error forecast processing.
The proposed MicroGrid Central Controller has the following main functionalities:

- RES production, load and energy prices forecasting;
- generators and electricity trade quantities dispatching;
- forecast error processing.

The dispatch decisions are corrected by a forecast error processing. The proposed control system also has to keep the balance between load and demand by controlling the MicroGrid: namely MicroGrids are characterized by limited load aggregation, negligible rotating inertia and high penetration of weather dependant generators. The control inputs are obtained by solving a stochastic optimization problem. The proposed control system exploits forecasts and stochastic techniques to generate schedules meeting the demand. The sources of uncertainty taken into account to develop a stochastic operational optimization of MicroGrid operations are:

- demand,
- local production,
- energy prices.

Then, the developed stochastic scheduling system aims to improve the schedule quality through the development of:

- an effective uncertainty model, which best captures the dynamics of the sources of uncertainties.;
- a stochastic optimization problem.

The proposed approach extends the stochastic programming framework to production planning and exploit recourse actions to adjust pre-scheduled production levels in reaction to realized deviations from the forecasts. Existing methods are adopted to generate scenarios: Support Vector Machine, which is exploited to compute forecasts and Hidden Markov Model, which is employed to build a discrete distribution of the errors in demand forecasts, based on historical data. A well-known clustering algorithm is adopted to select the most meaningful scenarios and reduce the scenario number; then a computationally tractable integer scenario-based stochastic program is solved.
The stochastic model accounts for future uncertainty realizations. The recourse function is a penalty function for violating random constraints: we want to compensate deficiency in the schedule after observing random data realizations, but the correction actions have a cost. We keep always feasible if the schedule is able to respond to any possible disturbance realizations immediately.
Then the proposed stochastic approach introduces forecasting and scenario generation, as well

as recourse actions in the control system described above, in order to determine MicroGrid operations minimizing the number of recourse actions to be taken to balance the MicroGrid. Recourse actions are needed when the actual realizations does not match the expected sources of uncertainty values.
This stochastic optimization problem is the combination of two main functions:

- Economic Dispatch (ED);
- Unit Commitment (UC).

The UC can be defined as the scheduling of power production from generation units over a daily to weekly time horizon while respecting various generator and system constraint. The objective function includes costs associated with energy production and start-up and shut-down decisions, along with possible profits. As the number of units increases, the UC problem grows exponentially. Mathematically, the problem is commonly stated as a MINLP which consists of integer variables for thermal unit commitment and continuous variables for economic renewable thermal dispatch. The resulting problem is a large-scale MINLP for which there is no exact solution technique.
Due to the problem's complexity and because of the large economic benefits that could result from its improved solution, considerable attention has been devoted to development of better optimization algorithms.
The stochastic optimization problem in the proposed framework is stated as a Mixed Integer Linear Problem, applying well known linear approximation techniques of nonlinear cost functions and formulating complex operative constrains as linear constraints. By doing so, the problem can be solved very efficiently by standard algorithms. Moreover, the formulation developed is very flexible and can be applied to any size of power system. Detailed dynamic models are not used since interest lies on steady state effects..
Solving the stochastic optimization problem will provide in one run:

- how much energy has to be purchased and/or sold when the MicroGrid is in the grid-connected mode;
- which controllable micro-source must be committed and when;
- active and reactive power levels of the controllable micro-sources;
- load shedding/curtailment (which controllable loads must be shed/curtailed and when);
- how much energy has to be stored.

Objectives:
The proposed project will have the following objectives:

- to adapt the developed forecasting and optimization routines to the laboratory equipment:
- to test the operation of the MicroGrid central control system under laboratory conditions: parameter sensitivity analysis, energy cost savings measures will be performed, and the strategy control will be assessed in term of emissions, energy production, system reliability and peak reduction

These objectives require the following from the TA infrastructure:

- a MicroGrid with distributed generators, storage devices and controllable loads;
- load and micro-generation controllers;
- data acquisition monitoring and storage to files for further processing;
- measurement of active and reactive power flows at specific points in the system and the possibility to transfer the data to the control system;
- user training on safety procedures would be expected. Health and safety assessment will be performed before the beginning of the experimental work;
- communication functionalities to transfer data from/to the MGCC and the local controllers

A series of trading and operational sessions will be run, during which the operation of the system will be evaluated. Possible unforeseen issues would be documented and analysed. The effect of stochastic and arbitrary micro-generation owner behaviour will be tested. The most significant

uncertainty that is likely to hinder the project development regards unexpected practical difficulties that are usually faced in the laboratory. This would be tackled by careful planning and by providing ample time for each task.
Experimental software is expected to behave unpredictably, so appropriate emergency shutdown procedures will be implemented.

Expected Outcome
The expected outcome is addressing the following questions:

- what is the added value of the proposed control strategy?
- how much does the quality of the predictions matter for the MGCC?
- how robust is the proposed control scheme to model parameter mismatch?

The experimental results will show whether it is possible to find optimal feasible solutions that improve the operating conditions of the micro-grid with respect to the ones obtained as a result of the generators local controllers.

Moreover, the results obtained will demonstrated whether the proposed control strategy is superior to those obtained by applying state-of-the-art optimization methods, in terms of:

- global cost and emissions,
- system stability,
- computational resources requirements.

Fundamental Scientific and Technical value and interest
The main interest is to increase the value of distributed energy resources in the power system and in the energy market and to find solutions to the problems caused by the variable output of intermittent resources: promising approaches are adding energy storages into the system, creating more flexibility on the supply side to mitigate supply intermittency and load variation, and increasing flexibility in electricity consumption. All these aspects are addressed in the proposed control system.

Originality and Innovation of proposed research – Broader Impact

Increasing needs for electrical power, progress in power deregulation, tight construction constraints on new high voltage lines for long distance power transmission, and global environmental concerns have created increased interest in alternative energy generation. Hybrid combination of renewable sources can significantly improve their reliability and better deliver power to customer loads without reliance on centralized electricity production. It is expected that MicroGrids can reduce the burden on the utility grid by generating power close to the consumer will penetrate the existing grid-infrastructure in the near future. Nevertheless, uncontrolled integration of power sources in the distribution system may have negative effects on efficiency and working parameters. Global optimization of distributed generation in the system is not available, but MicroGrids arrangements make it possible to the design management systems which are able to control their working parameters and give fast responses to internal events without affecting the distribution system The novelty of this work is the application of advanced stochastic methods to the MicroGrid power management problem given complex constraints and objectives including fuel/resource availability, and economic considerations. Moreover, the proposed modeling approach of the power management control problem allows reduction of computational load related to optimization algorithm.
The controller should therefore be enabled to take advantage of demand shifting in order to deal with load fluctuations. The proposed scheme is well suited to reach the goal of load shifting and decreasing of peak electricity demand with respect to a given load profile. An economic incentive is given for adhering to such demand response (DR) schemes.

In conclusion, if the proposed system is proved to be successful and feasible, it would have the following advantages:

1. high penetration of RES in a reliable and efficient fashion,
2. optimal distributed generation and storage taking uncertainty into account,
3. demand response integration.

The economical and environmental benefits as well as the demand peak reduction obtained by applying the described control scheme will be evaluated through the proposed research

Proposed Host TA Infrastructure/Installation – Justification

As described above, the proposed project requires micro-grid installations which include low-level controllers: a hierarchical approach is adopted, which allows to simplify the problem formulation, because it is assumed that each sources and load has its own local control The proposed host TA Infrastructure is the CRES MicroGrid in Greece, for the following reasons:

- the hierarchical structure of the proposed system is already present;
- the MicroGrid comprises several DER, programmable loads and storage technologies;
- the system includes a power quality meter for monitoring quantities like active and reactive power flows;
- load controllers and Distributed Generation unit controllers may be applied in order to implement demand side and energy management optimization;
- a visualisation for supervision, monitoring and control has been developed in LabView;
- the controllable loads can be used to simulate arbitrary consumer behavior;
- the controls are fully automated which means that through the interface the operator can perform any desired experiment;
- capabilities for data acquisition monitoring and storage to files for further processing are provided;
- the infrastructure staff has extensive experience in aspects of design, development and operation of MicroGrid.

For the above reasons, it is assumed that the infrastructures offered by CRES are very well suited to the scope of the proposed project and provide more than adequate means for its successful completion projects.

Dissemination – Exploitation of results

The results of the tests performed in the infrastructure would be disseminated in appropriate journals and/or conferences. Some possibilities would be:

- International Journal of Renewable Energy Technology
- Control System Technology

Time schedule

Week No.	1	2	3	4	5	6	7	8	9	10
Introduction to the laboratories, identification of requirements, develop safety procedures	■									
Adaptation of the developed control system functionalities to equipment:		■	■	■	■					
• Development of interaction between local controllers and central controller		■	■							
• Introduction of the Microgrid component parameters in the control system routines				■						
• Data processing				■	■					
Setting up the equipment					■	■				
Testing						■	■	■	■	
Analysis of results								■	■	■

Description of the proposing team

- *GRACE* is the acronym of Group for Research on Automatic Control Engineering, Università del Sannio, Italy. The Group was instituted in 1999 by prof. Luigi Glielmo with the aim of contributing to the application of modern modeling and control strategies for the solution of engineering problems inspired by realistic applications. GRACE activity is also aimed to improve collaborations between universities, research centers and industries which work in the field. GRACE has several methodological expertise such as: Analysis of complex systems, Analysis and control of nonsmooth systems, Simulation of complex and nonlinear systems, Identification and Kalman filtering, Genetic algorithms and neural networks, Real-time control systems, Hardware-in-the-loop and rapid control prototyping, Simulation and optimization of manufacturing systems.

  GRACE had many collaborations and open projects with research centers and companies among whitch:

  - Automotive: Centro Ricerche FIAT, ELASIS, Istituto Motori CNR, Magneti Marelli, AnsaldoBreda, Ferrari Gestione Sportiva, Volkswagen, DaimlerChrysler,
  - Railway: AnsaldoBreda
  - Manufacturing: Fabbrica Motori Avellino, Centro Sviluppo Materiali, Europea Microfusioni Aerospaziali
    Home automation: Siemens
  - Agro-food industry: Parco Scientifico e Tecnologico di Salerno, Torregaia, Siprio.

  GRACE's members have also started and are involved in several spin-off companies: *Mosaico, Smartfreeze, mdtech, KES*.

  GRACE members have contacts with researchers of the following academic institutions: ETH (Zurigo, Switzerland), Royal Institute of Technology (Stockholm, Sweden), University of Linz (Austria), Chalmers University (Sweden), Universidad Politécnica de Cataluna (Barcellona, Spain), University of Bristol (UK), University of Minnesota

(Minneapolis, USA), University of Michigan (Ann Arbor, USA), Ohio State University (USA), Boston University (USA), Purdue University (USA).

- Alessandra Parisio receives the Laurea degree in Computer Science Engineering from the University of Sannio, Benevento, Italy, in 2005 and the Ph.D. degree in Computer Science Engineering from University of Sannio, Benevento, Italy, in 2009. She is currently with the Group for Research on Automatic Control Engineering, University of Sannio, Italy. Her current research interests include the areas of manufacturing system simulation and scheduling and stochastic constrained control. From February 2008 to February 2009 she is academic guest at the Automatic Control Laboratory, Swiss Federal Institute of Technology (ETH), Zurich (Switzerland), and collaborates with the Automatic group on the project "Use of weather and occupancy forecasts for optimal building climate control (OptiControl)" (http://www.opticontrol.ethz.ch/). The project *OptiControl* aims at exploiting these developments for improving the indoor climate control of buildings. The goal is to reduce energy consumption while maintaining high user comfort and work productivity, at modest basic investment and operating costs. The achieved results of the project are the following:
    - Development of stochastic control methods using weather forecasts and occupancy-related information aiming at
        - improving the energy efficiency and comfort of buildings and
        - reducing peak electricity demand.
    - Development of software and information technology based tools and components for improved building climate control.
    - Benefit-cost analysis for different buildings and local climatic conditions.
    - Application to a demonstrator building or space unit.

Pubblications:

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- O. Barbarisi, C. Del Vecchio and A. Parisio, "*Hybrid Model for Crane Scheduling*", 17th IFAC World Congress, 2008.
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- O. Barbarisi, C. Del Vecchio and A. Parisio, "*Crane Control with Time-Based and Position Constraints*", 46th IEEE Conference on Decision and Control, 2007.
- O. Barbarisi, C. Del Vecchio and A. Parisio, "*Multiple Crane Control with Tasks Deadlines and Priority Constraints*", European Control Conference, 2007.
- O. Barbarisi, C. Del Vecchio, G. Palmieri and A. Parisio, "*A Software Simulator For Manufacturing Plant*", International Industrial Simulation Conference, 2007.