ANNEX 2: TEMPLATE FOR PROPOSAL UNDER DERRI

User-Project Proposal:

Use-Project Acronym	MSPC
User-Project Title	Microgrid Stochastic Predictive Control
Main-scientific field	Computer Science Engineering – Automatic Control
Specific-Discipline	Stochastic Optimization and Control

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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	31/05/2011
Re-submission	YES____X__ NO_______
Proposed Host TA Facility	CRES, Greece
Starting date (proposed)	September 12nd, 2011

Summary of proposed research
The proposed research aims at testing experimentally the benefits of applying a Model Predictive Control (MPC) approach to the problem of efficiently optimizing microgrid operations while satisfying a time-varying request and operation constraints. A typical microgrid comprises: storage units; Distributed Generators (DGs), which are dispatchable units; Renewable Energy Resources (RESs), which are non controllable devices; and controllable loads, which can be curtailed/shifted when it is more convenient. In addition a microgrid can purchase and sell power to and from its energy suppliers.
The proposed research is intended to be a continuation of the proposal SOCP-Microgrid, Stochastic Optimal Predictive Control for Microgrids, which was carried out from 18 April 2011 to 20 May 2011. In the SOPC-Microgrid project, the proposed scheme for the microgrid central controller is based on feedback and stochastic optimization: the operative points of the microgrid components at each time step (e.g. 15 minutes, 1 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. Curtailment policies for controllable loads are also included in the formulation of the optimization problem. At each time step, the optimum allocation of active power sources as well as load shedding/curtailment

programs are obtained, based on locally measured signals. 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 objective of this new proposal is to further improve and test the stochastic control algorithm by including:

1) reactive power dispatch;
2) greenhouse gas emissions reduction;
3) thermal local production and demand and heat recovery capabilities;
4) additional demand side policies (e.g. shifting + recovery functionalities);
5) efficiency (for storage's inverter) depending on the storage's state of charge;
6) uncertain energy prices and heat/electricity demand.

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

The optimization of the microgrid system is extremely important to minimize the operation costs ([7]-[9]). 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 ([2], [4]-[6], [10]).
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.
In [11] is shown that microgrids can support the main grid and provide their thermal and electricity needs, but also enhance local reliability, reduce emissions, and power losses, and potentially lower costs of energy supply. It is clear that in order to achieve these benefits it is important to provide a coordinated decision making process, in order to balance demand and supply.
Additional functions in microgrid control can include renewable production, demand, and electricity prices forecasting. In [12], the economic operation of a microgrid participating in the emission markets and an estimation of the avoided emissions based on a novel methodology have been quantified.
The authors in [3] 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).

This paper in [1] aims at presenting a detailed analysis on the impact that demand side bidding (DSB) has on microgrids operation, taking into account variations in market prices, RES production, and seasonal demand for a typical LV network. It is shown that, especially for high market prices, DSB can help in reducing operating costs on top of the significant economic benefits achieved by the DG operation. Additionally, the customers can avoid high charges for low priority loads. Thus, even by simply denoting priority in their loads, the customers can help in further reducing costs for the whole microgrid.

In a stochastic framework, the authors in [14] propose an optimization algorithm based on Dynamic Programming.

To the best of our knowledge, very little work has been found in the literature that addresses Model Predictive Control for optimal dispatch in power systems and in microgrid in particular. The authors in [15], propose a look-ahead model predictive control algorithm to solve the economic dispatch problem with large presence of intermittent resources. However, many microgrid key features such as minimum up and down times, demand side programs, storages and on/off generators status are not considered. In [16] a model predictive controller is applied to controlling the energy flows inside a household system equipped with a 'micro' combined heat and power unit. In addition, the household can buy and sell electricity from/to the energy supplier; heat and electricity can be stored in specific storage devices.

The author in [13] propose a reactive power dispatch model that takes into account both the technical and economical aspects associated with reactive power provision in the context of the new operating paradigms in deregulated electricity markets. The main objective of the proposed model is to minimize the cost paid by the system operator to the generators for providing the required reactive power support.

In conclusion, from the literature one can learn that predictive control strategies as well as including heat demand, reactive power and emissions management as well as demand side policies in the control action provide potential benefits for energy efficient microgrid control

Moreover, in the aforementioned works, the optimization problem stays nonlinear and/or important features such as minimum up and down times and demand side programs are neglected. Moreover the approaches described above are typically either computationally intensive and not suitable for online applications, or can produce suboptimal solutions, since the overall problem is decomposed in order to make it tractable. In the proposed approach, the overall microgrid operation optimization problem is formulated and solved without resorting to heuristics or decomposition techniques. The proposed formulation is tractable and includes the specific key features of a microgrid.

References

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

The need to satisfy in sustainable ways the increasing energy demand requires active energy distribution networks and new energy management systems, able to optimally schedule the distributed generation in the distribution network. In this scenario, the microgrid concept is a promising approach. The optimization of the microgrid operations is extremely important in order to cost-efficiently manage its energy resources. The optimal scheduling of microgrid operations aims at minimizing the production costs of the local generators and the exchange with the utility grid subject to market conditions, while satisfying a predicted load demand of a certain period (typically one day) and complex operational constraints, such as the energy balance, and controllable generators minimum operation time and minimum stop time. A complete formulation of microgrid economic scheduling problem includes modeling of storage, demand side policies for controllable loads (Demand Side Management, DSM), energy exchanging with the utility grid, thermal and electrical energy as well as reactive power management, emissions reduction. The problem is generally formulated as a Mixed Integer Nonlinear Problem (MINLP) for which there is no exact solution technique. Due to the problem complexity and because of the large economic benefits that could result from its improved solution, considerable attention is being devoted to development of better optimization algorithms and suitable modeling frameworks. In the proposed control framework, the problem is posed as a mixed-integer linear programming model. The key difference is that no complex heuristics or decompositions are used; the full model is formulated and solved in an efficient way by using commercial solvers. This leads to significant improvements in schedule quality and in computational burden.

In this proposal, a control-oriented approach to microgrid modeling and optimization is presented and the use of Model Predictive Control (MPC) in combination with Mixed Integer Linear Programming (MILP) is proposed. By doing so, the optimization problems can be solved very efficiently by standard algorithms and the feedback mechanism can take into account the uncertainty in microgrid operations associated with (i) the RES power outputs; (ii) the time-varying load; (iii) time-varying energy prices. Then the control system also has to keep the balance between load and demand. The control inputs are obtained by solving a stochastic optimization problem and corrected by a forecast error processing. 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. The recourse function is a penalty function for violating random constraints: one wants to compensate deficiency in the schedule after observing random data realizations, but the correction actions have a cost.

The main objectives of the project are: (i) to show that the developed model of the overall microgrid system adopting a formalized modeling approach is suitable to be used in on-line optimization schemes; (ii) to prove that the proposed MPC scheme minimize the microgrid running costs and the emissions while satisfy the heat and electricity demand; (iii) the presentation of preliminary experimental results showing the effectiveness of the proposed optimization routine.

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, thermal and electrical 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;
- to test the benefits of demand side policies, such as curtailment and shifting programs;
- to test the control performance under different energy tariff structures.

These objectives require the following from the TA infrastructure:
- a microgrid with distributed generators, storage devices and controllable loads;
- distributed generators with heat recovery capabilities;
- 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;
- communication functionalities to transfer data from/to the central controller 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.

Expected Outcome
The expected outcome is addressing the following questions:
- what is the added value of the proposed stochastic control strategy?
- how much does the quality of the predictions matter for the stochastic control strategy?
- how much does that demand side policy matter for the stochastic control strategy?
- how much does that energy tariff matter for the stochastic control strategy?

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, a time-varying demand and real-time energy prices. All these aspects are addressed in the proposed control system.

Originality and Innovation of proposed research – Broader Impact

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, heat/electricity demand, emissions control and economic considerations. Moreover, the controller should 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.

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, efficient and green fashion,
2. optimal distributed generation and storage taking uncertainty into account,
3. demand response integration.

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:

- part of tthe proposed control scheme is already adapted to the microgrid equipment;
- 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;
- demand side policies can be implemented;
- the infrastructure staff has extensive experience in aspects of design, development and operation of MicroGrid.

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

Day No.	1	2	3	4	5	6	7	8	9	10
Adaptation of the developed control system functionalities to equipment:										
• Introduction of the Microgrid component parameters in the control system routines										
• Data processing										
Setting up the equipment										
Testing										

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.

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