NATIONAL PH.D. PROGRAM IN AUTONOMOUS SYSTEMS

Smart control systems for rural energy communities

Ph.D. candidate

Saba Askari Noghani

Cycle

Cycle XXXVIII

Tutors

Prof. Engr. Mariagrazia Dotoli

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1. Description of the research program

The lack of power supply to agricultural farms and the difficulties of renewable energy usage are two significant challenges in Rural Energy Communities (RECs). This research program will provide new decision and control techniques aimed at merging smart farms, renewable energy, and small rural consumers into RECs. This research will pay special attention to highlighting the unique characteristics of rural energy distribution in comparison to urban energy communities (ECs). It will focus on the need for significant network resilience and efficiency improvements, favoring the introduction of creative control frameworks to support the operation of rural energy systems and the sustainability of their future economic and industrial development. Thanks to the control framework and loads flexibility, the REC stakeholders will be able to trade local energy exchanges, optimally share common energy resources, and pursue instantaneous self-consumption while lowering overall costs and enhancing sustainability.

There is a significant amount of related research about managing energy in ECs and microgrids. These systems are crucial in the context of demand side management (DSM) because they allow users to react to market forces and choose the ideal timetable for energy related activities. Numerous strategies for energy scheduling are reported in the literature. Not surprisingly, Model Predictive Control (MPC) and game theory have recently attracted particular attention in the DSM of microgrids among several promising advanced control system techniques since they provide explicit accounting for respecting the system's dynamics and modeling the real system actors behavior, while optimizing some criteria. Investigations, particularly on residential and industrial scales, have theoretically and experimentally demonstrated the appropriateness of game theory and MPC to address DSM.

Despite this wide range of investigations, the development of game theory and MPC based algorithms has not been adequately studied in reference to rural regions and agricultural facilities. According to previous works, the performance of the control algorithms are evaluated in most relevant research over a short time horizon, often on a simulation horizon of one day. In the current project, we need to evaluate the potential of scheduling algorithms over a wide time window of study due to the potentially substantial variability of generation curves in renewable resources and variable consumption in smart farms over different times. The following issues are also a focus of the study:

- providing a pricing mechanism to increase the predictability and flexibility of aggregate smart farms and other rural consumers;
- evaluating the impact of prediction horizon length on the overall performance;
- considering detailed parameters (such as degradation of batteries) in the objective functions and pricing mechanism;
- putting robust and stochastic variations into practice;
- determining how improving load flexibility can help to reduce demand volatility further and enhance scheduling efficiency;
- modeling the behaviors of system actors in accordance with population/aggregative game perspective.

2. Schedule of the research activities

First academic year (planned)

	Description	**Period**	**Activity abroad**
Systematic literature review on predictive control	Study of model predictive control approaches as applied to energy management of RECs.	months 1-3	NO

Systematic literature review on game-theoretical control	Study of game-theoretical control techniques as applied to the energy management of RECs.	months 4-6	NO
Compilation of a literature review and bibliography on the research topics	Study of the existing control systems in ECs and RECs.	months 7-12	NO
Research work	Individual research activity and preparation of manuscripts.	months 4-12	NO

Second academic year (planned)

	Description	**Period**	**Activity abroad**
Definition of novel control techniques	Definition of new control architectures and framework based on MPC for rural energy communities.	months 1-6	NO
Experimentation	Simulation and testing of the defined decision and control policies using realistic scenarios of RECs.	months 7-12	NO
Research work	Individual research activity and preparation of manuscripts.	months 1-12	NO

Third academic year (planned)

	Description	**Period**	**Activity abroad**
Definition of novel control techniques	Definition of new control architectures and framework based on game-theory for RECs. Preparation of manuscripts. Activities to be conducted at the Delft University of Technology – Delft Center for Systems and Control	months 1-6	YES
Experimentation	Application of the control techniques to the real case studies of RECs.	months 7-9	NO
Research work	Individual research activity and preparation of manuscripts	months 7-9	NO
Preparation for final dissertation	Preparation for the final examination and the thesis	months 10-12	NO

3. Training and research activities plan

First academic year (planned)

	Description	Period	Final Exam	ECTS
A. Ph.D. courses	Duality-based decentralized and distributed optimization (DAUSY course)	June/July 2023	Yes	1
	Optimization and control of complex systems (SCUDO)	February 2023	Yes	2
	Applications of MATLAB (SCUDO)	June 2023	Yes	2
	Model Predictive Control (IMT School for Advanced Studies Lucca, online)	April 2023	Yes	2
	Learning-based predictive control (International Graduate School on Control - EECI)	June 2023	Yes	3
B. Master's degree courses	Dynamical Systems Theory (Automation Engineering MSc Degree - Poliba)	First semester	Yes	6
C. Soft skill courses	Linguistic Masterclasses		No	
D. Participation to seminars	Network dynamics and control (DAUSY seminar)	January-February or June 2023		3
	Sustainable exploitation of renewable energy sources (DAUSY seminar)	To be defined		1.5
	Learning influences in large scale dynamical social networks - a systems and control approach (DAUSY seminar)	March-July 2023		1.5
	Opinion dynamics (DAUSY seminar)	February/July/September 2023		1.5
E. Participation to international congresses or workshops				
F. Presentation of research products at international congresses or workshops				
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			23.5
G. Individual research activity	Study and simulations through experimental work at the laboratory. Study and research activities under the tutor's guidance.			26.5
H. Supervision of students				
I. Integrative teaching activities				
J. Preparation of manuscripts for conferences or journals	Research articles writing and submission.			10
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			36.5
	TOTAL OF ECTS			**60**

Second academic year (planned)

	Description	Period	Final Exam	ECTS
A. Ph.D. courses	PhD course selected among the available ones		Yes	2
	Winter or Summer Schools		No	3
B. Master's degree courses				
C. Soft skill courses				
D. Participation to seminars	Seminars			5
E. Participation to international congresses or workshops				
F. Presentation of research products at international congresses or workshops	Seminars and Workshops			3
	At least one paper			2
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			15
G. Individual research activity	Study and simulations through experimental work at the laboratory.			15
H. Supervision of students	Study and research activities under the tutor's guidance.			15
I. Integrative teaching activities				
J. Preparation of manuscripts for conferences or journals	Research articles writing and submission.			15
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			45
	TOTAL OF ECTS			**60**

Third academic year (planned)

	Description	Period	Final Exam	ECTS
A. Ph.D. courses	PhD course selected among the available ones		No	3
B. Master's degree courses				
C. Soft skill courses				
D. Participation to seminars	Seminars			5
E. Participation to international congresses or workshops				
F. Presentation of research products at international congresses or workshops	At least one paper			2
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			10

G. Individual research activity	Simulations and experiments at the laboratory.			15
H. Supervision of students	Study and research activities under the tutor's guidance.			15
I. Integrative teaching activities				
J. Preparation of manuscripts for conferences or journals	Research articles writing and submission.			20
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			50
	TOTAL OF ECTS			**60**

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Dr. Raffaele Carli

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