ECOLE DOCTORALE EEATS

Electronique, Electrotechnique, Automatique, Traitement du Signal

Proposal of Ph.D. thesis subject
to enter the competition for a Ph.D. public grant
starting with 2024-2025

Title: **Centralized *versus* decentralized inverter control strategies in a community AC microgrid context**

Thesis specialty: **Automatique – Productique (Control systems)**

Research structure: Grenoble Image Speech Signal Control Systems Laboratory – GIPSA-lab UMR 5216 / Grenoble Alpes University (UGA) – Grenoble, France

Starting date: 01/10/2024

Application dead-line: 07/06/2024, 23h59

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Thesis supervisor:
Associate professor *BRATCU Antoneta Iuliana* – antoneta.bratcu@grenoble-inp.fr
GIPSA-lab / Control Systems and Diagnostic Division / MODUS (Modeling and Optimal Decision for Uncertain Systems) team

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Context and research domain:

Within the energy transition context, this landscape is changing toward less domination of large conventional power plants with synchronous generators available for ancillary service provision, such as voltage and frequency regulation, the inverter-based microgrids are increasingly necessary to accommodate the distributed energy resources (DERs). Most of DERs are equipped with ***grid-following*** inverters (GFLIs). Unlike the synchronous generators, GFLIs are not intrinsically characterized by inertial responses, therefore this transition raises technical challenges for the grid's stability. A possible solution is adoption of ***grid-forming*** inverters (GFMIs) which can emulate the characteristics of synchronous generators if appropriately equipped with improved damping and virtual inertia1 [1]. Moreover, use of GFMIs combined with intelligent demand-side management can ***enhance grid reliability and resilience*** by enabling the provision of energy to critical facilities during power outages [2].

A ***community microgrid*** includes several GFMIs and is designed to serve the energy needs of a residential neighbourhood, a building complex, *etc.*, in both *grid-connected* and *standalone* operating modes. Community microgrids can be owned and operated by local communities in a decentralized manner, rather than by a centralized utility. A community microgrid may be defined as a *cluster of neighbouring microgrids* connected *via* interlinking converters, improving the reliability and economic performance of individual microgrids [3]. In this context, an individual microgrid might cooperate with neighbouring microgrids for back-up operations in emergencies and for economic purposes.

Some of the major issues, such as stability, protection coordination, privacy of community microgrids, and cyberattack threatens, were discussed in [4]. From the viewpoint of their integration in larger grids, community microgrids equipped with suitable control strategies appear as a good solution for grid restoration and resilience under relevant grid codes, provided their ability of supplying virtual inertia and other ancillary services, in both normal and emergency grid situations.

The proposed subject is an exploratory one.

It will contribute to advance research in the ***control of energy conversion systems at GIPSA-lab***, with broad applications in nowadays energy transition context. It will benefit from complementary advising – *i.e.*, from both power electronics technology and grid integration and also control systems viewpoints – within the collaboration initiated between thesis supervisor, A.I. Bratcu (with Grenoble Image Parole Signal Automatique – GIPSA-lab) and Swiss researchers – Mauro CARPITA and Mokhtar BOZORG – with University of Applied Sciences Western Switzerland (HES-SO) and Institute of Energies, Yverdon-les-Bains, Switzerland.

Description of the research topics:

This thesis is focused on providing pertinent control solutions in the larger context of community microgrids. Starting from studying the dynamic behaviour and control of a single GFMI, then continuing with a simple, yet representative microgrid topology – at least two GFMIs in interaction – the decentralized control of GFMIs equipped with improved damping and virtual inertia is aimed at. Based on devising suitable control-oriented mathematical models, a first step will be to identify which control strategies for GFMIs within a community microgrid are most effective in *grid-connected*, as well as in *standalone* modes. Ensuring a *smooth switching* between the two modes is also required. In a second step, closed-loop preliminary validations by numerical simulation will provide a basis towards experimental validation of a community microgrid on a laboratory scale.

Our study will in a first time concern the ***dynamic behaviour analysis and control of a single GFMI*** connected to a distribution grid. A comprehensive review, classification and critical comparison of several control strategies for GFMIs in a simulation case study can be found in [5], where four major categories of GFMI have been identified: a) droop control; b) virtual synchronous machine; c) matching approach; and 4) virtual oscillator-based control. The key challenges were summarized to be further investigated prior to large-scale integration of GFMIs into low-inertia grid infrastructure.

Taking into account operation of a single GFMI in a community microgrid context, control strategies must already envisage embedding a maximum of its microgrid operation constraints, that is, a decentralized control vision should be adopted from the very beginning. Use of ***droop control*** in both grid-connected and standalone operating modes can reasonably be taken as a baseline; other strategies should be further assessed against this latter. Not at least, the ***fault ride-through*** requirements of a community microgrid, considering load imbalances and short circuits, should also be taken into account in the control design. In order to satisfy the requirements set by relevant ***grid codes*** (*e.g.*, SR 734.27 in Switzerland [6]), ***robustness*** and ***optimality*** of the proposed control strategy must be addressed. With this respect, the formalism of $\mathcal{H}_\infty$***-based robust control*** design can provide a pertinent framework leading to very well-performing closed-loop behaviour [7]–[9].

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Thesis objectives:

This thesis will address the following points:

- bibliographical search focused on identifying the most pertinent state-of-the-art control-oriented modelling and control methods of inverters in a community microgrid context
- PLECS – MATLAB®/Simulink® simulation of models and control strategies of a single inverter in both grid-following (grid-connected) and grid-forming (standalone) microgrid cases, yielding a critical assessment of performances in terms of advantages and drawbacks of each control strategy
- simulation analysis of smooth switching between the two connection cases
- study of implementation constraints on hardware microgrid topologies available at the Institut des Énergies at Yverdon-les-Bains in Switzerland
- formalization of constraints and requirements (including the grid codes) and integration into a suitable control design framework – *e.g.*, robust control
- extensive simulation tests for assessing advantages and drawbacks of each control approach: which of them is the most effective in *grid-connected* and *standalone* operational modes with a community microgrid context?
- real-time implementation of the most effective control on hardware microgrid topologies available at Yverdon-les-Bains

As regards valorisation, publication of results is aimed at by means of at least two conference papers, if possible, in both of the scientific areas of this thesis, namely:
- in prestigious control systems conferences (*e.g.*, tri-annual *IFAC Symposium on Control of Power and Energy Systems* – CPES, annual *IEEE Conference on Control Technology and Applications* – CCTA, annual *European Control Conference* – ECC, *etc.*)
- and also in power electronics conferences (*e.g.*, *European Power Electronics Conference* –EPE ECCE, *IEEE Industrial Electronics Conference* – IECON, *etc.*)

Following the same strategy, publication in prestigious journals is envisaged (e.g., *IEEE Transactions on Control Systems Technology*, *IEEE Transactions on Power Electronics*, *Electric Power Systems Research*, *etc.*).

Scientific, material and financial conditions:

Material conditions: laptop computer with PLECS – MATLAB®/Simulink® software licenses, dSPACE system and *Texas Instruments* microcontroller for preliminary *hardware-in-the-loop-simulation* (HILS) control validation. Manipulation of these resources do not involve special security requirements.

Towards the end of the thesis: access to hardware microgrid topologies available at Yverdon-les-Bains, for on-site validation purposes (https://heig-vd.ch/rad/instituts/ie/systemes-electriques/infrastructures).

This subject enters the EEATS Doctoral School competition for public Ph.D. grants (approx. 2100 Euros per month gross salary). The Ph.D. student will also benefit from budget of GIPSA-lab MODUS team (depending on global team needs), *e.g.*, for participation to national and international scientific meetings.

A Ph.D. student is allowed to dedicate 1/6 of her/his annual worktime to another remunerated activity, *e.g.*, teaching hours or technical/scientific expertise.

Partial reimbursement of transport expenses (home – workplace) is ensured.

International collaborations:

This thesis will be run as part of a collaboration initiated between Antoneta Iuliana BRATCU, Associate Professor HDR with GIPSA-lab at Grenoble Alpes University (UGA) and Grenoble Institute of Engineering and Management, and Professor Mauro CARPITA and Associate Professor Mokhtar BOZORG, both with University of Applied Sciences Western Switzerland (HES-SO) and Institute of Energies, Yverdon-les-Bains, Switzerland.

In this context, applications for funding in support of international mobility can be made at the level of UGA.

Profile and required skills:

Ideally, a person holding a master degree in **control systems engineering** and having a strong background in mathematical modelling of dynamical systems for linear and nonlinear control purpose is necessary, with interest and skills in **technology and applications of power electronic converters** for energy conversion is sought for.

Proficiency in **PLECS – MATLAB®/Simulink®** is indispensable.

Proficiency in technical English is highly expected.

Good skills in scientific writing and text processing software tools (*e.g.*, Microsoft Word and LaTex) are necessary.

Proven high academic performance (excellent transcripts and ranking) is expected and must be provided. A record of publications in high-level journals and/or scientific conferences is a plus (but not mandatory).

References:

[1] Z. Li, M. Shahidehpour, F. Aminifar, A. Alabdulwahab and Y. Al-Turki, "Networked microgrids for enhancing the power system resilience," *Proceedings of the IEEE,* vol. 105, no. 7, pp. 1289-1310, 2017.

[2] B. Chen, J. Wang, X. Lu, C. Chen and S. Zhao, "Networked microgrids for grid resilience, robustness, and efficiency: A review," *IEEE Transactions on Smart Grid,* vol. 12, no. 1, pp. 18-32, 2020.

[3] L. Che, M. Shahidehpour, A. Alabdulwahab and Y. Al-Turki, "Hierarchical coordination of a community microgrid with AC and DC microgrids," *IEEE Transactions on Smart Grid,* pp. 3042-3051, 2015.

[4] M. Alam, S. Chakrabarti and A. Ghosh, "Networked microgrids: State-of-the-art and future perspectives," *IEEE Transactions on Industrial Informatics,* vol. 15, no. 3, pp. 1238-1250, 2018.

[5] A. Tayyebi, F. Dörfler, F. Kupzog, Z. Miletic and W. Hribernik, "Grid-forming converters–inevitability, control strategies and challenges in future grids application," *CIRED,* 2018.

[6] *734.27 Ordonnance sur les installations électriques à basse tension (OIBT),* Berne: Le Conseil fédéral suisse, 7 novembre 2001.

[7] Q.-L. Lam, A.I. Bratcu, C. Boudinet, M. Thomas, A. Labonne and D. Riu, "Primary frequency H∞ control in stand-alone microgrids with storage units: a robustness analysis confirmed by real-time experiments," *International Journal of Electrical Power and Energy Systems*, 115, art. no. 105507, 2020.

[8] Q.-L. Lam, A.I. Bratcu and D. Riu, "Multi-variable H∞ control approach for voltage ancillary service in autonomous microgrids: design and sensitivity analysis," *IEEE Access*, 9, pp. 140212–140234, 2021.

[9] Q.-L. Lam, D. Riu, A.I. Bratcu, A. Labonne and C. Boudinet, "Power hardware-in-the-loop validation of primary frequency robust control in stand-alone microgrids with storage units," *Electrical Engineering*, 105 (1), pp. 317-333, 2023.

Contact:

Applications should be done following the link below:

https://www.adum.fr/script/candidature/index.pl?site=edeeats

Any additional question should be addressed to:

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