IDEAL4GREEN – Stability and control of decentralised DC microgrid interconnection for the electrification of rural Africa

The IDEAL4GREEN project

The objective of the MSCA Doctoral Networks IDEAL4GREEN (Building decentralised, distributed and local microgrids for decarbonisation electrification challenge) project aims at pioneering decentralized energy solutions to meet global decarbonization targets through innovative microgrid technologies. This project addresses the urgent challenges of climate change and the global shift towards sustainable energy systems. It focuses on developing and integrating microgrids, which are crucial in managing the variability of renewable resources and achieving decarbonization targets. The project aligns with the European Commission's commitment to carbon neutrality by 2050 by empowering energy communities and optimizing local supply and demand. The project proposes a comprehensive doctoral training network aimed at developing skilled engineers with interdisciplinary and intersectoral expertise. This network diverges from conventional university-based research, maintaining strong industry links and emphasizing practical implementation. IDEAL4GREEN consists of 8 public universities and 11 partner organizations, recruiting 15 doctoral candidates to undertake research on microgrids' planning, design, operation, control, and impact assessment.

The research encompasses innovative frameworks and methodologies for integrating microgrids and transforming traditional grids into sustainable energy systems. The Doctoral Candidates will engage in a mix of academic and industrial experiences, including secondments and networking meetings, ensuring their exposure to both theoretical knowledge and practical skills. The Doctoral Candidates will actively participate in comprehensive training programs aimed at enhancing both technical and transferable skills. This includes workshops, seminars, and conferences that cover areas such as advanced control systems, resilience strategies, and economic planning for microgrids. Additionally, each Doctoral Candidate will collaborate closely with industry partners through 18-month secondments, where they will apply their research in real-world industrial settings, gaining hands-on experience and refining practical solutions for energy systems. The Doctoral Candidates will also contribute to project reporting, provide regular updates on their research progress, and ensure project milestones are met. Their findings will be communicated and disseminated, e.g. through presentations at international conferences and contributions to peer-reviewed publications.

Thesis general information

This thesis, in collaboration between G2Elab (Grenoble Electrical Engineering lab) and Nanoé, will start in September 2025 and will be mainly based in Grenoble. A 6-month stay at Nanoé's office in Ambanja, Madagascar, will be necessary to link theory and field observations, while the rest of the thesis takes place between G2Elab and Nanoé's French office in Grenoble. The thesis lasts 36 months, through a doctoral contract with a gross salary of 3258€ per month, and the doctoral diploma will be awarded by the Université Grenoble-Alpes.

This thesis is part of the European IDEAL4GREEN project comprising 15 industrial theses, including 2 G2Elab/Nanoé theses. This thesis will thus interact with another G2Elab thesis focusing on microgrid interconnection planning and optimization. Due to the European nature of the project and to favour international mobility, the Doctoral Candidates must have lived less than 1 year in France over the last 3 years, which must be justified in the motivation letter.

Context of the thesis

The technological choices for the design and operation of electrical grids depend on numerous heterogeneous parameters, often determined by scientific innovations over time. One example is the choice between alternating current (AC) and direct current (DC). Indeed, as the development of power electronics only started in the 1950s, AC has become widespread at all voltage levels. However, with the rise of DC resources, such as photovoltaics, storage and certain domestic loads (LEDs, chargers), the question of DC grids arises in order to avoid AC/DC conversion stages that can increase costs and generate losses. This is even more relevant in non-electrified areas with high potential for renewable solar energy. Adopting this approach, the French-Malagasy company Nanoé is proposing a progressive model for scalable decentralized rural electrification, as illustrated in Figure 1. The concept is to deploy autonomous and collective low-voltage systems called nanogrids, which can then be interconnected to form microgrids, connected or not to an existing medium-voltage grid, with the aim of pooling resources, reducing costs and improving quality of supply. Nanoé has already deployed more than 2 800 nanogrids in 500 villages in northern Madagascar, electrifying more than 12 000 households and businesses.

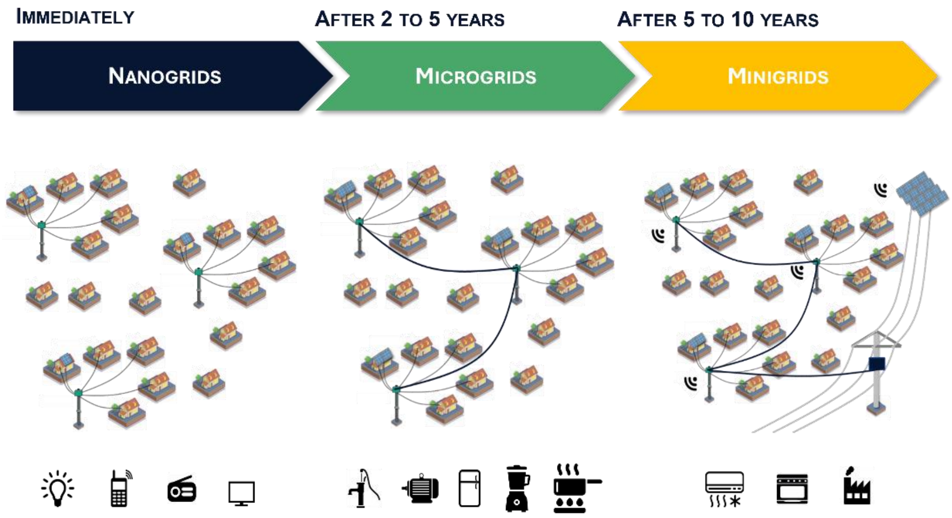

Figure 1 : Progressive and decentralized approach of the Lateral Electrification model proposed by Nanoé

Objectives and methodology

An industrial thesis, carried out from 2020 to 2023 in G2Elab [1] with Nanoé, has proposed a microgrid structure (Figure 2) and control as well as the sizing and the realization of a nanogrid interconnection module (a power electronics converter in blue and red in Figure 2). While the technical feasibility of these decentralized microgrids has been demonstrated theoretically and experimentally in the lab and in the field, questions naturally arise around the next stage of the Lateral Electrification model: how to interconnect microgrids with each other or with a main AC grid (if existing)? What technological choices should be made, from all DC to hybrid AC/DC, what voltage level, what protection plan? What control laws and power electronics converters are needed to implement such interconnections? How can we ensure the stability of such interconnections? These questions will first have to be studied using simulation software, before being validated experimentally in the laboratory.

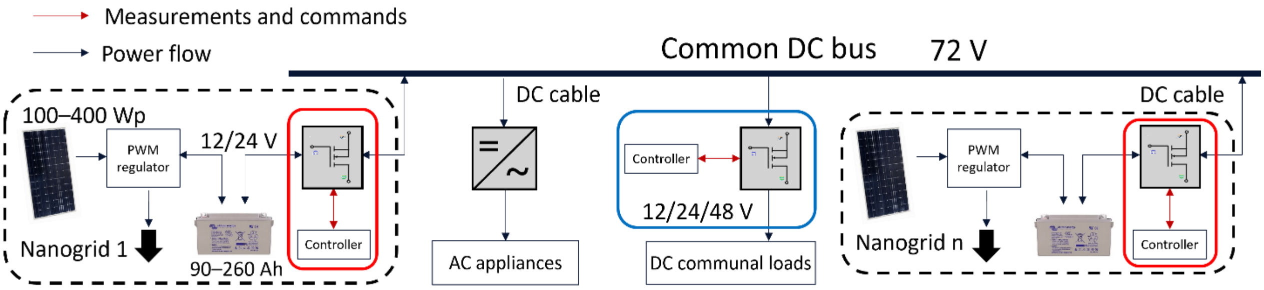

Figure 2 : Configuration of the proposed decentralized DC microgrid

This thesis aims at developing a technical solution for the interconnection of microgrids and their connection to an AC grid, by defining an interconnection structure (AC or DC, voltage level, radial or meshed, converters used) and its control law ensuring the desired functions and a wide stable operating zone. The thesis will be structured in several stages:

- **Literature review.** An in-depth literature review of stability analysis and control methods for grids with a high penetration of power electronics will enable to i) **Evaluate the various stability analysis methods** and determine which are best suited to the context of DC microgrids and their interconnection, and ii) **Draw up a global state-of-the-art on power grids entirely controlled by power electronics**, in particular their architecture, control law and power electronics/grid interactions in such systems, with feedback from existing power grids if possible.
- **Stability analysis:**
  - **Development of stability analysis tools for decentralized DC microgrids.** The first version of the microgrids deployed by Nanoé was designed with a hardware structure and a choice of components guarantying stability for microgrids interconnecting a few nanogrids. The objective here is to create a stability analysis tool [2] for these microgrids in order to analyse their current stability margin. This stability analysis tool will be developed to be easily replicated and integrated into a larger-scale stability analysis (interconnection of microgrids and/or connection to an AC grid).
  - **Stability sensitivity analysis for decentralized DC microgrids.** Using the tools developed, analyse the impact of various parameters (control, line length, power, number of customers, etc.). Highlight the limitations of the current system and the benefits of adding an interconnection to another microgrid and/or to a local AC grid.
- **Power electronics converter design for microgrid interconnection and/or connection to a local AC power grid:**
  - **Selection of the structure and topology for interconnecting microgrids with each other and/or with a local AC grid.** In collaboration with the second G2Elab/Nanoé thesis of the IDEAL4GREEN project, the various technical choices (voltage level, architecture, types of converters used) for the interconnection of microgrids and/or their connection to a local AC grid will have to be selected and validated. A global study, from a technical and economic as well as an environmental, legislative, operational and normative

point of view, will have to be carried out in order to identify and justify the best solution.

    - **Development of a control algorithm for interconnecting microgrids, guaranteeing a wide zone of stable operation.** A control algorithm guarantying the objectives associated with microgrid interconnection (e.g. power balancing between microgrids, increased reliability, supplying large consumption points, etc.) will be developed and validated through software simulations. The microgrid stability analysis tool will be extended to integrate microgrid interconnection (i.e. power electronic converters and their control algorithm) to ensure that stability is maintained during interconnection.

- **Experimental validation of the control algorithm and of the stability margins.** A laboratory test bench will be developed to reproduce as close as possible real microgrid interconnection conditions, as determined by the microgrids already deployed by Nanoé in Madagascar. This test bench will be used to validate the design of the control algorithms, fine-tune its settings and ensure the stability of the resulting system.
- **Definition of a roadmap for field deployment of the 3rd stage of the Lateral Electrification model within 1 year of the end of the thesis.** This will be done in collaboration with the second G2Elab/Nanoé thesis of the IDEAL4GREEN project.

Expected skills

- Master's degree in Electrical Engineering or Automation
- Operation of electrical grids
- Good knowledge of automation/stability and power electronics
- Proficiency in simulation and programming languages (Matlab, Simulink, Python)
- Experimental skills in power electronics
- Analysis and synthesis
- Fluency in French (C1) et professional knowledge of English (B2)

Supervisors

G2Elab supervisors : Jérôme Buire and David Frey
Nanoé supervisors : Lucas Richard

Contacts

jerome.buire@g2elab.grenoble-inp.fr
david.frey@g2elab.grenoble-inp.fr
lucas.richard@nanoe.net

[1] Richard, Lucas. *DC Solar Microgrids with Decentralized Production and Storage for the Lateral Electrification of Rural Africa: From the Lab to the Field*, PhD Thesis, Université Grenoble Alpes, 2023. Available online: https://theses.hal.science/tel-04465319
[2] H. Kirchhoff and K. Strunz, "Control and Stability of Modular DC Swarm Microgrids," in IEEE Journal of Emerging and Selected Topics in Power Electronics, Oct. 2022. Available online: https://ieeexplore.ieee.org/document/9759443