IDEAL4GREEN – Planning of decentralized DC power grids: a bottom-up approach 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 Comission'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 based between Grenoble in G2Elab office and Nanoé's office in Ambanja, Madagascar (through a 1-year stay in 1 or 2 missions). A collaboration with the socio-economic research sector is considered to adopt a multi-criteria approach to the problem. 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 on stability and control algorithm for microgrid interconnection. 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.

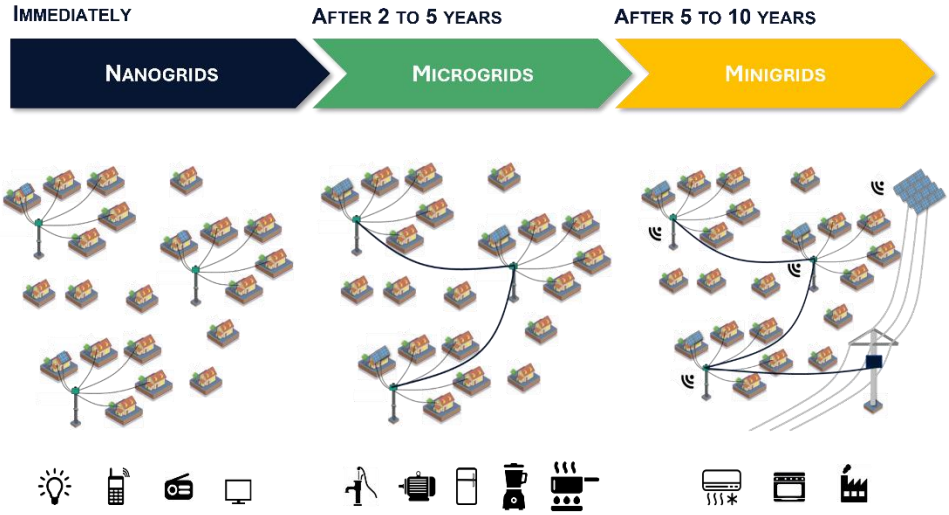

Figure 1 : Progressive and decentralized approach of the Lateral Electrification model proposed by Nanoé

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: Why and how to interconnect microgrids between them or to a local AC grid (if existing)? What technological choices should be made, from all DC to hybrid AC/DC, what voltage level, what protection plan? In which conditions microgrid interconnection is technically, economically and socially relevant? These questions will have to be analysed from a technical and economic, social, environmental, legislative, operational as well as regulatory perspective.

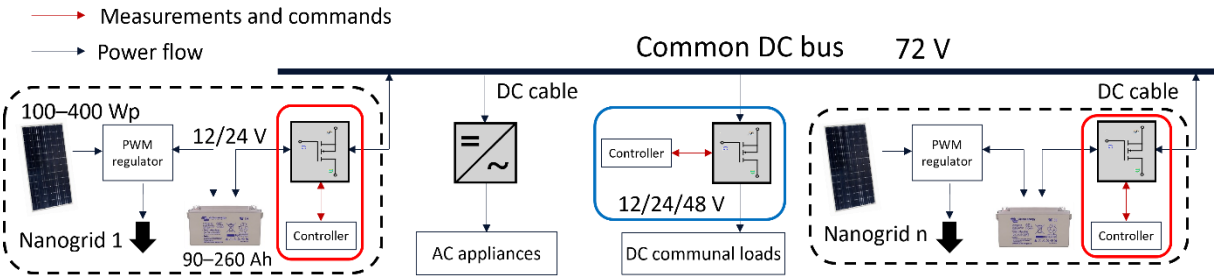

Figure 2 : Configuration of the proposed decentralized DC microgrid

This thesis aims at developing a planning model for the interconnection of microgrids and their connection to an AC grid, from already existing nanogrids and microgrids, in a multi-criteria approach. The thesis will be structured in several stages:

- **Literature review.** An in-depth literature review of the development of rural electrification solutions (microgrids, extension of the national grid, solar kits) will enable to i) **List the relevant performance indicators**, which may be technical, economic, environmental, social or regulatory, and ii) **Identify and evaluate existing optimization methods** for power grid planning.
- **Formalize and solve an optimization problem for microgrid interconnection planning.** Based on microgrids already deployed in Madagascar, the objective is to propose a solution for interconnecting microgrids by optimizing an "objective function" [2]. Various optimization methods will be considered and tested (linear programming, mixed programming, metaheuristics, combinatorial optimization, etc.), to analyse and compare the results according to the selected indicators. Particular attention will be paid to the various constraints, which may be technical and/or topological (i.e. taking into account geographical constraints based on on-site data) [3]. Analysis of the results should enable to assess the conditions in which microgrid interconnection is technically, economically and socially relevant.
- **Consider the opportunity to interconnect microgrids to a local AC grid,** by taking into account normative, regulatory, responsibility and coordination issues. Indeed, several operating modes can be envisaged, such as the provision of services by microgrids to the AC grid in the event of a production shortage, for example.
- **Integration of the developed algorithms within a tool that can be used by Nanoé for microgrid interconnection planning.** The algorithms developed should be integrated into a tool that can be easily upgraded and replicated on other Nanoé sites.
- **Definition of the 3rd stage of the Lateral Electrification model and a roadmap for field deployment 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 Applied Mathematics
- Good knowledge of optimisation (problem formulation and algorithms)
- Good knowledge of economic analysis
- Proficiency in simulation and programming languages (Matlab, Python, Julia)
- Knowledge of QGIS would be a plus
- Analysis and synthesis
- Fluency in French (C1) et professional knowledge of English (B2)

Supervisors

G2Elab supervisors : Rémy Rigo-Mariani and Marie-Cécile Alvarez-Hérault
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[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. Farias de Barros, M. -C. Alvarez-Herault, B. Raison and Q. T. Tran. *Optimal AC/DC Distribution Systems Expansion Planning from DSO's Perspective Considering Topological Constraints*, in IEEE Transactions on Power Delivery, vol. 38, Oct. 2023.
[3] Gadelha T. Filho Vinicius, Corigliano Silvia, Dimovski Aleksandar, Bolognesi Massimo, Merlo Marco. *Rural electrification planning based on graph theory and geospatial data: A realistic topology oriented approach*, Sustainable Energy, Grids and Networks, Volume 28, 2021.