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Federal Department of the Environment,
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Swiss Federal Office of Energy
Energy Research and Cleantech

Interim report from 15 November 2024

FORMIDABLE

Community-microgrid with grid-forming inverters equipped with improved damping and virtual inertia: their role on grid reliability and resilience

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Source: HEIG-VD/IE 2024

Publisher:
Swiss Federal Office of Energy SFOE
Energy Research and Cleantech
CH-3003 Berne
www.energy-research.ch

Co-financing:
Imperix SA
CH-1950 Sion
www.imperix.com

Subsidy recipients:
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SFOE contract number: SI/502668-1

Summary

The transition from synchronous generators to inverter-based distributed energy resources in modern power grids poses stability challenges due to the inability of grid-following inverters to emulate the inertial responses of synchronous generators. Grid-forming inverters, however, can mimic these characteristics and improve grid stability, reliability, and resilience, especially during power outages.

This project aims to explore the benefits and risks of grid-forming inverters, particularly by assessing their impact on a community microgrid's reliability and resilience. The project also seeks to develop a framework for grid restoration and resilience, investigate relevant grid codes, and enhance decision-making for deploying new distributed energy resources. To do this, the control algorithms for grid forming inverters will be developed, and experimental hardware will be built and tested in a laboratory community microgrid configuration.

The theoretical development phase in which the primary control of the grid forming inverter, the overload protection, and the management of unbalanced loads is completed. Currently, two experimental inverters are being assembled and tests are expected to begin shortly.

In the next phases of the project, the ability of grid forming inverters to generate and maintain a community microgrid will be tested in real life. The different practical manoeuvres such as black start, and synchronization will be assed as well. Furthermore, secondary control strategies, including decentralized strategies, will be evaluated and tested.

Zusammenfassung

Der Übergang von synchronen Generatoren zu inverterbasierten dezentralen Energiequellen in modernen Stromnetzen stellt eine Stabilitätsherausforderung dar, da netzfolgende Wechselrichter nicht in der Lage sind, die Trägheitsantworten synchroner Generatoren nachzuahmen. Netzbildende Wechselrichter hingegen können diese Eigenschaften imitieren und die Netzstabilität, -zuverlässigkeit und -resilienz verbessern, insbesondere während Stromausfällen.

Ziel dieses Projekts ist es, die Vorteile und Risiken von netzbildenden Wechselrichtern zu untersuchen, insbesondere ihre Auswirkungen auf die Zuverlässigkeit und Resilienz eines Mikrogrids in einer Gemeinschaft. Das Projekt zielt auch darauf ab, einen Rahmen für die Netz-Wiederherstellung und Resilienz zu entwickeln, relevante Netzvorschriften zu untersuchen und die Entscheidungsfindung bei der Bereitstellung neuer dezentraler Energiequellen zu verbessern. Dazu werden die Steuerungsalgorithmen für netzbildende Wechselrichter entwickelt und experimentelle Hardware in einer Labor-Mikrogrid-Konfiguration gebaut und getestet.

Die theoretische Entwicklungsphase, in der die Hauptsteuerung des netzbildenden Wechselrichters, der Überlastschutz und das Management unausgeglichener Lasten abgeschlossen sind, befindet sich derzeit in der Umsetzung. Momentan werden zwei experimentelle Wechselrichter zusammengebaut, und Tests sollen in Kürze beginnen.

In den nächsten Phasen des Projekts wird die Fähigkeit der netzbildenden Wechselrichter getestet, ein Gemeinschafts-Mikrogrid zu erzeugen und aufrechtzuerhalten. Dabei werden auch verschiedene praktische Manöver wie Black-Start und Synchronisation bewertet. Darüber hinaus werden sekundäre Steuerstrategien, einschließlich dezentraler Strategien, untersucht und getestet.

Résumé

La transition des générateurs synchrones vers les ressources énergétiques distribuées basées sur des onduleurs dans les réseaux électriques modernes pose des défis de stabilité en raison de l'incapacité des onduleurs suiveur de réseau à émuler la réponse inertielle des générateurs synchrones. Les onduleurs générateurs de réseau, cependant, peuvent imiter ces caractéristiques et améliorer la stabilité, la fiabilité et la résilience du réseau, en particulier lors de pannes de courant.

Ce projet vise à explorer les avantages et les risques des onduleurs générateur de réseau, notamment en évaluant leur impact sur la fiabilité et la résilience d'un micro-réseau communautaire. Le projet cherche également à développer un cadre pour la restauration et la résilience du réseau, à étudier les codes de réseau pertinents et à améliorer la prise de décision pour le déploiement de nouvelles ressources énergétiques distribuées. Pour ce faire, les algorithmes de contrôle des onduleurs générateur de réseau seront développés, et des onduleurs expérimentaux seront construit et testé en laboratoire dans une configuration de micro-réseau communautaire.

La phase de développement théorique, dans laquelle le contrôle primaire de l'onduleur générateur de réseau, la protection contre les surcharges et la gestion des charges déséquilibrées est terminée. Actuellement, deux onduleurs expérimentaux sont en cours d'assemblage et les tests devraient commencer sous peu.

Dans les prochaines phases du projet, la capacité des onduleurs générateur de réseau à fonctionner en micro-réseau communautaire sera testée en conditions réelles. Les différentes manœuvres telles que le démarrage et la synchronisation seront également évaluées. De plus, des stratégies de contrôle secondaire, y compris des stratégies décentralisées, seront évaluées et testées.

Contents

List of abbreviations

AC	Alternating Current
DC	Direct Current
DER	Distributed Energy Resource
GFL	Grid Following
GFLI	Grid Following Inverter
GFM	Grid Forming
GFMI	Grid Forming Inverter
MPC	Model Predictive Control
PLL	Phase Locked Loop
PWM	Pulse Width Modulation
RMS	Root Mean Square
ROCOF	Rate Of Change Of Frequency
SCADA	Supervisory Control and Data Acquisition
SFOE	Swiss Federal Office of Energy
SG	Synchronous Generator

1 Introduction

1.1 Context and motivation

Conventional power grids are dominated by synchronous generators that are responsible for ensuring the secure operation of the grid by providing ancillary services such as voltage and frequency regulation. However, the capacity of synchronous generators in modern power grids is reducing because of the transition to inverter-based distributed energy resources (DERs). The majority of DERs are equipped with grid-following inverters (GFLIs). Since GFLIs intrinsically cannot emulate the inertial responses of synchronous generators, this transition raises technical challenges for the grid’s stability. However, grid-forming inverters (GFMIs) equipped with improved damping and virtual inertia can alleviate this issue because they can emulate the characteristics of synchronous generators [1]. Additionally, the capacity of GFMIs can enhance grid reliability and resilience by enabling the provision of energy to critical facilities during power outages (using intelligent load shedding) [2].

In this project, we investigate the advantages and risks of GFMIs in modern power grids. To do so, we are using a 22 kVA fully programmable inverter provided by imperix to validate a suitable control strategy. We are also adapting a proprietary GFLI [3] into a 10 kVA GFMI prototype to have two separate hardware. We will then study the role of GFMIs in a community microgrid on grid reliability and resilience. Using GFMIs within a community microgrid will enhance Switzerland’s energy supply’s resilience to external drivers and will participate in laying the groundwork for the implementation of the Energy Strategy 2050 [4] in an affordable and secure manner.

The project aims to develop a new technical and organizational framework for grid restoration and resilience based on the community microgrid solution. This project will also investigate the relevant grid codes as well as the Federal Ordinance on Low-Voltage Installations (SR 734.27 [5]) concerning GFMIs within a community microgrid to provide grid restoration services. Another advantage of the proposed solution is the ability of the GFMIs used inside the community microgrid to supply virtual inertia and other ancillary services to support the secure operation of the grid in both normal and emergency situations. Decision-making will also be improved using the community microgrid solution, which will make the planning of new DERs to be deployed inside the distribution grid easier and more reliable.

1.2 Project objectives

The interaction of multiple GFMIs in a community microgrid in grid connected as well as standalone operation modes will be studied and tested by coupling the 22 kVA inverter provided by imperix with the proprietary 10 kVA inverter prototype. Other technical risks, including load imbalances and short circuits, will be studied with this community microgrid prototype.

The main objectives of this project are the following:

- First, the project aims to experimentally validate the operation and control of a community microgrid on a laboratory scale. The experimental validation of a community microgrid includes testing its performance in both operational modes as well as during the synchronization process. Note that unlike the GFLIs, the GFMIs can provide black-start capability. We will also focus on decentralized control for GFMIs equipped with improved damping and virtual inertia.
- Second, the project aims to use the experimental data to evaluate and quantify the advantages and risks of the proposed community microgrid framework. The following advantages and risks are anticipated to be quantified (among others that will become known following the experimental validation):
    - ✓ The improvement of the energy reliability provided to critical facilities.
    - ✓ The support of grid restoration after a significant grid incident.
    - ✓ The improvement of the resilience of the energy infrastructure.
    - ✓ The potential supply of ancillary services (e.g., frequency support and voltage support);
    - ✓ The threats posed by voltage instability, load imbalance, and short circuits, in both operational modes.

This project will introduce and study a new arrangement based on the community microgrid framework, which aids grid restoration when the share of decentralized renewable energy sources increases. The project will try to answer the following research question: How must concepts (technical and organizational) for grid restoration evolve with an increasing share of renewable energy sources? What arrangements will need to be made, when, and by whom?

To address the above question, the key technical and scientific questions of this project are as follows:

1) Which control strategies for GFMIs within a community microgrid are most effective in grid-connected and standalone operational modes?
2) What are the key infrastructure advancements and upgrades required in existing grid infrastructure to allow for the seamless integration of DERs into a community microgrid?
3) What grid monitoring and fault detection technologies can be used in a community microgrid with multiple GFMIs to enhance real-time situational awareness, identify potential issues, and speed up the grid restoration process?
4) What are the advantages and risks associated with creating a community microgrid with multiple GFMIs?
5) To what extent would a community microgrid enhance grid reliability and resilience?

2 Procedure and methodology

2.1 Work packages

This project is organized into five work packages (WPs).

- **WP1:** Project management,
- **WP2:** Control design of GFMI with improved damping and virtual inertia, as well as control design for a community microgrid,
- **WP3:** Adaptation of the imperix control hardware to the ReIne laboratory and performance verification of the designed control algorithm for GFMIs using imperix hardware,
- **WP4:** GFMI installed on the ReIne laboratory to establish a community microgrid,
- **WP5:** Analysis and dissemination of the experimental results.

In Figure 1, the interrelationships of different WPs are illustrated. As shown, systematic verification and validation will be done in this project to establish confidence that the designed control algorithm correctly exercises the requirements of both the system (i.e., community microgrid) and the components (i.e., GFMIs).

In WP2, the control architecture of community microgrids and GFMIs are investigated and simulated. In WP3, the imperix hardware is adapted to verify the performance of the designed control algorithm since it is readily modifiable and has many measurement points. A proprietary GFLI is also modified and integrated in the ReIne laboratory alongside the imperix hardware based on the derived control architecture. In WP4, the community microgrid framework is tested at the system level. Finally, the experimental findings are collected for system analysis in WP5. Using the experimental data, the advantages and risks of the proposed control design are assessed or estimated for increasing levels of GFMIs. WP5 will disseminate experimental data and accompanying analysis.

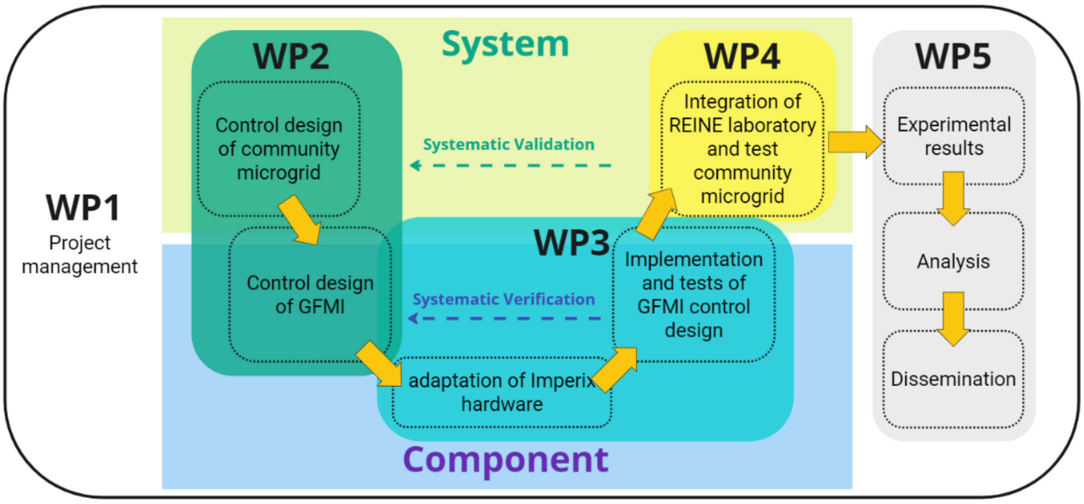

Figure 1: Interrelation of different WPs.

2.2 Milestones

Three milestones are considered for the project:

- **Milestone 1:** The first GFMI hardware is ready. Furthermore, the theoretical research for developing GFMIs is complete. Finally, the first inverter has effectively been modified to show the perceived functional behaviours of GFMIs.
- **Milestone 2:** It is the end of the control design. At this point, the control design strategy is being validated utilizing imperix hardware as well as a proprietary prototype inverter. Consequently, the final version of the control design is nearing completion.
- **Milestone 3:** The community microgrid is tested in both modes. Both operating modes of the community microgrid framework have been tested and validated. The experimental data is now accessible for further analysis and dissemination of the findings.

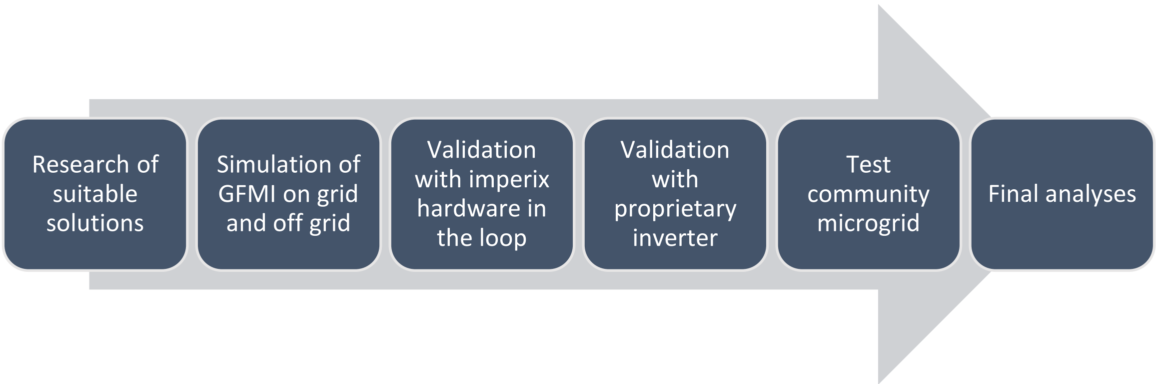

Figure 2: Approach and research methodology.

3 Activities and results

3.1 Control design of the grid forming inverters (WP2)

Grid forming inverters are controlled by generating voltage amplitude and phase references. Many different strategies have been proposed [6]. Following a bibliographic review, the control strategy that was chosen is a direct voltage control, which is based on the selfsync droop control, presented in [7].

3.1.1. Selfsync direct voltage droop control

This method does not rely on a phase locked loop (PLL) to function but rather generates the reference phase of the inverter based on active power, as well as the reference voltage amplitude, based on reactive power. The voltage amplitude and phase are directly used as input to generate the pulse width modulation (PWM) controlling the power modules. Figure 3 shows the control loops based on active and reactive power.

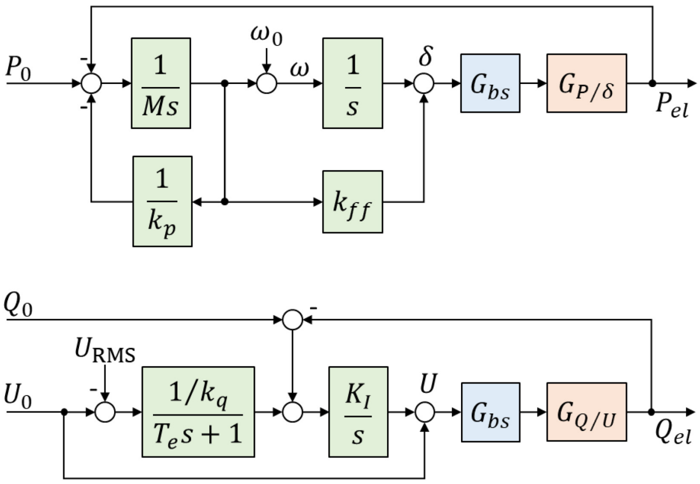

Figure 3: Active (top) and reactive (bottom) power control loops.

The virtual inertial appears in the active power loop in the variable M. P_0 and Q_0 are the active and reactive power references, P_{el} and Q_{el} are the measured electric active and reactive powers, and k_p and k_q are the active and reactive droop coefficients. U_0 is the nominal voltage and U_{RMS} is the root mean square (RMS) measured voltage. T_e is a low-pass time constant to control the dynamics the voltage regulation. G_{bs} is a band-stop filter to avoid feeding back a resonance present in the phase to active power transfer function $G_{P/\delta}$ as well as in the amplitude to reactive power transfer function $G_{Q/U}$.

The momentum M in which the inertia appears is defined hereafter in equation (3-1). However, it is common to define the inertia of a system by its inertia constant H which is independent of size.

$$M = J \cdot \omega_n = 2 \cdot H \cdot \frac{S_n}{\omega_n} = \frac{T_m}{k_p} \qquad (3\text{-}1)$$

Figure 4 shows the result of a simulation where the inverter is connected to a stiff grid that has its frequency vary from 50 Hz to 48.5 Hz with a rate of change of frequency (ROCOF) of 1 Hz/s. The simulation parameters are presented in Table 1.

Table 1 : Simulation parameters.

Nominal grid voltage (L-N)	U_g	230	[V]
Nominal grid frequency	f_g	50	[Hz]
Inverter nominal power	S_N	10	[kVA]
Inverter gain	K_{inv}	100	[kVA]
Inertia constant	H	5	[s]
Active power droop coefficient	k_p	5	[%]
Reactive power droop coefficient	k_q	10	[%]

The ideal response is plotted as well; however, it would be the response if the coupling between the virtual inertia and the grid were perfectly stiff, which it is not and is not desirable either. The ideal response is plotted to check that the steady state response to a frequency variation of the proposed algorithm is correct.

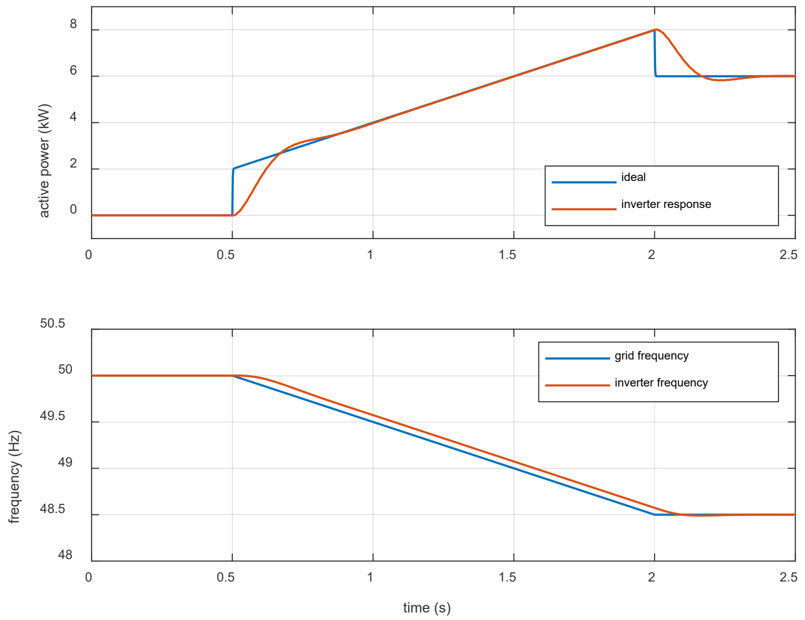

Figure 4: Active power response of the inverter to a frequency variation of the grid with a ROCOF of 1 Hz/s.

As shown in Figure 4, the active power response corresponds to what is expected, and the inverter stays synchronized with the grid despite a relatively large and rapid variation in the frequency. The full development as well as the grid synchronization is presented in Appendix 1 (as it is a living document, it will be made public with the project's final report).

3.1.2. Neutral balancing

The proprietary inverter as well as the imperix inverter are both designed for three phased balanced loads. Both of their topologies are composed of three legs as shown in Figure 5, and the neutral conductor is connected to the central point of DC bus capacitor banc.

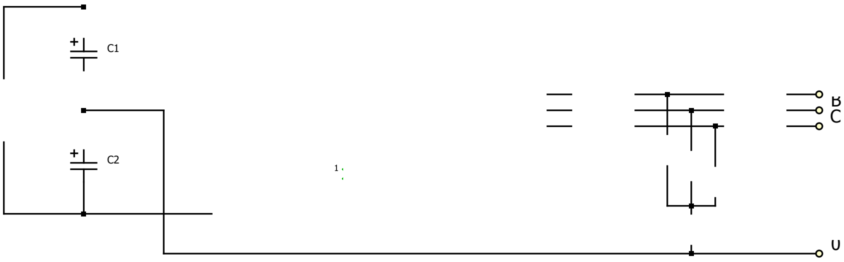

Figure 5: Three leg inverter topology with an LCL output filter and the neutral conductor connected to the central point of the DC bus capacitor banc.

In the case of an imbalanced load, the sum of the currents in phases A, B and C are no longer equal to zero. The difference flows through the neutral conductor. In case of a small symmetrical (AC) imbalance, the voltage across the DC bus capacitors will vary a bit. If the variation is small, it is not an issue. However, in the case of a large imbalance, or ever worse, if there is a DC component in the neutral current, the voltage across the capacitors will no longer be balanced. This can lead to overloading of the capacitors and ultimately to a catastrophic failure of the DC link. Therefore, it is paramount to manage the neutral current by balancing of the DC link capacitors. This can be done by adding an extra leg to the inverters [8] as shown in Figure 6.

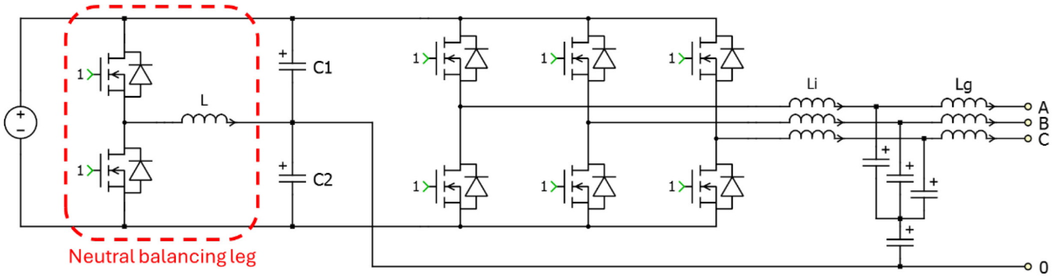

Figure 6: Three phase inverter with an additional leg to balance the DC link capacitor voltages.

Because the available inverters are not equipped with a fourth leg an external balancing system has been developed to manage the neutral current. The full development regarding the neutral balancing sizing and control can be found in Appendix 2 (as it is a living document, it will be made public with the project's final report).

3.1.3. Overload and short-circuit protection

Because GFMIs control their output voltage, the current depends on the load. Since the current is not controlled by the inverter, overload is a potential hazard for its integrity. With a three-phase system, loads can either be in Star or in Delta configuration. Limiting the current in the Star configuration can be done by implementing a single-phase current regulator that kicks in if the current passes over a predefined threshold. However, this solution does not work for the Delta configuration because there are always two phases involved, which creates a conflict between the current regulators.

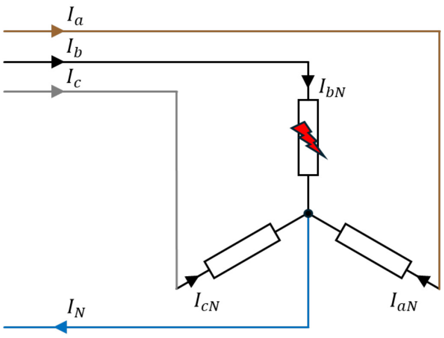

Figure 7: Fault in Star configuration.

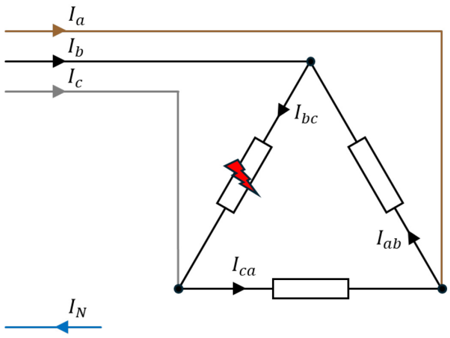

Figure 8: Fault in Delta configuration.

In practice, the loads connected to the grid are composed of a mix of Star and Delta configurations. The solution is to implement a virtual impedance in the inverter. The principle is the following: in the event of an overload, a voltage drop is applied to the voltage source inverter as if it had a higher impedance. Figure 9 shows a simplified single-phase schematic of a GFMI with a virtual impedance Z_v and an LCL output filter, that is connected to a grid that has an impedance Z_g.

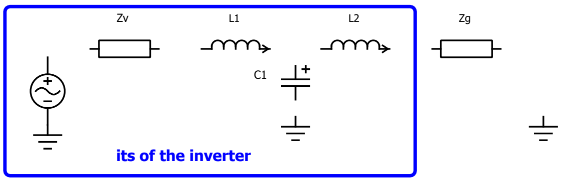

Figure 9: Simplified single-phase schematic of a GFMI with a virtual impedance.

The value of the virtual impedance is calculated for the inverter current to be limited to an upper threshold i_{up} (in per units) in the case of a hard short-circuit outside of the inverter limits. Figure 10 shows the algorithm to calculate the voltage drop on the virtual impedance $\left(\underline{Z_v} = R_v + j\omega L_v\right)$ and apply it proportionally between the lower threshold i_{dwn} and the upper threshold i_{up}.

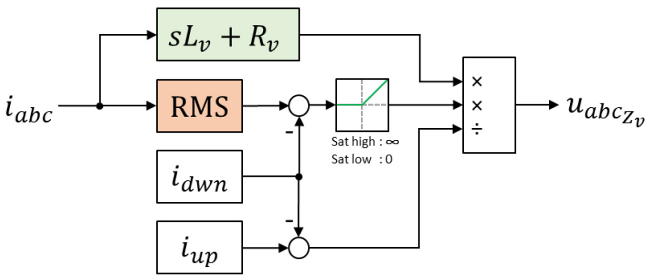

Figure 10: Calculation of the voltage drop on the virtual impedance.

The calculated voltage drop is then subtracted from the reference voltage which is given by the reactive power control loop (see Figure 13).

Figure 11 and Figure 12 show simulated the grid voltages and the inverter currents, where a phase-to-phase short-circuit occurs between 0.3 seconds and 0.6 seconds and a three phase short-circuit occurs between 0.4 and 0.5 seconds.

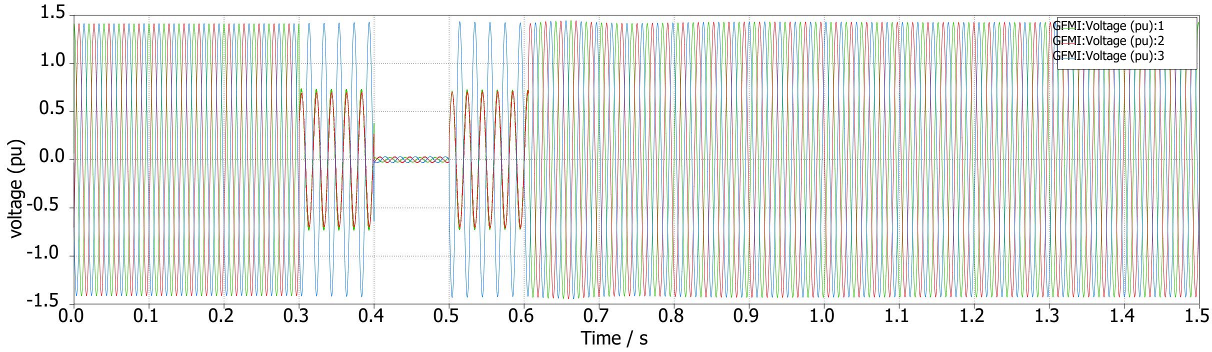

Figure 11: Grid side voltage on the three phases, with a phase-to-phase short-circuit between 0.3 and 0.6 seconds and a three-phase short-circuit between 0.4 and 0.5 seconds.

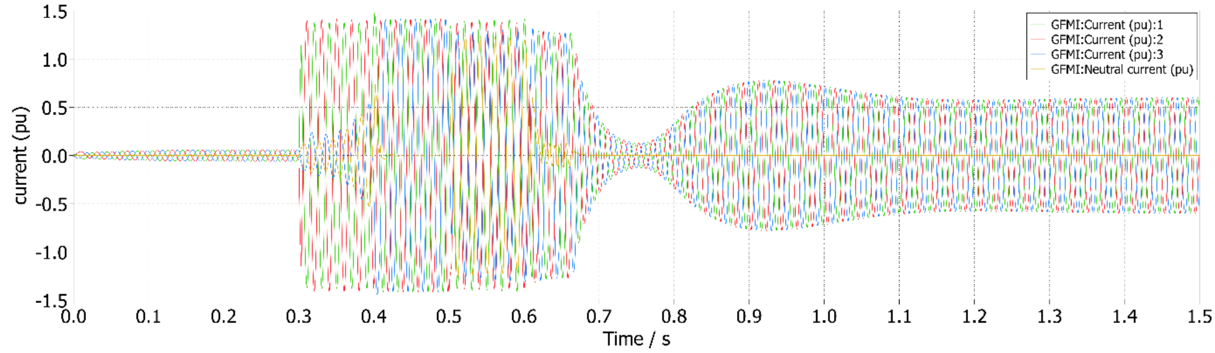

Figure 12: GFMI output currents with the short-circuits and the recovery transient following.

As shown in the two figures above, despite the volage shifting and decreasing rapidly during the simulated fault, the virtual impedance keeps the current within the nominal current with little to no overshoot. The full development regarding the overload and short-circuit protection can be found in Appendix 3 (as it is a living document, it will be made public with the project's final report).

3.1.4. Full structure of the GFMI control design

Figure 13 shows the full structure of the GFMI control design, without the synchronization part, that will be implemented in the two inverters.

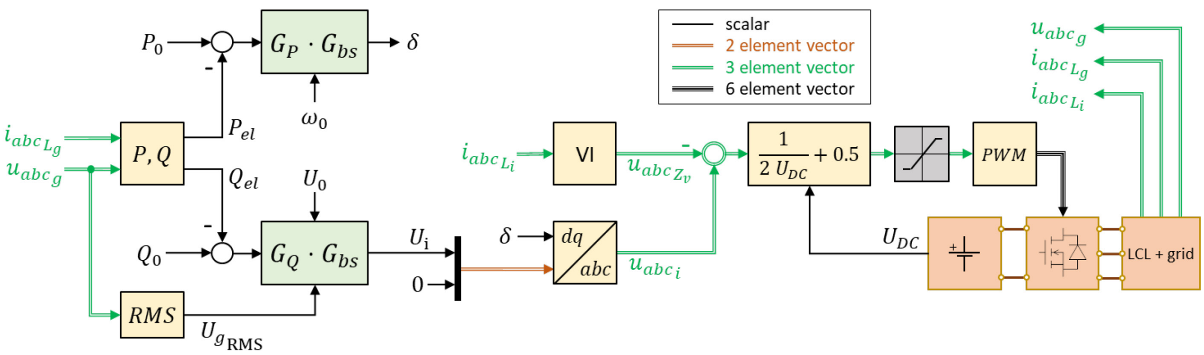

Figure 13: Full bloc diagram of the GFMI control design.

3.2 Experimental hardware (WP3)

3.2.1. Transformation and preliminary tests of the proprietary 10 kVA inverter

A 10 kVA proprietary inverter that was designed and built inhouse as a GLFI is being transformed to function in GFM mode. The transformation involves in modifying the output filter from a simple L (inductor) to an LCL filter to smooth the voltage when functioning in isolated mode. The inverter is installed in the ReIne laboratory [9] which is equipped with a REGATRON TC.ACS 50 kVA three phase grid simulator which allows us to generate the desired grid conditions to test a GFMI. These include frequency variations, voltage imbalances, and phase jumps. Figure 14 shows the 10 kVA inverter installed in the ReIne laboratory.

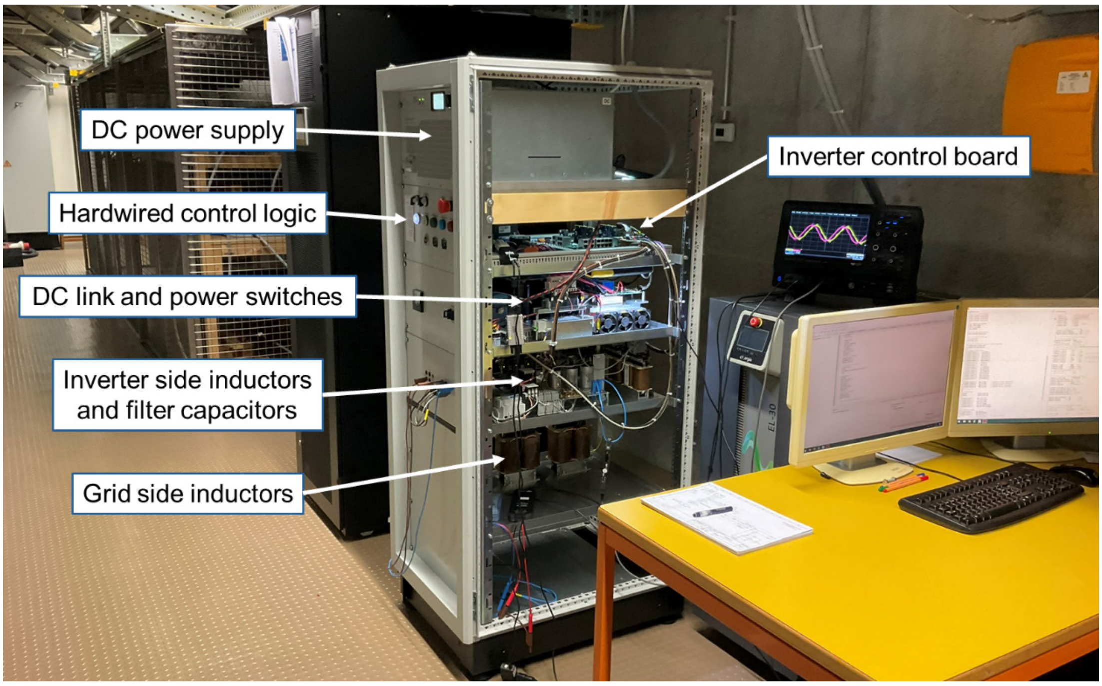

Figure 14: 10 kVA proprietary inverter already installed in the ReIne Laboratory.

Currently, the set-up is equipped with a single quadrant DC power supply, however a bidirectional power supply has been ordered to allow the inverter to absorb power from the grid as well. Preliminary tests were conducted on the inverter and showed that common mode currents are an issue, mainly because multiple power supplies are involved. To solve this problem, isolation transformers have been ordered to galvanically separate the DC power supplies from the rest of the system. This makes the DC power supply assemblies electrically as near as possible to batteries while limiting the risk associated with them.

The grid forming algorithm presented in Section 3.1.1 has been implemented in the inverter to test it in real life. Preliminary tests have shown that the algorithm functions as expected. Synchronization and connection to the grid generated by the grid simulator were also performed. Figure 15 shows the step response from 0 to 10 kW with an inertia constant of H = 1s.

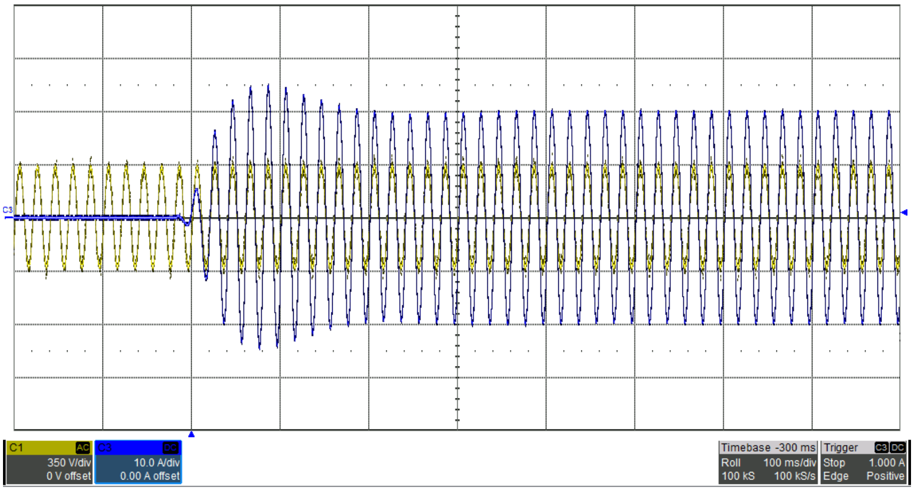

Figure 15: Oscilloscope screenshot of the voltage and current of an active power reference step from 0 to 10 kW, with an inertia constant of H = 1s.

3.2.2. Adaptation and preliminary testing of the imperix 22 kVA inverter

The project's industrial partner imperix has provided a TPI8032 22 kVA programmable inverter [10] to be used as the second inverter in the proposed community microgrid. The built-in output filter is an LC filter. Therefore, the inverter has been modified for the application by adding grid side inductances to the output filter. Following this, preliminary (desktop) tests have been performed on this inverter to program it as well as test its communication capabilities. The programming is done using PLEC standalone [11], which has the advantage of allowing the programmer to simulate the behaviour before testing it on the hardware.

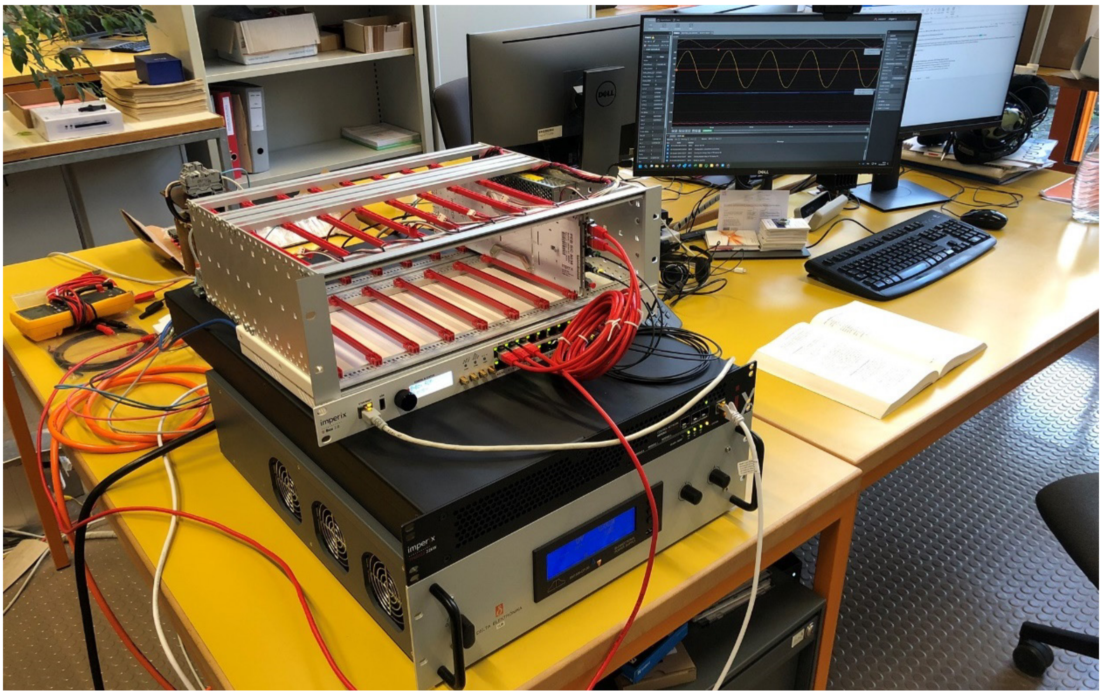

Figure 16: Preliminary desktop testing of the imperix hardware to familiarize with the programming environment.

Figure 17 shows the imperix inverter being integrated in the electoral cabinet for its integration in ReIne laboratory. As shown, a 30 kVA, Delta/Star, 1:1, isolation transformer has been added as well as a bidirectional DC power supply to emulate a battery. The assembly is expected to be installed in the ReIne laboratory by the end of the November 2024.

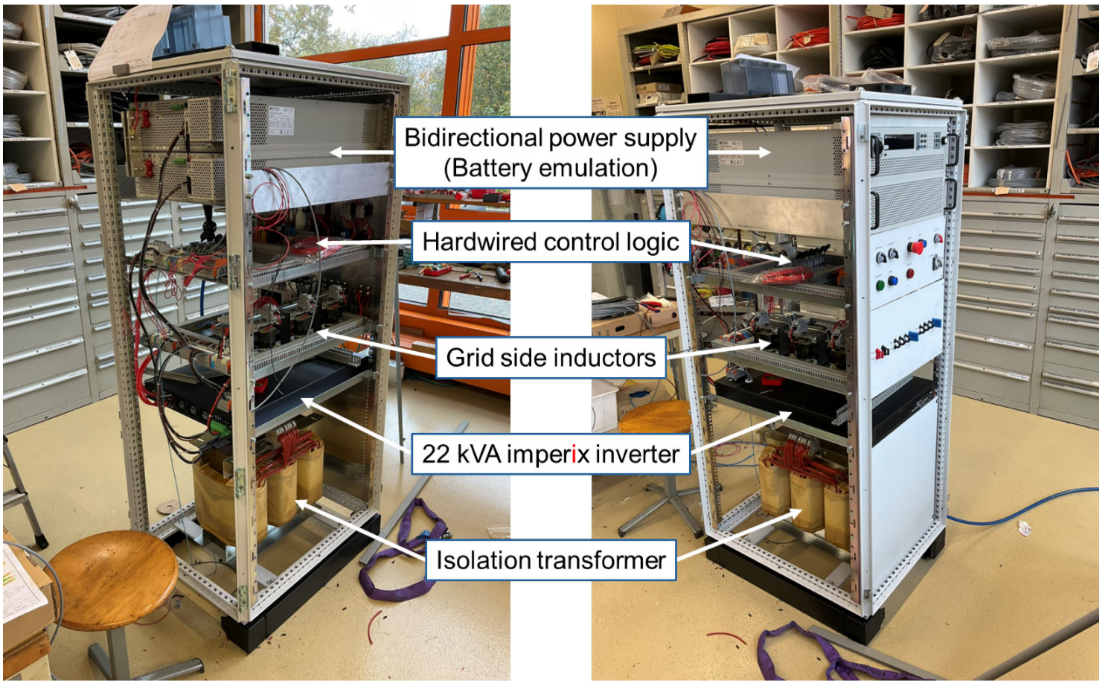

Figure 17: Assembly of the 22 kVA imperix inverter that will be installed in the ReIne laboratory.

3.2.3. Communication and remote control

Both inverters are equipped with CAN bus communication capabilities. Therefore, it was decided to use this capability to implement a Supervisory Control and Data Acquisition (SCADA) to control and monitor both inverters. This will allow us to test secondary control algorithms remotely as well as stream and log the measurements done locally by each inverter.

4 Next steps

The first milestone has been completed in 2024. The theoretical development to control GFMIs as well as initial tests to demonstrate the expected behaviour is complete. The next step (milestone 2) is to implement the full control in the hardware and perform a full battery of tests to validate the development. These tests will include short-circuits, load unbalances, and phase jumps. Following these tests, the microgrid topology (with the two inverters working together) will be tested and validated in grid connected mode as well as in standalone mode (milestone 3). Finally, the results will be documented and published.

Practically, the next steps are the following:

- Modification of the proprietary inverter with the addition of an isolation transformer.
- Integration of the imperix inverter assembly in the ReIne laboratory.
- Build and integration of the neutral balancing on both inverters (proprietary and imperix).
- Programming and commissioning of the hardware.
  - ✓ Because both hardwares are different, the full control algorithm must be programmed in two different programming languages and fully tested.
  - ✓ The following commissioning tests will be performed on each hardware: Black start, synchronization, grid connection, dynamic response to frequency changes, dynamic response to phase and voltage jumps, short-circuit (single phase, phase to phase) and fault ride through.
- Implementation of a SCADA to remotely control and log the performance of the inverters.
  - ✓ The communication bus (CAN bus) will allow us to emulate and monitor different control strategies from a centralized position. These emulated control strategies can be centralized or decentralized.
- Theoretical study of the decentralized control strategies (PLECS simulations).
  - ✓ The full control strategy developed theoretically will be integrated into a PLECS library to allow students and researchers to integrate the developed GFMI into their studies.
  - ✓ Using the PLECS library, secondary control rules will be implemented and tested to see if a decentralized control is possible following specific rules.
- Testing of the decentralized control strategies in the ReIne laboratory.
  - ✓ Real life tests will be performed to challenge the control strategies simulated in the previous phase.
- Reporting in the final report.

5 Conclusions and outlook

The project's objective is to design, develop and test GFMIs and asses their ability to increase grid reliability and resilience. Furthermore, because small GFMIs in a community microgrid will certainly be privately owned, decentralized controls strategies are investigated as well. Therefore, the two aspects of the control are developed: the primary control at the hardware level and the secondary control for the community microgrid level. Practically this is done by developing specific control algorithms for the GFMIs, then building experimental hardware to test the control on it.

Currently, the control design is complete and the experimental hardware necessary to validate the control has been designed and is being assembled. In the control design, there are two aspects that do not appear in GFLIs that must be tackled: the first is managing unbalanced loads and the second is protecting the inverter from overloads. Since GFMIs are voltage source inverters, by nature the current is not a controlled variable. Therefore, unbalances as well as overloads will occur. Appropriate solutions have been developed and simulated and will be tested on the experimental hardware.

The next steps consist in finishing the build and integration of the experimental hardware in the ReIne Laboratory. Following this, the hardware will be programmed and commissioned to assure the specifications are met. Furthermore, a SCADA will be implemented to control and log data during the next tests. The community microgrid configuration will then be tested in grid connected mode as well as in stand-alone, and in the transitions form one to other. In parallel, a full PLECS GFMI simulation model will be developed and made available to be used by students and researchers to develop and simulate secondary control strategies. These will notably consider different parameters, such as available resources and forecasts. Strategies such as model predictive control (MPC) or model-free predictive control will be investigated as well. Finaly, the developed control strategies will be tested in real life to challenge them in a real environment.

Currently there are no setbacks, and no major difficulties are foreseen for the successful completion of the project. Our research team is optimistic and believes that GFMIs will play a major role in the future structure of the electrical grid.

6 Publications and other communications

P. Morey, M. Pellerin, D. Houmard, M. Bozorg, and M. Carpita, "Sizing and experimental validation of a selfsync droop-based grid forming inverter with direct voltage control," *Sustainable Energy, Grids and Networks*, vol. 38, p. 101332, Jun. 2024, doi: 10.1016/J.SEGAN.2024.101332.

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