07-03-2023 WP-2 Final

IMPROVEMENT Project

Integration of Combined Cooling, Heating and Power Microgrids in Zero Energy Public Buildings with High Power Quality and Continuity Requirements

Presenter: Antonio Moreno Muñoz

University of Cordoba

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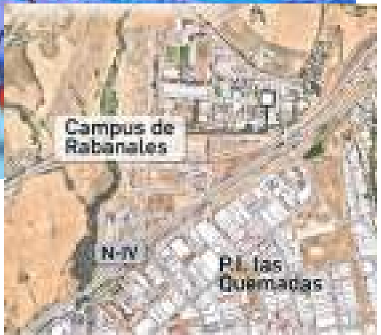
Partners, Location & Participants

- SPAIN: National Hydrogen Center. Leading partner (CNH2).
- SPAIN: University of Castilla la Mancha.
- FRANCE: National Higher School of Mechanics and Aerotechnics (ENSMA).
- PORTUGAL: Higher Technical Institute (IST).
- PORTUGAL: National Laboratory of Energy and Geology (LNEG).
- SPAIN: General Secretariat of Industry, Energy and Mines of the Junta de Andalucía
- **SPAIN: University of Córdoba.**
- SPAIN: Andalusian Energy Agency.
- FRANCE: University of Perpignan Via Domitia.



UCO team:


Moreno Muñoz, Antonio


Bellido Outeiriño, Francisco José


Garrido Zafra, Joaquín


Gil de Castro, Aurora


Pallarés López, Víctor


Savariego Fernández, Rafael

Execution Period & Objectives

Start: 01/10/2019 Execution Period End: 31/03/2023

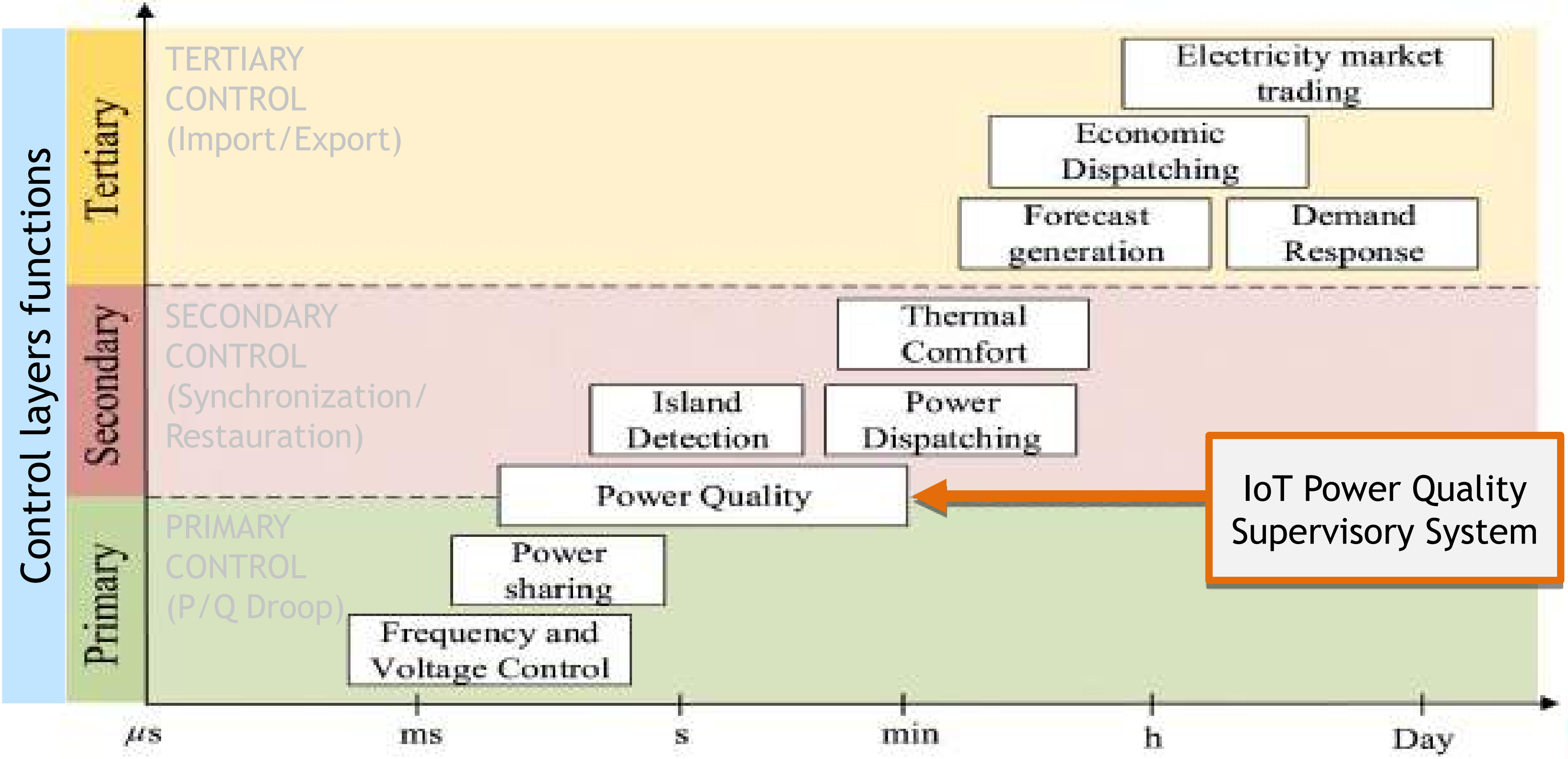
General objective:

Transforming existing public buildings into Nearly Zero-Energy Buildings (NZEB) by integrating Renewable Energy Microgrid with Combined cooling, heat & power (CCHP), and Hybrid Energy Storage System (HESS).

Specific objectives:

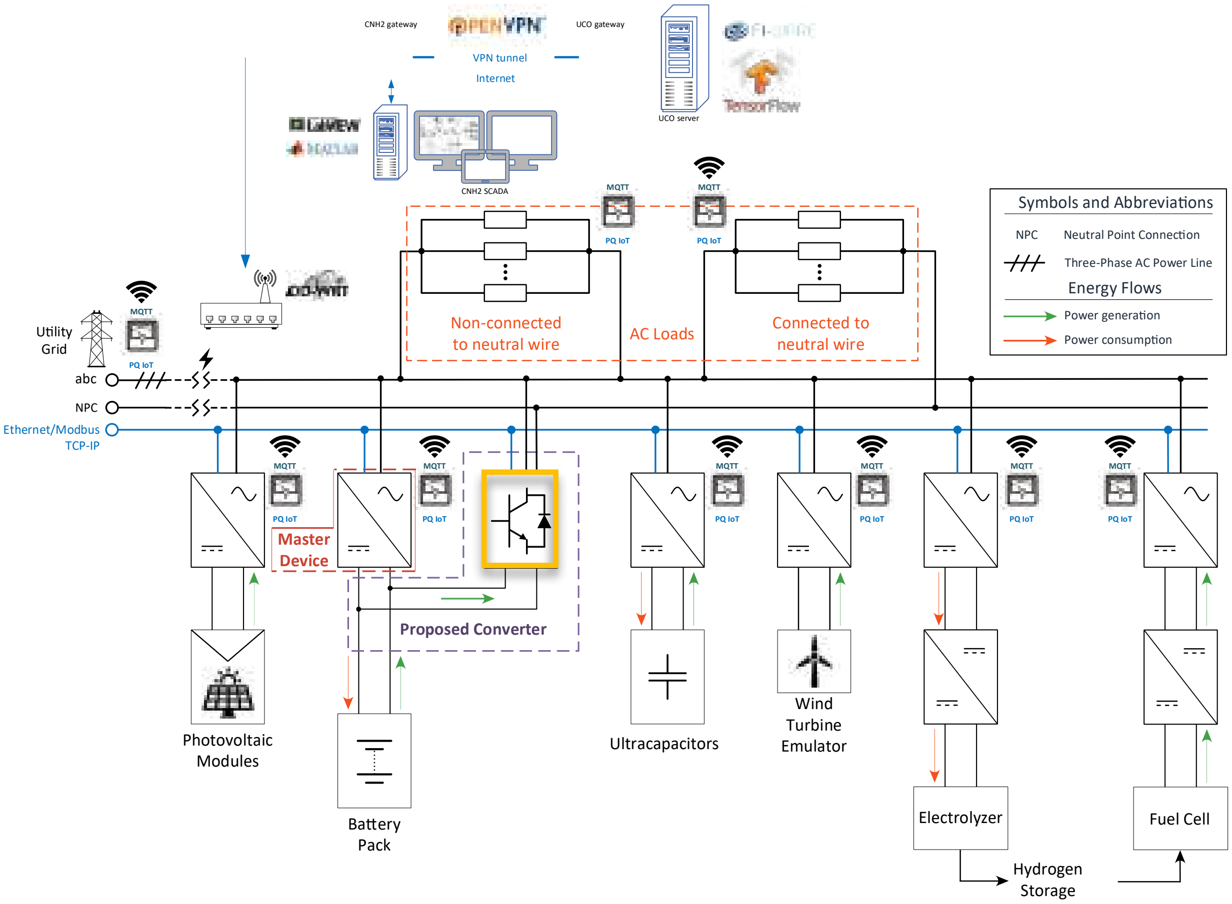
- ✓ Development of **Solar Heating & Cooling system**, with the incorporation of active and passive techniques for Nearly Zero-Energy Buildings (NZEB).
- ✓ Development of a **fault-tolerant power control system for microgrids** under **high Power Quality & Reliability** design criteria.
- ✓ Development of an **EMS** for renewable energy microgrids with Hybrid Energy Storage System (HESS) **under criteria of minimum degradation**, **maximum efficiency and priority in the use of renewable energies.**

IMPROVEMENT[1] Microgrid control layers



[1] Integration of combined cooling, heating and power microgrids in zero-energy public buildings under high power quality and continuity of service requirements (**IMPROVEMENT**), co-financed by the *Interreg SUDOE* Programme and the *European Regional Development Fund* (ERDF). Ref. SOE3/P3/E0901.

IMPROVEMENT Microgrid project original scheme



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Power quality data analytics

Power quality data analytics[1] is a discipline that specializes in collecting waveform-based power system data, extracting information from it, and applying the findings to solve a wide variety of power system problems beyond traditional power quality concerns, such as condition monitoring and fault diagnosis.

EDGE COMPUTING IN IOT PQ SENSOR

Monitoring and Data Log
- **PQ Event Log**
- **PQ Steady-state Disturbances Log**

Site PQ Reporting
- **Event Classifications**
- **Apply temporal and spatial aggregation windows**
  - *10/12 cycles*
  - *150/180 cycles*
  - *10 min*
  - *2 h.*
  - IEC Std. 61000-4-30
- **Statistical evaluation of the Compliance Limit** (e.g. Std.EN-50160)

CLOUD COMPUTING

Visual Data Analytics
- **Create Data Log Trends, Histograms, Profiles, Scatter Charts, and Statistical Summary Tables**
- **Generate ITIC, SEMI-F47, and Custom Voltage Sag Magnitude-Duration Charts**

Diagnostic Models
- **Site PQ&R global index**
- **Identify, Analyze, and Locate Faults**
- **Correlate PQ and Fault Events**
- **PQ event log correlation with *EMS* operation logs**
- **Continuously diagnose of low-voltage ride-through capability**

Predictive Models
- **Alarms** (e.g. IEEE 1547)
- **Trend forecasting**
- **Anticipated faults detection thanks to early-stage alerts.**
- **Identify and proactively manage reliability issues, establishing clearly whose responsibility it is, e.g. in insurance claims**

Prescriptive Models
- **Evaluate future predicted alternatives**
- **Recommend optimal scheduling focused on preventative maintenance**

Time

Descriptive Analytics tells you what happened in the past

Diagnostic Analytics helps you understand why something happened in the past.

Predictive Analytics forecast what is most likely to happen in the future

Prescriptive Analytics recommend several different possible actions and guide them towards a solution.

Std. EN 50160 specifies main characteristics the grid voltage must meet at the user's supply terminal. It applies to public low, medium and high voltage AC electricity grids under normal operating conditions.

[1] **IEEE Working Group on Power Quality Data Analytics**

The IoT Power Quality Sensor developed

Hardware

- Current and voltage inputs
- Signal conditioning circuits
- Specific purpose IC MCP-3909 for energy measurements
- System on chip ESP32

Firmware

Use of the real-time operating system *FreeRTOS* for managing the following task:

- Waveform acquisition
- PQ parameter calculation
- PQ parameter transmission

Vrms, Irms, P, Q, S, tPF and industrial frequency (IEC 61000-4-30)

Detection of both magnitude and duration of voltage disturbances (IEC 61000-4-30)

Low power consumption (<3.5 W)

Vh and Ih up to 50^{th} order, THDv and THDi (IEC 61000 4-7)

Several communication interfaces: MQTT, HTTP, TCP, UDP…

Flexibility over the waveform acquisition layer

IoT Power Quality Sensors: Main versions

Single-Phase version

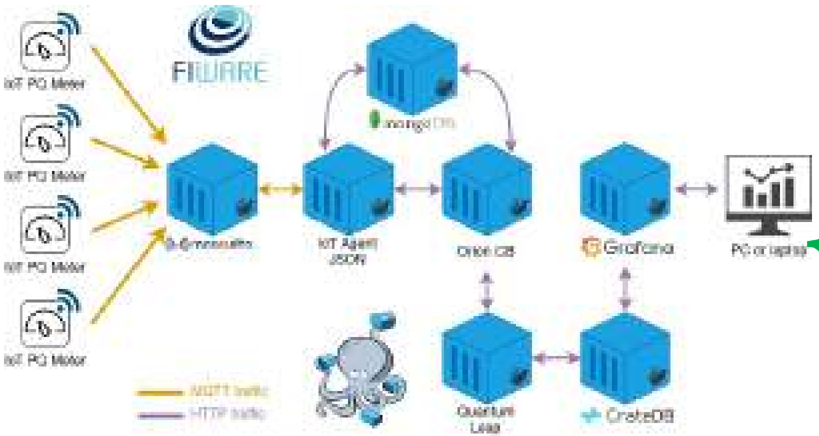
Three-Phase version

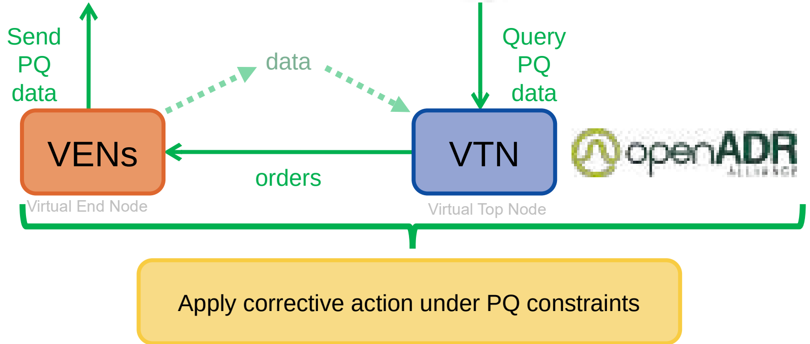
Also incorporated:

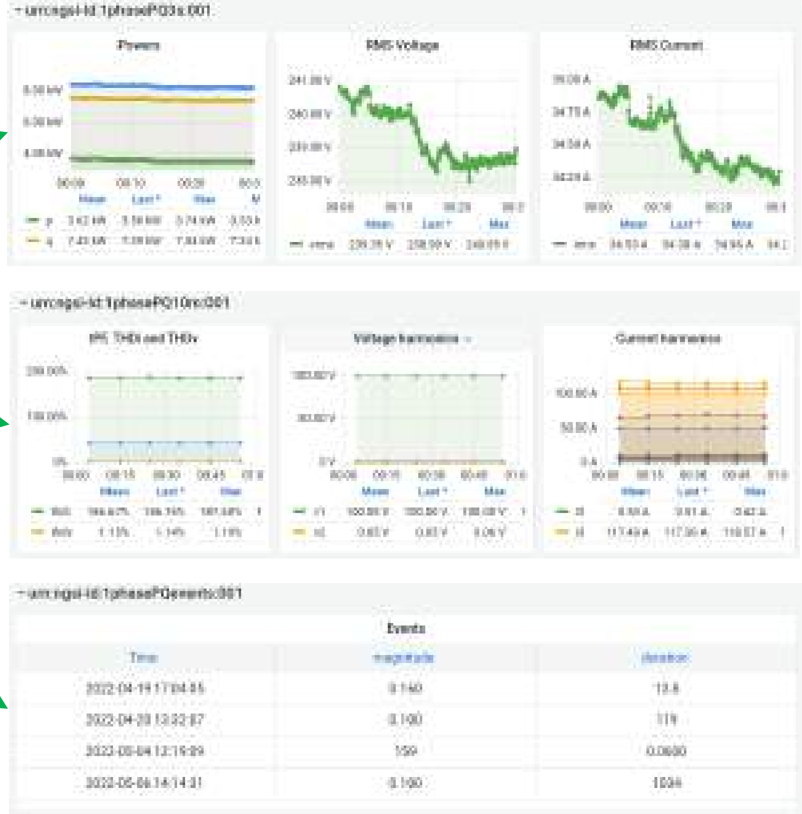
- Serial communication (via EIA/TIA-485 protocol)
- UEXT connector (power and three serial buses: Asynchronous, I^{2}C, SPI)

IoT FIWARE Ecosystem Architecture deployed

The FIWARE infrastructure is hosted on a dedicated server at the CNH2 pilot plant.



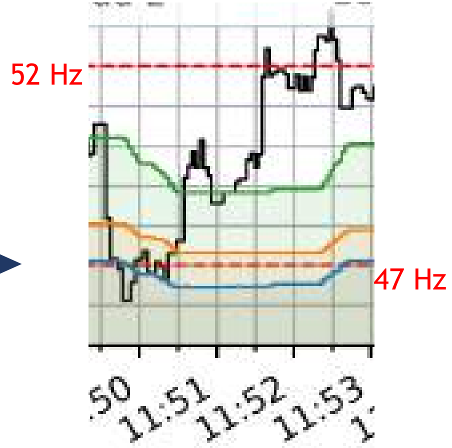




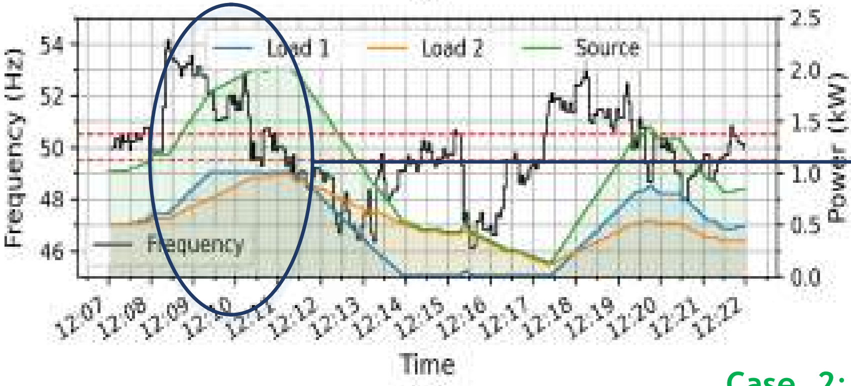
Protective Functionalities provided by the device

Frequency deviations

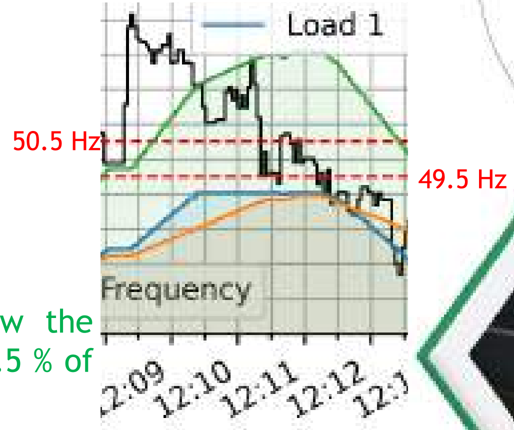
a)



Case 1: Red dashed lines show the limits given by **EN 50160** for 100 % of the year: 47 – 52 Hz



b)



Case 2: Red dashed lines show the limits given by **EN 50160** for 99.5 % of the year: 49.5 – 50.5 Hz

Std. EN 50160 specifies main characteristics the grid voltage must meet at the user's supply terminal. It applies to public low, medium and high voltage AC electricity grids under normal operating conditions

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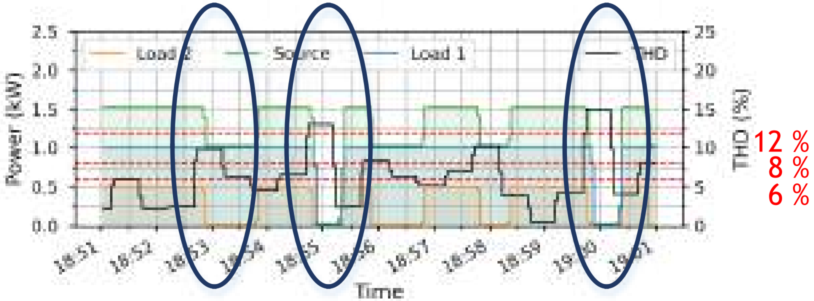
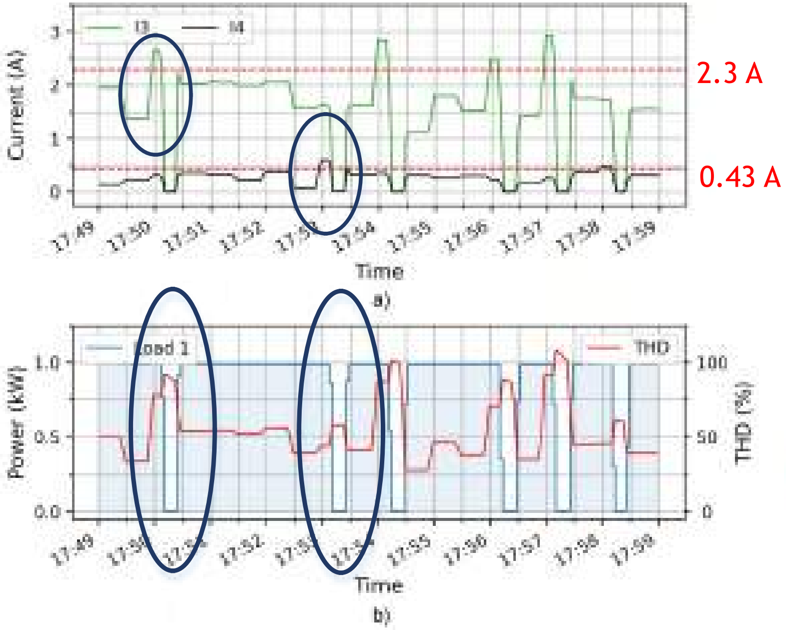
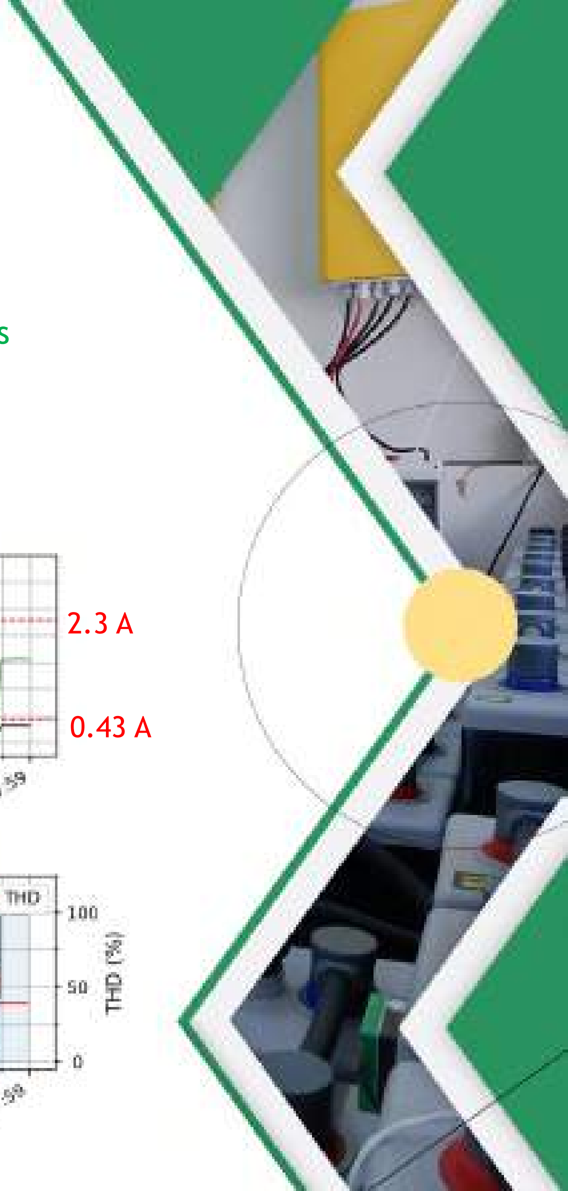
Voltage and current harmonic distortion

Case 1: Standards IEEE 519 and EN 50160 have been employed as references to limit the **voltage THD** in loads 1 and 2 respectively (12 and 8 %). The value 6 % is the reconnection criterion.



Case 2: The standard IEC 61000-3-2 has been used as a reference to limit the magnitude of **individual current harmonics**. Concretely, 3rd and 4th harmonics are generated.





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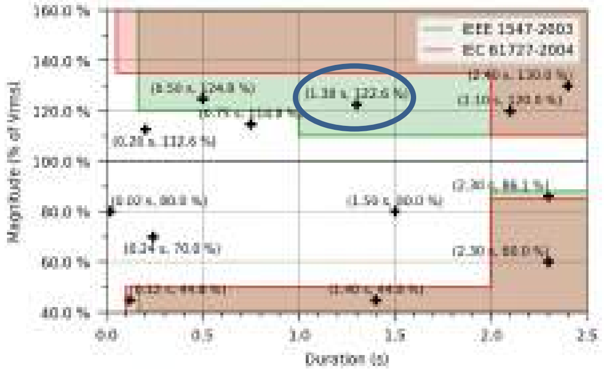
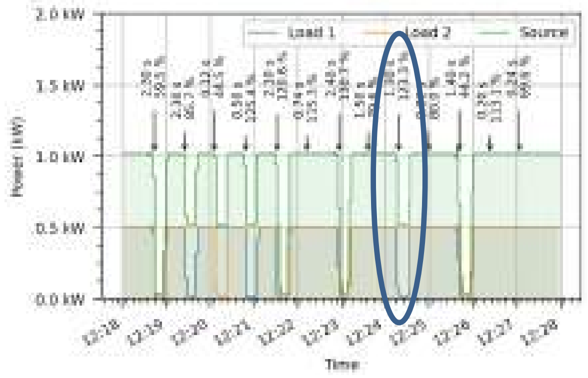
Tests with OpenADR + Single-phase IoT Sensor: Voltage dips test



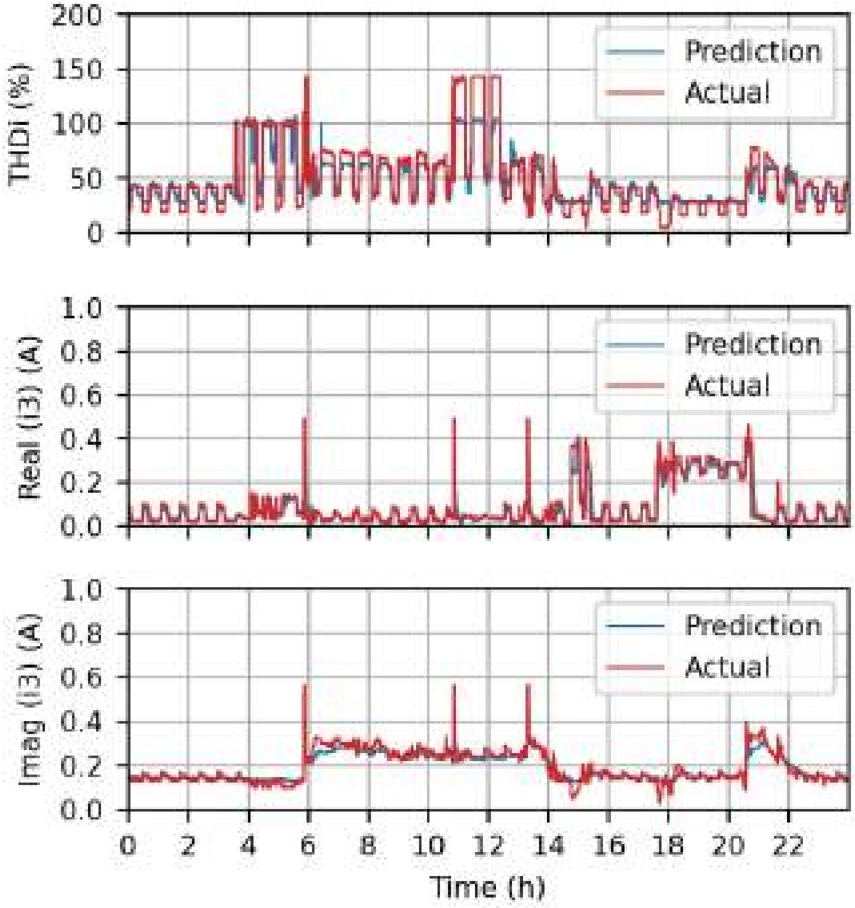
a) Voltage disturbances configured for the test and limits defined by standards IEEE 1547 – 2003 and IEC 61727 – 2004.



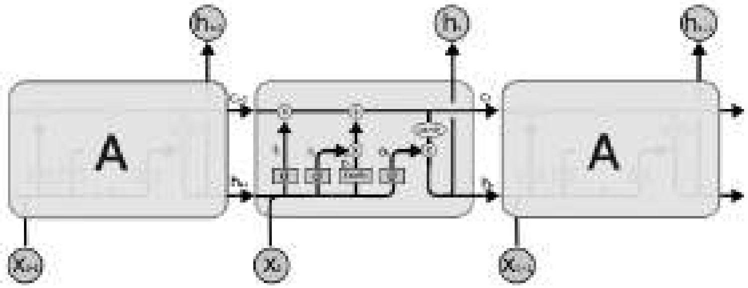
b) Voltage disturbances identified by the IoT Sensors and power consumption of loads during the test.

- IEEE 1547-2018 - IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces
- IEC 61727:2004 Photovoltaic (PV) systems - Characteristics of the utility interface

PQ time-series forecasting based on LSTM Recurrent Neural Network



Several LSTM networks has been proposed to forecast the **steady-state of some PQ indices** time-series which evaluate the current distortion at the PCC (e.g., I1, I3, THD)



The main contributions are the prediction of both the real and imaginary components of the current harmonics and the use of highly granularity datasets.

Some of the outcomes of all this work

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Thesis

- G. Z. Joaquín, “Research on demand-side flexibility in Smart Grids: direct load control”, PhD Thesis, Dept. Ingeniería Electrónica y de Computadores, Univ. of Cordoba, Cordoba, Spain, 2022. [Online]. Available: http://hdl.handle.net/10396/24061

Research on demand-side flexibility in Smart Grids: direct load control

Investigación sobre la flexibilidad de la demanda en redes eléctricas inteligentes: control directo de cargas

Ver:
20220000002572.pdf (7.600Mb)

Autor
Garrido Zafra, Joaquín

In recent decades, the European Union has made decisive efforts to maintain its global leadership in renewable energies to meet climate change targets resulting from international agreements. There is a deliberate intention to reduce the usage of non-renewable energy sources and promote the exploitation of renewable generation at all levels as shown by energy production data within the Eurozone. The electricity sector illustrates a successful implementation of these energy policies. The electricity coming from combustible fuels was at historical lows in 2018, accounting for 83.6 % of the electricity generated from this source in 2008. By contrast, the pool of renewables reached almost 170 % of the 2008 production. Against this background, power systems worldwide are undergoing deep-seated changes due to the increasing penetration of these variable renewable energy sources and distributed energy resources that are intermittent and stochastic in nature. Under these conditions, achieving a continuous balance between generation and consumption becomes a challenge and may jeopardize the system stability, which points out the need of making the power system flexible enough as a response measure to this trend. This Ph.D. thesis researches one of the principal mechanisms providing flexibility to the power system. The demand-side management, seen from both the demand response and the energy efficiency perspectives. Power quality issues as a non-negligible part of energy efficiency are also addressed. To do so, several strategies have been deployed at a double level. In the residential sector, a direct load control strategy for smart appliances has been developed

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Publications (I)

- J. Garrido-Zafra, A. Gil-de-Castro, R. Savariego-Fernandez, M. Linan-Reyes, A. Moreno-Munoz and F. García-Torres, "A Novel Microgrid Responsive Appliance Controller," 2020 IEEE International Conference on Environment and Electrical Engineering and 2020 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), 2020, pp. 1-6, doi: 10.1109/EEEIC/ICPSEurope49358.2020.9160723.

- F. Garcia-Torres, C. Bordons, J. Tobajas, J. J. Márquez, J. Garrido-Zafra and A. Moreno-Muñoz, "Optimal Schedule for Networked Microgrids Under Deregulated Power Market Environment Using Model Predictive Control," in IEEE Transactions on Smart Grid, vol. 12, no. 1, pp. 182-191, Jan. 2021, doi: 10.1109/TSG.2020.3018023.

- J. Garrido-Zafra, A. Moreno-Munoz, A. R. Gil-de-Castro, F. J. Bellido-Outeirino, R. Medina-Gracia and E. Gutiérrez-Ballesteros, "Load Scheduling Strategy to Improve Power Quality in Electric-Boosted Glass Furnaces," in IEEE Transactions on Industry Applications, vol. 57, no. 1, pp. 953-963, Jan.-Feb. 2021, doi: 10.1109/TIA.2020.3029758.

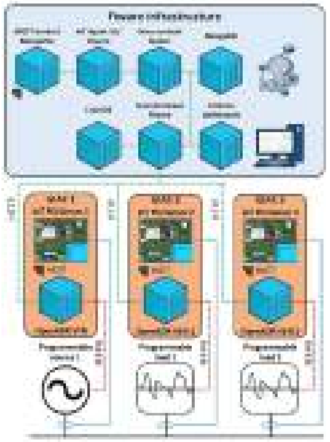
- M. Linan-Reyes, J. Garrido-Zafra, A. Gil-de-Castro, and A. Moreno-Munoz, “Energy Management Expert Assistant, a New Concept,” Sensors, vol. 21, no. 17, p. 5915, Sep. 2021, doi: 10.3390/s21175915.

- Savariego, R., Moreno-Munoz, A., Abascal-Castaneda, I. M., González-Cuenca, M. I., Silva, C. S., Tobajas-Blanco, J., ... & Loureiro, D. (2023). Integration of CCHP microgrids in NZEB with critical loads under high PQR requirements, a position paper. *Energy Reports*, *9*, 403-409. https://doi.org/10.1016/j.egyr.2023.01.003

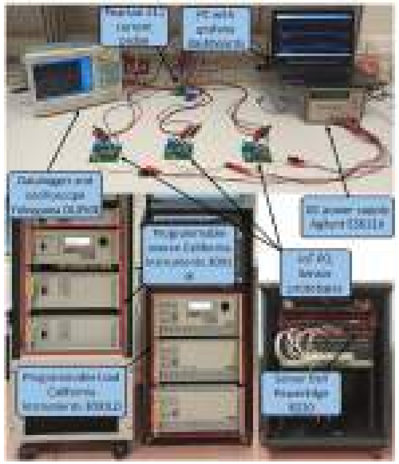
Publications (II)

- F. J. López-Alcolea et al., "Detection and Compensation of Current Harmonics in a Microgrid Using an Active Power Filter Supported by an IoT Sensor Network," 2021 IEEE International Conference on Environment and Electrical Engineering and 2021 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), 2021, pp. 1-6, doi: 10.1109/EEEIC/ICPSEurope51590.2021.9584592.

- J. Garrido-Zafra, A. R. Gil-de-Castro, R. Savariego-Fernandez, M. Linan-Reyes, F. Garcia-Torres and A. Moreno-Munoz, "IoT Cloud-Based Power Quality Extended Functionality for Grid-Interactive Appliance Controllers," in IEEE Transactions on Industry Applications, vol. 58, no. 3, pp. 3909-3921, May-June 2022, doi: 10.1109/TIA.2022.3160410.



- Power limit test
- Sags and swells test
- THDv limit test



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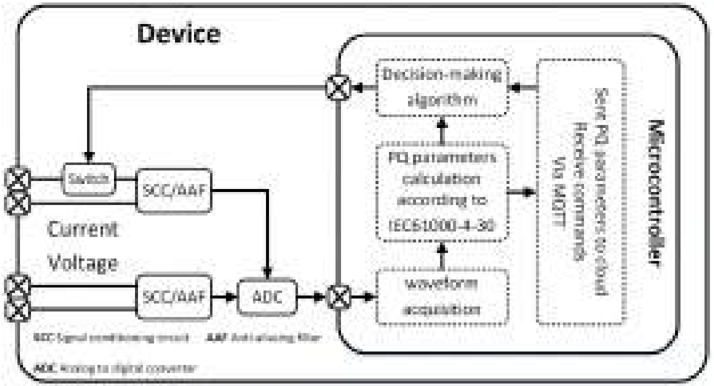
Patent

- A patent was requested to the Spanish Patent and Trademark Office (Oficina Española de Patentes y Marcas).



GOBIERNO DE ESPAÑA

MINISTERIO DE INDUSTRIA, COMERCIO Y TURISMO

Oficina Española de Patentes y Marcas

Acknowledgement of receipt

We hereby acknowledge receipt of your request for grant of a European patent as follows:

Applicant	UNIVERSIDAD DE CÓRDOBA
Country	ES
Title	IOT PLATFORM FOR DIAGNOSIS AND MANAGEMENT OF POWER QUALITY IN MICROGRIDS

TRIBALYTE IDEAS

Source: https://ideas.tribalyte.com

Books

- H. Haes Alhelou, A. Moreno-Muñoz and P. Siano, Eds., Industrial demand response: methods, best practices, case studies, and applications.
- The book is published and available

- A. Moreno and N. Giacomini, Eds., Energy smart appliances: applications, methodologies, and challenges.
- The final version of the chapters were sent on August 31.

Participation in the IEEE Task Force (TF) on "*Flexible Grid-interactive Efficient Buildings (GEBs) to Enhance Electric Service Resilience*"

IEEE PES Smart Buildings and Customer Systems (SBCS) Subcommittee
IEEE PES Smart Buildings, Loads, and Customer Systems (SBLC) Technical Committee

Its aim is to survey, validate and benchmark existing and emerging frameworks, paradigms, and toolkits about modeling and simulation, sensors and communications, and computation and control to utilize flexibility resources in individual or aggregated GEBs to enhance the outage prevention, survivability and recovery of electric services in building, campus or community, microgrid, distribution, and transmission levels endangered by low-probability but high-impact risks.

The main objectives are as follows:

- Perform a taxonomy of extreme events and identify necessary resilience services.
- Build a technology repository in the three thrusts: modeling and simulation, sensors and communications, computation and control. The repository will include existing ones and potential new technologies that can be beneficial for enhancing grid resilience.
- Build use cases where GEBs are providing resilience services and showcase the value propositions.
- Provide prioritized technology upgrade recommendations from existing ones to new technologies.

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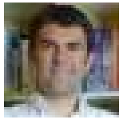
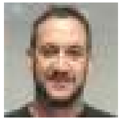
Integration of Combined Cooling, Heating and Power Microgrids in Zero Energy Public Buildings with High Power Quality and Continuity Requirements

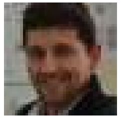
UCLM – LEICE

Location of the laboratory


Roncero-Sánchez, Pedro


Vázquez, Javier


Parreño Torres, Alfonso


Payo Gutiérrez, Ismael

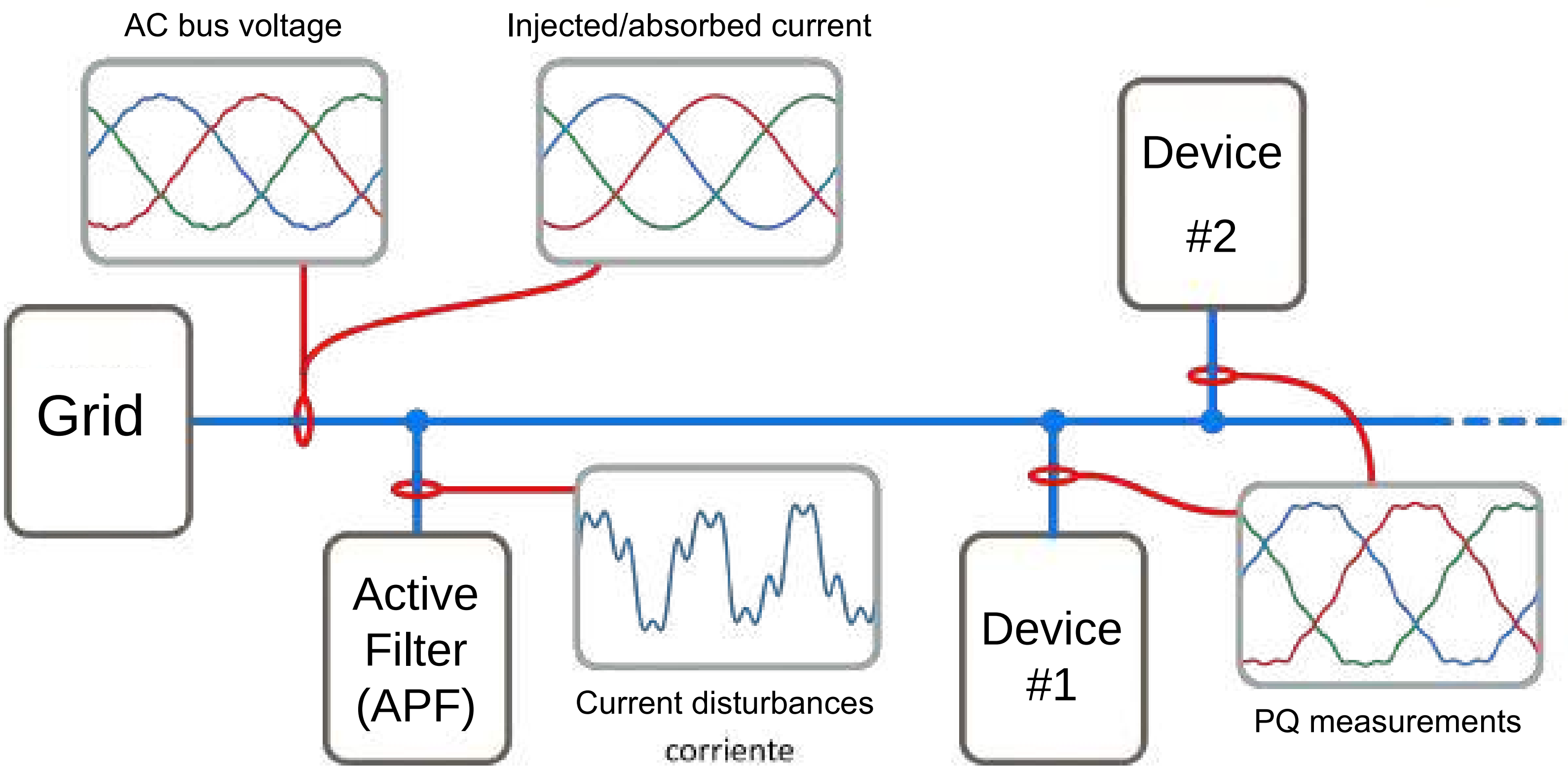

López-Alcolea, Fco. Javier


Molina-Martínez, Emilio J.

Introduction

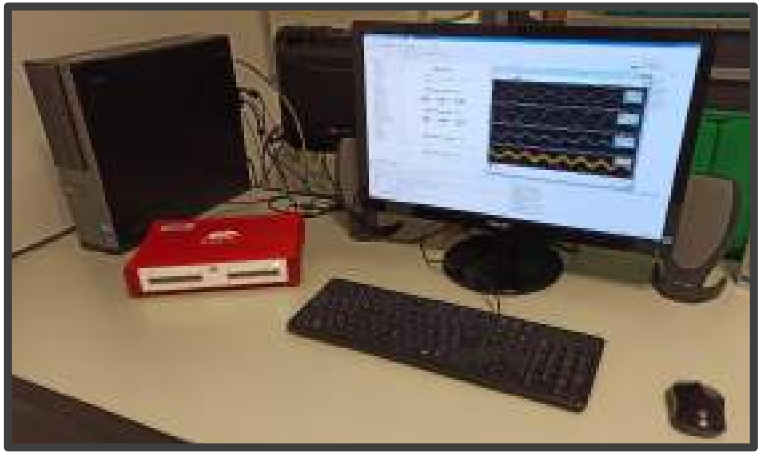
- Objective
  - Development of a power control system for microgrids with high power quality requirements
- Main activity: WP2
  - Development and implementation of an Active Power Filter (APF) with active neutral control
  - Improve performance under non-linear loads, current imbalances and current harmonics in the microgrid
    - Grid-connected mode
    - Islanded mode

Description of the system

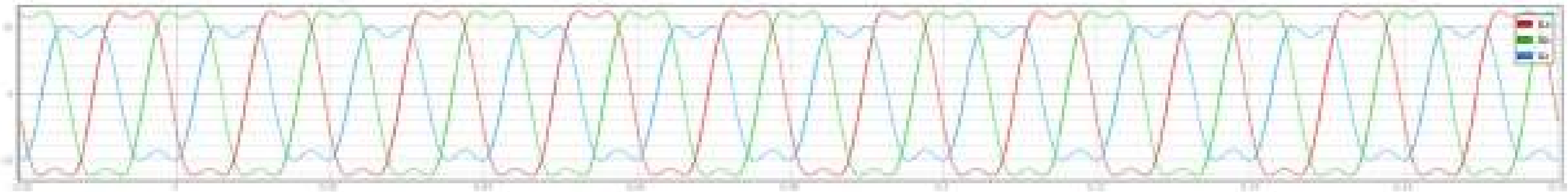


Simulation

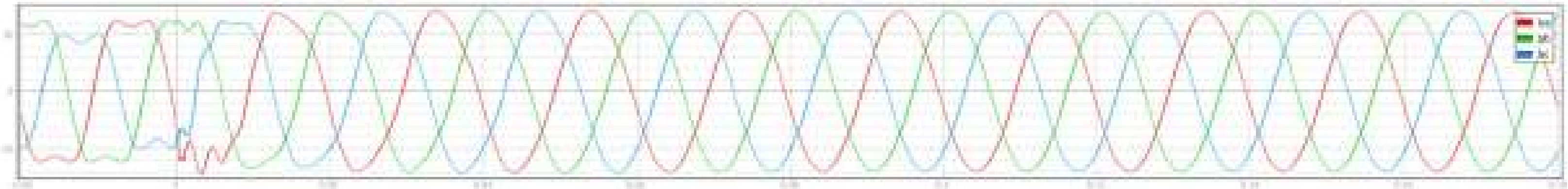
- Hardware-in-the-loop



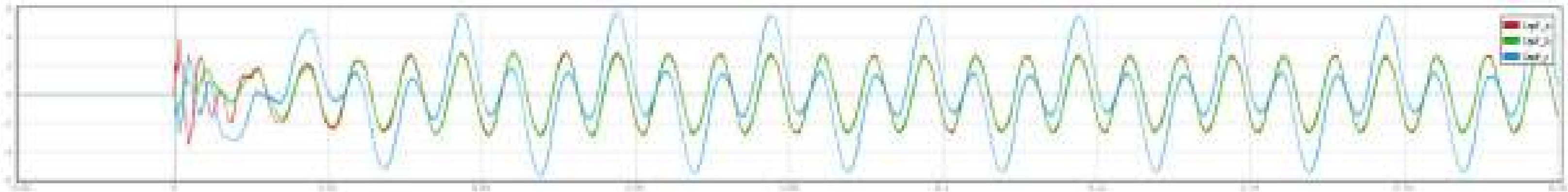
Load



Grid



APF



Prototype

Front doors

Front panel

Rear panel

Experimental testing

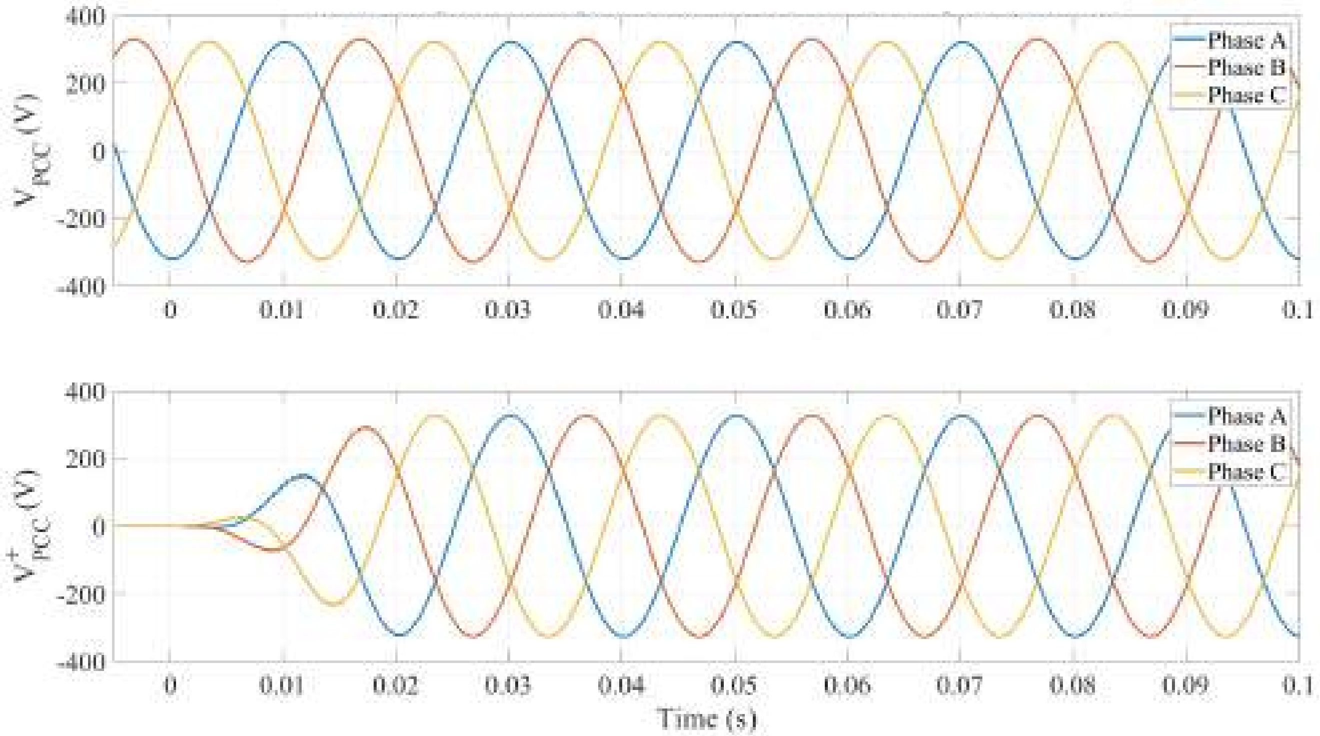
- Experimental testing in LEICE facilities

Experimental testing

- Grid synchronization
  - Balanced voltage
  - Balanced voltage with harmonics
  - Unbalanced voltage with harmonics

Experimental testing

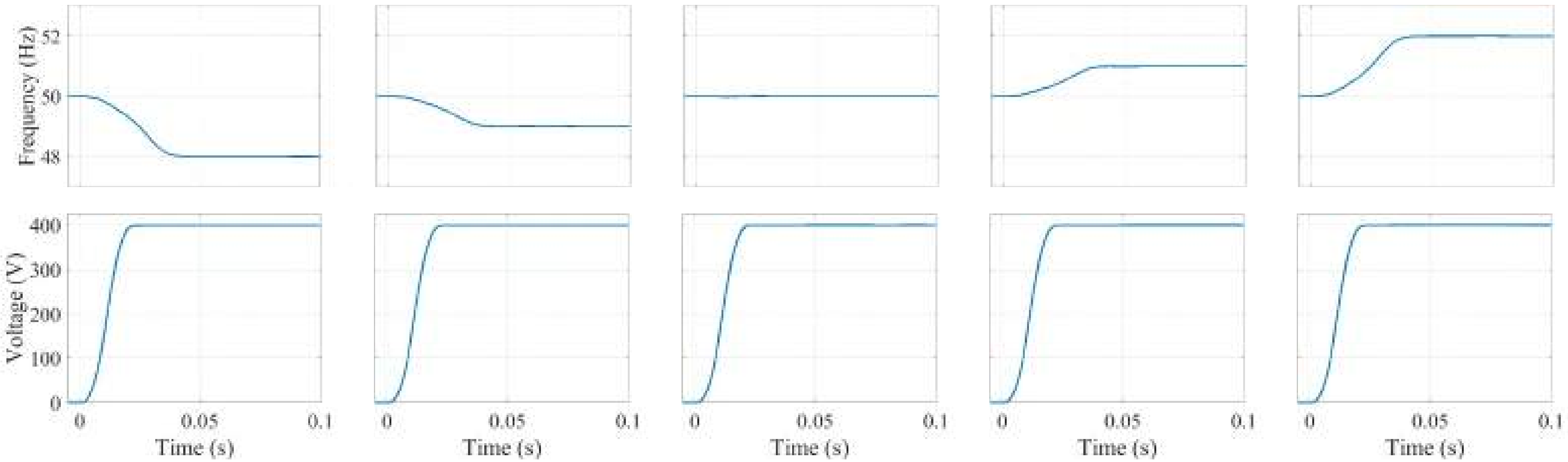
- Positive sequence component extraction (f_{GRID}: 50 Hz)



Experimental testing

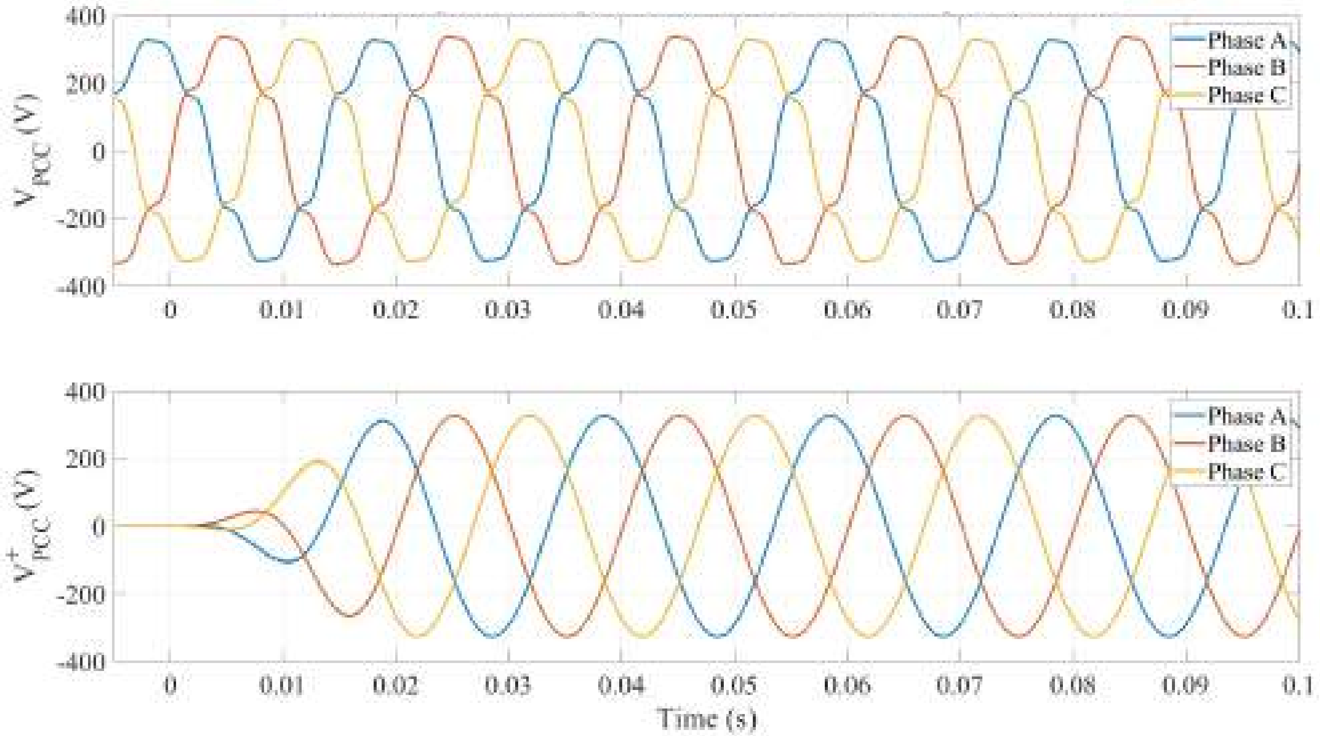
- Balanced voltage

f_{GRID}: 48 Hz f_{GRID}: 49 Hz f_{GRID}: 50 Hz f_{GRID}: 51 Hz f_{GRID}: 52 Hz



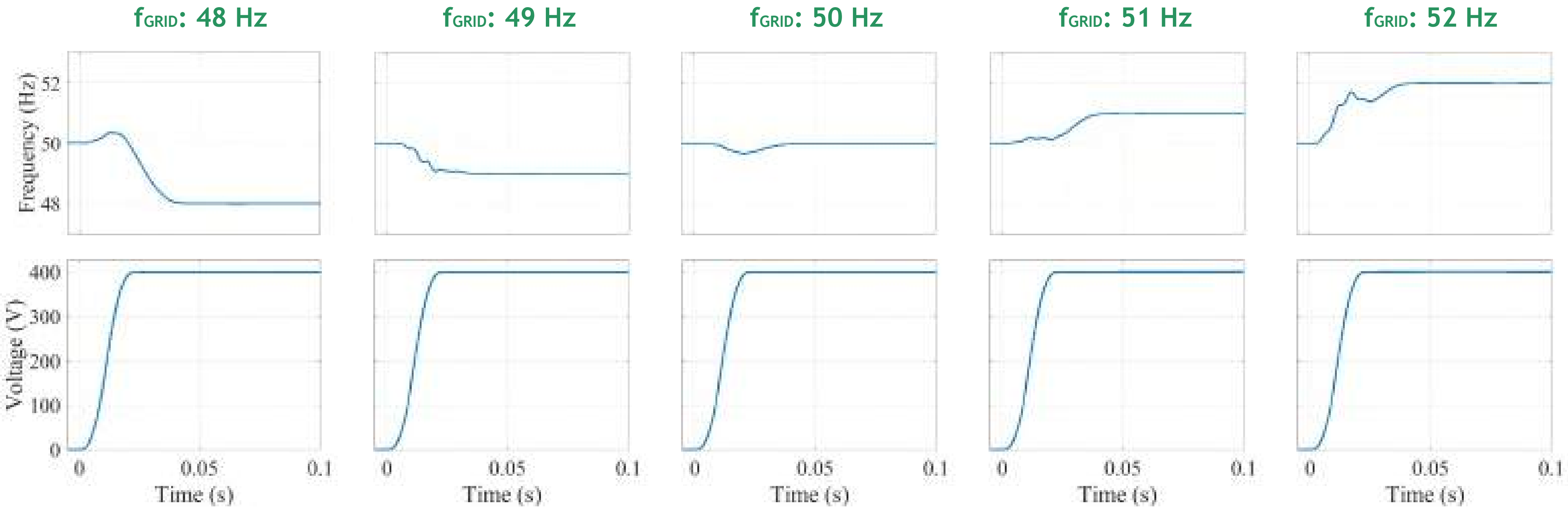
Experimental testing

- Positive sequence component extraction (f_{GRID}: 50 Hz)



Experimental testing

- Balanced voltage with harmonics



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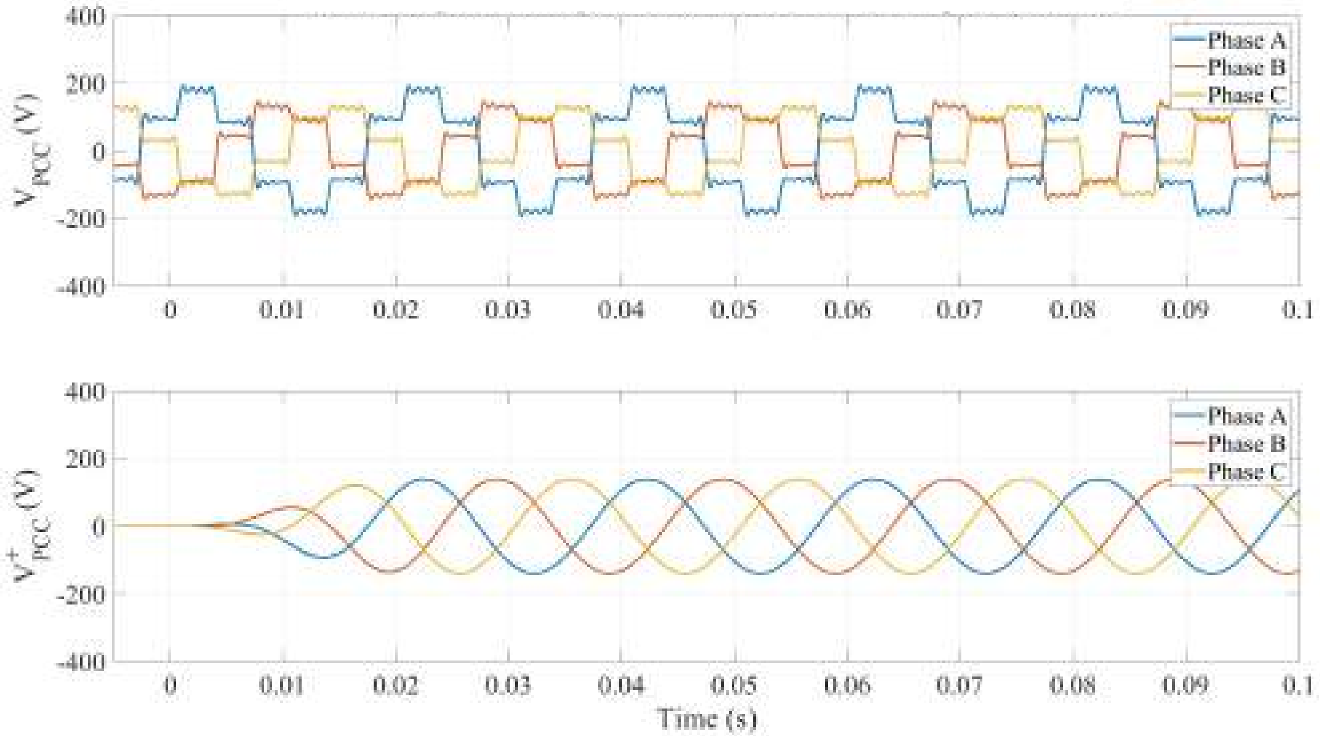
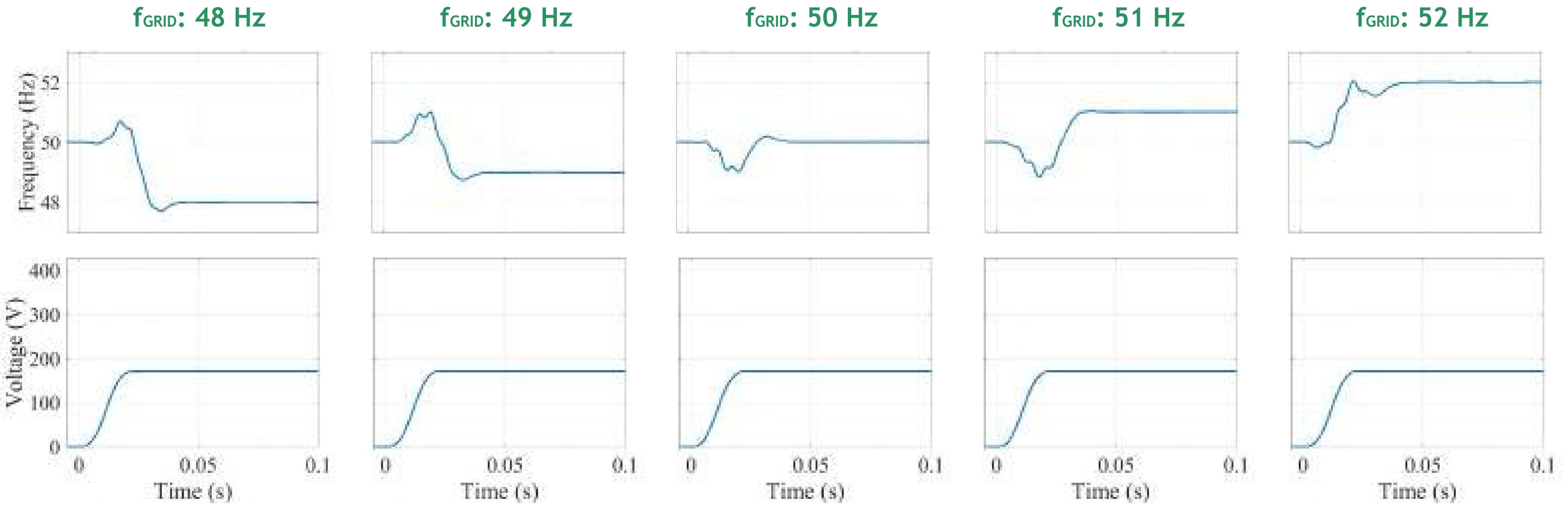
Experimental testing

- Positive sequence component extraction (f_{GRID}: 50 Hz)



Experimental testing

- Unbalanced voltage with harmonics



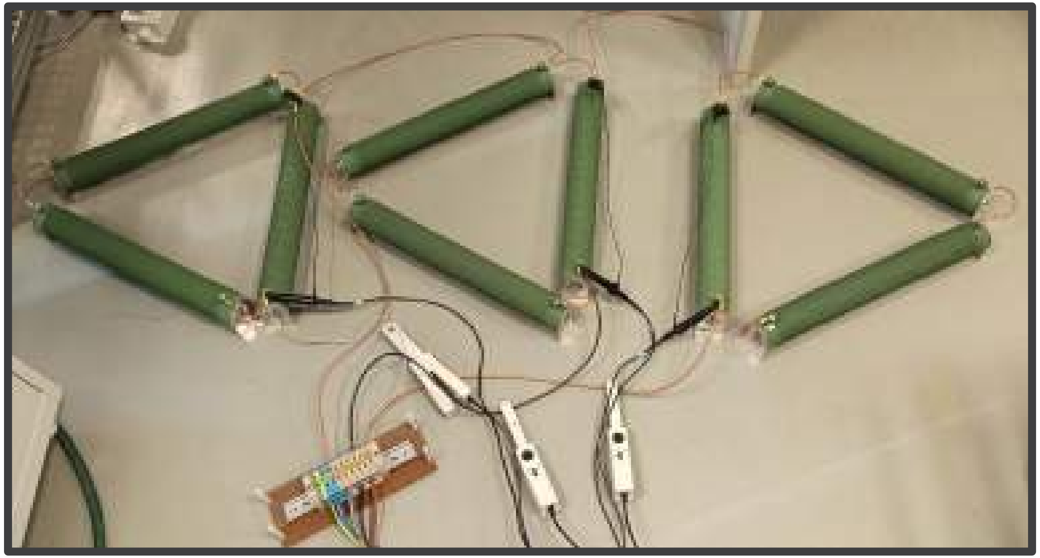
Experimental testing

- APF performance
  - Resistive load
    - Ideal PCC voltage
    - Unbalanced PCC voltage
    - Unbalanced PCC voltage with harmonics
  - Non-linear load
    - Unbalanced PCC voltage with harmonics

Experimental testing

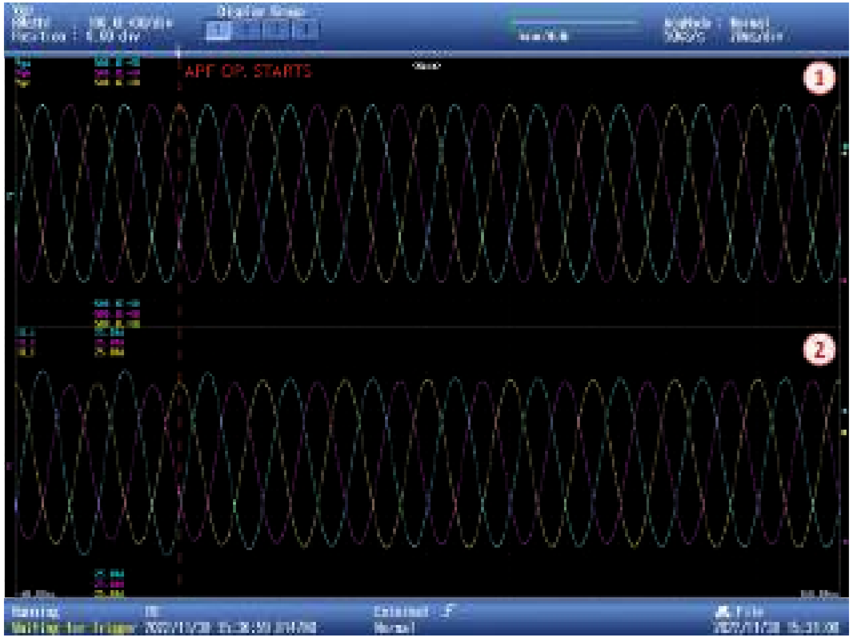
- Unbalanced resistive load

A: 19 Ω/phase   B – C: 22.7 Ω/phase

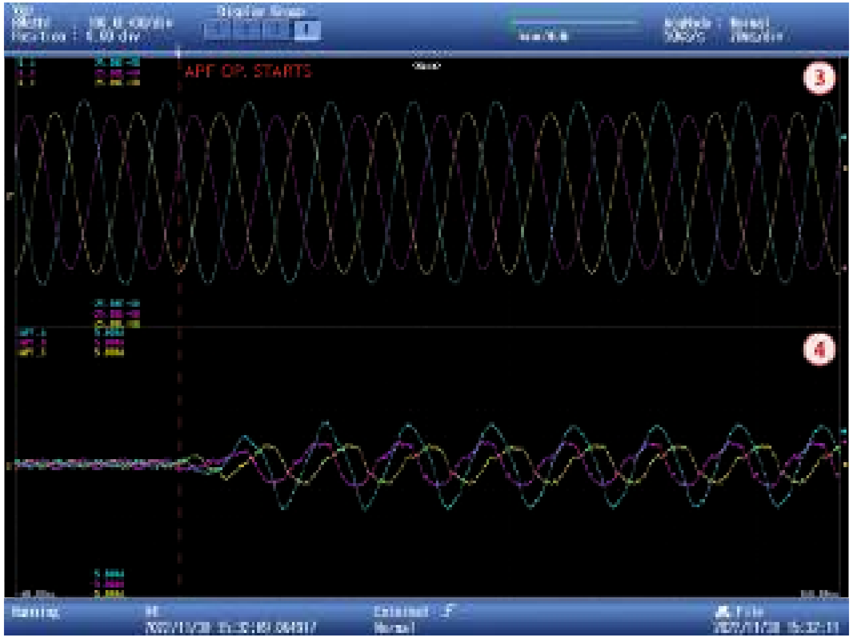


Experimental testing

- Ideal PCC voltage with unbalanced resistive load



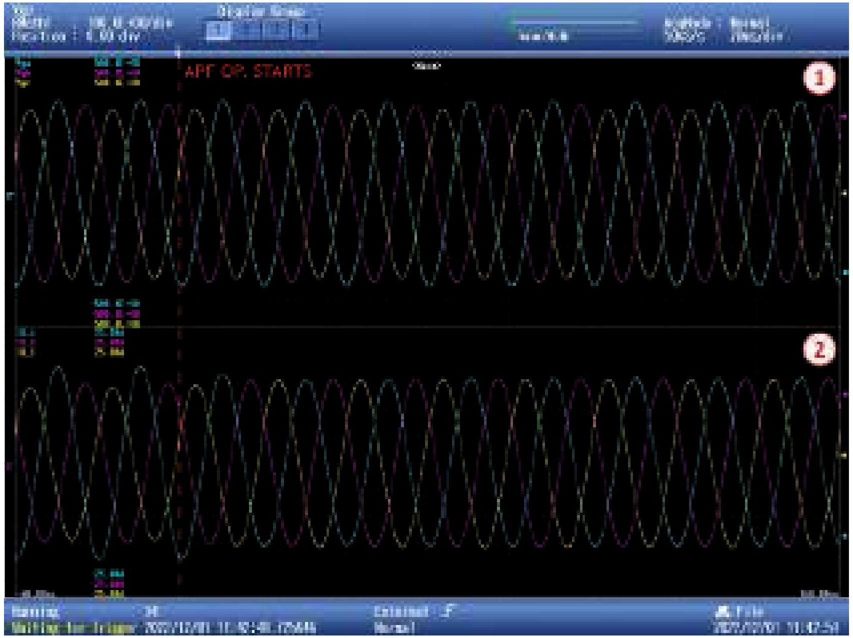
(1) PCC voltage and (2) Source current



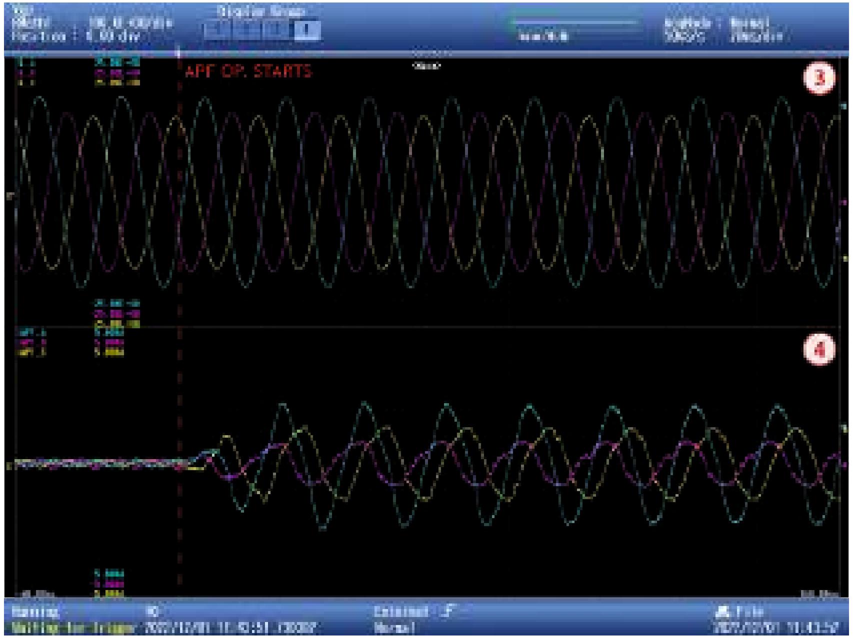
(3) Load current and (4) APF current

Experimental testing

- Unbalanced PCC voltage with unbalanced resistive load



(1) PCC voltage and (2) Source current

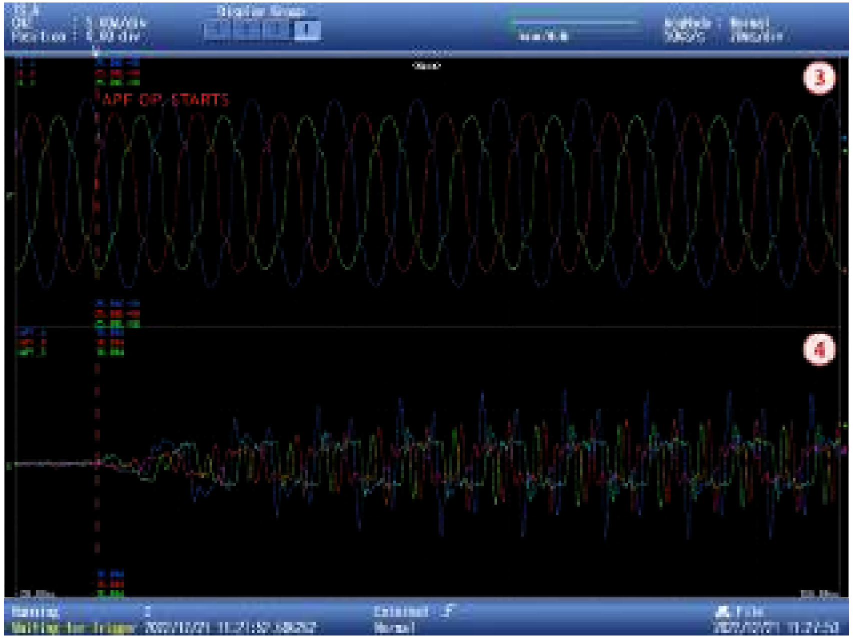


(3) Load current and (4) APF current

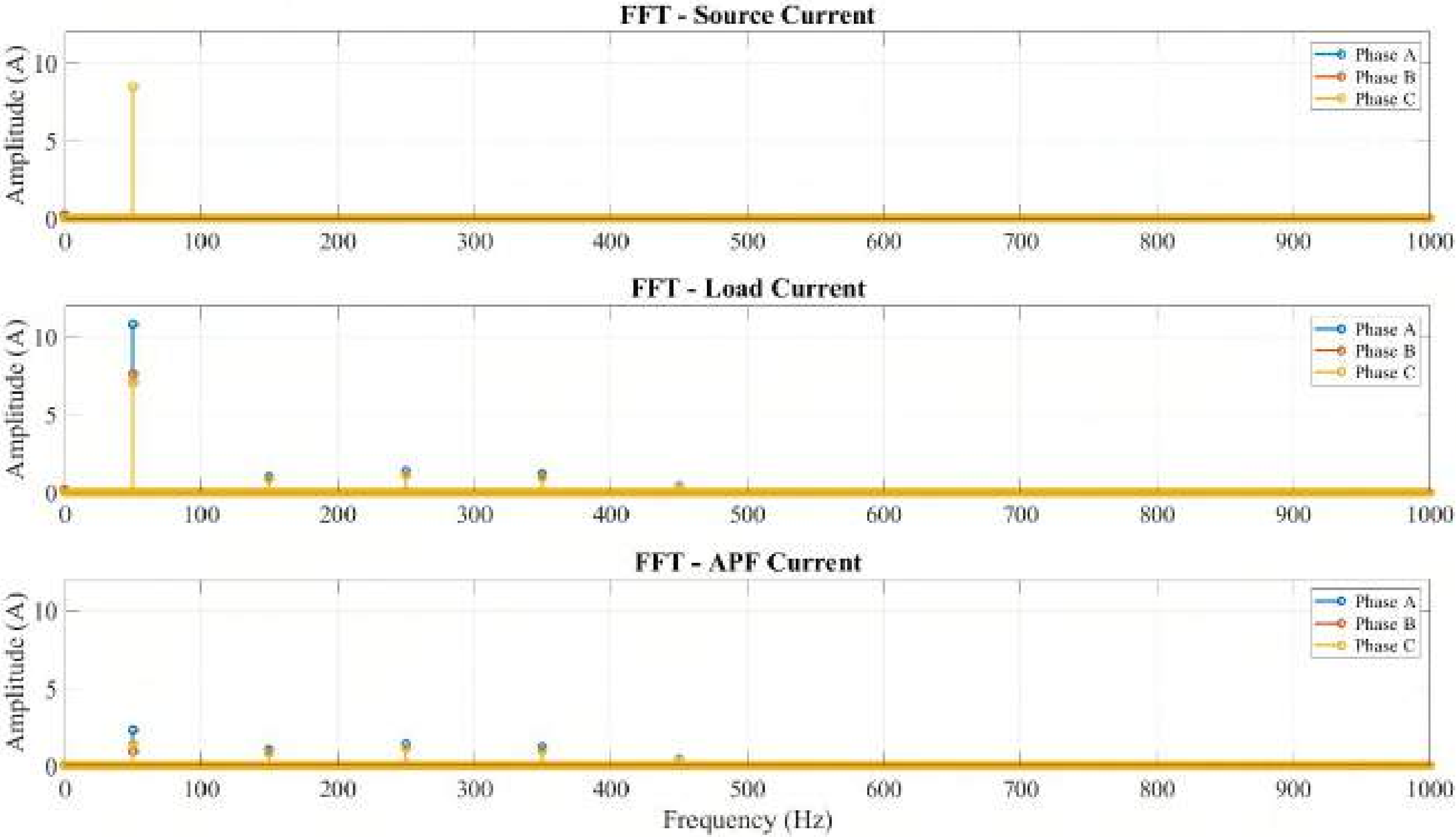
Experimental testing

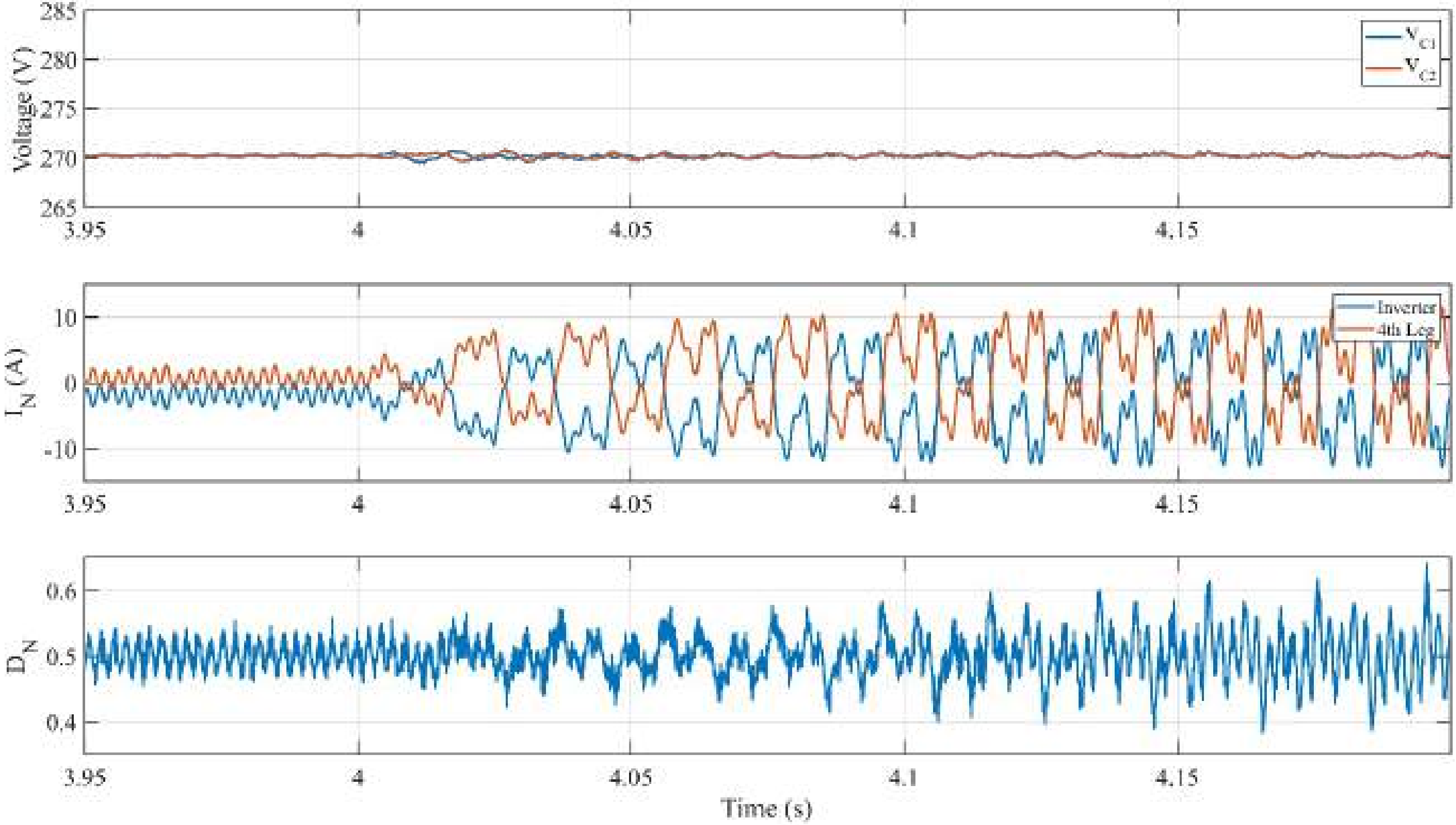
- Unbalanced PCC voltage with harmonics (3th, 5th, 7th, 9th) and unbalanced resistive load

(1) PCC voltage and (2) Source current



(3) Load current and (4) APF current


FFT - Source Current
Amplitude (A)
Phase A
Phase B
Phase C
FFT - Load Current
Amplitude (A)
Phase A
Phase B
Phase C
FFT - APF Current
Amplitude (A)
Phase A
Phase B
Phase C
Frequency (Hz)

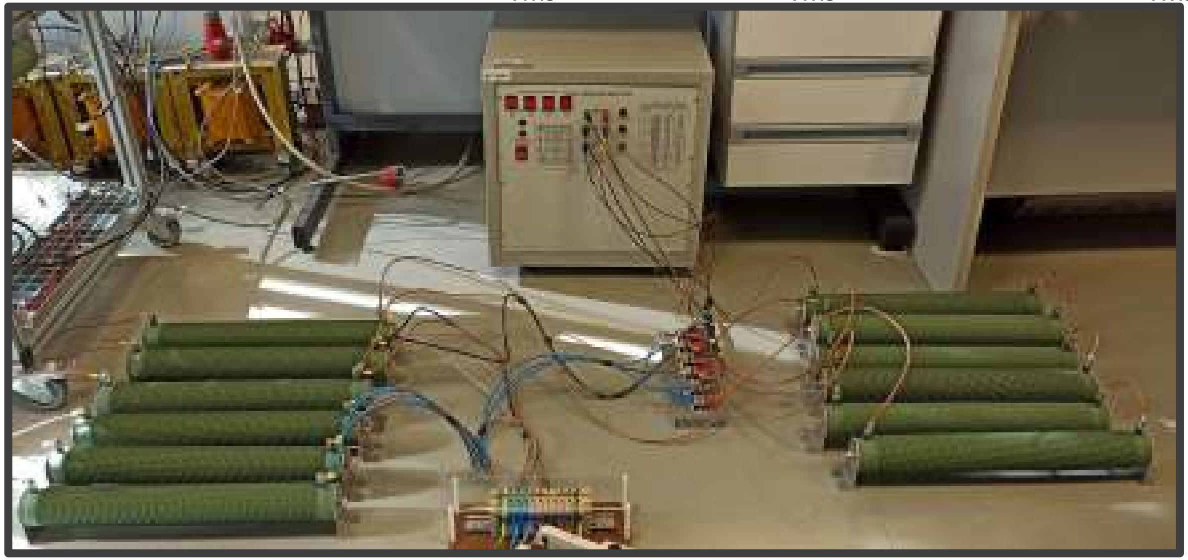


285
280
275
270
265
Voltage (V)
V_{C1}
V_{C2}
3.95
4
4.05
4.1
4.15
10
0
-10
I_N (A)
Inverter
4th Leg
0.6
0.5
0.4
D_N
Time (s)

Experimental testing

- Non-linear load: A - B – C: 44 Ω || Three single-pase rectifiers (69 Ω + 210 mH)

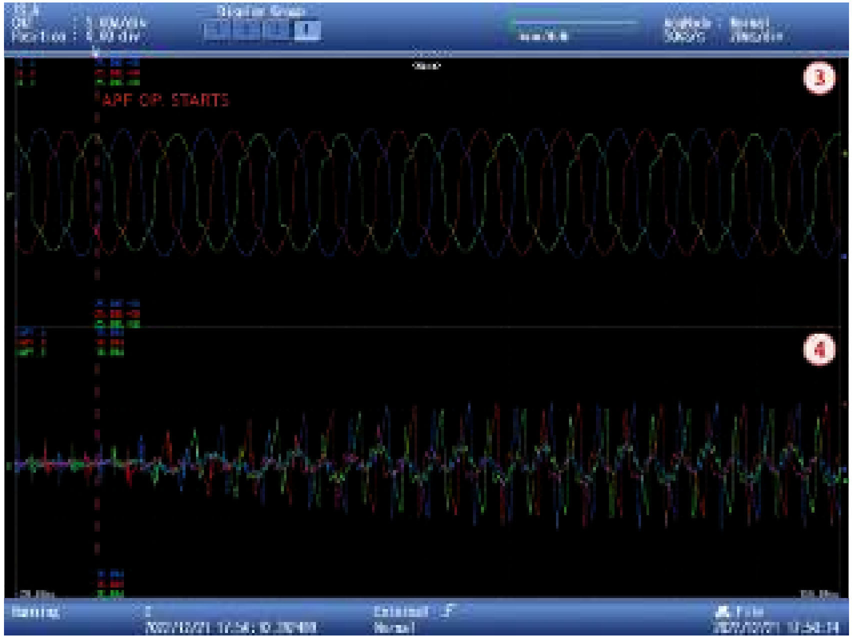
- Unbalanced PCC voltages: Van_{rms}=240V, Vbn_{rms}=230V and Vcn_{rms}=220V



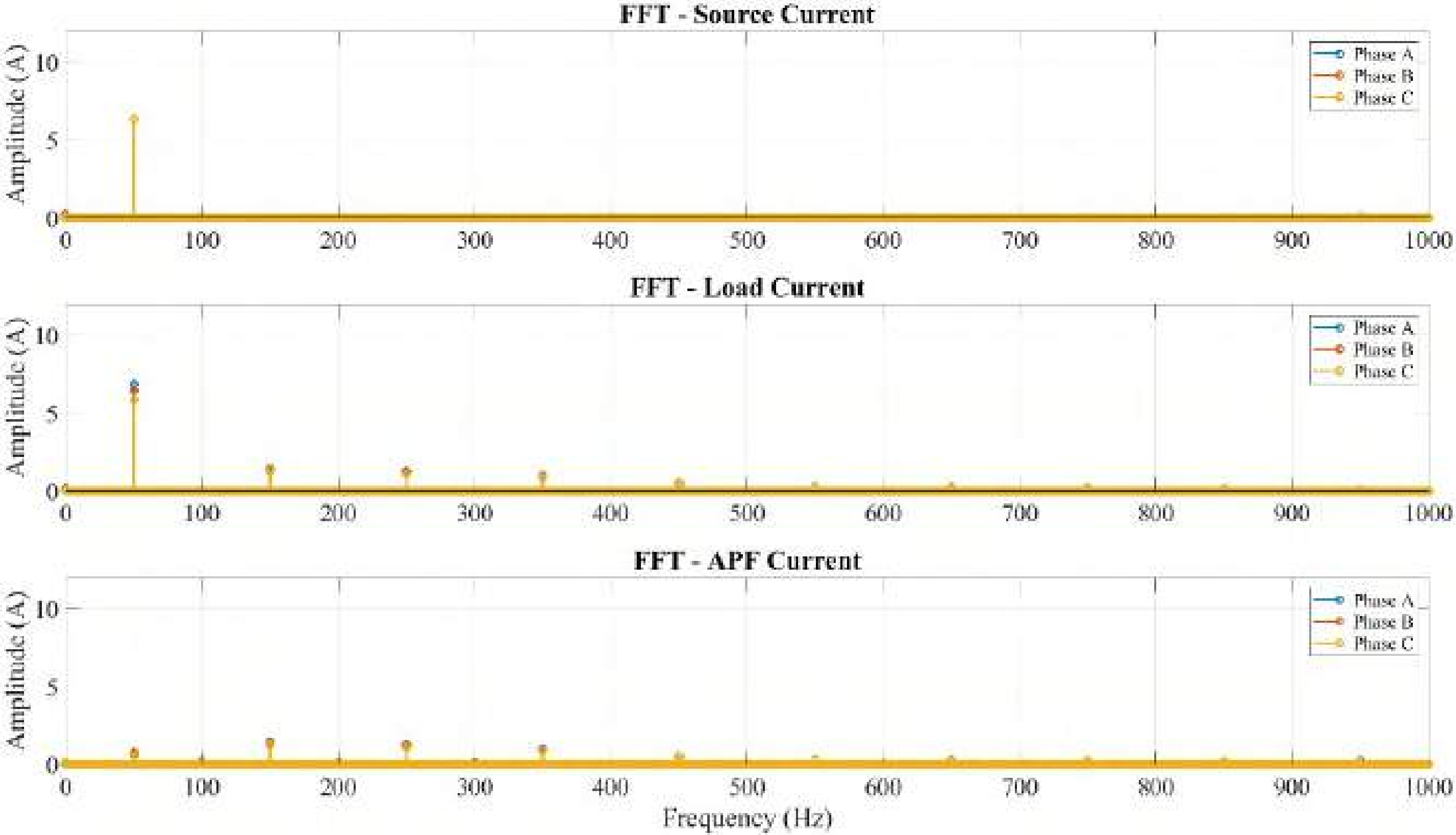
Experimental testing

- Unbalanced PCC voltage with harmonics and non-linear load

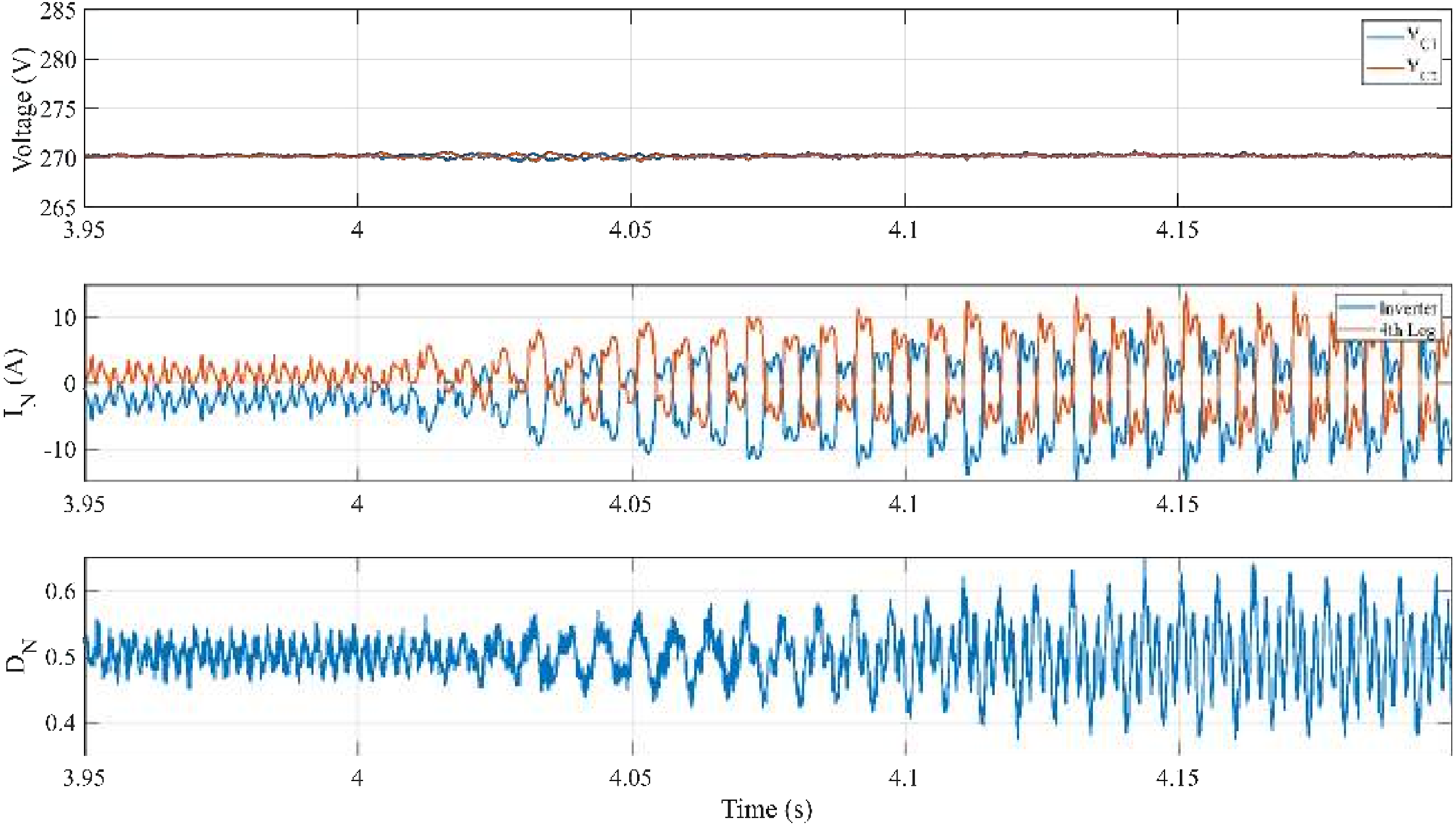
(1) PCC voltage and (2) Source current



(3) Load current and (4) APF current



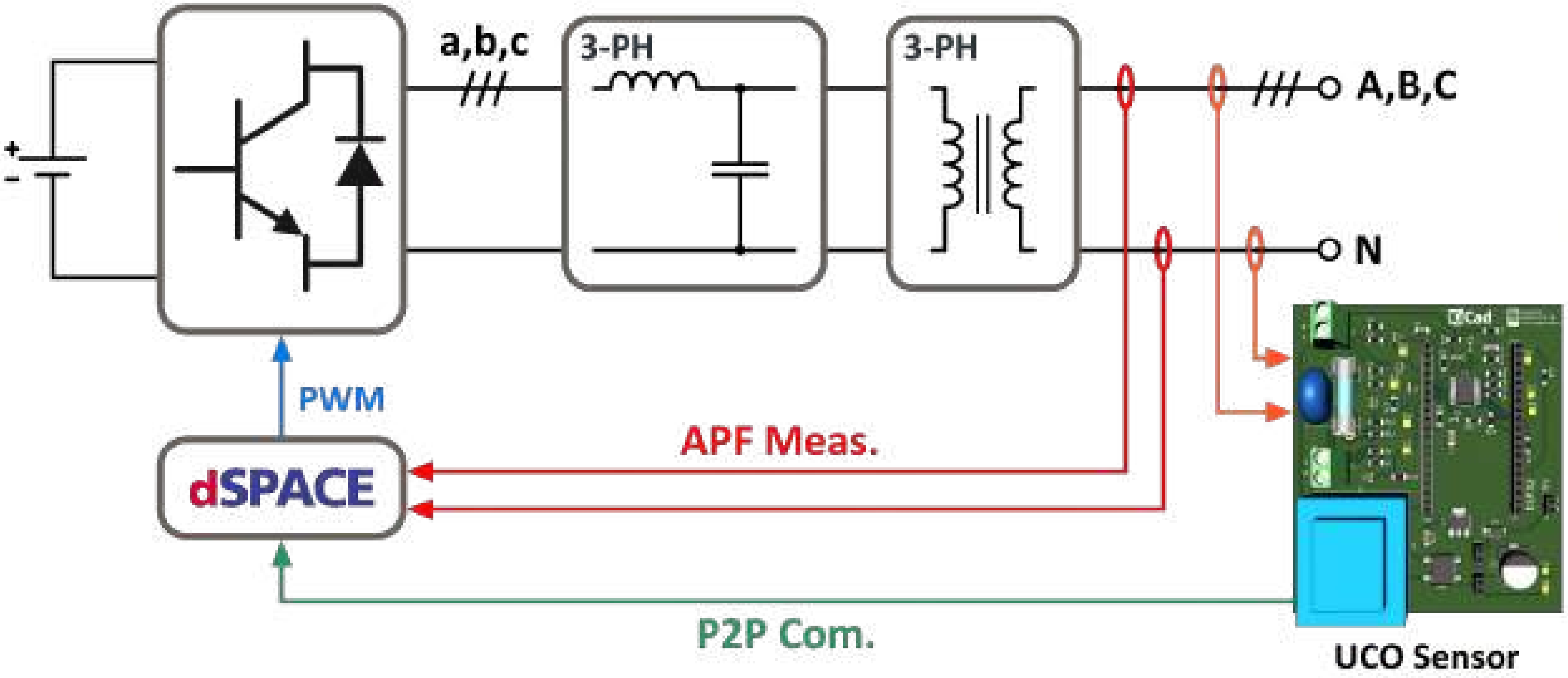
FFT - Source Current
FFT - Load Current
FFT - APF Current
Amplitude (A)
Frequency (Hz)
Phase A
Phase B
Phase C
0
5
10
0
100
200
300
400
500
600
700
800
900
1000



Voltage (V)
285
280
275
270
265
V_{C1}
V_{C2}
3.95
4
4.05
4.1
4.15
I_N (A)
10
0
-10
Inverter
4th Leg
D_N
0.6
0.5
0.4
Time (s)

Interreg Sudoe
IMPROVEMENT

UCO-UCLM Collaboration



Interreg Sudoe
IMPROVEMENT

CNH2-UCLM Collaboration

Communication tasks

- A. Parreño Torres, F. J. López-Alcolea, P. Roncero-Sánchez, J. Vázquez, E. J. Molina-Martínez and Felix García-Torres; “Current Control of a Grid-Connected Single-Phase Voltage-Source Inverter with LCL Filter”; 22nd European Conference on Power Electronics and Applications (EPE'20 ECCE Europe), Lyon, France; ISBN: 978-9-0758-1536-8; 2020

- F. J. López-Alcolea, E. J. Molina-Martínez, J. Vázquez, A. Parreño Torres, P. Roncero-Sánchez, A. Moreno-Munoz, J. Garrido-Zafra and Felix García-Torres; “Detection and Compensation of Current Harmonics in a Microgrid Using an Active Power Filter Supported by an IoT Sensor Network”; 21st International Conference on Environment and Electrical Engineering (EEEIC 2021 BARI), Bari, Italy; ISBN: 978-1-6654-3613-7; 2021

- P. Roncero-Sánchez, A. Parreño Torres, J. Vázquez, F. J. López-Alcolea, E. J. Molina-Martínez and Felix García-Torres; “Multiterminal HVDC System with Power Quality Enhancement”; Energies; 2021

- F. Garcia-Torres,S. Vazquez, I.M. Moreno-Garcia, A. Gil-de-Castro, P. Roncero-Sanchez, A. Moreno-Munoz; “Microgrids Power Quality Enhancement Using Model Predictive Control”; Electronics 2021.

- E. J. Molina-Martínez, F. J. López-Alcolea, A. Parreño Torres, Ismael Payo, J. Vázquez and P. Roncero-Sánchez; “Control Discreto con Reguladores Anidados para la Corriente Inyectada a la Red con un Inversor Monofásico y un Filtro LCL”; 29º Seminario Anual de Automática, Electrónica Industrial e Instrumentación (SAAEI 2022), Lérida, Spain; ISBN: 978-84-9144-411-4; 2022

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Communication tasks

- F. J. López-Alcolea, E. J. Molina-Martínez, J. Vázquez, A. Parreño Torres, P. Roncero-Sánchez, A. Moreno-Munoz, J. Garrido-Zafra and Felix García-Torres; “Detección y Compensación de Armónicos de Corriente en una Microrred utilizando un Filtro de Potencia Activo con una Red de Sensores IoT”; 29º Seminario Anual de Automática, Electrónica Industrial e Instrumentación (SAAEI 2022), Lérida, Spain; ISBN: 978-84-9144-411-4; 2022

- J. Tobajas, F. Garcia-Torres, P. Roncero-Sánchez, J. Vázquez, L. Bellatreche, E. Nieto; “Resilience-oriented schedule of microgrids with hybrid energy storage system using model predictive control”; Applied Energy, Volume 306, Part B, 2022

- F. J. López-Alcolea, E. J. Molina-Martínez, J. Vázquez, P. Roncero-Sánchez, A. Parreño Torres and Ismael Payo; “Use of resonant terms in a 2DOF control scheme for the current control of an active power filter”; 48th Annual Conference of the IEEE Industrial Electronics Society (IECON 2022), Brussels, Belgium; 2022

- R. Savariego, A. Moreno-Munoz, I. M. Abascal-Castaneda, M. I. González-Cuenca, C. S. Silva, J. Tobajas-Blanco, F. J. López-Alcolea, E. J. Molina-Martínez, Romain Mannini, Stéphane Grieu, Ana Estanqueiro and D. Loureiro; “Integration of CCHP microgrids in NZEB with critical loads under high PQR requirements”; Energy Reports, 9, 403-409; 2023; https://doi.org/10.1016/j.egyr.2023.01.003

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Thank you very much!

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