CHIL AND PHIL APPLICATIONS FOR PROTECTION, CONTROL, AND OPTIMAL OPERATION OF ACTIVE DISTRIBUTION NETWORKS AND MICROGRIDS

ALKISTIS KONTOU, ALEXANDROS PASPATIS, DIMITRIS LAGOS, PANOS KOTSAMPOPOULOS, NASOS VASILAKIS GEORGE KORRES, NIKOS HATZIARGYRIOY

NATIONAL TECHNICAL UNIVERSITY OF ATHENS

SMART GRIDS RESEARCH UNIT – SMART RUE

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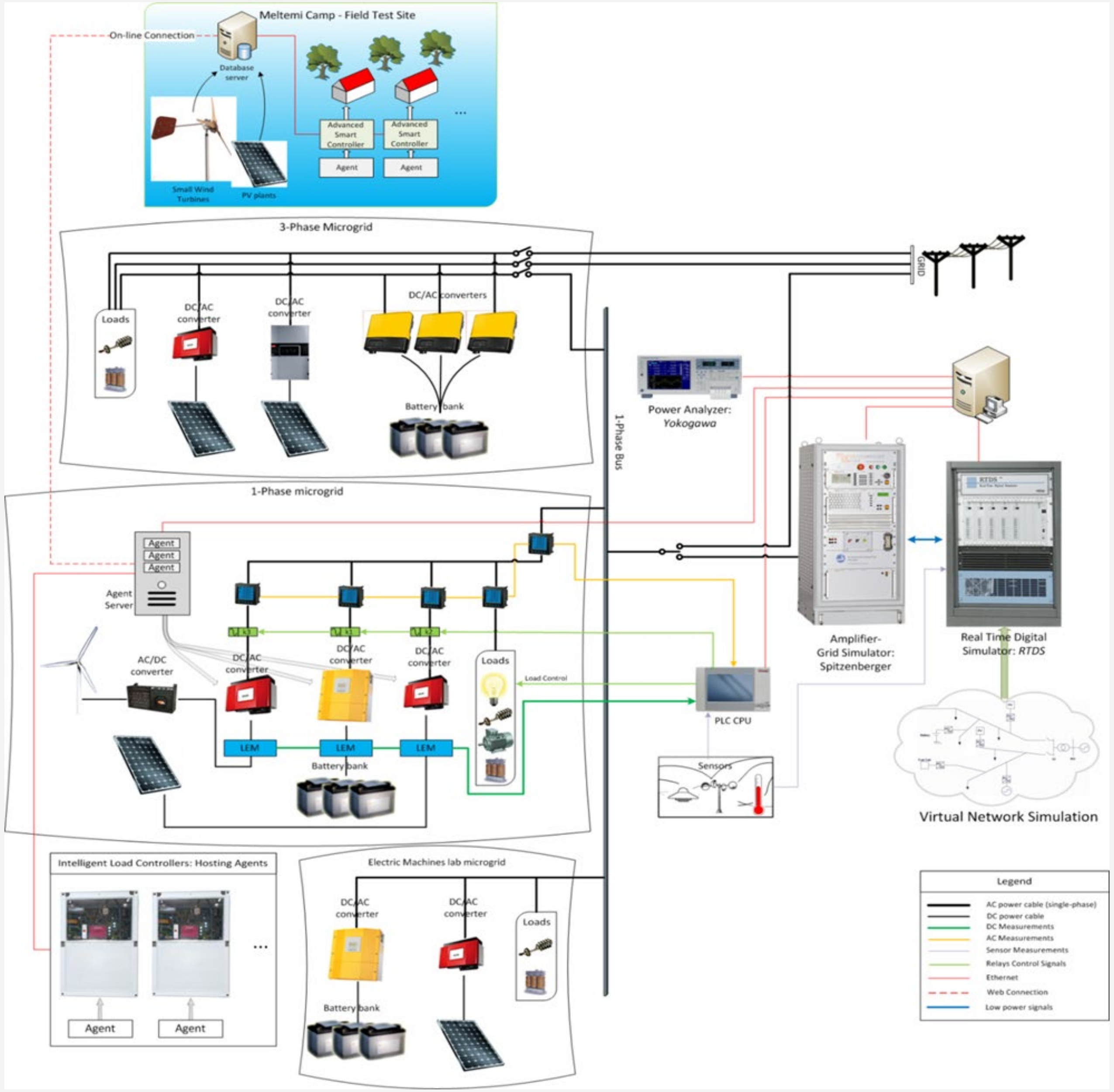
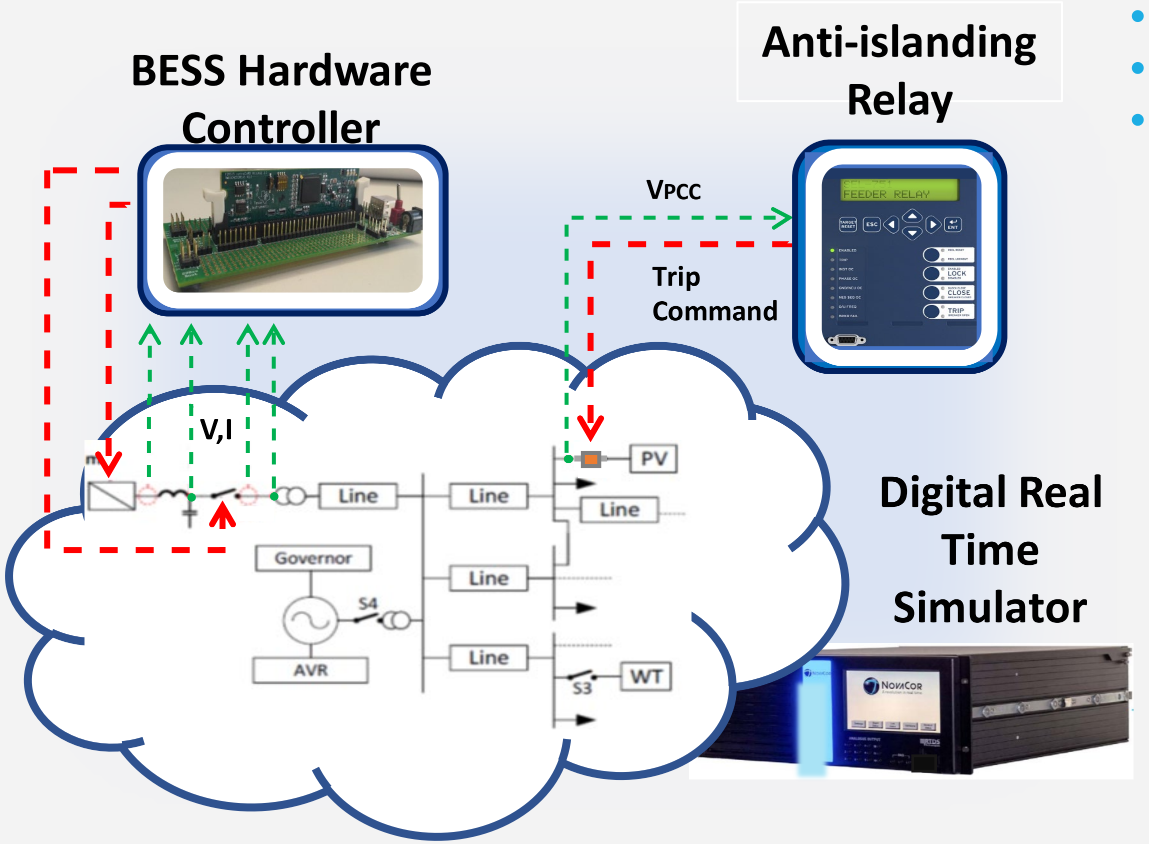
OUTLINE

- Electric Energy Systems Laboratory (EESL)
- Protection in Island Systems Operating with High RES
- Testing of Industrial Controller according to Grid Code Requirements
- Microgrid seamless mode transition control
- Testing of EMS systems with Digital Twins
- Extended range of high-fidelity setups for PHIL testing
- Geographically Distributed Real Time Simulation
- Conclusions

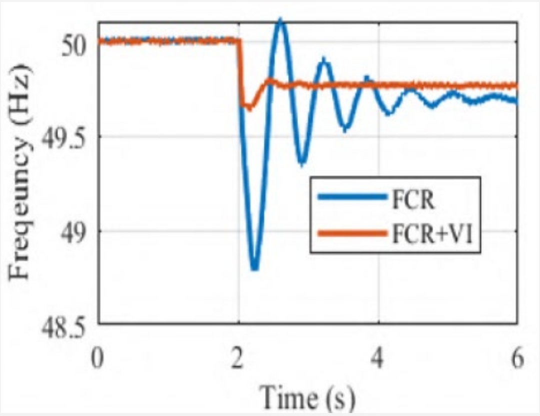
ELECTRIC ENERGY SYSTEMS LABORATORY ICCS-NTUA

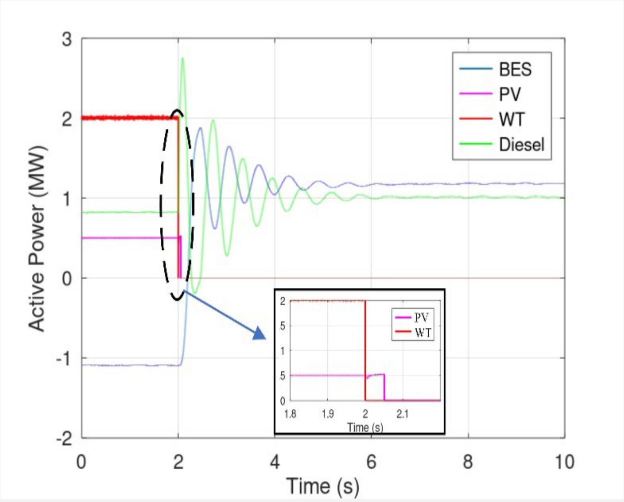


INTERACTION OF INVERTER PROTOTYPE CONTROLLER WITH ISLANDING DETECTION PROTECTION: HIL TESTBED



- BESS Controller: FCR, synthetic inertia, GFL and FGM controls
- Industrial relay operates under LoM protection functionalities
- Investigation of erroneous anti-islanding relay tripping during frequency events in weak systems (e.g. islands with high RES penetration).



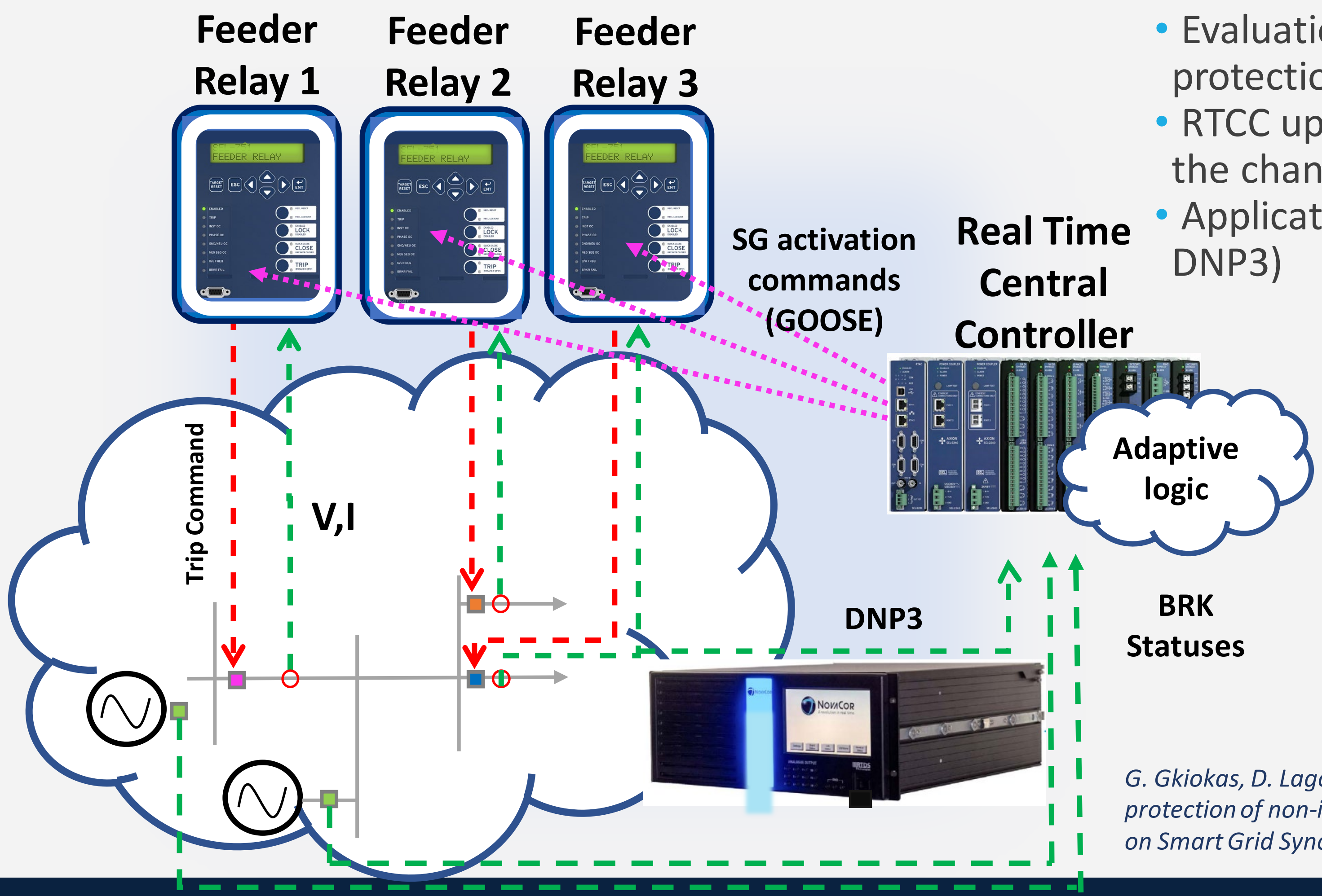


1) WT disconnection resulted in the frequency event
2) PV disconnected in short time after the WT due to anti-islanding relay tripping of ROCOF functionality

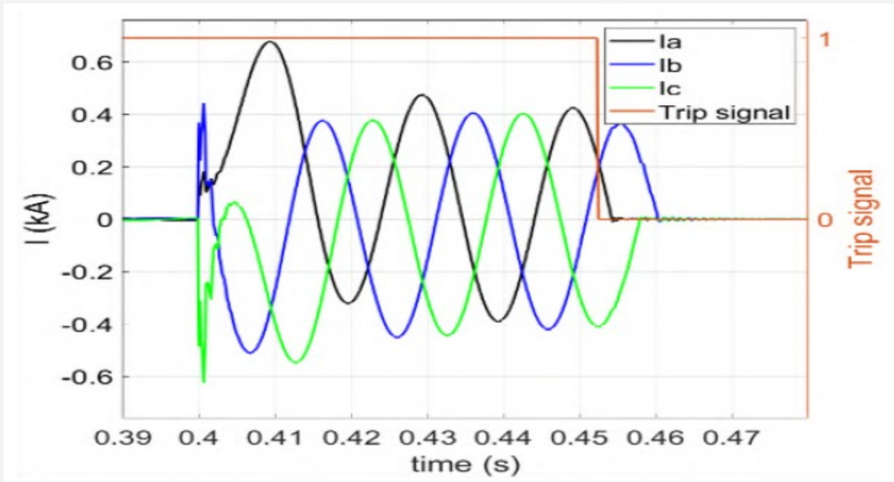
D. Lagos et al, "Protection in Island Systems Operating with High RES Penetration: Case Study Astypalea". CIGRE Session 2022

ADAPTIVE PROTECTION SCHEME: HIL TESTBED

Received the Clayton Griffin student paper award - Georgia Tech University (D. Lagos)



- Evaluations of protection devices coordination in an adaptive protection scheme to deal with short circuit faults
- RTCC update the active setting groups of the relays based on the changes of the network topology
- Application of industrial Communication Protocols (IEC 61850, DNP3)



Short Circuit and relay response

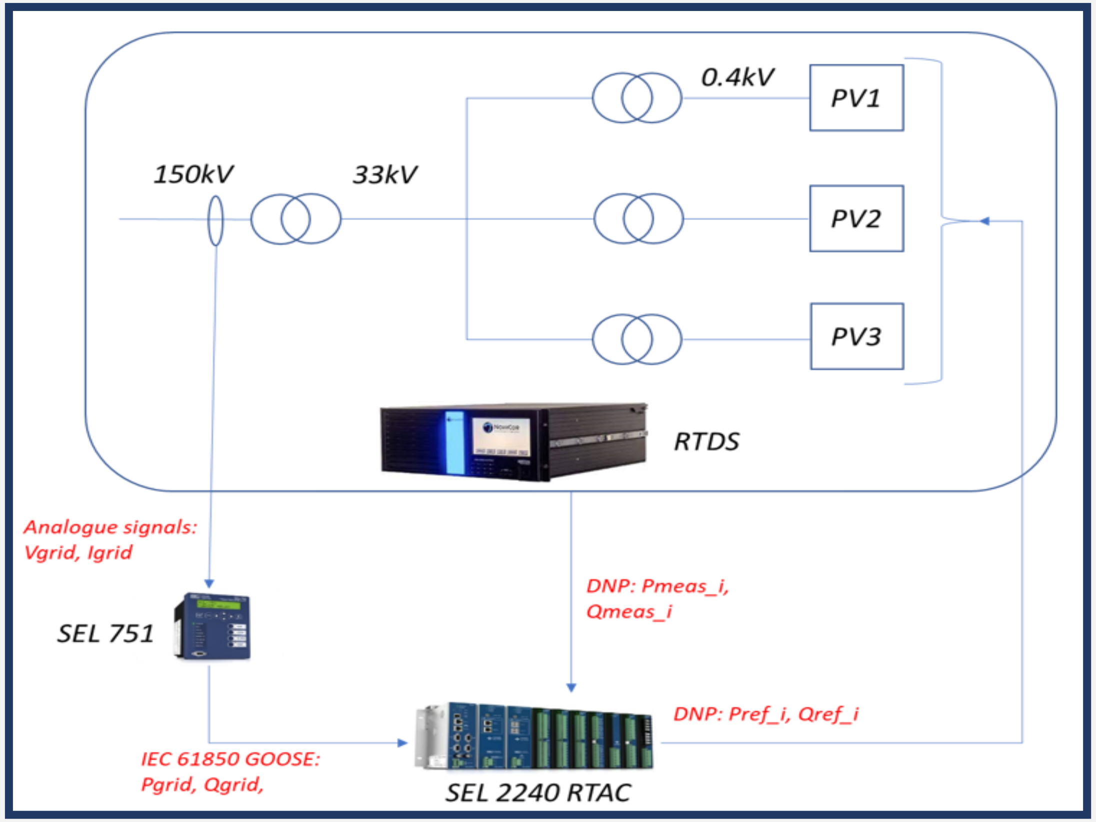
G. Gkiokas, D. Lagos, G. Korres and N. D. Hatziargyriou, "A hardware in the loop testbed for adaptive protection of non-inteconnected island systems with high RES penetration," 2022 International Conference on Smart Grid Synchronized Measurements and Analytics (SGSMA).

HIL TESTING OF INDUSTRIAL CONTROLLER ACCORDING TO GRID CODE REQUIREMENTS (GREEK SYSTEM)

- DGs must abide by the Network Code of EU Requirements for Generators (RfG)

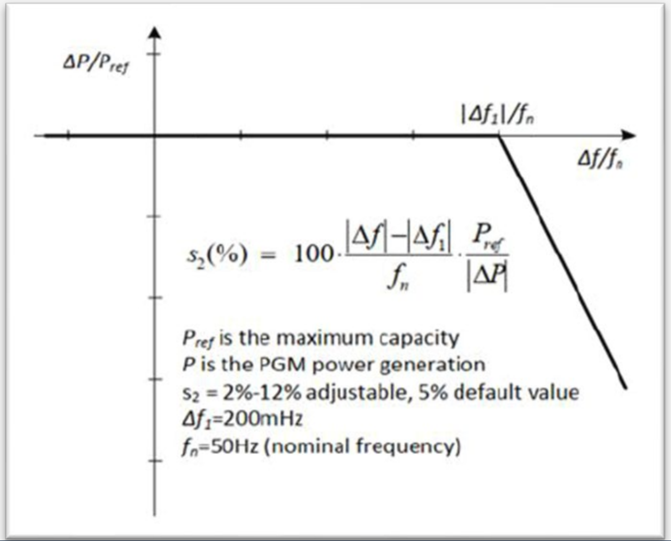
- The Network Code lays down the requirements for grid connection of power-generating facilities:
  - Reactive Power Control at PCC
  - Power Limit Control at PCC
  - Frequency Regulation at PCC

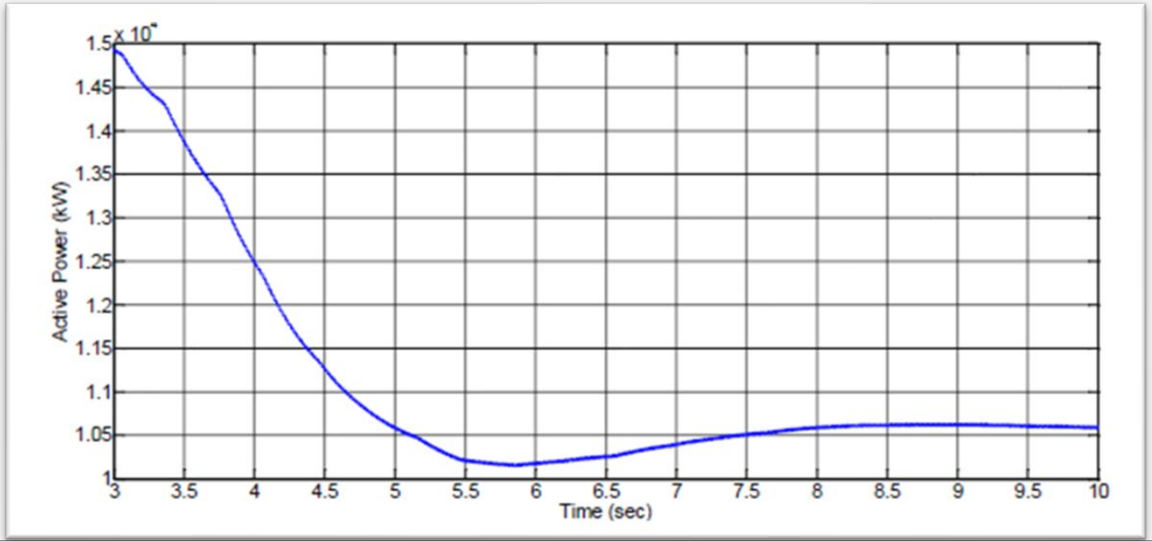
- Industrial PV Plant Controller testing for compliance with RfG (European Union regulation 2016/631).



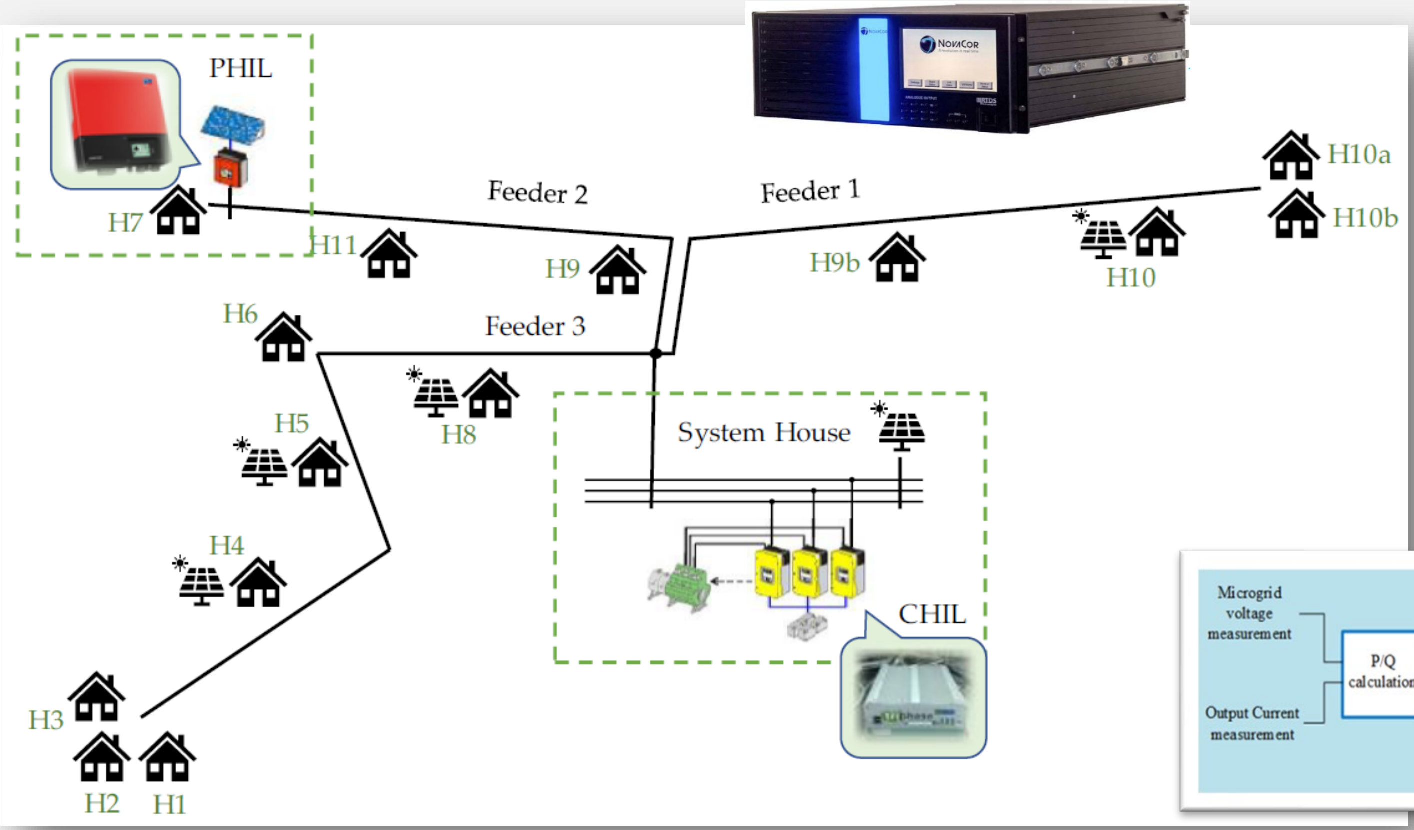
HIL TESTING OF INDUSTRIAL CONTROLLER ACCORDING TO GRID CODE REQUIREMENTS (GREEK SYSTEM)

- Limited Frequency Sensitive Mode – Overfrequency (LFSM-O)
- According to EU RfG code, the power plant under consideration shall be capable of activating the provision of active power frequency response
- Frequency threshold 50.2 Hz, adjustable droop between 2-12%, 5% default value
- Should be activated with a delay less than 2 sec and will prevail over any other active power setpoints



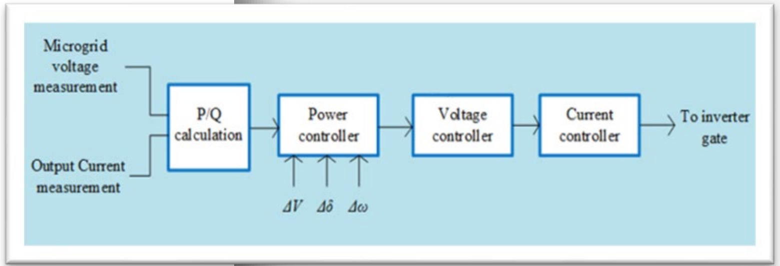


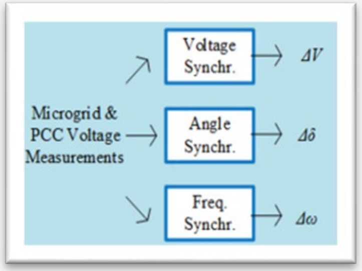
MICROGRID SEAMLESS MODE TRANSITION CONTROL: HIL TESTBED



Combined CHIL and PHIL test at the transition of the Gaidouromandra (Kythnos) microgrid from grid connected to islanded and FRT

- Novel grid-forming inverter controller is designed, and a possibility of grid-connection is assumed
- The grid-forming inverter manages the transition between grid-connected and islanded mode
  - Grid-synchronization voltage, frequency and angle correction terms are inserted into the droop controller to match the voltages before and after the microgrid interconnection switch





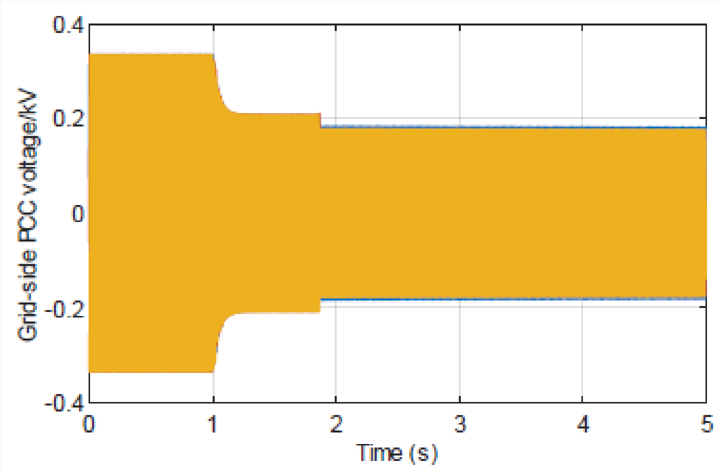
1. Paspatis, Alexandros; Kontou, Alkistis; Kotsampopoulos, Panos; Lagos, Dimitris; Vassilakis, Athanasios; Hatziargyriou, Nikos (2023). *Advanced hardware-in-the-loop testing chain for investigating interactions between smart grid components during transients. TechRxiv. Preprint.* https://doi.org/10.36227/techrxiv.22491295.v1
2. *A. Paspatis et. al, "Advanced hardware-in-the-loop testing chain for investigating interactions between smart grid components during transients", EPSR, 2023 (under review)*

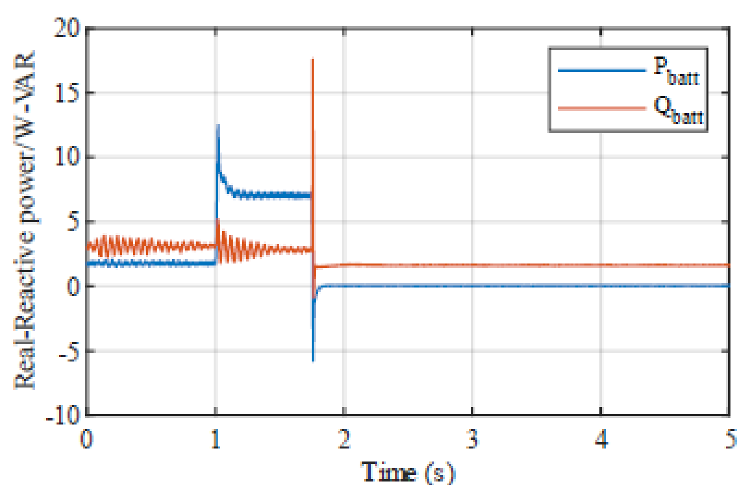
MICROGRID SEAMLESS MODE TRANSITION CONTROL: HIL TESTBED

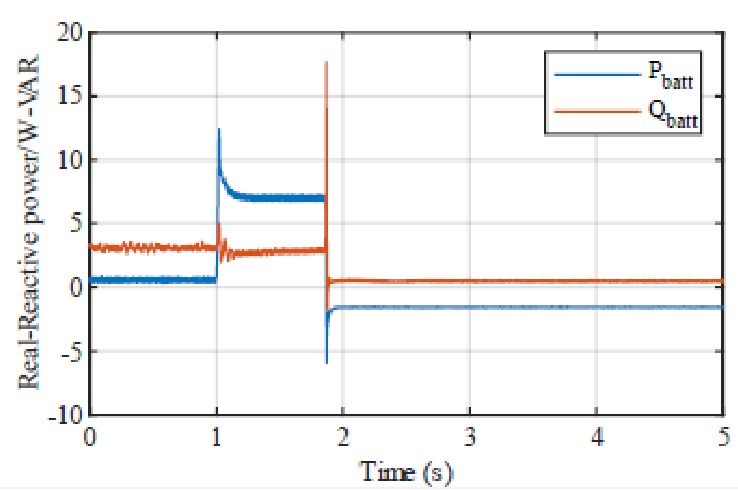
FRT and transition from grid-connected to islanded

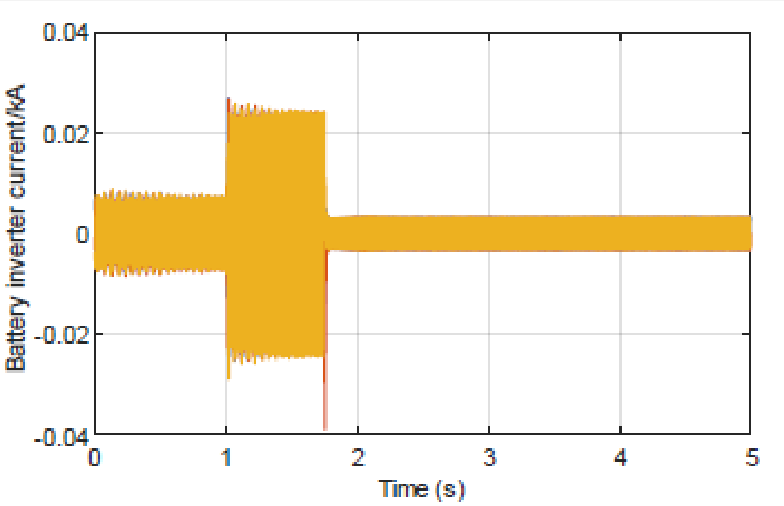
CHIL

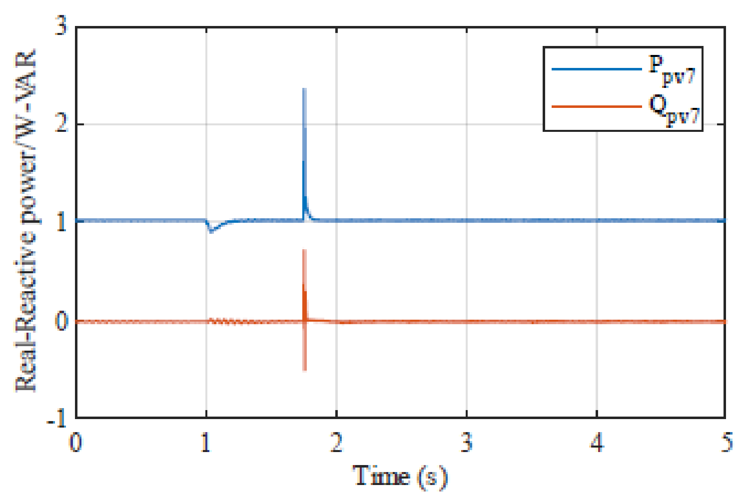
Combined CHIL&PHIL

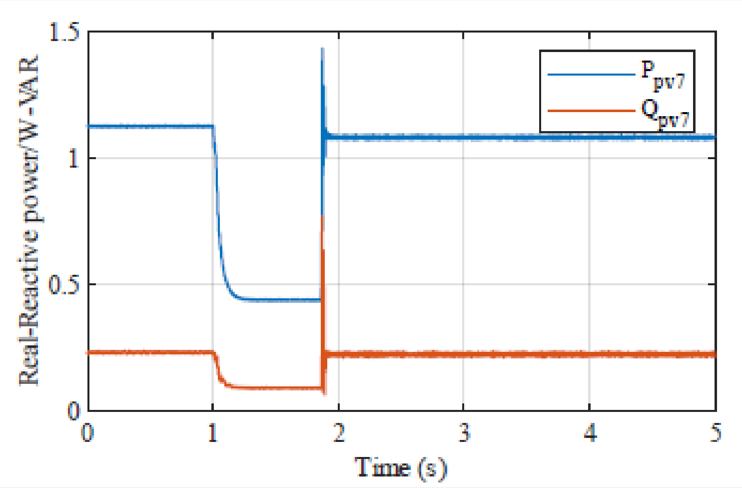












OVERVIEW OF THE H2020 RE-EMPOWERED PROJECT

This project has received funding from the European Union's Horizon 2020 research and innovation under grant agreement No 101018420.

DST@50 1971-2021 DEPARTMENT OF SCIENCE & TECHNOLOGY

Partners					
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1	ICCS - NTUA (European Coordinator)	Greece	8	Indian Insitute of Technology Kharagpur (Indian Coordinator)	
2	Imperial College London	United Kingdom	9	Indian Insitute of Technology Bhubaneswar	
3	Danmarks Tekniske Universitet	Denmark	10	Visvesvaraya National Institute of Technology	
4	Bornholms Varme As	Denmark	11	CSIR - Central Mechanical Engineering Research Institute	
5	Protasis Sa	Greece	12	Indian Institute of Science	
6	Deloitte Advisory, S.L.	Spain	13	Indian Institute of Technology Delhi	
7	DAFNI	Greece	14	Lab Concern India (LCI)	

Duration: 42 months as of 1 July 2021

This work is financially supported by the European Union's Horizon 2020 Research and Innovation Program and the Department of Science and Technology (DST), India through the RE-EMPOWERED Project under Grant Agreement No 101018420 and DST/TMD/INDIA/EU/ILES/2020/50(c) respectively

ECOMICROGRID TOOL

This project has received funding from the European Union's Horizon 2020 research and innovation under grant agreement No 101018420.

ecoMicrogrid is a tool for microgrid operators, to optimize energy management of the multiple vectors within the local energy system.

- **Reduction of energy cost and utilization of RES** as well as the reliable and secure operation.
- **Multi vector optimization.** Capable to integrate different scales of microgrids (Electrical and Cooling systems).
- **Predictive control strategies** utilize forecast to pro-actively engage assets and loads to achieve maximum system performance.

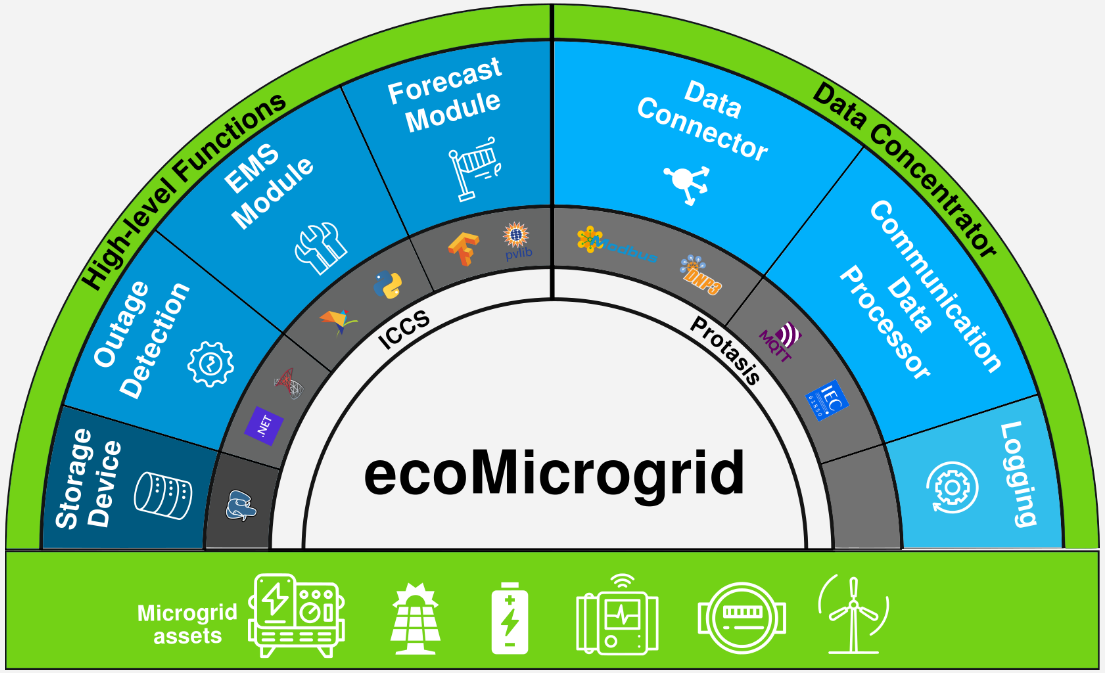

Fig.: Key system components of the ecoMicrogrid tool.

Test the tool using real time data in industrially relevant environment (protocols, real time data, etc.) and identify potential threats prior to the installation.

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ECOMICROGRID TOOL TESTING

The procedure for implementing the experiment is as follows:

- A 3-phase **digital twin model** was built of the actual network in RSCAD. (network's distribution lines, house loads, PV productions, DG, Batteries with its SoC modeling, HVAC and control's room thermal model)
- Define the communication protocols and the variable list of inputs and outputs.
- RTDS produces more analytical data (P, Q, I, V, SoC, Temperature, assets status) and feeds the data produced to our tool via Modbus TCP protocol.
- "ecoMicrogrid" tool process in real time the data and following an optimization algorithm makes decision regarding Diesel Generator and HVAC on/off status which feeds back closing the loop to RTDS (via modbus TCP).

Actual site
Real time data

Modbus TCP

P, Q
Measurements

RTDS implemented
microgrid's Digital Twin

P, Q, I, V, SoC, Temp, Assets Status
RTDS Products

Modbus TCP

eco Microgrid Tool

Industrial PC &
Zenon Platform

Modbus TCP

Optimized handling of DG & HVAC on/off status feedback

Tool Evaluation

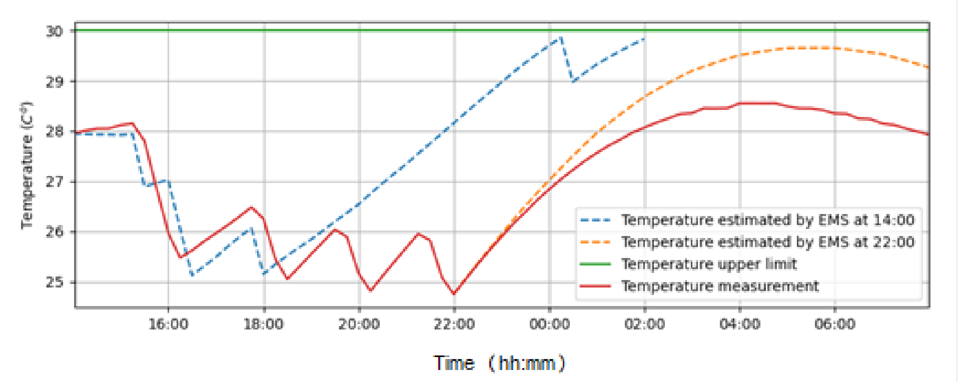
Assessment on:
- Communication success
- Optimization decisions
- Robustness

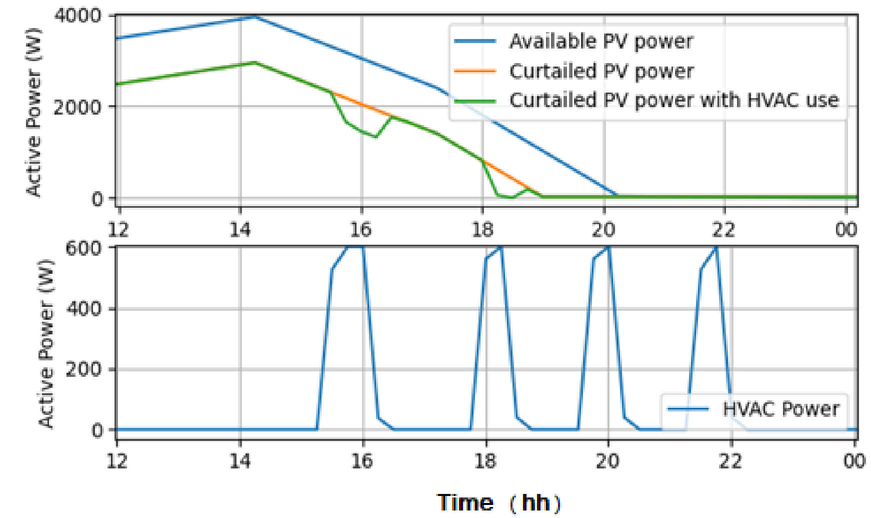
ECOMICROGRID TOOL TESTING – OPERATIONAL SCENARIO

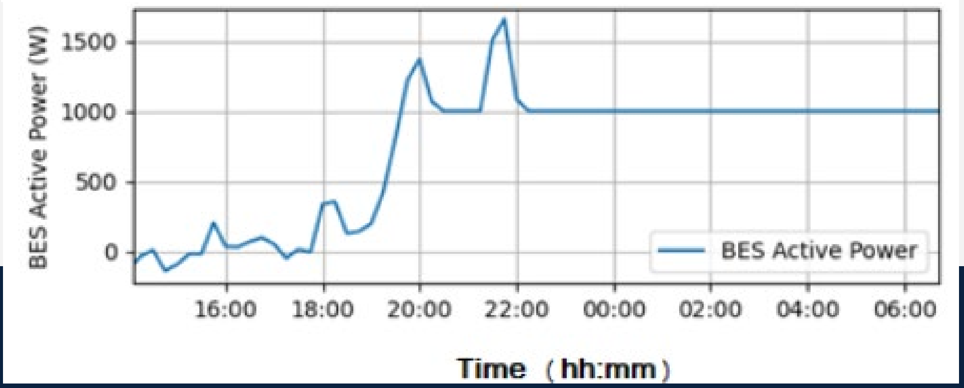
<u>Scenario - Pre-cooling System House Control Room</u>

Aim: minimize HVAC usage during night and reduce RES power curtailment

- Normal Operation on 16/07/2023, starting from 10:00 am with batteries fully charged > 90%. At 10:00 am, the initial room temperature was 28°C, and the load conditions resembled those observed in the Gaidouromadra MG.
- This scenario represents a **typical summer day** with PV power curtailment, resulting in increased room temperature during the night due to thermal load introduced by the inverters.
- The EMS's desired performance in this test is to utilize the HVAC system during periods of RES curtailment to proactively cool the room before nightfall.

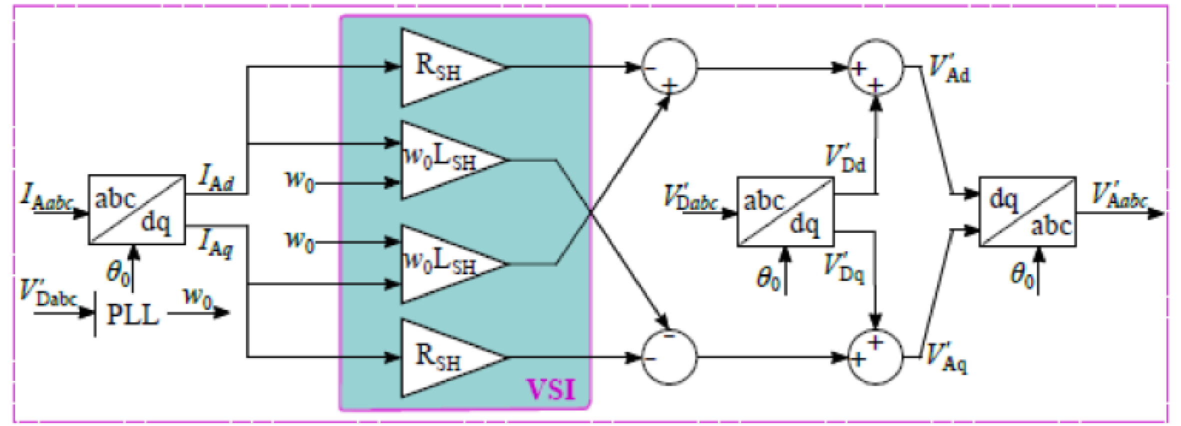


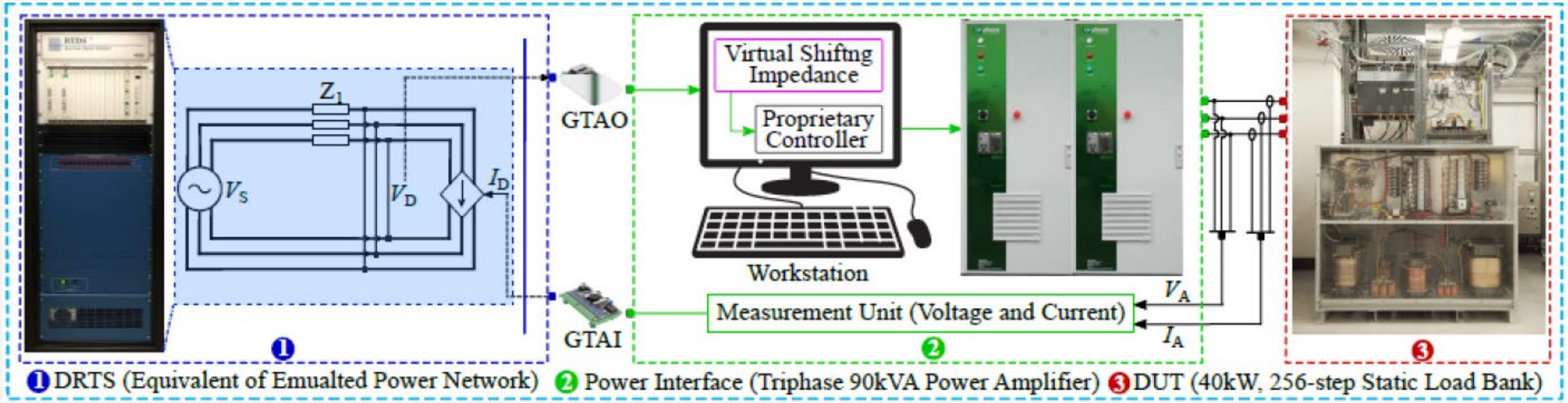




EXTENDED RANGE OF HIGH-FIDELITY SETUPS FOR PHIL TESTING

- Virtual Shifting Impedance: aims at the Sifting Impedance method virtual implementation through the controller of the power amplifier
- Proven improved performance compared to feedback filter method



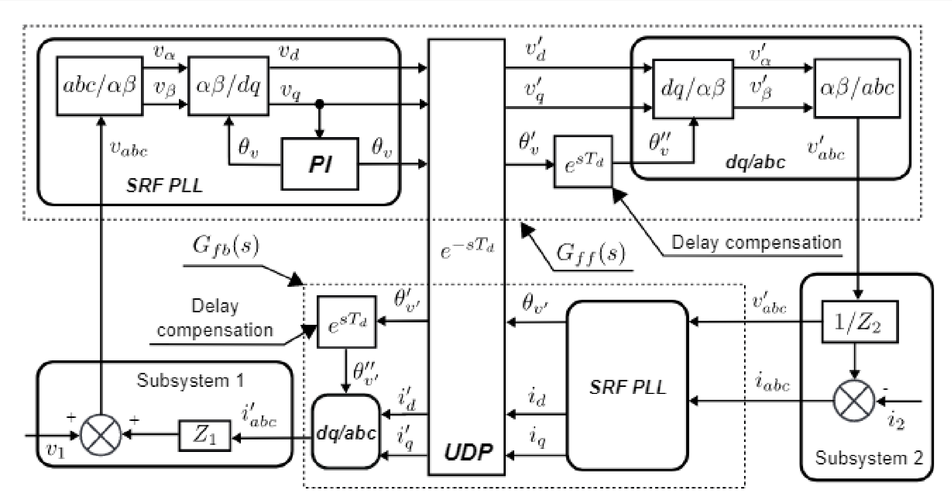


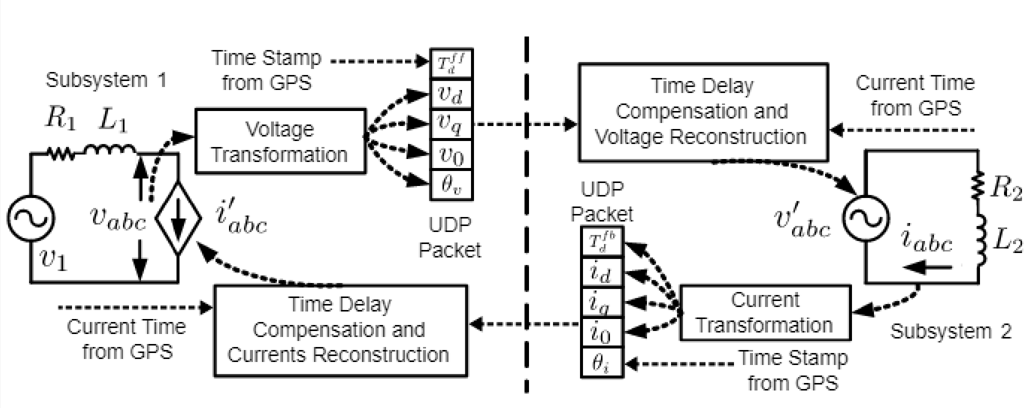
A. Paspatis et al., "Virtual Shifting Impedance Method for Extended Range High-Fidelity PHIL Testing," in IEEE Transactions on Industrial Electronics, 2023, doi: 10.1109/TIE.2023.3269467

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 870620.

GEOGRAPHICALLY DISTRIBUTED REAL TIME SIMULATION REALIZING ROBUST SETUPS

Connecting European Smart Grid Infrastructures



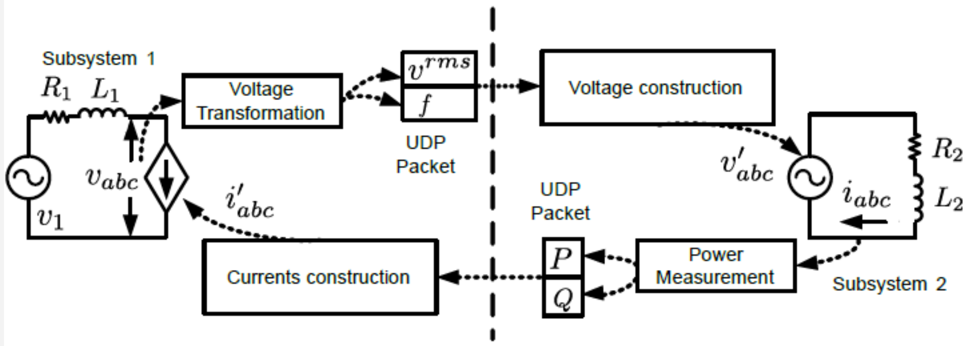


Synchronously coupled GDS &
Asynchronously coupled GDS

- ## Challenges
  - Existing stability analysis is not adequate
  - Stability enhancement techniques are limited to static impedance ratios
- ## Solutions
  - Detailed stability models

University of Strathclyde

Led by: UoS



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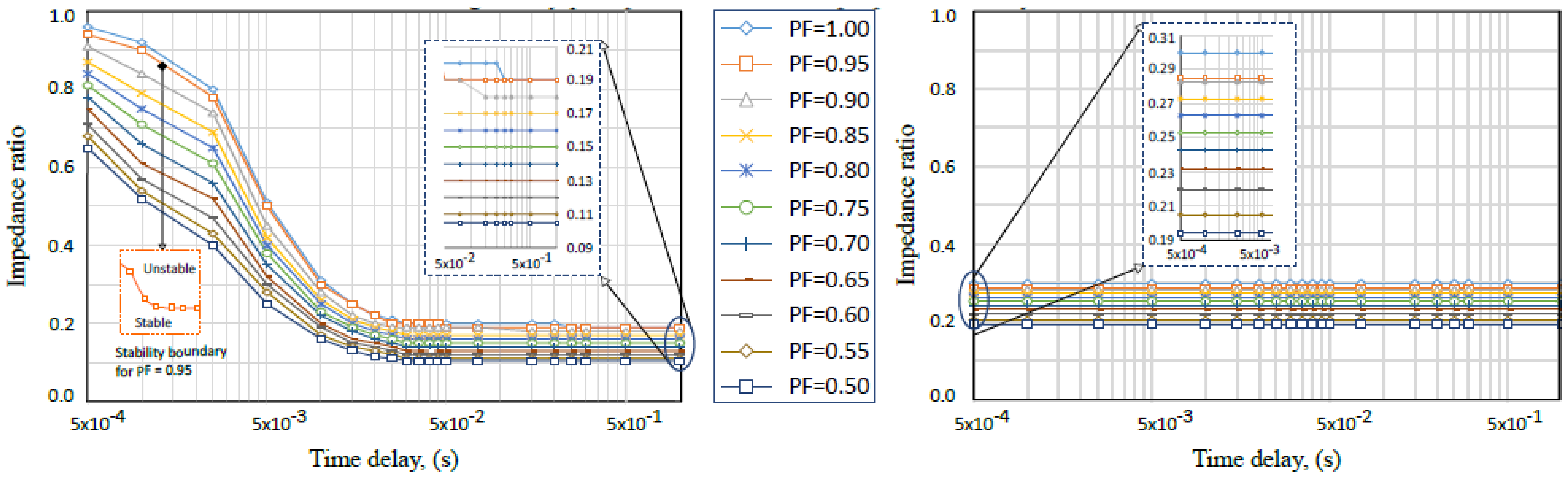
RTDS Technologies AMETEK

GEOGRAPHICALLY DISTRIBUTED REAL TIME SIMULATION

Stability boundary conditions for GDS setups



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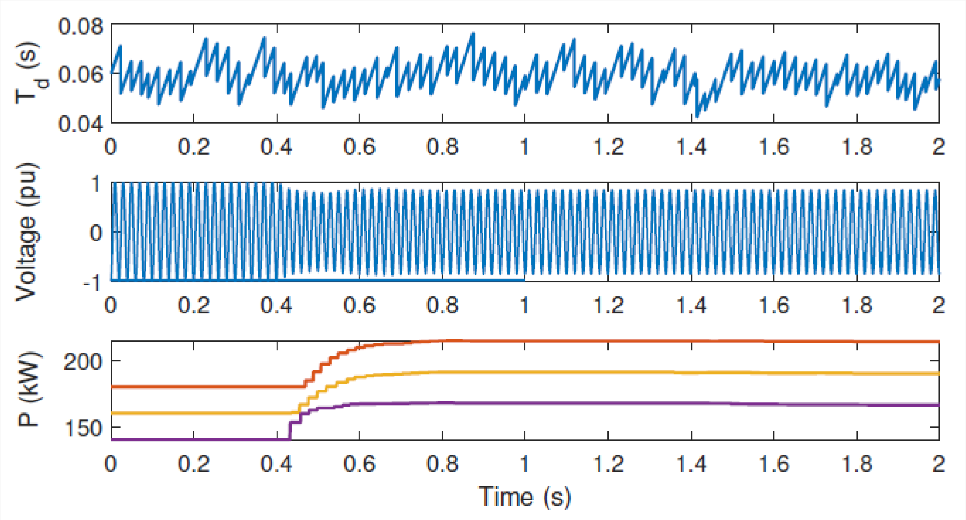
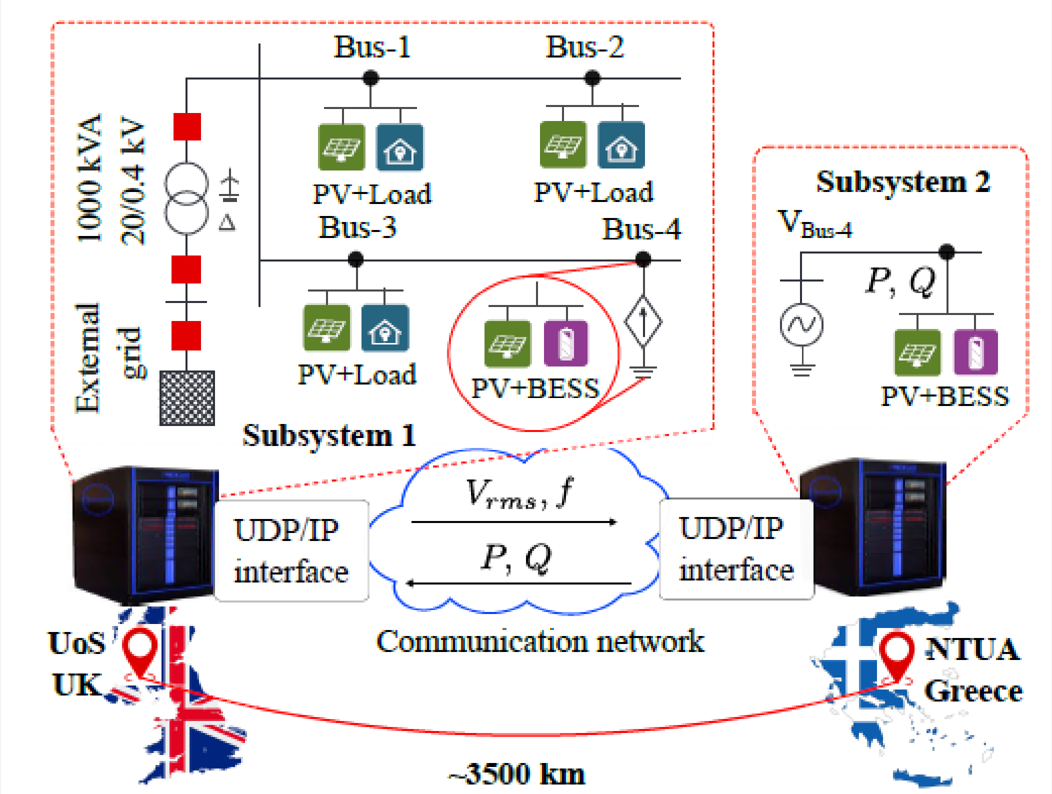
GEOGRAPHICALLY DISTRIBUTED REAL TIME SIMULATION

- Cloud Interconnection of Laboratories
- Existing stability analysis is not adequate
- Stability enhancement techniques are limited to static impedance ratios
- Solution: Detailed stability models





M. Syed et al., "Applicability of Geographically Distributed Simulations," in IEEE Transactions on Power Systems, 2022, doi: 10.1109/TPWRS.2022.3197635.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 870620.

CONCLUSIONS

- HIL can be useful in a wide range of applications, from HV to LV systems
- HIL can be used to study the behavior of the HUT but also to reveal the interactions between various components
- For PHIL applications emphasis should be placed in the analysis of the stability and accuracy of the the set up itself

THANK YOU FOR YOUR ATTENTION!

Contact: alkistiskont@mail.ntua.gr
kotsa@power.ece.ntua.gr

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